Committee for the Environment

Report on the Committee's Inquiry into Wind Energy
Volume 4

Written submissions relating to the report

Ordered by the Committee for the Environment to be printed 29 January 2015

Mandate 2011/16 **Seventh Report - NIA 226/11-16**

Membership and Powers

The Committee for the Environment is a Statutory Departmental Committee established in accordance with paragraphs 8 and 9 of the Belfast Agreement, section 29 of the Northern Ireland Act 1998 and under Standing Order 48.

The Committee has power to:

- Consider and advise on Departmental budgets and annual plans in the context of the overall budget allocation;
- Consider relevant secondary legislation and take the Committee stage of primary legislation;
- Call for persons and papers;
- Initiate inquires and make reports; and
- Consider and advise on any matters brought to the Committee by the Minister of the Environment

The Committee has 11 members including a Chairperson and Deputy Chairperson and a quorum of 5. The membership of the Committee since 9 May 2011 has been as follows:

Ms Anna Lo MBE (Chairperson)
Ms Pam Cameron (Deputy Chairperson)[1]
Mr Cathal Boylan
Mr Colum Eastwood[2]
Mrs Sandra Overend[3, 4]
Mr Alban Maginness[5, 6]
Mr Ian McCrea[7, 8, 9, 10]
Mr Barry McElduff[11, 12]
Mr Ian Milne[13, 14]
Lord Morrow
Mr Peter Weir

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[1] With effect from 10 September 2013 Ms Pam Cameron replaced Mr Simon Hamilton as Deputy Chairperson

[2] With effect from 18 June 2012 Mr Colum Eastwood replaced Mr John Dallat

[3] With effect from 23 April 2012 Mr Tom Elliott replaced Mr Danny Kinahan

[4] With effect from 04 July 2014 Mrs Sandra Overend replaced Mr Tom Elliott

[5] With effect from 23 April 2012 Mrs Dolores Kelly replaced Mr Patsy McGlone

[6] With effect from 07 October 2013 Mr Alban Maginness replaced Mrs Dolores Kelly

[7] With effect from 20 February 2012 Mr Gregory Campbell replaced Ms Paula Bradley

[8] With effect from 01 October 2012 Mr Alastair Ross replaced Mr Gregory Campbell

[9] With effect from 07 May 2013 Mr Sydney Anderson replaced Mr Alastair Ross

[10] With effect from 16 September 2013 Mr Ian McCrea replaced Mr Sydney Anderson

[11] With effect from 08 May 2012 Mr Chris Hazzard replaced Mr Willie Clarke

[12] With effect from 10 September 2012 Mr Barry McElduff replaced Mr Chris Hazzard

[13] With effect from 07 April 2013 Mr Francie Molloy resigned as a Member

[14] With effect from 15 April 2013 Mr Ian Milne replaced Mr Francie Molloy

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List of abbreviations

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The Department	Department of the Environment
AM	Amplitude Modulation
AONB	Area of Outstanding Natural Beauty
CIEH	Chartered Institute of Environmental Health
DETI	Department of Enterprise, Trade and Investment
DOE	Department of the Environment
EIA	Environmental Impact Assessment
ETSU	Energy Technology Support Unit
EU	European Union
HSENI	Health and Safety Executive Northern Ireland
MW	Megawatt
NIAPA	Northern Ireland Agricultural Producers Association
NIE	Northern Ireland Electricity
NIRIG	Northern Ireland Renewables Industry Group
NREAP	National Renewable Energy Action Plans
PAD	Pre-application Discussion
PfG	Programme for Government
PHA	Public Health Agency
PPS	Planning Policy Statement
QUB	Queen’s University Belfast
RES	Renewable Energy Systems
SPPS	Single Planning Policy Statement
ToR	Terms of Reference
UFU	Ulster Farmer’s Union
UU	University of Ulster

List of submissions

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9.	Board Gais Energy
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26.	Deise Against Pylons Ireland
27.	Department of Enterprise Trade and Investment
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29.	Emma Kiely
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31.	Committee for Employment and Learning
32.	ESB Generation and Wholesale Markets
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Committee Chairperson Anna Lo MBE
Committee for the Environment
Parliament Buildings
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BT4 3XX

28th February 2014

By email to: committee.environment@niassembly.gov.uk.

Re: Response to Wind Energy Inquiry

Dear Chairperson Lo,

Viridian, through Energia, is one of Northern Ireland's leading providers of sustainable green energy. In Northern Ireland Energia has over 173MW of operational renewable electricity capacity contracted within its energy portfolio and a further 97MW in construction. Energia has contracts with over 600MW of wind projects giving a 25% market share of wind generation capacity throughout the Island of Ireland.

Power from the wind farms is used to supply Energia's retail customer base. In Northern Ireland Energia offers all its customers the ability to be supplied by green energy from these wind farms. I am pleased to say that the majority of its customers take up this offer and use sustainable energy to power their businesses. We welcome the opportunity to respond to the Environment Committee's Wind Energy Inquiry. Energia is a member of the Northern Ireland Renewable Industry Group (NIRIG) and is fully aware of its response. We support the NIRIG response to this inquiry, and would like to reiterate that a stable policy framework is required to allow clear and necessary progress towards our low-carbon energy future.

We support the positions taken by NIRIG and reiterate the following points:

- We believe that the benefits of developing our wind resources far outweigh the perceived negatives, and a considerable number of policies are already in place and enforced to mitigate any of the potential impacts of wind energy development;
- PPS18, the key planning policy document for renewable energy in Northern Ireland, is the product of extensive public consultation, and we believe that PPS18 and the associated guidelines are balanced and play an important role in achieving 40% of our electricity generation from renewable energy sources by 2020 in a manner which is sustainable and sensitive to the environment;

- We strongly believe that the forthcoming Strategic Planning Policy Statement should maintain the current language and approach of PPS18 to enable our Strategic Energy Framework targets and beyond;
- Planning policy has been based on robust research and evidence and has been scrutinised by experts in their field. Based on the advice of planning policy, a wind farm which can operate within the noise limits which have been derived according to ETSU-R-97 is considered to be acceptable. An additional Good Practice Guidance now underlies the policy and we believe that such expert-led policies are appropriate for the purposes of wind farm noise assessments;
- Buffer zones or separation distances are not required by statute in the UK or Ireland and we believe that an effective means of managing wind turbine noise impacts is to set noise level limits at the noise sensitive receptors likely to be significantly affected, and require these to be met by planning conditions. Separation distances are arbitrary and are likely to be detrimental to future development of windfarms. Noise limits are more appropriate for ensuring no impact on a case by case basis;
- We would like to highlight that positive community engagement over and above statutory requirements is regularly carried out by wind farm developers in Northern Ireland and we believe that the renewables sector may be considered a leader in good practice on community engagement in Northern Ireland.

We would also like to highlight the need for positive leadership from across the political spectrum for the development of our substantial renewable energy resources. Our sustainable energy aims as laid out in a wide range of Executive and Departmental policies, as well as party political manifestos, will only be met through an increasingly diverse and low-carbon electricity system. In delivering these aims the combined efforts of policy-makers, industry and communities will be vital. We continue to look forward to and are committed to making progress on developing our renewables sector, and in particular the most cost-effective scalable technology, onshore wind.

In conclusion we would like to thank the Committee for the opportunity to engage on this issue and look forward to continued support for the development of our enviable renewable resources and the necessary progress towards meeting our low-carbon commitments.

Yours sincerely,

Ian Thom
Group Chief Executive
Viridian Group

West Tyrone Against Wind Turbines

Dear Ms Mawhinney,

Please find attached a written response to the above Inquiry on behalf of West Tyrone Against Wind Turbines. I have also emailed to you this afternoon 16 Additions to this Submission.

I would be grateful if you could acknowledge receipt of same. Any queries, let me know.

Yours sincerely,

Owen McMullan, Chairman, West Tyrone Against Wind Turbines

Ms Sheila Mawhinney
Clerk
Committee for the Environment
Room 247
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Belfast
BT4 3XX

28 February 2014

Dear Ms Mawhinney

Inquiry Into Wind Energy

The Assembly Committee for the Environment's announcement in early January of this year that it intends to carry out an inquiry into Wind Energy is most welcome.

We refer to our meeting with the Committee for the Environment at Stormont in May 2013 where we advised that wind farms and single wind turbines in Northern Ireland were being approved by Planning Service in contravention of EC legislation. We further advise that The European Court of Justice (ECJ), on 13 February 2014, ruled that the Government of the United Kingdom and Northern Ireland has not complied with Articles 3(7) and 4(4) of the Aarhus Convention. This is a very serious breach of EC legislation; we therefore call for an independent investigation to be conducted to establish who authorised the approval of wind farms and single wind turbines in Northern Ireland and to establish why EC requirements were so flagrantly ignored in Northern Ireland.

The Northern Ireland Assembly now needs to impress upon Minister Durkan, our Environment Minister, the urgent need to introduce an immediate embargo on the approval of all planning applications for commercial wind farms and single wind turbines until the Environment Committee's Inquiry Into Wind Energy is complete and the true and full facts in relation to wind energy are fully and independently established, verified and consulted upon widely with all key stakeholders and the general public.

It is very difficult for us as inhabitants of an Area of Outstanding Natural Beauty (AONB) to understand how PPS21 is so prescriptive in its policy of controlling the construction of single dwellings by rural dwellers in the open countryside and yet PPS18 allows massive inefficient (20% efficiency or thereabouts) wind turbines to be constructed on our skylines within AONB's, ASSI's and EC protected areas of blanket bog-land throughout Northern Ireland.

The aforementioned ECJ ruling affirms the legislative requirement that member state Governments of the EC are obliged to carry out independent Environmental Impact Assessments for all major strategic projects such as commercial wind farms and in some instances single wind turbines where cumulative impact is an issue. That important legislative requirement, we believe, has not been ignored by the Planning Service in Northern Ireland to date. It follows therefore that wind farms and some single wind turbines already approved have been approved in contravention of EC legislation and are therefore operating illegally. A senior Planning Service official claimed at a meeting representatives from West Tyrone Against Wind Turbines had with Minister Mark H Durkan and Mr Joe Byrne MLA on 20 November last year that European environmental legislative requirements were not applicable in Northern Ireland and would not be applicable until 2015. That claim is totally incorrect.

We believe, that for far too long now the wind industry has been allowed to act with impunity throughout Northern Ireland and indeed the Republic of Ireland to the considerable detriment of our beautiful rural landscapes. We also believe that the rural environment and the needs and desires of the rural communities who struggle so hard to maintain those beautiful, and in some instances, protected landscapes for the enjoyment of everyone have been essentially ignored by the wind industry. In addition, our beautiful rural landscapes are a major and essentially untapped tourist asset that can be expanded upon now that we have relative political stability in Northern Ireland. Are we going to bite off the hand that feeds? Our Assembly needs to address this very serious matter with extreme urgency.

We believe that some of the practices employed by the wind industry warrant comprehensive investigation. There was a well-publicised instance in the Loughgiel area of Co Antrim during 2013 where the developer of a proposed wind farm offered a paltry £200.00 per year payment to locals (towards their electricity costs) if they agreed not to object to their wind farm proposal; is this bribery? We certainly believe that it is.

A senior representative from REI wind energy company (who incidentally claimed to have many years' experience in the wind industry) even had the audacity to state at a so called public, but very poorly advertised, consultation event in Gortin last year concerning the proposed wind farm at Lisnaharney Road, Gortin (close to Gortin Glen Caravan Park) that there were no adverse health issues associated with wind farms. He did not elaborate on what independent research he had at his disposal that enabled him to arrive at that opinion nor did he agree to share that information with the concerned local residents present. Promotional literature distributed by REI at that particular meeting was subsequently found to be inaccurate; the Advertising Standards Authority upheld a number of complaints that were submitted to them by concerned local residents (Lisnaharney Residents Action Group).

In view of the above we now wish to record our very serious concerns about the wind industry and the manner in which it is operating throughout Northern Ireland. We will address our concerns in line with the Terms of Reference as agreed by the Environment Committee as follows:

Adequacy of PPS18

First and foremost we believe that PPS18 was essentially written by the wind industry for the wind industry. We also believe that the Planning Service did not have the requisite resources to undertake the research and preparation that was required to prepare a comprehensive Draft Policy Document for public consultation. The current PPS18 Policy document is fundamentally flawed and for that reason we reiterate our call made above for an immediate cessation in the approval of all planning applications for wind farms and single wind turbines. In addition to that we would also call for an immediate embargo on the commencement of work on the construction of all wind farms and single wind turbines already approved but not commenced until the final report of the Environment Committee's Inquiry is published. That course of action would help protect isolated rural communities throughout Northern Ireland against any inappropriate development activity on the part of those involved in the wind industry.

The separation distance general rule specified in PPS18 at the greater of 500 metres or 10 times the rotor diameter is totally inadequate and, we believe, not based on independent scientific evidence. In Scotland for instance there is a policy relating to wind farm development that states “In all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby”. Policy in Scotland specifies that set-back distance of 2000 metres of wind turbines from the nearest dwellings be provided. We believe that a similar set back distance should be specified in Northern Ireland as a minimum and even increased if scientific evidence should dictate otherwise.

We have found, upon inspecting planning files that the information provided with planning applications for wind farms and single wind turbines is too general. No specific make and model of wind turbine is specified in planning applications and separation distances illustrated are mostly too general to enable accurate assessment of noise levels and shadow castings. Furthermore, we have found that the Environmental Impact Assessments (EIA’s) submitted with planning applications generally play down the adverse visual and environmental impact of proposals. We have relayed those concerns to Planning Service in relation to the proposed Slieveard Wind Farm but are not confident that they have been taken on board as amended EIA’s have not been requested for further consideration by Planning Service, ourselves and the general public. Little or no mention is made of damage to the flora and fauna on the proposed sites and adjacent lands and it is not clear how the sites will be reinstated at the end of the life span of the wind turbines or indeed who will be responsible for the complete reinstatement of those sites. We believe that a Planning Condition regarding complete reinstatement of wind farm sites at demolition stage is essential in all planning approvals and that the obligation to demolish should rest with the wind farm operator and all their successors in title. A legally binding Bond (sufficient to cover full site reinstatement costs) must be in place prior to issue of Planning Approval; that requirement would avoid the ludicrous situation that we currently have on Rathlin Island for instance where three wind turbines known locally as “The Three Sisters” erected just a few years ago are no longer operational and no one seems to be able to order their complete demolition and reinstatement of the site or accept responsibility for same. The United States of America too, has numerous examples of lax planning regulation allowing wind farm operators off the hook by not compelling them to fully reinstate their obsolete wind farm sites.

The main problem at present is that wind technology is progressing much more rapidly than the legislation designed to regulate it. ETSU-R-97 is obsolete and quite simply totally inadequate to regulate present wind farm proposals where turbine heights are in the 200 metre plus category and the capacity of turbines is in the 3 MW range. Robust, independently assessed research is urgently required to ensure that turbines of this scale will not impact adversely upon the amenity and health of those living closest to the wind farms. The Planning Service, Environmental Health Departments of Local Authorities and the Health & Safety Executive state that they do not have the requisite expertise in the relevant areas of wind energy technology at present to regulate it to the standard that is required. This fact underpins our call for an immediate cessation on the approval of all planning applications for wind farms and single wind turbines.

It should be noted that the life of a wind farm in PPS18 from approval to demolition is described as ‘temporary’, that reference is totally inappropriate, unacceptable and in urgent need of amendment. The life span of a wind farm (according to the wind industry) is approximately twenty five years or approximately one third of the expected life span of a human being. Any rural dweller unfortunate enough to have a wind farm in close proximity to their home would certainly feel that a twenty five year period is most definitely not a temporary one, PPS18 needs to be amendedurgently to reflect that serious shortcoming. In Scotland for instance the life span of a wind farm is referred to as ‘long term’, that is much more realistic. Could it be that the wind industry has found Northern Ireland and its legislatures to be a soft touch and that that may explain the unsustainable exponential growth in the wind industry here?

Wind Turbine Noise and Separation Distances

The main issue with the recording of noise from wind farms is that the acceptable noise levels are far higher than for other renewable energy technologies and exist for much greater distances from wind farms than from other renewable technology sites. Noise levels specified in the aforementioned ETSU-R-97 are different to those specified in ANSI and ISO and that anomaly explains why wind farm noise eventually causes noise nuisance and sleep disturbance to those living nearby once the wind farm commences operation.

Wind farms can currently operate legally at up to 40dBA at night whereas ambient background noise will be in the 25-30dBA range and that creates a significant noise nuisance problem and significant sleep disturbance problems for those living nearby. PPS18 needs to be urgently amended to ensure that allowable night time noise levels are no higher than the background noise level of 25-30dBA. Wind turbines today are five times the size of those upon which the ETSU-R-97 guidelines were based, ETSU-R-97 was supposed to be reviewed within two years but that never happened – Why? The ETSU-R-97 noise guidelines allow higher levels of noise at night than during the day and that anomaly we believe is what creates the sleep disturbance issue. The noise levels are set at the upper limit of what can be tolerated rather than at the ambient background night time noise level for a particular location and that noise level can vary considerably from one location to another. Acceptable noise levels need to be set for individual wind farms that do not exceed the ambient night time background noise levels. Particular wind conditions also need to be assessed at individual sites as topography of the surrounding lands will affect noise levels. Characteristic 'thumping' effects are often heard from wind farms at night when atmospheric pulse levels are higher and this is completely overlooked in noise assessment reports that accompany EIA's as they are carried out during daylight hours.

Low frequency noise often referred to as infrasound is completely ignored in PPS18. More worrying is the fact that the wind industry would try to make us believe there is no such thing. The World Health Organisation has recognised the infrasound issue and specified that special attention must be given to it particularly in locations with low background noise levels where combinations of noise and vibration may exist. There are many factors that affect the production of infrasound such as the turbine make/design, power output, wind speed, land topography and proximity of other turbines which may create a situation where the wake from one turbine enters the blades of another turbine. Infrasound is inaudible but the human ear can detect and responds to it, the inevitable result is that receptors of infrasound suffer from disturbed sleep patterns and a wide range of associated health issues. There is evidence in Australia that proves that livestock grazing on pastures close to wind farms do not thrive as well as those grazing on similar quality pastures further away from the wind farms. Given that Northern Ireland is a predominantly agricultural economy we believe that impact on livestock needs to be urgently researched by independently qualified experts.

The infrasound issue cannot simply be ignored and is worse inside receptor houses when doors and windows are closed. The Keane Family were forced to leave their Co Roscommon home in September 2013 as a result of infrasound emissions from a nearby wind farm operated by Gaelectric. That issue was well documented on RTE Radio and in the local press. The Murphy Family who live in close proximity to the SSE operated Bessie Bell Wind Farm outside Omagh suffer greatly too in their home and would move away but for the fact that no one is prepared to purchase their home because of its close proximity to the wind farm.

Shadow flicker according to PPS18 only applies within a distance of 10 times the rotor diameter of a wind turbine and this is totally incorrect. Wind turbines located to the east/south east or west/south west of receptor dwellings will cast shadows for distances far in excess of 10 times rotor diameter particularly when the sunlight is strong and at low level in the sky such as during winter months. The 30 hour per year exposure to shadow flicker specified in PPS18 is totally inadequate and should be increased significantly. EC legislative requirements are, we believe, being clearly breached as the relevant authorities in Northern Ireland claim that they have neither the remit nor expertise to measure and assess the impact of shadow flicker, that situation is totally unacceptable and needs to be urgently addressed.

PPS18 also ignores the safety impacts of wind farms. It is worrying that no agency in Northern Ireland is prepared to accept responsibility for ensuring that accidents are properly categorised and recorded and that the experiences and statistics obtained are used to frame future policy thinking for the wind industry. In the five year period up to 2011 there were 1,500 reported wind farm accidents in the UK alone. Were other accidents covered up? We believe that cover-ups abound and that it is policy within the wind industry to obscure the frequency of turbine accidents. Blade failure is the most common occurrence and is particularly dangerous for those living nearby. Blade fragments can be sizeable and can travel for significant distances as a direct result of blade velocity at the time of fragmentation, blade fragments have been recorded as travelling through the air for up to one mile. This is why we feel that a 2000 metre set back from dwellings and workplaces is an absolute minimum. Research undertaken by Loughborough University revealed that 8-10% of wind turbines will suffer blade failure; that 7% of turbines will suffer brake failure and that 3% of turbines will suffer structural failure during their lifetime. It is reasonable to assume that those accident rate statistics will increase significantly as the turbines age and will increase exponentially if maintenance standards set by the manufacturers are not strictly adhered to.

Extent of Engagement by Wind Industry With Local Communities

We firmly believe that the wind industry is a keen advocate of the 'mushroom management' approach i.e. feeding us s**t and keeping us in the dark. The wind industry to date has, we believe, paid scant regard to the needs and aspirations of local communities throughout Northern Ireland. Proposals to construct wind farms in rural locations have been known to cause significant disagreement, even within families and closely knit communities; that damage cannot be underestimated or realistically quantified in monetary terms. The so called community benefits paid by the wind farm developers to local community projects should be viewed as nothing other than 'sweetners' and are a short term benefit for the long term inconvenience and loss of amenity that the local communities will suffer.

As a result of the tireless work by a number of committed individuals rural communities throughout Northern Ireland are becoming increasingly aware of the divisive manner in which the wind industry operates and are only too aware that those who will suffer most from wind farm developments are the ones least likely to benefit from the 'sweetner' grants. The market value of properties within 2000 metres of any wind farm will be zero as the general public are now acutely aware of the adverse health impacts that are associated with wind farms. This is far too high a price to pay and is in fact a significant economic disadvantage that far outweighs the grossly over inflated benefits to our rural communities that the wind industry try to make us believe accompany wind farm development.

Propaganda spread through our newspapers, television programmes and limited community consultation events refer to the significant numbers of homes that new wind farms will supply and the numerous jobs that will be created. The propaganda claims, we believe, are grossly over inflated presumably in an effort to hoodwink us into believing that wind energy is the be all and end all. The propaganda fails to highlight the fact that not one fossil fuel fired power station in Northern Ireland will be closed as a result of our over reliance on unreliable wind energy. The simple reason for that is that when the wind does not blow the wind turbines will not generate electricity and consumer reliance for electricity generation will revert to the fossil fuelled power stations.

In the Omagh area we have found so called community engagement events or public information days to be extremely badly advertised by the wind industry; we believe that that is a deliberate tactic. Planning applications are submitted to coincide with traditional holiday periods presumably on the assumption that potential objectors will be too busy with other business and therefore less likely to object at such times. A minimum neighbour notification requirement should be that details be placed in all local newspapers of forthcoming community engagement events/public information days and that all households within a 2000 metre radius of a proposed wind farm should be notified individually in writing too. The current practice of leaving wind farm application details in the local Planning Office and Library quite simply does not suit those who work full time and particularly rural dwellers who are forced to commute considerable distance to work on a daily basis. Hard copies of wind farm planning applications must be provided for all stakeholder groups within say a ten kilometre radius of aproposed wind farm site. We have found information provided in EIA's to be misleading and believe again that that is a deliberate tactic on the part of the wind industry and their agents in an effort to reduce the likely level of local opposition to proposals.

Concise community engagement standards need to be introduced and strictly adhered to when all wind farm or single wind turbine planning applications are being considered. The onus should be on the applicant to prove to Planning Service that he/she/they have met those standards prior to issue of any determination by Planning Service.

General Issues of Importance

The decision by Minister Atwood to increase Northern Irelands' target for renewable energy production from 20% to 40% by 2020 was not, we believe, a decision that was taken on the back of meaningful consultation with Assembly colleagues or the general public and that is a real concern for us. Given that the United Kingdom and Northern Ireland signed up to an agreement to produce 15% of energy from renewable sources by 2020 what was the motive for Mr Atwood's decision? The British Government has at last realised that wind energy is not the energy solution they were led to believe it was by the wind industry and has decided to opt for nuclear power generation in order to be confident that future power demand can be met.

We believe that a full and substantive option ranking exercise was not undertaken and that the Northern Ireland target of producing 40% of its energy requirement from renewable sources by 2020 is neither sustainable nor realistic. Subsidies to the wind industry by way of ROC payments for the three years to 2013 totalled 142 million. It is likely that that level of subvention to the wind industry from the public purse could have yielded a much better return had it been invested elsewhere. Had that money been paid to households for example to enable them to upgrade the insulation standards in their homes it could have yielded a much greater benefit in the form of reduced energy demand and ultimately cost to the householder. Experience suggests that such savings would be disposed of in other ways by households to the overall benefit of the economy. Much needed employment could have been created in our beleaguered construction sector, demand for insulation materials and energy efficient windows and doors from Northern Ireland manufacturers could have arose with consequential increase in demand for labour and resultant increase in revenue flow by way of income tax and VAT to the Exchequer. Improved insulation standards in the residential sector could also go some way to addressing Northern Irelands' growing fuel poverty crisis that is due to rapidly spiralling electricity costs.

The energy performance standards specified for new homes in Northern Ireland needs to be significantly increased, that again would make a significant contribution towards reducing the requirement for heat and power, address the fuel poverty issue and ultimately reduce CO2 emissions. Other innovative and even risk taking measures need to be considered and potential savings quantified. Could alternate street lights for instance in our built up areas be switched off between the hours of 1.00am and 6.00am on week nights and if so what saving could that yield to the public purse. It is essential that we think smart and laterally if we are to make significant inroads to the reduction in energy demand.

The attached Appendices A-C detail a number of links that we believe should also be considered during the conduct of the Inquiry

We trust that our comments above will be considered fully by the Committee for the Environment in the conduct of their Inquiry and we will be very happy to make oral representations if required in due course.

Yours sincerely

Owen McMullan
Chairman

Appendix A

Schedule of Relevant Links

1 Daily Telegraph "Rising Energy Costs Contributed to 31,000 winter deaths in England and Wales in 2012/13. www.telegraph.co.uk/health/10474966/energy -row -erupts -as-winter-deaths-spiral-29-per-cent-to four-year-high-of-31000.html

2 German Government Report: Scrap All Green energy Subsidies. www.quixoteslaststand.com/2014/02/27/german-government-report-scrap-all-green-energy-subsidies

3 Do Wind Farms wreck Lives? Stephen Moss Investigates/Environment/The Guardian. www.guardian.co.uk/environment/2007/may/24/energy/communities

4 14,000 Idle Wind Turbines A testament To Failed Energy Policies. www.thenewamerican.com/tech/energy/item/15069-14-000 idle-wind-turbines-a-testament-to failed-energy-policies

5 ASA bans house price claim in wind farm leaflet- Utility Week. www.utilityweek.co.uk/news/asa-bans-house-price-claim-in- wind-farm-leaflet/981802#. Uw9AZ38gGSO

6 EU Green Energy law is Flawed – Adviser to EU Top Court. www.mobile.reuters.com/article/idUSBREAOR10620140128?irpc=932

7 DOE Planning Statistics on Renewable Energy 2014. www.doeni.gov.uk/renewable-energy-applications-jan14.xls The planning approval process for wind energy planning applications appears to be a rubber stamping exercise

8 CIVITAS Electricity Costs: The Folly of Wind Power - Ruth Lea. www.civitas.org.uk/economy/electricitycosts2012.pdf

9 The Green Mirage by John Constable. www.civitas.org.uk/economy/GreenMirage.pdf

10 Derrybrien, Gort, Co Galway - The Struggle of a small rural community to have its voice heard. www.woodlandleague.org/communities/deerbrien/H18

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Appendix B

Schedule of Relevant You Tube Features

1 Wind Turbine Failure – You Tube. www.youtube.com/watch?v=OovHFTSBQ54

2 Wind Turbine Destruction- You Tube. www.youtube.com/watch?v=KCR0N2NGLY1

3 Wind Turbine Syndrome, a Matter of bad Prevention. www.youtube/Rm1b11YCwWg

4 Windwatch Tyrone on You Tube:

Michael and Dorothy Keane from Co Roscommon
West Tyrone Movie
The McGlinchey Story

Appendix C

Schedule of Relevant Web Sites

1 www.windwatch.co.uk

2 www.epaw.org

Hi Sheila,

Please find attached Addition No.16 to our Submission by West Tyrone Against Wind Turbines on Wind Energy. This is our final Additional to our main Submission which addressed the points in the Inquiry.
Here we address the issues on "community benefits".
I would be grateful if you could acknowledge receipt of same.

Yours sincerely,

Owen McMullan, Chairman, West Tyrone Against Wind Turbines,

Omagh/Strabane Council Report on Community Benefits from the Wind Industry

- West Tyrone Against Wind Turbines (WTAWT) represents the interests and articulates the views of those communities, families and individuals in Omagh and Strabane Districts that are adversely affected by proposals to construct large commercial wind farms too close to their homes.

- WTAWT believes that both Omagh and Strabane District Councils are being exploited by the wind industry and that they are being used as a platform to promote the wind industry's interests at the expense of those in the rural communities. In addition, WTAWT believes, that the wind industry should pay publicly-elected representatives and rural communities throughout West Tyrone due respect by making them aware of full the impact that commercial wind farms will have on their rural communities.

- The term "Community Benefits" used by the wind industry is a glossy term for what economists call "motivation crowding" where external intervention through monetary incentives is used to undermine intrinsic motivation (in the case of wind farms to limit objections to proposals).

- Is the fact that the wind industry is prepared to pay meagre sums to community projects within eight miles of their wind farms an admission on their part that their wind farms have significant detrimental effects upon the rural environment, its inhabitants and its flora and fauna?

- WTAWT believes that the ultimate objective of the community benefit payments made by the wind industry is to muster support from those living further away from the wind farm hazards whilst at the same time isolating the lesser number living closest and most affected by shadow flicker, infrasound, loss of amenity and property devaluation etc. etc.

- Wind energy was supposed to result in lower electricity charges for consumers; the opposite is the case with 40% increase in the recent past. Consumers (commercial and residential) are the ones who are ultimately compelled to meet the cost of the unsustainable ROC subsidies and meagre community benefit payments made by the wind industry. What affect will these substantial energy cost increases have on Northern Ireland's burgeoning fuel poverty crisis and industry decisions to relocate elsewhere abroad where energy costs are lower?

- WTAWT believes that all commercial wind farms currently operating in Northern Ireland are doing so in contravention of EC legislation. It is an EC requirement (Aarhus Convention) that full and meaningful community consultation is completed and that member state governments carry out independent Environmental Impact Assessments (EIA's) prior to approving major strategic infrastructural projects.

- WTAWT also believes that EIA's submitted for current wind farm projects at planning application stage generally play down the adverse effects of proposals on the visual amenity of rural areas and the detrimental effect upon rural communities and their environment and bio diversity.

- The term "wind farm" applies to a single turbine or a group of two or more turbines with a hub height in excess of 15 metres. The recent exponential growth in planning applications by individuals for approval to erect 225kw wind turbines all fall within the requirements to have EIA's completed. WTAWT believes that Planning Service is not adhering to that requirement at present and planning approvals are being issued in contravention of legislation.

- No matter what level of community benefit is paid by the wind industry it cannot adequately compensate for the massive negative impacts such as sleep deprivation due to exposure to infrasound and the many associated health issues that are triggered by sleep deprivation. There is significant peer reviewed evidence in an article (Hanning & Evans) that appeared in the British Medical Journal that highlights the health related effects of sleep deprivation.

- It should be noted that the Environmental Health Departments of Omagh and Strabane District Councils do not have the equipment or staff suitably qualified to carry out infrasound checks. Rural communities are at the mercy of the wind industry.

- Legislation governing wind farms was introduced (ETSU-R-97) and was to be reviewed within two years. That legislation is now obsolete; not fit for purpose and in urgent need of renewal as the size of wind turbines has increased significantly in the intervening period.

- A representative of a wind farm company recently stated at a so called community engagement event in Gortin that there were no health issues associated with wind farms. Propaganda material circulated at that very same event by the wind farm operator was found to be inaccurate; several objections lodged by the Lisnaharney Action Group to the Advertising Standards Authority were upheld.

- WTAWT believes that claims about job creation and the number of houses that proposed wind farms will supply are grossly exaggerated, no proper breakdown of the methodology used to calculate the job creation and housing supplied statistics is ever given. NIREG states that there 1300 people are directly employed by the wind industry in Northern Ireland whereas DECC figures state there are 239 jobs - a substantial difference. Who should the general public believe?

- WTAWT believes that Northern Ireland is over reliant on wind energy at a time when other European countries are abandoning or scaling back considerably their on shore wind energy programmes. DECC Report 2012 stated "Wind energy is not delivering as the UK only achieved 0.96% of electricity from on shore wind" That energy cost £1.2 billion in 2012.

- Every wind turbine requires 2 tonnes of rare earth elements. The production of that 2 tonnes creates 2000 tonnes of mine tailings many of which are highly toxic and radioactive; storage of such tailings requires a special licence in the United States. Rare earth elements are mined is several countries that have very poor environmental policies. The overall effect of rare earth elements on the global environment needs to be considered.

- There are a number of significant non-quantifiable adverse effects directly attributable to the operation of wind farms namely:
    - Property devaluation and resultant loss of rates revenue for local government
    - Fall in rural tourism as has been evidenced in Scotland and Cornwall
    - Acrimonious splits in rural communities and even within families
    - 3.7 jobs lost for every one renewable energy associated job created (Verso Economic Study in Scotland)
    - The loss of CO2 retention capacity where wind farms are built on areas of raised bog-land
    - Forest clearance to make way for wind farms
    - Exposure of rural communities to accidents. There have been 1500 reported accidents to date (Renewables UK statistics) some of which were fatal. Insurance industry statistics indicate that every turbine has a major incident every four years. Government held Health & Safety information has reported parts of turbines flying up to 1600 metres
    - Adverse impact on livestock profitability. The Irish Bloodstock Industry has highlighted their grave concern about the adverse impact of wind farms on their sector, the value of which is 1.1 billion euros annually to the Irish state.

West Tyrone Against Wind Turbines

From West Tyrone Against Wind Turbines

Introduction

The Consumer Council is asked to consider the current situation in Northern Ireland regarding the wind industry. National Policy favours the development of wind farms, and excludes a proper evaluation and critical analysis of the sustainability of wind farms. There is a substandard analysis of their impact on the receiving environment, their impact on public health, (noise related); their potential to undermine the local economy through loss of visual amenity, property devaluation and the potential for tourism development. Consideration should also extend to the weighting given to wind farms over other "alternative forms of energy", and the potential for this in the long term to undermine economic viability.

These aspects will all be given a brief exploration in the course of this submission.

ENVIRONMENT

The term environment has a broad base interpretation. What essentially is described here is the interrelationship and interdependence of human beings; flora and fauna; land and water; air climate etc.

The requirement to describe the impact of the development is set out in EU Directive 85/337/EC, commonly known as the EIA Directive. Article 3 of the Directive says: "*the environmental impact assessment shall identify, describe and assess in an appropriate manner in the light of each individual case and in accordance with Articles 4-11 the direct and indirect effects of a project on human beings, flora and fauna, water, climate etc. resulting from the proposed project."* It also requires a description of the likely significant effects of the proposed project on the environment.

NOISE AND HUMAN HEALTH

In the case of wind farm development the impacts of noise, including low frequency noise and infrasound on human health has become increasingly an issue of concern. This situation is largely brought about by the relatively recent development of large-scale industrial wind farms close to human habitations. Dr. Christopher Hanning the UK leading specialist on sleep deprivation, and Professor Alun Evans, published a peer-reviewed editorial on the effects of wind turbine noise on human health in the British Medical Journal in March 2012. Among the concerns raised in that editorial were the effects of sleep disturbance, and in particular infrasound and low frequency noise on affected residents. Identified symptoms included nausea, headaches, irregular heartbeat, and the possibility of disruption to the endocrine pathways of the body.

The Shirley Wind Project Low Frequency sound study that was partly sponsored by the Wisconsin Public Service Commission, found sufficient evidence to classify low frequency sound and infrasound emanating from turbines as a serious issue for public health. This study was published in December 2012 and perhaps most alarmingly, found that some homes affected were over 3 km from the operational wind farms. According to Dr Hanning a minimum safe distance from large industrial turbines, is 1.5 km, if one is to avoid the negative impacts of infrasound. While it is argued by the industry that inaudible sound cannot affect a human being, research carried out by NASA in the 1980s came to different conclusions and Dr. Salt of Washington University has recently published his own study adding weight to this theory, that wind turbine noise, low frequency and infrasound does affect the human body.

The existing guidelines and the methodology used to establish noise levels and undertake noise assessment for wind farms is now much discredited; of course it does not include an assessment for infrasound and low frequency noise emanating from turbines because the industry continues to ignore this inconvenient truth. The existing guidance used in Northern Ireland is not evidence based, and indeed is contrary to the best evidence. Of particular concern is the use of fixed limits or setback distances without consideration of individual local circumstances and therefore cannot provide a measure of the significance of the impact of noise.

When a new noise source is introduced into a quiet area the residents are used to their familiar noise environment and the new noise is highly perceptible. A noise assessment must therefore be clearly related to the existing situation or a baseline noise survey. Regard must be had to the methodology to be used in the assessment and the technical process needs to be translated into a measure of the significance of the impact of turbine noise, guidance is required for the specific assessment of low frequency noise, tonal noise and amplitude modulation.

The suggestion that a level of 45 dBa for example is considered appropriate to provide protection to people living within the footprint of the wind farm is seriously flawed. Not only is it unsupported by evidence but evidence generally suggests that this assertion is unsupported in rural areas where after all most wind farms are sited. The World Health Organisation Guidelines published in 2009, show that this level is 5 dB above the level required for restoration of sleep. At this time the WHO recognized environmental noise as a source of concern for public health. Unfortunately it did not address wind farm noise at this time.

FLORA AND FAUNA

EU Council Directive 92/43/EEC on the conservation of Natural Habitats and Wild Flora and Fauna known as the Habitats Directive sets out to protect species and habitats across a network of sites in the European context known as Natura 2000 and includes sites classified under Directive 79/409/EEC on the conservation of wild birds, The Bird’s Directive.

The development of wind turbines in areas of peat in particular is highly destructive to a priority habitat; despite the status of blanket bog and upland montane blanket bog, a staggering percentage of wind farms in Northern Ireland are located in these highly sensitive eco systems which also provide a host habitat for a wide range of protected species of flora and fauna. Resulting from developments in these areas are the direct and indirect impacts on hydrology. The hydrology of these sites is necessary for the maintenance of this eco system and extremely vulnerable to alteration. The effects on local and surface ground water include the infiltration of sediment peat and other pollutants . This can come about in a number of ways with the main effects due to increased run off from paved surfaces for roadways and hard standing areas etc associated with the development of the wind farm. Sediment and peat which finds its way into local water courses will affect the spawning grounds of salmon and trout and in some instances the fresh water pearl mussel; which is totally intolerant to any diminished quality of the water. An additional impact on all of these three species is increased flow rates associated with increased run off and temperature change.

Among the avifauna species directly impacted by wind turbines built in these areas are hen harrier, golden plover, merlin, curlew and migratory speciesof the whooper swan, white fronted geese etc. Bats are also vulnerable to wind farm developments and a high attrition rate has been recorded for bats at wind farm sites throughout the British Isles. One factor, which is a likely cause, is the sudden drop in air pressure that causes multiple organ failure in bats, this is associated with the vacuum created by the rotating blades. All the species mentioned are protected under the provisions of 79/409/EEC. While salmon and native brown trout and fresh water pearl mussel are listed for conservation under the Habitat's Directive 92/43/EEC.

MONTANE PEATLANDS

Peat lands are a rich and diverse habitat listed as a priority habitat for the whole island of Ireland. What is not often appreciated is their role as a natural carbon sink and the role that peatlands play in regulating the environment, acting as a natural filtration system for water and controlling run off in heavy rain falls. It makes no logical sense to develop wind farms in such habitats, on the basis that these are "green projects". Once the peat is disturbed it will dry out and die, releasing the stored carbon.

Member States of the EU are committed to measures halting the loss of biodiversity throughout the community and governments have been directed to reinforce their national legislation if necessary to meet this commitment. By allowing these developments in these sensitive environments leading to the loss of habitat and the displacement of species, we are going in the opposite direction.

The impact significance is a combined function of the value of its affected feature, its ecological importance, the type of impact and the magnitude of the impact. It is necessary to identify the value of ecological features in order to evaluate the significance and magnitude of possible impacts. Unfortunately in Northern Ireland there is no systematic evaluation of ecological importance below the level of designated sites, and furthermore this evaluation tends to be biased in favour of wind farms. Council Directive 85/337/EC as referred to earlier has been found wanting in regard to the appropriate benchmarks used to establish the level of assessment required for these projects and in the case of human beings while noise and socio economic factors are included in the criteria it has not been considered appropriate that the Directive addressed issues of public health in practice. This has provided a loophole with the consequence that this area is not being properly addressed and not only in relation to wind farm developments but other large-scale developments that can impact on human health and well being.

MATERIAL ASSETS

Landscape and visual amenity are important material assets to the fabric of the Northern Ireland economy allowing large scale industrial developments of wind farms in areas of natural beauty can only be described as a retrograde step in establishing the Province as an attractive and relatively unspoilt area for tourists to visit. In the majority of cases even domestic dwellings would not be allowed permission in some of these locations, yet the justification for wind turbines is based on the premise that these developments will provide green alternative energy and therefore are in the interest of the greater good. A proposition that has not been substantiated by any critical analysis and detailed evaluation of the actual carbon footprint of these developments, their impact on the receiving environment, issues of public health concern associated with noise related impact, their effect on flora and fauna, the devaluation of property and the psychological imprint for local residents of drastic landscape change.

POLICY CONTEXT

Against all of that, no quantitive analysis of the actual input of wind into the national grid which on review of the figures for Northern Ireland shows a relative annual average of less than 33% of their installed capacity.

The fundamental principle of power generation is that ‘supply must meet demand’ as wind power is intermittent and therefore an unpredictable source of power it requires a spinning reserve of conventional power plants. With these power plants in idling mode they generate greater levels of emissions than if working at full capacity. The grid operator must have a standby that can be brought into production at 30 seconds notice. On this basis any projected savings on carbon emissions associated with wind generation is lost. There is also the increased cost factor, and consumers are asked to pay for that via a levy on their bills.

CONCLUSION

Wind cannot therefore be described, as an “alternative source of energy” as it is intermittent, and unpredictable, and undermines the fundamental principle of ‘supply must meet demand’. The long-term objective of placing an increased emphasis on wind power and its increased presence on the grid undermines the viability and stability of the national grid and therefore its dependent consumers. This has the potential to seriously impact on the local economy in the future and its ability to function. This is a very serious issue that has not been addressed by government. The dependency of the wind industry on subsidisation that is paid for by the consumer is an unacceptable state aid to an industry that cannot sustain itself without public support. In circumstances where this industry is foisted on the public without the public’s participation in the development of policy as under the Aarhus Convention, the environmental and economic cost of such a policy must be seriously questioned. And the point is made again that no critical analysis of the contribution of wind power or its wider environmental impact has ever been carried out. No evidence base has been established to support its dominant position. Setting aside of convention in national policy where the range of cumulative impacts is on such a scale and where the integrity and long-term viability for a functioning society and the natural environment, is highly questionable and must be addressed.

HSE

Health and Safety Executive

Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines

Prepared by **MMI Engineering Ltd**
for the Health and Safety Executive 2013

RR968
Research Report

Health and Safety
Executive

Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines

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Wind power is becoming an increasingly significant contributor to the UK energy mix and a significant proportion of this is onshore. Onshore wind power generation ranges from large utility scale wind farms, through medium size brownfield type developments, to the small end domestic wind power generation. Although HSE is only a statutory consultee for developments of 50 MW or larger, HSE is often approached for advice on new wind developments at all scales. A number of organisations have previously provided risk assessments for wind power developments, but these are normally bespoke to a particular application.

The work presented in this report has two main components. Firstly, research has been carried out to determine publicly available data for wind turbine failures and failure rates. Data has been drawn from a number of sources, including: HSE incident reports, a trade association, a renewable energy research organisation, web-based literature and published papers. The second component to the work has been to develop a 'standard' methodology for the risk assessment of harm to people from wind turbine failures. This methodology produces contours of probability of harm, and fatality by direct and indirect impact of thrown wind turbine blades or blades fragments. The contours produced by the methodology may be assessed as Location Specific Individual Risk when they are combined with the frequency of failure of the wind turbine.

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HSE Books

First published 2013

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Nick Summers, Health and Safety Executive

CONTENTS

EXECUTIVE SUMMARY

In order to support its responsibilities for health and safety the HSE commissioned MMI Engineering Ltd (MMI) to carry out this study to determine risks to persons in the vicinity of wind turbines. The aims of the study have been two-fold:

- To carry out a literature search and industry survey to locate publicly available data which could be used reliably to develop failure rates for wind turbines; and,
- To produce a methodology to assess risk presented to persons from wind turbines. This methodology would be general in its format so that it could be applied to a wide range of cases.

The literature review carried out has been wide ranging, using academic search engines in addition to web-based searches and liaison with a renewable energy industry professional and trade body. The literature search has confirmed that there is no readily available database meeting HSE's requirements for recording wind turbine failures. However, there are a number of sources of data which are potentially of use to determine failure frequencies.

To provide further information on wind turbine failures, MMI has collaborated with the US National Renewable Energy Laboratories (NREL, part of the US Department of Energy). NREL has provided further information on aspects of wind turbine design, construction operation and failure, which is included in this report.

Several strands of development have been required to create the methodology for risk assessment for persons in the vicinity of onshore wind turbines. These have been the development of a "human vulnerability model" and a "harm transmission model" which have been brought together in the risk assessment methodology.

The human vulnerability model has been developed from literature searches and data on the vulnerability to persons from airborne debris. Wind turbine failure can take a variety of forms but the assumption is made that a typical structural failure generates a range of debris sizes, masses and velocities. Human vulnerability to impact from debris falls into two broad categories: (i) direct impact: the debris from the failed turbine follows a trajectory and makes contact with one or more people; (ii) indirect impact: debris from the failed turbine follows a trajectory and makes contact with an enclosure housing one or more occupants; the enclosure then fails in some manner, collapsing onto the occupants. Furthermore, debris may be considered falling into two types: (i) smaller debris impacting specific parts of the human body, associated with penetrating and cutting type injuries (fragment impact), and (ii) larger debris impacting the whole body, associated with non-penetrating crushing and tearing injuries (blunt trauma). Categorising the impact and debris in this way has allowed the definition of debris energy levels which will cause fatality due to direct impact or indirect impact.

The harm transmission model is the application of Newton's second law of motion modified for the effect of drag and wind. A number of references have been found in the literature search that use a similar approach. Although wind turbine blades have an aerodynamic, lift-generating profile, the lift force is not included in the harm transmission model and this limits the potential throw distance. This is a reasonable approach as aerodynamic bodies must be held in a particular orientation for lift to be effective, whereas debris from a wind turbine failure is likely to tumble.

The risk assessment methodology developed in this work has used the results of the human vulnerability and harm transmission models to calculate contours of probability of "harm" - i.e. the probability of impact of debris at a specific location, and contours of probability of fatality due to direct and indirect impact. The calculated probability of fatality due to direct or indirect impact can be considered as a *conditional* Location Specific Individual Risk (LSIR). (ie conditional that wind turbine blade failure has occurred). Thus, by multiplying this conditional probability of fatality with the known or estimated frequency of failure of the wind turbine blades, a Location Specific Individual Risk may be obtained.

The methodology uses a Monte Carlo model to assign random values with user-specified data distributions to the variables which determine the trajectory of debris (blade fragments) thrown from a failed wind turbine. The algorithm generates a large number of instances (typically 10^6) of the variables set which provide the set of fragment trajectories required for statistical assessment.

This methodology, has been coded in an Excel spreadsheet using VBA scripts. The programme is operated by a series of GUIs which allow the user to specify wind turbine design detail, information on the blade fragment to be calculated, meteorological data and control over the number of calculations in the Monte Carlo method and results presentation.

The methodology has been applied to a case study to determine probabilities of fatality by direct and indirect impact of failed blades from a 2.3 MW turbine. Sensitivity studies are carried out and the results of the analysis are converted to LSIR and compared with other societal risks. The outcome of this comparison shows that for a single 2.3MW turbine the risk of fatality from impact of a failed turbine blade or fragment is low.

1. INTRODUCTION

The UK has a legally binding target set through the EU Renewable Energy Directive to generate 15% of energy demand from renewable sources by 2020. This is equivalent to a seven-fold increase in UK renewable energy consumption compared with 2008 levels [1]. Wind power is an increasingly important part of the UK energy mix and according to modelling by the UK Department for Energy and Climate Change onshore and offshore wind may account for 30% of the UK's energy mix by 2020 [1]. There are currently 267 onshore wind farms in the UK producing 3,848 MW of electricity; compared with 13 offshore wind farms producing 1,341 MW. There are a further 220 (4,756 MW) onshore wind farms under construction or consented; and 11 (3,750 MW) offshore. It is clear from these figures that although offshore wind farms typically have larger per farm generating capacity, onshore wind currently provides the greater proportion of wind power (availability issues aside) and will do for the foreseeable future.

The HSE is a statutory consultee for all onshore wind developments with > 50 MW generating capacity. This is in addition to HSE's role in investigating incidents where there has been harm, or the potential for harm, to persons in the vicinity of wind farms. This includes both workers and the general public and given the increasing number of wind power schemes proposed, the potential for harm to persons needs to be well understood.

Currently there is no comprehensive, publicly available, database containing details of real life occurrences of wind turbine failures that includes accurate measurement of throw distance, fragment size and details of the wind turbine model. A number of wind turbine manufacturers, operators, research organisations, trade associations, public forums and pressure groups have compiled separate databases for wind turbine failures worldwide. However, much of the data compiled by manufacturers, operators, research organisations and trade associations is proprietary or confidential due to the nature of the failures, public concerns and manufacturers' business concerns. Wind turbine data compiled by pressure groups may be unreliable and is often only partially complete. In these cases failure databases are often based upon estimates from eyewitness testimony or un-validated reports, rather than accurate measurement of distances. Throws are often not distinguished between full blade throw and fragments, and fragment sizes are typically not given.

Consequently the HSE do not currently have a database of wind turbine failures on which they can base judgements on the reliability and risk assessments for wind turbines.

In determining risk to workers and the general public, a number of organisations have produced risk assessments for wind turbine operation. These tend to be tailored to specific needs: e.g. land use planning applications in different countries, potential for impairment of power lines or gas transmission pipelines and other buried services, or potential for impairment to neighbouring sites with particular safety concerns (e.g major accident hazards installations). Typically, the risk assessments employed in these studies are bespoke to the application, and contain a number of site specific or "worst case" assumptions. They are typically not sufficiently general and not publicly available for use as a general risk assessment tool for wind turbines or to recommend in an advisory capacity to planning authorities, developers, etc.

Hence HSE commissioned MMI Engineering Ltd to produce the current report to satisfy two aims:

- Carry out a literature search and industry survey to locate publicly available data which could be used reliably to develop failure rates for wind turbines.
- Produce a methodology to assess risk presented to persons in the vicinity of wind turbines. This methodology would be general in its format so that it could be applied to a wide range of cases.

It has been understood from the outset of the work that the existing fleet of wind turbines is relatively young, that manufacturers tend not to publicise failure data and consequently that the amount of available data on which to base and validate the methodology is sparse. The approach has been to produce a methodology that produces a "cautious best estimate" of risk to persons in the vicinity of wind turbines and in parallel, recommend areas where data needs to be developed.

This report describes the work carried out in the project to meet these aims. Section 2 describes the literature search and industry survey to determine data for a failure database and failure analysis of wind turbines. The industry survey has been carried out in collaboration with the National Renewable Energy Laboratories (NREL), part of the US Department of Energy. Section 3 describes the investigation for human vulnerability models. The human vulnerability model is required in the risk assessment methodology to determine the energy required by a fragment to cause injury or death to persons - the fragment being projected as a result of a wind turbine failure or collapse. Section 4 addresses the harm transmission modelling. Fragments projected from a failed wind turbine are the source of potential harm to persons in the vicinity of the wind turbine. Their "transmission" is essentially an application of Newton's laws of motion to determine where the fragment will be projected. There are a number of variables affecting the fragment's flight, such as mass of the fragment, initial velocity vector, wind conditions, drag, etc. These are incorporated in a Monte Carlo analysis to determine the probability of a particular fragment landing at a particular point from the wind turbine. The risk assessment methodology itself is described in Section 5; the methodology combines the output of the human vulnerability model and harm transmission model to determine risk contours around a single wind turbine's location. The methodology itself has been coded in Microsoft Excel using VBA scripts and is run via a GUI coded in Excel. The work is concluded in Section 6, with additional information provided in Appendices.

2. FAILURE DATABASE AND FAILURE ANALYSIS

2.1. LITERATURE SURVEY

Methodology

A broad-ranging literature review has been carried out, using both internet and two academic search engines (Science Direct, Scopus) to find sources of data for wind turbine failures. The material identified fell into the following categories:

- Pressure group databases, news items and reports
- Peer reviewed papers in academic journals and papers presented at conferences
- Reports by government agency and agency-funded bodies reports (UK, US)
- Books on wind energy
- Video of wind turbine failures
- Research theses

Following the literature review, each item was graded: 1 (directly relevant to scope of study), 2 (supporting information) or 3 (background information) and a synopsis was prepared for each item. The full database [2] has been provided separately to HSE.

A review of the material was carried out on the following topics:

- Reported blade failures and estimation of failure frequencies
- Wind turbine subassemblies and failure modes
- Failure frequencies for subassemblies
- Incident reports and fragment distribution data

A synopsis for each of these categories is provided below.

Reported Blade Failures and Estimation of Failure Frequencies

No freely available industry database has been located worldwide which gives the failure frequency for blade detachment or fragment generation, although such data for subassembly failure are available and are discussed below.

Generally the failures of wind turbines discussed in published literature are divided into three scenarios: blade breaking off, fall of rotor/nacelle and failure of mast/tower. In his work for the California Wind Energy Collaborative, Larwood [25] provided an excellent review of published wind turbine failure rates. This review is summarised and shown in Table 5 (Section 4.2) with the discussion of data used for the development of the harm transmission model of the risk assessment methodology.

Results of a previous study were provided to MMI by HSE. They describe failure frequencies for three accident scenarios associated with blade detachment but it is unclear how these values are derived. Should it be necessary to determine an independent blade failure rate, an example of an estimation of the order of magnitude of blade failure frequency is provided in Appendix A.

Wind Turbine Sub-Assemblies and Failure Modes

Wind turbines are classified into subassembly systems. In addition to the tower and support structure, the nacelle (shown in Figure 1) has a number of systems which, if they fail, may ultimately lead to blade throw. The blades, rotor hub (item 5), gearbox (item 8) and brake (item 9) are part of the system that maintains the physical integrity of the WT and controls the rotation speed of the system between safe operating parameters.

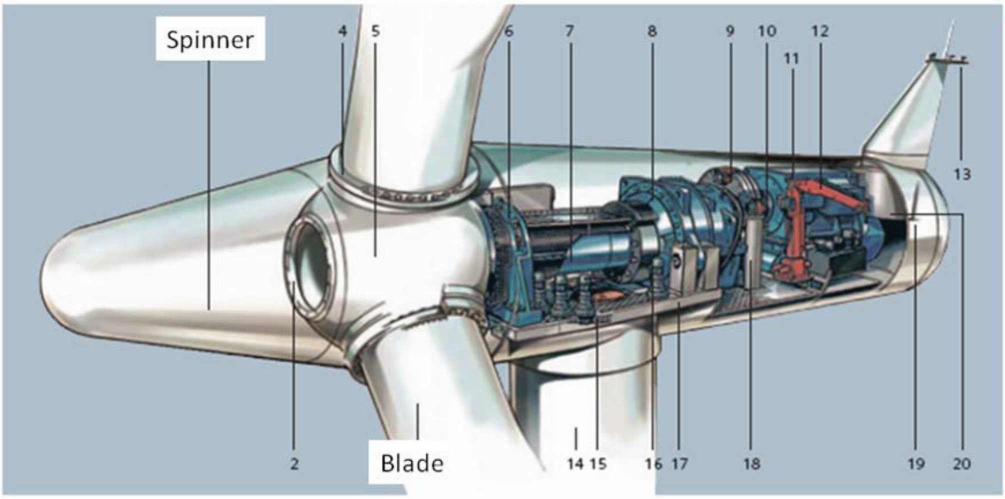


Figure 1 Wind turbine subassemblies and components (modified from Siemens brochure [36])

Wind turbine downtime is generally reported as a function of subassembly classification. Different countries use different terminologies for each subassembly as described by Tavner [3] and repeated in Table 1. Other classifications of terminology have also been used e.g. by Spinato [4]. It is recommended that any future analyses of data or use of subassembly failure rate data also includes a review for consistency of the subassembly classifications used.

Fatigue resistance of wind turbine subassemblies is an important aspect of preventing structural failure of one of more of the subassemblies that might lead to blade throw. Partial safety factors can be used to determine an optimum design for a target failure probability. For the components given in Table 2, Veldkamp [5] identified the different types of loads on four subassemblies causing structural failure (and likely to lead to blade throw). A number of environmental factors (e.g. wind speed, turbulence) and wind turbine operating parameters (control system, aerodynamic parameters) influence the calculation of fatigue, and highlight the importance of the use of data specific to a wind turbine class. It also is possible that the characteristics of the fragment size and velocity distribution released during a blade throw are linked to the type of load that is applied. As part of future analyses of incidents, it may be appropriate to identify the load type that caused failure and to correlate it with the fragment size and distribution.

Table 1 Wind turbine subassembly names [3]

Subassembly name	*Subassembly name used in Germany*	*Subassembly name used in Denmark*
Rotor blades	Rotor	Blades, hub
Air brake	Air brake	Air brakes
Mechanical brake	Mechanical brake	Mechanical brake
Main shaft	Main shaft	Main shaft, coupling
Gearbox	Gearbox	Gearbox
Generator	Generator	Generator
Yaw system	Yaw system	Yaw system
Electrical controls	Electrical controls	Electrical control
Hydraulics	Hydraulics	Hydraulic control
Grid or electrical system	Electrical system	Electrical control
Mechanical or pitch control system	Mechanical control	Pitch Control
Other	Other, instrumentation, sensor, windvane	Other

Table 2 List of components, loads acting on it and consequences of failure [5]

Component	*Load causing failure*	*Consequences*
Blade	Edgewise moment Flapwise moment	One blade fails and is destroyed.
Hub	Edgewise moment Flapwise moment	The hub fails and is destroyed: the rotor (hub and blades) falls down.
Machine frame	Driving moment Tilt moment Yaw moment	The machine frame (nacelle) fails and is destroyed: the rotor (hub and blades) falls down.
Tower	Tower base side-side moment Tower base fore-aft moment	The tower fails, and the entire wind turbine collapses

Failure Frequencies for Subassemblies

A large body of subassembly reliability data exists and has been gathered over more than 10 years by the WindStats initiative [6]. The data are predominantly for German and Danish wind turbines although data for other countries is also included. The data extracted from WindStats by Ribrant [7,8] are summarised in Table 3.They can be used to give quantitative values of failure frequencies for the subassemblies associated with fragment throw following blade damage. Note that the >15 year German data are very similar to those presented by Hahn *et al.* [9] and are assumed to cover the same 15 year period and over 35000 reports of failures.

Table 3 Failure rates per year for wind turbines [6]

Subassembly	***Swedish data [8]***	***German data [8] (04-05)***	***German data [8] (> 15 years) (1)***	***Finnish data [7]***
Entire unit	0.011	N/A		0.00
Structure	0.006	0.07	0.09	0.09
Yaw System	0.026	0.13	0.18	0.10
Hydraulics	0.061	0.21	0.23	0.36
Mechanical Brakes	0.005	0.10	0.13	0.04
Gears	0.045	0.12	0.10	0.15
Sensors	0.054	0.16	0.24	0.12
Drive Train	0.004	0.05	0.05	0.00
Control System	0.050	0.26	0.41	0.10
Electric system	0.067	0.49	0.55	0.11
Generator	0.021	0.05	0.10	0.08
Blades/Pitch	0.052	0.22	0.17	0.20
(Rotor) Hub	0.001	0.01	0.11	0.01
Other	N/A	N/A	N/A	0.06
Unknown	N/A	N/A	N/A	0.03
Total failures per turbine	0.4	1.9	2.4	1.4

Note that these data are reported as downtime per subassembly and no detailed information is given on the type of failure. The focus of these studies is on establishing the mean time between failures, and defining methods for reducing downtime via preventative maintenance, as linked to condition monitoring, rather than establishing the failure rates for subassemblies with the potential to cause harm. The failure mode and failure rate data are dependent on the type and age of the wind turbine, as well as other factors (e.g. weather conditions).

Failure frequencies and other data can be used in conjunction with event tree analysis and reliability methods to calculate overall WT reliabilities [10]. The data also indicate that the subassembly failure frequencies are reducing with time [7] presumably due to improved design and manufacturing. Statistical methods as presented by Guo *et al.* [11] can be used to address limitations in the available dataset (e.g. incomplete or biased data). They fitted the data from the WindStats database for two populations of German and Danish WTs (using two different statistical techniques) to a type of Weibull distribution suited to including the information on "past running time" following a particular failure.

From the WindStats data reported for three separate months in 1994 in [11] blade failure is between 3% and 10% of the subassembly failures for the Danish wind turbines. Note that only a proportion of those failures are linked to blade throw. In addition whole turbine failure contributes a further 8 - 9 % of the total. Other subassembly failures (e.g. hub, nacelle, airbrake) may also lead to blade throw. In total between 14 and 24% of subassembly failures have the potential to lead directly to blade throw. (More complex interactions between subassembly failures are not considered here). For comparison, over four consecutive quarters in 1996, the combined total of rotor, air brake and mechanical brake failures for German wind turbines make up between 18% and 22% of the total of subassembly failures.

The statistical analysis of these data provides failure rate functions for the Danish and German wind turbine populations as a function of time. For example, the failure rates at the end of the data reporting period for Danish wind turbines ranges between 6×10^{-5} /hr and 7×10^{-5} /hr. For German wind turbines the failure rates range between 1.1×10^{-4} /hr and 1.4×10^{-4} /hr.

The wind turbine failure rate data and an estimation of the proportion of failures which could lead to blade throw could be used to provide a conservative upper bound to the failure rate leading to blade throw. However, without data supporting an event tree type analysis, it is not possible to quantify what proportion of each subassembly failure class might lead to wind turbine throw. From the limited number of reported blade throw incidents, it is clear that this proportion will be small (less than 0.1 %). Using subassembly failure classes and statistical analysis of overall WT failure rates to estimate blade throw failure rates is therefore an overly conservative approach.

It should be borne in mind that the aim of the WindStats database is to provide information on the operation of wind turbines. In this context "failure" implies "failure to produce electrical energy to the grid". It does not imply that blades have become detached or fragments generated or other incidents which might pose harm to persons in the vicinity of the wind turbine. Judgement must therefore be exercised for the appropriateness of the WindStats failure rate data used in a risk assessment for harm to persons.

Incident Reports and Fragment Distribution Data

A large number of blade throw incidents have been reported in the public domain worldwide but blade throw data are not reported publicly except in a very limited number of cases. Although the blade throw from one wind turbine failure in Japan has been quantified [12], it occurred during typhoon wind conditions with gust velocities up to 90 ms^{-1}. In another survey, Manwell *et al.* [13] determined from tests of 60 prototype wind turbines that the furthest distance for fragment throw (single blade) was 56 m; this was from a 4 kW turbine. No information was available on the blade length, but from the power rating it can be assumed to be in the range 2-4 m. This compares with the blade length of 40-50 m for the modern generation of wind turbines with power ratings around 1 MW.

It is a statutory requirement in Great Britain that generators of high voltage electricity are required to report certain events (only fire, explosion, death or injury to members of the public and others or an event likely to cause these outcomes) to the HSE Electrical Incident Database (EID). Information was provided from this database to MMI by the HSE Electricity Networks Team.

HSE has provided MMI with blade fragment distribution data following an incident at a wind farm in March 2010 when a 45 m section of blade became detached from a 2.3 MW wind turbine. This is probably the most detailed fragment data following a wind turbine failure that MMI has accessed during this work.

2.2. COLLABORATION WITH RENEWABLEUK

RenewableUK (formerly the British Wind Energy Association, BWEA) is the trade and professional body for the UK wind and marine renewables industries. It was formed in 1978, and currently has over 650 corporate members.

In 2006, RenewableUK instigated a "lessons learnt" database to record details of accidents, incidents and "near events" across the wind industry in all phases of a project from development activity, construction and operation. Data is provided to the database by RenewableUK members on a non-attributable basis. The full "lessons learnt" data is only available in confidence to RenewableUK members, although a publicly available summary of the data is published annually by RenewableUK[24]. The confidential nature of the database should encourage incident reporting by RenewableUK members.

The four years running of the database is a relatively short period, and to be able to establish statistically valid data on failure rates will require a longer period. However, the database is likely to become an important resource to determine failure rates for UK wind turbines in the future.

2.3. COLLABORATION WITH NREL

The US National Renewable Energy Laboratory (NREL) is a facility of the U.S. Department of Energy (DOE) for renewable energy and energy efficiency research, development and deployment. NREL were subcontracted during this project to provide further information and experience in wind turbine design and failure rates and modes.

The remaining information within Section 2.3 was provided by NREL.

Classification of Wind Turbines

Wind turbines are often classified as small or large. Small turbines are defined in IEC TC-88 61400 standards as having rotor swept areas less than 200 m^2. Standard practice also categorises small wind turbines as those which produce less than 100 kW of power. Therefore, a large wind turbine is categorized as a wind turbine whose swept area is greater than 200 m^2, and produces greater than 100 kW of power. Sometimes a third category is added, which defines a medium wind turbine to be one that generates between 100 kW and 1 MW of power.

A typical large turbine produces about 1.8 MW of power and is about 80 m in height, with a rotor diameter of 90 m (swept area of 6360 m^2), a nominal rotational speed of 14.5 rpm, and a weight of 250 tonnes. The majority of the weight, around 150 tonnes, is associated with the tower, with the nacelle weighing around 70 tonnes and the hub around 18 tonnes. The blades are typically made from light-weight composites, and only weigh about 6700 kg.

Small-scale turbines, on the other hand, are typically less than 40 m tall, have rotor diameters less than 8 m, have rotational speeds between 50 and 500 rpm, and weigh between a few kg and 20 tonnes. Residential turbines are typically small scale, and remote turbines can be at the even smaller micro scale, with some being only 100 W.

Description of Power Regulation and Over-speed Control Method

The probability of a wind turbine failure significantly increases during high winds and fault conditions, so it is very important to distinguish between different methods of power regulation and fault protection. Wind turbines use one of three primary approaches for power regulation and over-speed control: pitch regulation, stall regulation, or furling. An over-speed fault is the condition where rotor speed of the wind turbine increases above the intended operating speed, which can occur as a result of component failure or fault, and loss of generator load, and can be exacerbated by high winds. Rotor speeds generally need to be controlled for the safety of the wind turbine and the public and therefore all wind turbines today are required to have at least two redundant systems for conducting emergency shut downs and preventing over-speed. One of these systems must also be completely independent of the control system.

Pitch control machines have active systems that can rotate the blades to a benign position where torque cannot be generated (pitch is rotation about the long axis of the blade's length). This is referred to as "feathering" the blades. When power output reaches rated power the controller commands the blades to feather, changing the angle of attack on each of the blades in unison to maintain power output as the wind speed increases. Most wind machines have a cut-out wind speed in very high winds where the turbine is commanded by the controller to shut down to prevent excessive wear and tear on the machine. This is achieved by a rapid feathering of the blades to a safe position where significant torque on the shaft is no longer possible. This active system of controlling pitch is also the primary system used to protect the system in the event of a fault such as over-speed, loss on line, or drive train equipment failure. Pitch systems have hydraulic accumulators which allow the blades to feather in the event of control system or communication failure.

Most utility scale turbines use independent pitch control to regulate power and also to provide fault protection. Smaller turbines might also use this approach but generally will not implement independent pitch on all blades. Independent pitch control means that all three blades can be pitched in unison or separately using independent control systems. In the event of a fault, all three blades are commanded by their control systems to pitch to feather, but any one of the three blades is capable of stopping the machine independently, providing triple redundancy. This method of controlling rotor speed is often called “aerodynamic braking”. Prior to the development of independent pitch control (c.2000) many wind turbines were deployed with collective pitch systems and a mechanical shaft brake to provide redundancy for emergency shutdown. These systems worked satisfactorily under most conditions but were less reliable and could introduce high drivetrain loads that could damage gear systems. Many of these turbines are still in service. Today, most utility scale wind turbines have mechanical brakes, which are designed only to hold a stopped rotor, but are not designed to stop a rotor under emergency conditions.

The majority of small wind turbines use passive stall to control the power output of the turbine. In stall control machines, the blades are fixed at a specific pitch angle. They are designed such that as the wind speed increases, the angle of attack on the blade airfoil increases and eventually stalls, which reduces the lift force and increases the drag force acting on the rotor. When the rotor stalls the power output is limited to a safe level, which the machine is designed to safely withstand. Stall regulated machines almost always depend on a mechanical shaft brake as their primary means of controlling over-speed and fault conditions. Redundancy may be provided by means of either redundant independent mechanical braking systems or alternatively, through aerodynamic spoilers that are actuated only in the event of a fault or emergency shutdown. Blade aerodynamic control surfaces, such as ailerons, flaps, tip brakes, and spoilers, can be deployed to counter the aerodynamic loading of the blades. These devices are typically installed over a short span of the blade near the tip or the trailing-edge. They are flaps and plates that can be deployed to change the flow over the blades, resulting in an increase in drag. Aerodynamic control devices can be a significant safety hazard, because they can become detached and be thrown from the turbine. The failure risk due to the separation of one of these devices is more probable than the throwing of a blade. None of the top small-turbine manufacturers are presently using aerodynamic control devices, but there is active research in including these devices to control vibration in the blades to help increase performance.

Stall regulation was very common in the wind industry during the 1980’s and 90’s, but most utility scale turbines have moved to pitch control systems. Some older machines use this method of regulation and a few companies are currently developing stall control wind turbines. Another control method, used exclusively by smaller turbines, is furling. Furling reduces aerodynamic loading on the rotor by turning the rotor axis out of alignment with the wind. Furling systems can be a simple tail vane that can change its angle relative to the rotational shaft axis, or mechanical offsets that are designed in between the centre of thrust and some pivoting mechanism that rotates the rotor when thrust forces increase.

Component Materials

The materials used for the components of a wind turbine can differ greatly between large and small turbines. Small machines tend to use lighter weight castings to reduce costs. Many parts are die cast aluminium in small machines, while the larger machines use steel castings to meet strength and structural fatigue requirements. The tower is typically made of a steel lattice or monopole structure. The tower must have enough strength to resist aerodynamic loads and support the large turbine/rotor. Other materials used for towers are concrete and aluminium. Pre-stressed concrete towers are gaining interest, especially for offshore applications where corrosion is a problem, but will still require steel reinforcement. For example, the utility scale wind turbine manufacturer, Acciona, is using a concrete tower for its 3 MW wind turbine.

Most rotor blades are built using glass-reinforced composites but some of the smaller turbines use aluminium. The two primary resin systems used in blades are epoxy and vinyl-ester. Other panel core materials such as foam and balsa wood are used to stiffen the large unsupported panels in blades. Adhesive bond lines are typically formed from epoxy or methacrylic resins. Construction techniques for fibreglass structures include VARTM (Vacuum Assist Resin Transfer Moulding), hand lay-up, and "prepreg" (now being used by Gamesa). Carbon fibre is increasingly used as one of the principal load carrying materials. Carbon is used in the high-stress regions of the blade and generally combined with fibreglass which is used in areas which are primarily aerodynamic, including blade skins. Carbon is primarily used in blades through "prepreg" materials. Carbon prepreg has one advantage observed over other techniques which is the ability to keep fibre alignment near perfect. Wood was used as the primary blade material in the past, but has been mostly abandoned due to the availability of high quality laminates and the limitations in its ability to be moulded. The nacelle is a strong hollow shell that contains the inner working of the wind turbine, and is usually made of fibreglass.

Wind Turbine Failure Modes - Tower Collapse

Risk arises from a wind turbine when it experiences a failure of one of its subsystems, or in the event a full system catastrophic event where the whole tower and rotor system is lost. Component failures can occur due to normal wear of components, abnormal wear due to overload or quality issues, operator error, or due to force majeure events such as lightning, earthquakes, floods, etc. Most components are fail-safe and as such their failure does not result in a dangerous situation or a cascade of multiple failures, but some exceptions are possible.

The collapse of the tower and rotor system is very rare occurrence for modern wind turbines. This type of failure could occur if the tower fastening system was not installed properly, possibly due to improper torquing of the base or yaw system bolts. In this case the tower would fall over as it loosened and then became severed at the base flange. The rotor would then impact the ground with the potential to scatter debris over an area significantly larger than the machine itself.

The tower can also collapse under a buckling failure at some point mid-way up the tower if the overturning design loads on the tower base are exceeded due to an extreme event. Wind turbines are generally designed to withstand the expected 50-year return wind speed at a particular site. Based on anecdotal evidence, blade failure is more likely to occur than tower buckling, but exact statistics are not available.

There is also the potential for the tower to fail if the wind turbine exceeds the design thrust loads under operation. Wind turbines are not designed to operate under over-speed conditions, so there are usually redundant "fail-safe" control systems in place to prevent this from happening. However, in the event that these control systems fail to control speed, the rotor can "run away", reaching rotational speeds and loads that far exceed the design limits. During over-speed conditions, the thrust loads can exceed the turbine tower strength and cause a full system collapse. This is considered a very rare event on modern wind turbines but there have been some documented cases where operators have disabled the control function and inadvertently cause these events to happen. It is also possible that there could be simultaneous failures of multiple systems that could lead to this event. In the event of an over-speed runaway, the outcome is highly dependent on the wind speed. Under some conditions this may result in a blade tower strike due to high blade loads, which in turn could collapse the tower, or it could simply buckle the tower due to extreme bending forces.

Wind Turbine Failure Modes – Fire

The nacelle is fully enclosed on utility class wind turbines so a component failure inside the nacelle could not project into the environment where it could do harm to persons nearby. However, electric failures or some mechanical failures involving friction or high heat can lead to a fire in the nacelle. Nacelle fires are usually short lived but cannot be extinguished via ground based fire-fighting equipment due to the height of the tower. Most turbines have fire suppression equipment inside the nacelle that is activated in the event of fire. In such cases, fire poses a hazard to personnel inside the nacelle and tower, and to people directly below the nacelle. In this case, burning embers can fall from the nacelle and cause local grass fires within the project area that need to be contained. Lightning can also cause fires on wind turbines. Anecdotal information from wind farm operators of modern utility-scale turbines leads to the assessment that electrical fires (excluding lighting strikes) are most prevalent during commissioning or repair procedures, indicating human error as the root cause.

Wind Turbine Failure Modes – Blades

Most blades are made as one piece from a composite moulding process and it is unlikely for fragments of blades to become severed during normal operation. In over 100 blade tests conducted at NREL, there was not one blade failure where complete separation of the structure at a composite fracture zone occurred during static load testing.

Another type of blade failure is a blade throw, in which the entire blade becomes separated from the hub at the metal to metal root joint. This could occur if there is an instantaneous failure of the bearing or hub/root flange fastening system. Fortunately, if these systems fail, the progression is usually slow enough that the control system will detect an abnormality (vibration, imbalance, under power, etc) and the machine will fault and shut down. If this control function does not happen then the blade could be thrown from the hub and propelled a long distance. Blade throws may be more likely on small machines with fast rotating blades.

Classification of Blade Failures

Blade failures are currently not subject to a detailed classification system. Observational methods currently used to report failures identify blade failure in very general terms. Much information is derived from photographs taken in the proximity of the wind farms by reporters or industry groups. Most of the time, information on failures is not provided by owners and operators. A general approach to classifying blade field damage and failure would consider the following causes:

- Root connection failure
- Catastrophic structural buckling or separation
- Leading edge, trailing edge, or other bond separation
- Lightning damage
- Erosion
- Failure at outboard aerodynamic device

It is necessary to make generalisations in operational failure characteristics due to a typical lack of information being available at the time of the failure. Turbine manufacturers and operators are not required to provide a detail root-cause assessment in a publicly available forum. This detailed information may be available, but only shared between manufacturer and certification agency.

Laboratory blade test standards do include a detailed classification system for failures and the resulting severity. Blade test practices are based on the IEC 61400-23 technical specification, with the following general classifications:

Catastrophic Failures:

- Breaking of primary blade structure
- Complete failure of structural elements
- Major parts become separated from main structure

Functional Failures:

- Reduction in stiffness (5 to 10%)
- Permanent deformation
- Substantial change of cross section shape
- After unloading the blade, a mechanism is no longer capable of performing its design objective

Superficial Failures:

- Small cracks not causing significant strength degradation or bond line *w*eakening
- Gel coat cracking
- Paint flaking
- Surface bubbles
- Minor elastic panel buckling
- Small de-laminations

During testing, failures and damages from the above list are recorded and communicated to the design and manufacturing groups for evaluation. If a blade has catastrophic or functional failures a redesign or process improvement is required. Superficial failures can also lead to design modifications.

Laboratory testing includes static strength evaluations which test the blade in multiple directions to simulate quasi-static maximum load events. Fatigue test loads of millions of test cycles are applied to the blade to simulate the 20-year equivalent life of a blade. Even with the standard test requirements in place, there are still many blade failures being observed in the field. One point to note is that only a single blade is required to be tested under the blade test specification, which may not be sufficient to detect failures due to variations in the manufacturing process. Part of the on-going work at NREL is to assess current test practices with field observations to improve the process.

A notable gap in the existing certification process for wind turbines is that there is not a design standard for wind blades. Efforts are currently underway to develop an IEC technical specification for the design of wind turbine blades under the remit of IEC TC-88 as IEC 61400-5. The development of the blade design specification should encourage the development of more robust design, inspection, and repair specifications and practices.

Normal Operation Mode Failures

Wind turbine blades are typically constructed at a target price of \$5 USD/lb (£7 GBP/kg). When comparing this with aircraft and other performance composite structures that have target prices of \$100 - \$1000 USD/lb, it is understandable that the quality and inspection techniques for wind turbine blades is less rigorous than for aircraft. Although manufacturers employ various techniques to minimize manufacturing errors, they are inevitably propagating into production blades. Figure 2 provides a photograph of an observed failure with a broken blade in the mid-span region (not at the blade root plane or near the tip).

Figure 2 Example of a mid-span blade failure

Structural failures of the nature shown in Figure 2 might indicate a flaw in the laminate or a design limitation. In the root region of the blade, the structural shape of the blade transitions from a cylinder to an aerofoil. In this area the laminate is relatively thick in order to withstand the high bending moments at the root of a cantilevered structure. The combination of thick laminates (with common manufacturing defects) and rapid transition in geometry make the mid spans susceptible to catastrophic failures. Additionally, the large laminate panels employed near the maximum chord promote buckling sensitivity, making the ~20% to 40% span of the blade (measured from the root) a common area for failure.

Figure 3 Wind turbine damage due to lightning strike

When lightning does strike a wind turbine blade it can be a significant cause of blade damage at scales resulting in minor repairable damage but also at scales which can lead to widespread blade damage and result in catastrophic failures. Figure 3 provides a photograph of damage to a blade due to a lightning strike; in this case the damage from lightning is near the tip. The figure clearly shows surface damage from the strike, but in many cases when the evidence of strike is minor there can be significant sub-surface damage. Lightning damage near the tip is often repaired, but strikes closer to the root often require additional inspection to determine the extent of the damage before a repair or replace decision can be made.

Figure 4 Erosion on the leading edge of a blade

Failure Modes - Other

Impact and erosion are additional sources of blade failures and Figure 4 provides a photograph of typical damage to the leading edge of a wind turbine blade. Blades typically employ advanced coating or tapes on the leading edge to limit such damage but these methods are not fail-safe and in many instances need periodic replacement. Erosion is typically first indicated through visual observation and through the loss of system performance. If left unchecked erosion will eventually progress into the structural laminates on the leading edge or allow water penetration into the bond line. These events can progress into much larger structural failures extending to a significant span of the blade.

Description of the Nature of Blade Failures

Blade failure may be caused by multiple factors: operating conditions outside of design envelope; control system failure; human error; improper design; and poor manufacturing quality. Operation outside of normal design criteria is an issue which is gaining additional research and development attention at NREL. Abnormal site-specific conditions, low-level jets, and wake effects are some of the conditions currently being studied. Design problems are anecdotally considered a significant source of failure, with a recent blade failure being attributed to a lack of a non-linear analysis of the composite. Notwithstanding the possibility of abnormal conditions and design problems, blade manufacturing is considered to be the principal root-cause of most blade failures.

It is instructive to look at the issues which are generally acknowledged by manufacturers and designers to be the primary sources of incipient blade failures to infer some of the root-cause problems observed in the field. The primary problems observed with blades are detailed as:

Adhesive bond defects:

- Thickness out of tolerance
- Voids

Laminate Defects:

- Ply wrinkling and waviness
- Misplaced laminates
- Fibre orientation and alignment deviations

Fibre/Resin Ratio Problems:

- Resin-rich regions
- Laminate dry spots

Most turbine manufacturers produce blades with independent components including a high-pressure skin, low-pressure skin, and shear webs. These components are bonded together in a secondary process after the skins and webs have cured. The resulting bondlines are a significant source of problems as de-bonding can lead to weakened structures susceptible to softening and buckling. At least one manufacturer uses a single-shot process with a closed mould to fabricate the entire blade structure.

Another problem common to blade construction is the aspect ratio of the blades. Wind turbine blades are relatively long, thick composites compared with other industries. This high aspect ratio presents problems in keeping fibres aligned and fully wetted-out. Fibre shifting, fibre misalignment, and resin voids are very common in the industry. Processes such as "prepreg" can reduce fibre alignment issues to some extent but no entire blade structure can be produced with this method, as secondary infusion is typically required for skins and webs.

An important item to note from blade failure represented by Figure 2 is that the main structure of the blade has remained attached to the balance of the structure after failure. Utility-scale blades are manufactured using composite materials which are essentially fibrous. When failures do occur, the composite matrix, or resin, will be observed to fail, however the composite fibres will keep the structure intact, albeit crippled, for an extended period of time. This extended time period is often enough to park the machine before continued operation and distortion of the blade would lead to a complete separation of the failed member.

Damage to outboard stations of blades is more commonly due to manufacturing defects including improper bond lines, or external conditions including lightning or erosion. As the blade structure is a uniformly tapering aerofoil with minimal geometric and laminate schedule changes, the stability of the structure is relatively greater than at inboard stations, and the thinner laminates are less susceptible to manufacturing defects. Additionally the specific strength of the blade is greater in outboard regions. As tip speeds are much greater than the speed at the root, erosion with resulting damage to the leading or trailing edges is expected to be greater near the tip. Lighting can initially strike blades near the tip potentially causing separation of high-pressure and low pressure skins near the tip, or separation of the skins from the shear webs. Separation can be caused by direct damage to the bondlines or through rapid expansion of the air inside the blade causing bondlines to fail due to excess pressure or indirect peeling of the joint.

Failure Modes - Tower Strikes

A tower strike occurs when a wind turbine blade hits the support tower; these are relatively infrequent occurrences for operation of modern wind turbine blades. Strikes are typically due to a failure of a component, with wind turbine blade failure being one such source. Design and certification standards necessitate that the blade clearance between tip and tower be at a minimum of 1.5x the calculated deflection of the blade under extreme static operating conditions. Tower strikes can be due to a loss of stiffness in the structure of the blade but this strike condition would be a secondary effect of a blade failure in progress. Operating load conditions above design conditions can also cause tower strikes.

Failure Modes - Over-Speed

Over-speed failures are typically considered a secondary failure mode with respect to blade damage and failure, as a component failure or control system failure is often necessary for this condition to occur. Damage to a blade will not, in almost all cases, directly lead to the system over speeding. When significant damage to a blade does occur it will typically lead to out-of-balance conditions which can be detected by basic sensing system sensors, including accelerometers. When these out-of-balance conditions are observed, the turbine *S*upervisory Control and Data Acquisition (SCADA) system would normally place the wind turbine in a shutdown mode.

Failure Modes - Lightning

Lightning can be a significant source of blade damage, depending on the geographic location of the particular wind turbine. Informal surveys have indicated that several large wind farms in the Midwest region of the USA have seen a large population of their turbine blades, and in some cases all blades, being struck by lightning. All megawatt scale blades are equipped with lightning protection systems. These systems employ receptor pucks on the surface of the blade at the tip, with either copper or aluminium conductors connecting the pucks to a grounding source. However, the Midwest region of the USA is an example of an area which is prone to frequent lightning strikes.

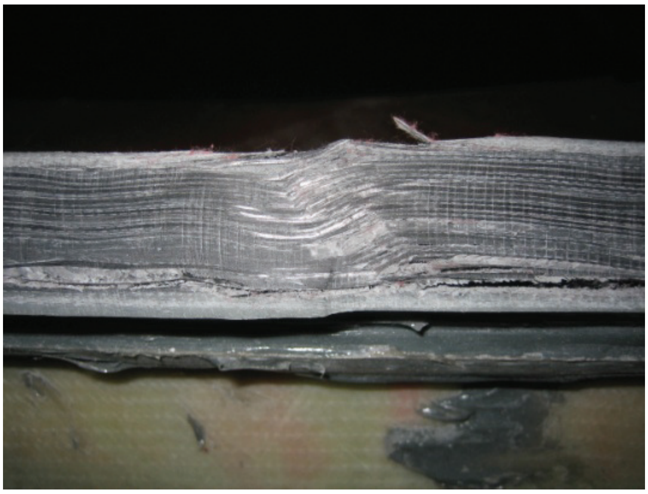


Figure 5 An example of a laminate wrinkle

Figure 5 provides a photograph of a laminate wrinkle. This photograph is of a carbon spar cap (main structural element) with the plane of view in the span-wise direction. Even small defect such as this can be the root cause of catastrophic failure.

Turbine blades are statically balanced into blade sets with balancing typically achieved through the addition of steel or lead shot into ballast boxes built into the blade. The ballast boxes are formed as part of the composite structure during fabrication. Sizes and locations vary, but the size of a hollow ballast box would be of the order of 0.25 m^3 with spanwise locations varying from 50% to 80% span. When blade finishing is mainly complete, a weight and CG procedure is performed which establishes a static root moment. Sets of blades are then grouped based on their static properties, essentially ranking blades by moment. The sets of blades are balanced as a set by adding a slurry of steel shot and thickened epoxy into the ballast box. The ballast hole is sealed with a composite and surface finished.

Ballast boxes have been observed to come loose inside of the blade, either through loose shot/epoxy rattling around or more significantly the entire box separating inside of the blade. Most modern turbines will have a 'knock' sensor in the nacelle which purportedly will detect this type of failure. If not detected through knock sensors or field observation, separation of ballast weight can cause damage to blade close-outs (platform at root).

An 'Out of Balance' condition is a prescribed IEC load case intended to ensure that if an out of balance condition is observed, the resulting short-term dynamic loads are not critical. Long-term operation with an out of balance condition can increase the lifetime fatigue cycles and damage the turbine will experience.

3. HUMAN VULNERABILITY MODELS

3.1. INTRODUCTION

This section discusses human vulnerability to debris generated by wind turbine failures and concludes with suitable vulnerability functions for inclusion in the risk assessment tool. Wind turbine failure can take a variety of forms but it is reasonable to assume that a typical structural failure will generate a range of debris sizes, masses and velocities.

Human vulnerability to impact from debris may be considered to fall into two broad categories: (i) direct impact: the debris from the failed turbine follows a trajectory and makes contact with one or more people; (ii) indirect impact: debris from the failed turbine follows a trajectory and makes contact with an enclosure housing one or more occupants; the enclosure then fails in some manner, collapsing onto the occupants.

Furthermore, debris may be considered falling into two types: (i) smaller debris impacting specific parts of the human body, associated with penetrating and cutting type injuries (fragment impact), and (ii) larger debris impacting the whole body, associated with non-penetrating crushing and tearing injuries (blunt trauma).

The type and severity of injury may be classified as [15]:

- Cutting and penetrating injury where the severity depends on the fragment energy times velocity squared ($m.v^4$)
- Crushing and tearing injury where the severity depends on fragment energy ($m.v^2$)
- Impulsive injury where the severity depends on fragment momentum (mv)

Each type of impact is discussed in the following sections.

3.2. DIRECT IMPACT

Fragment Impact

Fragments are considerably smaller than the human body such that they will impact only part of the body. The mass of such fragments will typically range from a few grams to tens of kilograms. The velocity of such fragments may range from a few metres per second (for simple dropped objects) to hundreds of metres per second (for items ejected from turbine tips) and will only experience limited air drag due to their small size. Typical examples relating to wind turbines include nuts and bolts, small pieces of casing/cladding and individual mechanical components.

Work carried out by Feinstein in the 1960s [16] considered that impacts onto the human body affected one of three parts, each with differing sensitivities to impact: (i) thorax – the most sensitive part of the body to impact; (ii) head; (iii) abdomen and limbs – the least sensitive parts of the body to impact.

The sensitivity data was obtained from a range of physical tests. Feinstein characterised the severity of fragment impact energies ranging from superficial through to lethal and this was used, along with test data, to produce fatality curves. The work concluded with an average fatality curve due to impacts on any part of the body, assuming an equal chance that the individual was standing, sitting or prone. This average curve is shown in Figure 6.

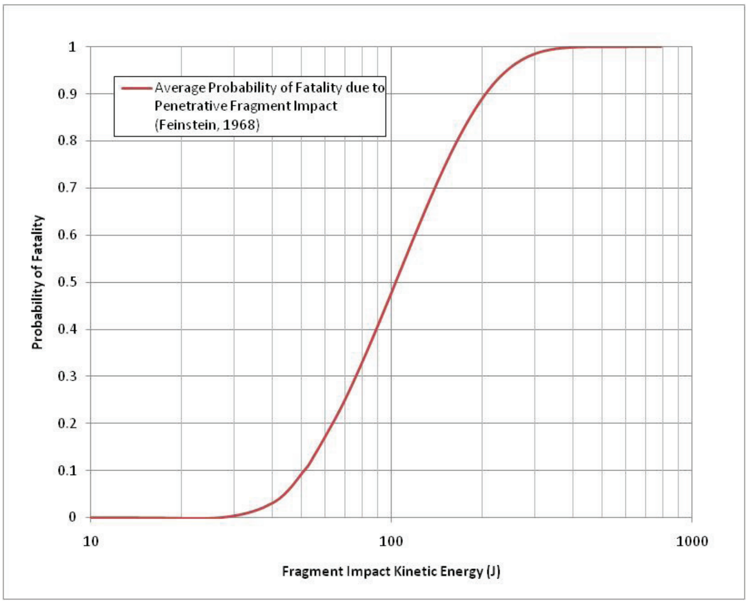


Figure 6 Average probability of fatality from fragment impacts (after Feinstein [16])

Blunt Trauma

Blunt trauma results from impact by debris large enough not to cause cutting or penetration. The mass of such debris will typically range from tens of kilograms to several tonnes. The velocity of such debris may range from a few metres per second (for simple dropped objects) to tens of metres per second (for sudden release of turbine blades) and may be slowed by air drag due to their large size. Typical examples relating to wind turbines include turbine blades, motors, gearboxes and turbine structural components.

The first data source considered for guidance on blunt trauma fatality probabilities was HSE's own contract research reports [17,18]. These documents considered the consequences of a building occupant being impacted by various building cladding components. The raw data used in this document was based on total body decelerative impacts, presented by Baker *et al.* [19]. Working with an average body mass of 80 kg, this data is presented in Figure 7 in a comparable format to the fragment impact graph.

Research into the consequences of blunt trauma has found that the probability of injury is a function of the diameter of the debris and the mass of the person hit by the debris. For the purposes of this study Reference [20] was used to obtain the form of the Cooper Thorax Blunt Trauma equations, based on research by the UK Biomedical Laboratories in the 1980s. These equations allow the minimum kinetic energy to induce blunt trauma to be estimated. A 13cm wide object hitting an 80 kg person was assumed for the purposes of the calculation.

As an alternative method, Neades [21] was used to calculate the impact energies associated with 0% and 100% probability of fatality due to blunt trauma. Working with a body mass of 80 kg and assuming an impacting debris width of 13 cm, the kinetic energy for 0% fatality and 100% fatality were estimated and are shown in Figure 8 for comparison with the Baker *et al.* curves. Also included is a lower threshold of injury as extracted from the Cooper Thorax Blunt Trauma equations [20]. Since this is interpreted as the threshold for injury, it falls below the fatality threshold. The data was found to be consistent but one might expect that the raw data sources were ultimately the same and so this is perhaps not surprising.

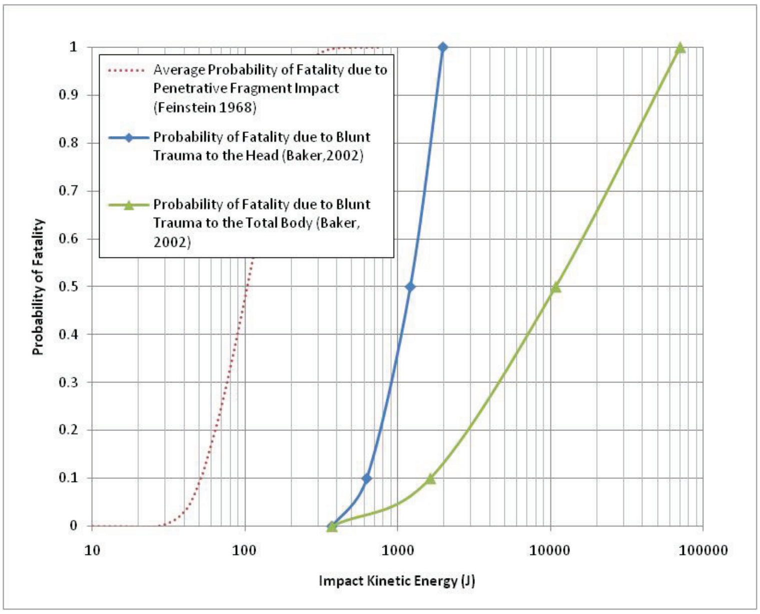


Figure 7 Probability of failure from blunt trauma impacts

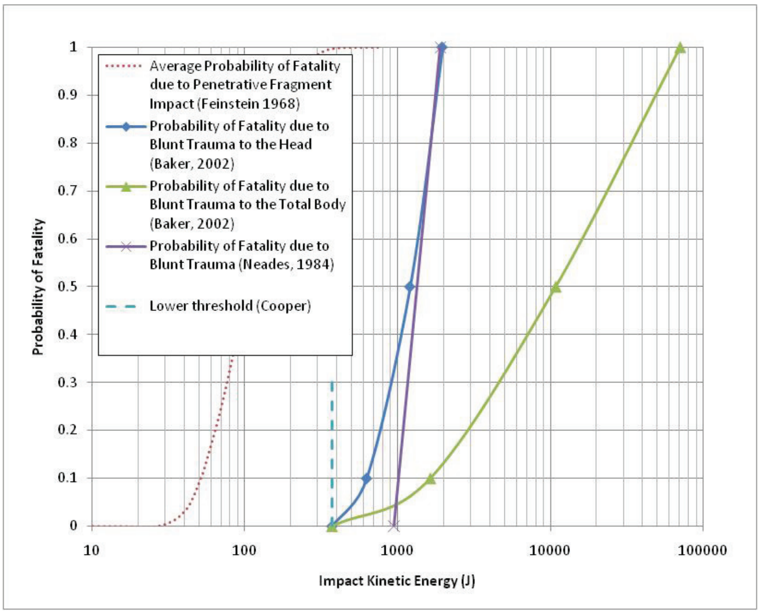


Figure 8 Probability of fatality from blunt trauma impacts

Recommendation

It is therefore recommended that the risk simulations consider two fatality conditions resulting from direct impact:

- For small fragments with a mass < 5 kg assume fatality if the kinetic energy > 100 J and assume that a person occupies an area of 0.25 m^2

  This is based on the Fragment Impact data presented in Figure 6. The selected kinetic energy value, 100 J, relates to 50% probability of fatality. This is often referred to as LD50 in Health and Safety executive documentation.

- For larger fragments with a mass > 5 kg assume fatality if the kinetic energy >1000 J and assume that a person occupies an area of 1 m^2

  This is based on the Blunt Trauma data presented in Figure 7 and Figure 8. As the Baker blunt trauma to the head and Neades (alternative source) blunt trauma data were nearly coincident for probability of failure of 50% and greater, these were used to set the limiting energy. (The energy required from Baker for fatality due to blunt trauma to the whole body was significantly higher and hence bounded by the lower limit.)

  From Figure 8 the 50% probability of fatality occurs circa 1300 J; to add a small amount of conservatism, this has been reduced to 1000 J. Again, as this is the 50% probability of fatality energy, it can be interpreted as LD50 for reference to other Health and Safety Executive documentation.

3.3. INDIRECT IMPACT

Smaller Fragments

When smaller fragments impact with an enclosure such as a building or a vehicle, they may penetrate but are unlikely to cause progressive collapse. Many fragments will be arrested by the fabric of the enclosure. Therefore, an occupant within the enclosure is exposed to a lesser level of risk than if he were out in the open.

Due to the lack of data for these types of failure it is proposed at this stage to include small fragments within the discussion for larger fragments.

Larger Fragments

Larger fragments have the potential to cause local failure and collapse of the fabric of an enclosure. Research into the likely degrees of structural damage resulting from external impacts has been carried out in support of this study.

Guidance within the HSE Contract Research Reports [17, 18] indicates that where partial collapse occurs it should be assumed that the number of fatalities is in proportion to the percentage floor area which collapses. For total collapse it is recommended that 60% of the building occupants are assumed to be fatalities i.e. the building ultimately offers some protection, even in a collapse scenario. Partial collapse will occur if individual roof panels or individual columns are destroyed. Total collapse will occur if there is sufficient impact energy to cause outright collapse or to destroy sufficient structure such that progressive, or disproportionate, collapse occurs.

Building regulations require that key structural elements, such as columns, are capable of withstanding a static pressure of 34 kPa. A 3.5 m high by 0.5 m wide column with an ultimate resistance of 34 kPa and a natural frequency of 10 Hz, may sustain an impulse of about 4000 Ns before collapse, based on a collapse ductility of 10. The loss of a single column would typically not result in collapse of more than 10-15% of the floor area. Taking a fatality ratio of 0.6 this equates to a fatality probability of about 0.1.

Baker *et al.* [19] indicated that typical roof claddings would start to experience damage at impulses of about 5 Ns. Such impact damage would have no consequences for occupants i.e. a zero fatality probability.

Partial collapse of domestic masonry buildings, up to about 25% of the floor area, may be expected due to modest vehicle impacts, say a 1000 kg car travelling at 20 mph, giving an impulse of about 9000 Ns. Using the 0.6 fatality ratio, 25% collapse would equate to a fatality probability of about 0.15.

Haugen & Kaynia [22] discussed damage to unreinforced masonry buildings from debris flows, and noted that dynamic forces of 3-4 MN, with duration of 1s, caused complete destruction. Assuming the dynamic force to adopt a triangular distribution with time, this implies impulses of 1.5 to 2 MNs. As a cautious estimate, the lower value is assumed to cause complete destruction of unreinforced masonry domestic properties. This is assumed to equate to a 0.6 fatality probability.

On the basis of this very limited data set it is suggested that the following damage and fatality functions could be used, Table 4, with the same data presented graphically in Figure 9.

Table 4 Probability of fatality within occupied buildings subject to fragment impact

Impact Impulse (N-s)	***Percentage collapse of masonry building***	***Probability of Fatality of Each Occupant***
5	0%	0
5,000	10-15%	0.1
10,000	25%	0.15
1.5E6	100%	0.6

Recommendation

At this stage it is recommended that the probability of fatality per occupant of a building impacted by debris from a failing wind turbine be based on Figure 9. This makes the assumption that domestic unreinforced masonry structures are representative.

Although this is considered reasonable within the available data, it is acknowledged that the dataset is limited and has introduced a certain degree of subjectivity into the analysis. To test the consequence of this subjectivity, sensitivity studies have been carried out in the Case Study (Section 5.4). The sensitivity study considers the same shape of probability of fatality function as shown in Figure 9, but modified for 2x the probability of failure and 0.5x probability of failure with respect to specified impact impulse shown in Figure 10.

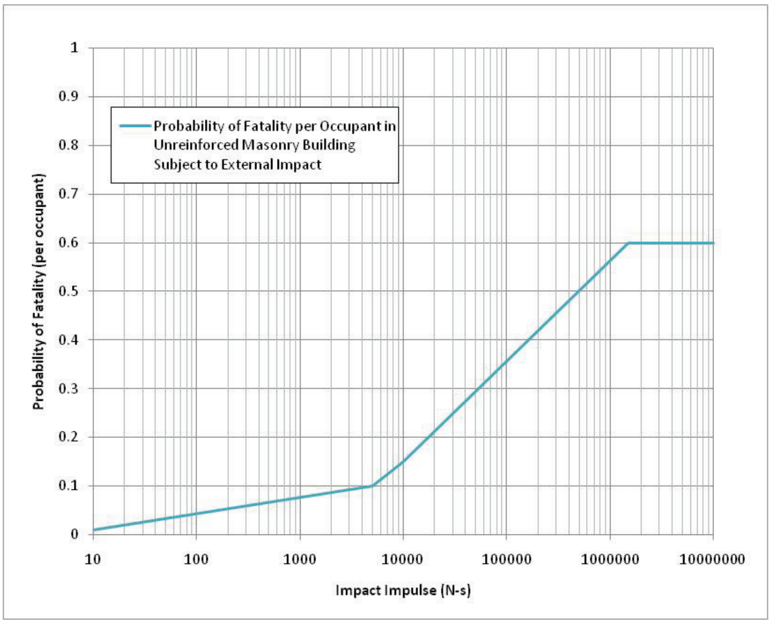


Figure 9 Probability of fatality within occupied buildings

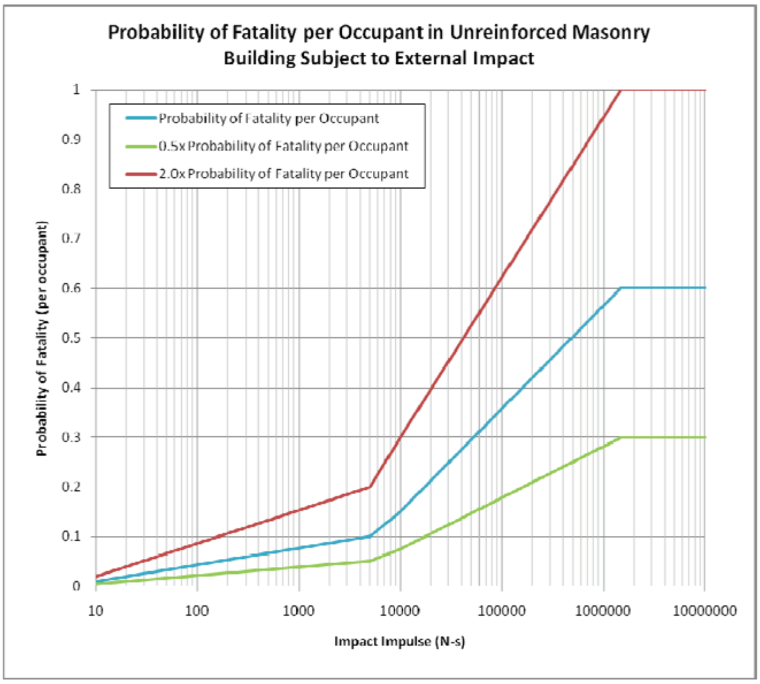


Figure 10 Indirect impact probability of fatality functions for sensitivity study.

4. HARM TRANSMISSION MODELS

4.1. INTRODUCTION

The “harm transmission model” is the name given to the part of this work which describes how fragments and debris generated as a result of a wind turbine failure are projected and ultimately come into contact with the ground, persons or other objects in the vicinity of the wind turbine. To develop this aspect of the work a review was first undertaken of existing blade throw models from third parties. Note that “blade throw” is often assumed as the worst case debris from a wind turbine failure. There are recorded incidents of this having happened, due to failure of the rotor or blade root.

4.2. LITERATURE REVIEW

Existing Blade Throw Models and Limitations

Previous work undertaken for HSE considered the risks presented to a major hazard site. The objective of the work was to create a simple model for blade throw and apply it to a proposed wind farm neighbouring a civil nuclear installation. The authors used a simple model to estimate the blade throw distance based on the aerodynamic theory and a Monte Carlo simulation to aggregate the combined effects of the calculation variables.

The authors compared two methods for the estimation of impact probabilities of full or partial blade loss. Firstly, a constant wind speed of 30 ms^{-1} and a beta distributed blade speed were considered. The beta distribution used 0.75, 2.5 and 1.0 times the maximum rotational speed (18.4 rpm) to define the minimum, maximum and mode of the blade speeds. Secondly, a truncated Weibull wind speed and related blade speed were used. The blade speed at the time of detachment was assumed to be a linear function of the wind speed. This varied from zero to either the speed at which the blade tip reaches 0.9 Mach, or the speed at the normal operating conditions, whichever is less. Based on the first method, 99th percentile throw distances were found to be between 155 and 198 m for a full blade, and 312 and 1462 m for a 10% blade fragment depending on the assumed level of drag. There is no appreciable difference in the results obtained through the second method.

In the work, the wind direction was assumed to be always perpendicular to the blade plane. This may not be a worst case, as in the event that the turbine’s the yaw control fails, it is conceivable that the plane of the wind turbine may be parallel with the wind direction. Also the authors did not consider the influence of the turbine size in the model.

Another piece of work developed a model to predict the risk of damage to buried services due to the failure of wind turbines. It proposed an exclusion zone of 1.5 times mast height from the buried services to avoid damage. This distance was based on the assumption that a broken blade could only impact the buried services if its centre of gravity hits the pipeline route. The authors used a ballistic model without considering the air resistance on the blade.

There are a number of published studies which consider similar wind turbine failure scenarios. Larwood [25] developed ballistic models to estimate the probabilities of impacts on an annular region. The models assumed the blade throw with no aerodynamic drag, lift or wind effects on the fragments considered. California County ordinances [26] suggested setback distances for wind turbines of 1.25 to 3 times the overall turbine height based on the location. Morgan & Bossanyi [26] developed a risk assessment methodology for ice throw from wind turbines using a ballistic model which did include aerodynamic drag in a Monte Carlo simulation. Additionally they incorporated the “slingshot” effect for ice being thrown from the turbine blades. From the resulting model they proposed a safety threshold of 200-250 m from any wind turbine. However, the work was limited in that the influence of the size of the wind turbine was not considered. Macqueen, et. al [27] proposed a methodology to estimate the risks to people and properties considering both drag and lift. They concluded that the probabilities of striking a fixed target and people are less than 10^{-7} and 10^{-9} per year per turbine respectively. Again, their model was limited by omitting the influence of the wind turbine’s size.

Probability of Wind Turbine Failure

Generally the failures of wind turbines discussed in published literature are divided into three scenarios: blade braking off, fall of rotor/nacelle and failure of mast/tower. In his work for the California Wind Energy Collaborative, Larwood [25] provided an excellent review of published wind turbine failure rates. This review is summarised and shown in Table 5 with the addition of data from HSE.

Table 5. Summary of published probability of wind turbine failure

Source Description	*Component*	*Probability of Failure per turbine per year*
Solar Energy Research Institute (SERI) – Reliability study on wind turbine component by Edesess and McConnell [28]	Rotor	1.2×10^{-2}
Failure data observed from 2000 to 2003 reported in the Alameda County study [29]	Blade	5.4×10^{-3}
	Tower	6.9×10^{-4}
Failure data observed in Denmark from 1993 and in Germany from 1996, both up to Spring 2004 as reported in WindStats [6]	Blade	$3.4 \text{ x } 10^{-3}$
	Turbine	$1.0 \text{ x } 10^{-4}$
	Rotor	$1.5 \text{ x } 10^{-2}$
Survey of manufacturers and 133 reported turbine failures by de Vries [31]	Rotor (Netherlands)	2×10^{-2}
	Rotor (Denmark)	3 to 5×10^{-3}
	Rotor (US)	3×10^{-3}
Data used in a HSE study to develop guidelines for placing the wind turbines near to buried services.	Blade	8.4×10^{-4}
	Tower	1.3×10^{-4}
	Rotor	3.2×10^{-4}

The data provided to MMI by HSE is not in as good agreement as the other sources quoted by Larwood. For example the probability of rotor failure is one to two orders of magnitude less likely and the probability of blade failure is an order of magnitude less likely.

Overall, the reported data shows the annual probability of blade failure is approximately in the order of 10^{-3} to 10^{-4}; rotor failure 10^{-2} to 10^{-3}; and tower failure 10^{-4}.

Size of Installed Wind Turbines

In the UK, 267 onshore wind turbine sites are in operation with over 2800 wind turbines generating 3848 MW power [1]. There are a wide variety of wind turbines installed from different manufacturers, with different sizes, power ratings and age. The Wind Energy Market [30], is a web-resource provided by the German Wind Energy Association (BWE). This trade body provides an international industry and technology portal, which includes details for around 80 wind turbines installed throughout world. This database is populated strongly by German manufacturers but it is thought likely that it is representative of the UK fleet of onshore wind turbines too. A summary of this data from the Wind Energy Market is provided in two tables in Appendix B. The first table (Table 13) contains the details of the rated power, rotor type and its material, and the control and protection system. It is anticipated that in future work these data may be used to help derive or allocate the probability of failure for each system. The second table (Table 14) contains the specification of the rotors; this data has been used later in the current work to provide a relationship between blade length and mass for proposed wind turbines which have limited data available.

4.3. PROPOSED BLADE THROW MODEL

In the current work, the trajectory of the whole blade or fragments of the blade has been calculated using Newton's Laws of motion and simple kinetic theory.

Assumptions

The following assumptions have been made in the calculation

1. The mass of the fragment can be represented by a point mass.
2. Sliding and bouncing of the blade or fragment after landing on the ground are ignored. Including these aspects in the model would be excessively complex due to uncertainties in quantifying parameters such as: ground conditions; shape of the blade/fragment; plastic deformation of the ground and blade/fragment; etc. The final throw distance of the blade/fragment has been taken as the distance where its centre of mass first hits the ground.
3. The blade detaches from the rotor instantaneously and no energy loss during the detachment, i.e., the rotational speed of turbine is fully transferred to the blade. Similarly, blade fragments detach from the blade instantaneously and with the rotational speed of the blade.
4. The rotor speed control system is fully effective; hence the turbine speed is independent of the wind speed to some extent.
5. Similarly yaw control system is fully effective; hence the rotor plan is always perpendicular to the wind. The rotor plan has also been assumed to be perpendicular to the ground, i.e no tilt of the tower.
6. The density of blade is constant throughout its length. In reality, its density varies with respect to the distribution of the materials in its construction.
7. The coefficient of drag is constant throughout the blade or fragment flight. In reality, the coefficient changes significantly with the orientation of the fragment. However compensation is made in the analysis methodology by setting an appropriate probability distribution for the exposed area.
8. Aerodynamic lift on the blade is ignored. Although wind turbine blades have lift generating profiles, it is very unlikely that blades or fragments will remain in the correct orientation for lift to be effective. If during its flight the blade/fragment does tumble into the correct orientation for lift to be effective, the lack of restraint on the blade fragment will most likely cause any moment imparted by the lift to rotate the blade or fragment out of the lift generating orientation (i.e. it will "stall").
9. The wind speed is constant for whole turbine height: i.e., no variation with altitude or time. In reality, the wind speed increases with height above the ground and the wind profile with height

is dependent on the ground surface conditions (fields, woods, urban areas, etc). One commonly used profile is for the wind speed to vary with 1/7th power of altitude. Usually, wind speed reported at any station will be at a height of 10 m from the ground level. Taking a common turbine hub height of 100m and using the 1/7th power law, the wind speed at the hub level will be around 40% higher than that at the 10m level.

10. The wind direction is constant throughout the fragment's flying period.
11. The ground is flat with no inclines, undulations or surrounding structures.
12. In assessing the risk of fatality due to direct impact, the average height of a person is taken as 1.6 m and the blade/fragment's energy at half this height is used to estimate average conditions. To estimate the risk of fatality from indirect impact (building collapse) the height of the target is assumed to be 3 m.

Throw Model

When a blade or fragment travels through air, the two principal forces affecting its flight are gravity and drag. The acceleration due to gravity acts in the negative Z direction and the gravitational force in vector form is:

$$\left\{\vec{F}_G\right\} = \begin{Bmatrix} 0 \\ 0 \\ -mg \end{Bmatrix} \tag{1}$$

Where, m is the mass of the fragment and g is the acceleration due to gravity (9.81 ms^{-2}). The drag force acts in the opposite direction to its velocity, and is proportional to the square of the speed of the blade/fragment relative to the surrounding air. The velocity vector of the fragment at detachment and wind velocity can be represented as:

$$\{\vec{v}\} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} \qquad \{\vec{w}\} = \begin{Bmatrix} w_x \\ w_y \\ w_z \end{Bmatrix} \tag{2}$$

Where v_x, v_y, and v_z are the velocity component of the fragment in x, y and z directions; and w_x, w_y, and w_z are the velocity component of the wind in x, y and z directions. The magnitude of the velocity of the fragment ($|\vec{v}|$) and wind ($|\vec{w}|$) can be represented as:

$$|\vec{v}| = \sqrt{v_x^2 + v_y^2 + v_z^2} \qquad |\vec{w}| = \sqrt{w_x^2 + w_y^2 + w_z^2} \tag{3}$$

The unit vector of the velocity vector of the fragment is,

$$\left\{\frac{\{\vec{v}\}}{|\vec{v}|}\right\} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} \left(\frac{1}{|\vec{v}|}\right) = \begin{Bmatrix} \cos(\alpha_v) \\ \cos(\beta_v) \\ \cos(\gamma_v) \end{Bmatrix} = \hat{v} \tag{4}$$

$$\cos^2(\alpha_v) + \cos^2(\beta_v) + \cos^2(\gamma_v) = 1 \tag{5}$$

α_v is the angle between the velocity vector of the fragment and *x*-axis as shown in Figure 11; β_v is the angle between the velocity vector of the fragment and *y*-axis; γ_v is the angle between the velocity vector of the fragment and *z*-axis.

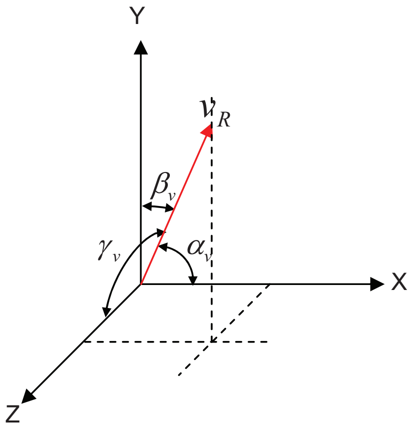


Figure 11. Definition of unit vector for velocity

Similarly, the unit vector of the velocity of the wind is,

$$\left\{\frac{\{\vec{w}\}}{|\vec{w}|}\right\} = \begin{Bmatrix} w_x \\ w_y \\ w_z \end{Bmatrix}\left(\frac{1}{|\vec{w}|}\right) = \begin{Bmatrix} \cos(\alpha_w) \\ \cos(\beta_w) \\ \cos(\gamma_w) \end{Bmatrix} = \hat{w} \tag{6}$$

Where α_w is the angle between the velocity vector of the wind and the *x*-axis; β_w is the angle between the velocity vector of the wind and the *y*-axis; γ_w is the angle between the velocity vector of the wind and the *z*-axis

$$\cos^2(\alpha_w) + \cos^2(\beta_w) + \cos^2(\gamma_w) = 1 \tag{7}$$

The resultant of the wind and fragment velocities is:

$$\{\vec{v}_R\} = \begin{Bmatrix} v_{Rx} \\ v_{Ry} \\ v_{Rz} \end{Bmatrix} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} - \begin{Bmatrix} w_x \\ w_y \\ w_z \end{Bmatrix} = |\vec{v}|\,\hat{v} - |\vec{w}|\,\hat{w} \tag{8}$$

This can be rewritten as:

$$\{\vec{v}_R\} = |\vec{v}|\hat{v} - |\vec{w}|\hat{w} \tag{9}$$

The unit vector of the resultant velocity is:

$$\hat{v}_R = \begin{Bmatrix} v_{Rx} \\ v_{Ry} \\ v_{Rz} \end{Bmatrix} \left(\frac{1}{|\vec{v}_R|} \right) \tag{10}$$

Finally the drag force can be calculated using Equation 11:

$$\vec{F}_D = -\frac{1}{2} \rho C_D A |\vec{v}_R|^2 \hat{v}_R \tag{11}$$

Where, ρ is the air density, C_D is the coefficient of drag and A is the projected area of the blade/fragment to the direction of motion. By Newton's second law, the total force, i.e., the sum of drag and gravitational forces is equal to the product of mass and acceleration:

$$\vec{F}_D + \vec{F}_G = \vec{F}_I = m\{\vec{a}\} \tag{12}$$

Where the components of the acceleration vector are:

$$\{\vec{a}\} = \begin{Bmatrix} a_x \\ a_y \\ a_z \end{Bmatrix} \tag{13}$$

a_x, a_y, and a_z are the components of acceleration for the blade/fragment in the x, y and z directions Equation 12 can then be rearranged to calculate the acceleration acting on the blade/fragment at any time:

$$\{\vec{a}\} = -\frac{1}{2m} \rho C_D A |\vec{v}_R|^2 \hat{v}_R + \frac{\vec{F}_G}{m} \tag{14}$$

Steps Involved in the Calculation of Throw Distance

At this point in the procedure, the known or assumed parameters will be: the initial position and velocity of the blade/fragment; its mass; exposed area; drag coefficient; the air density; and wind speed. Having determined the resultant acceleration of the blade/fragment using Equation (14) the trajectory of the blade/fragment can be determined using the common formulations of Newton's Laws of motion. The set of ordinary differential equations which are formed can be solved using a simple iterative scheme:

- Step 1: Find the unit vectors describing the blade/fragment's velocity and wind speed based on the chosen coordinate system.
- Step 2: Select a time step (the interval between successive calculations of the blade/fragment's position).
- Step 3: Calculate the resultant velocity using the fragment's speed and wind speed
- Step 4: Calculate the acceleration in the x, y, and z directions using Equation (14).
- Step 5: Estimate the velocity and position of the fragment after each time step from Equations (16 and 17):

$$\{\vec{v}\}_{i+1} = \{\vec{v}_R\}_i + \{\vec{a}\}_i \Delta t \tag{16}$$

$$\left\{\vec{X}\right\}_{i+1} = \left\{\vec{X}\right\}_i + \left\{\vec{v}_R\right\}_i \Delta t + \frac{1}{2}\left\{\vec{a}\right\}_i \left(\Delta t\right)^2 \tag{17}$$

Where, Δt is the time step, the subscript i indicates conditions at the current time step and the subscript $i+1$ indicates conditions at the next time step. Steps 3 through 5 are repeated until the blade/fragment reaches the target position.

These steps describe an explicit forward-differencing in time; it is simple to construct and implement because the position and velocity of the blade/fragment at the new time are entirely dependent on conditions at the old time. It is valid to apply this scheme as the ordinary differential equations are parabolic. However, the drawback to a fully explicit scheme is that it essentially assumes that the "old" value of acceleration at time, t, exists as a constant right across the time step until it suddenly jumps to the "new" value at time $t + \Delta t$. To maintain accuracy and stability in the scheme it is necessary to use small time step; a validation exercise was carried out on the calculation method to identify the dependence on time step and is included in Appendix C.

5. RISK ASSESSMENT METHODOLOGY

5.1. INTRODUCTION

The methodology has been developed to provide HSE with a standard tool for assessing risks to persons in the vicinity of wind turbines. The methodology uses the information developed for the Human Vulnerability Model (Section 3) and Harm Transmission Model (Section 4) together with the turbine specific data and wind conditions, to calculate contours of probability of "harm" (i.e. a fragment landing at a particular location) and fatality due to direct and indirect impact. In a single run of the model these contours are calculated for a single blade (or fragment of a blade) being ejected from a single wind turbine.

These contours can be interpreted as Location Specific Individual Risk (LSIR) conditional upon the blade failure occurring. If the user requires LSIR values, the probabilities calculated by the methodology must be multiplied by the frequency of blade failure.

5.2. MONTE CARLO SIMULATION

Monte Carlo Algorithm

The risk assessment methodology which has been developed in this work is based on a Monte Carlo simulation. Monte Carlo methods are widely used in risk analysis in both engineering and business. They mainly depend on repeated random sampling of variables where a precise problem definition is not possible or appropriate.

The general Monte Carlo method contains the following steps:

1. Identify a domain of possible inputs and categorize as either constant or random variable.

   From blade throw model, the following inputs are identified as influencing parameters: the height of the turbine; length of the blade; the mass and exposed area of the fragment; the velocity of the fragment at detachment; angle of detachment; wind speed; and drag coefficient. Of these, the exposed area of the fragment, angle of detachment of the fragment, the fragment's speed, wind speed and its direction are defined as random variables. The rest of the inputs are constants dependent on the specific turbine.

2. Generate values for the random variables using a specified probability distribution.

   Generating the random numbers according to the distribution is the heart of Monte Carlo simulation. Computers generally generate uniformly distributed random numbers between 0 and 1. This uniform random number can be transformed to another random number with the appropriate statistical characteristics required of random variable. The inverse transformation technique is commonly used for this purpose. The techniques for different distributions are discussed below.

3. Compute the fragment's trajectory using the randomly selected input variables.

   A large number of sets of random variables are generated. For the blade throw problem 1,000,000 sets of random numbers are generated which results in a 1,000,000 domain problem, each domain representing a separate realization of the blade throw problem. For each set of data (domain), the blade throw distance is calculated using the throw model.

4. Aggregate the fragment's throw trajectory from the individual computations to provide the final result.

   The target plane is set at: (i) ground level for the harm model, (ii) 0.8m height from the ground in case of the human vulnerability model with direct impact, and (iii) 3m height above the ground in case of the human vulnerability model with indirect impact. The target plane is divided into a Cartesian reference grid with cell size selected by the user. The probability of impact of the blade fragment in any particular grid cell is calculated from the number of trajectories ending in that cell. Finally, a contour plot is produced for visual interpretation of the results.

5.3. DATA DISTRIBUTIONS USED

As described above, the Monte Carlo method used initially generates uniformly distributed random numbers between 0 and 1 for each variable in the problem. These must then be transformed to random variables having a specific (non-uniform) probability distributions function to match the characteristics of each variable. The different distributions which have been used in the risk assessment methodology are: Uniform, Beta, Weibull, Rayleigh, and Normal distributions. These are described in full in Appendix D.

Choosing the appropriate data distribution function for each random variable is most important in the simulation. As discussed earlier, the throw distance mainly depends on the wind turbine details such as height of the tower, mass and exposed area of the fragments, and the throw speed which is the function of the rotor rotational speed. Quantifying these parameters can be complicated due to substantial differences in wind turbine design and operation, different materials used, choice of aerofoils and design tip speed. These can vary considerably between wind turbine manufactures.

Data has been collected to identify typical values of these parameters. By examining the data recommendations for the appropriate distribution for each influencing parameter have been made.

Mass of the Blade

The mass of the fragment is an important parameter in the blade throw analysis. It varies with the blade material and construction. Data provided by HSE assumed the mass of the full and fragmented blade as 6600 and 660 kg respectively. Macqueen, et. al [27] reported the mass of the blades, manufactured by British Aerospace, Boeing MOD-2 and Hamilton WTS-4 as 16,000, 16,000, and 12000 kg respectively. Reference [34] reported the mass of the blade of very large wind turbines, shown in Table 6.

The mass of the BARD VM blades are reported to be much heavier than the REPower 5M blades. It is difficult to draw direct trends for blade masses from this data due to the different materials and construction methods used, choice of aerofoil section and design tip speed. However, LM Wind Power Blades [35] report that their blades currently mounted on more than one in three wind turbines throughout the world; the mass of the LM blades is shown in Table 7. Table 8 shows similar blade details for wind turbines manufactured by Siemens [36].

Table 6 Wind turbine blade mass [34]

Wind Turbine Plants	*Rotor Diameter (m)*	*Blade Mass (kg)*
BARD VM	122	26000
E112	114	20000
M5000	116	17000
REPower 5M	126	18000

Table 7 LM Wind Power Blade Masses

Power Generated (kW)	*Rotor Diameter (m)*	*Blade Length (m)*	*Blade Mass (kg)*
1300	63	29.15	4400
1500	77	37.25	5590
1500	82	40.0	6100
1500-1600	86.7	42.13	5930
1500-1600	88	43.50	6500
2000	70	34	5720
2000	82	40	6290
2000	92.5	45.2	8100
2500	80	38.8	8700
2500	90	43.8	10400
3000	100	48.7	10700
3000	109	53.2	11955
5000	126	61.5	18841

Table 8 Wind turbines manufactured by Siemens

Wind Turbine Plants	*Hub Height (m)*	*Rotor Diameter (m)*	*Rotor Speed (RPM)*	*Blade Length (m)*	*Tip Chord (m)*	*Root Chord (m)*	*Rotor Mass (kg)*
SWT-2.3-82VS	80	82.4	6-18	40	0.80	3.10	18000
SWT-2.3-93	80	93	6-16	45	0.80	3.5	20000
SWT-2.3-101	80	101	6-16	49	1.00	3.4	20600
SWT-2.3-107	80	107	5-13	52	1.00	4.2	31600

If the density of the blade can be assumed to be constant throughout its length, then the mass of the fragment can be estimated easily from the mass of the blade. Most blades are constructed from composite materials with internal supporting structure and this may be considered a reasonable assumption.

Table 6 - Table 8, the relationship between blade length and mass is presented in Figure 12. A quadratic curve can be fit to the data with linear regression (R^2) with a value of 0.89. The equation for the mass of the blade is thus:

$$M_b = 6.2L_b^2 - 76.4L_b \qquad (1)$$

Where, M_b is the mass of the blade and L_b is the length of the blade.

Hence, if the blade's manufacturer is known, then the mass can be selected from the relevant table above. Otherwise, the mass of the fragment will be estimated using from Figure 12 or using Equation (1).

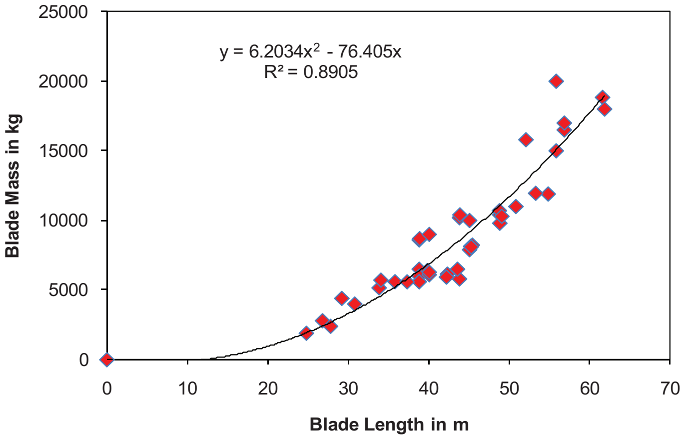


Figure 12. Blade mass vs. blade length

Exposed Area of the Fragment

The "exposed area" of the fragment is the largest cross-sectional area of the fragment normal to its trajectory, or the area of the fragment projected onto a plane normal to the trajectory.

The effect of exposed area in the analysis with a proposed range of 10 to 80 m^2 has been studied previously. Macqueen, *et al.* [27] reported exposed areas of 60 to 104 m^2 for different blade manufacturers and took the exposed area of the fragment to be 10% of the total surface area.

In the current work, the exposed area of the blade fragment has been based on the chord length of the blade, Figure 13. The chord varies from the blade tip to the root, and detail of Siemens manufactured blades is provided in Table 8. This shows that the chord varies from 0.8 m at tip for smaller turbines and 1 m at tip for larger turbines, to roughly 3.5 m at root.

In this study, the chord length at the tip is considered as 1m. The length of the chord at fragment is taken as the sum of length of tip chord and 0.6m per 10 m fragment, which is derived from the table. While the fragment is in flight, the exposed area varies significantly. To find the minimum exposed area, the thickness to chord ratio is assumed to be between 10-15%.

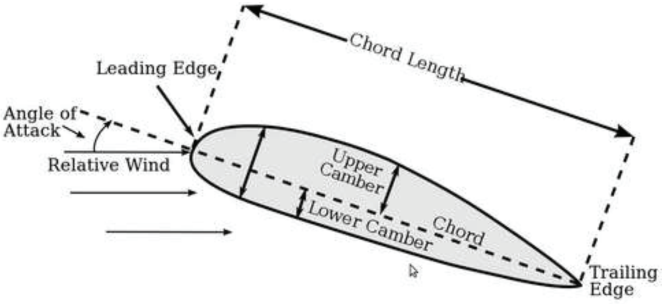


Figure 13. Cross section of an aerofoil (turbine blade)

The orientation of the blade is arbitrary while flying, hence the probability distribution for the exposed area is taken as uniform. The parameters for the uniform distribution are calculated as follows:

- Length of tip chord = 1 m
- Length of root chord = 1m + 0.6m/10m of blade length
- Length of chord at any distance from the tip = 1m + 0.6m/10m of fragment's length
- Maximum exposed area = (Tip chord + Chord length at fragment) x length of the fragment
- Minimum exposed area = 10% of maximum exposed area

Fragment Velocity

Previous work considered two Beta distributions to generate initial blade velocity. In the first distribution, minimum, mode and maximum velocities of fragment are assumed to be the radial velocities at centre of gravity of the blade corresponding to 0.75, 1 and 2.5 respectively of the maximum operational angular speed. The maximum operational rotational speed was assumed to be 18.4 rpm. In the second distribution, rotational speed was represented as a linear function of wind speed. The function passes through the origin (0,0) and the point corresponding to the nominal operational wind speed and the blade's nominal operational speed. At the same time, the tip velocity of the blade must be less than 0.9 Mach (0.9 x 343 m/s ≈ 310 m/s). The nominal operational wind speed and blade rpm are assumed to be 15 m/s and 16.1 rpm respectively. In both the distributions, the blade detachment was assumed only to occur when the wind speed was greater than 75% of the recommended operational wind speed.

In the current work, the fragment velocity has been calculated from the rated rotor speed. Table 14 (Section 8) contains the rated rotor speed for different wind turbines; the mean rated rotor speed is calculated to be 16.1 rpm. As most current wind turbine designs contain active pitch control to regulate the rotor speed, the maximum operational rotor speed will be the cut-out wind speed of 25 ms^{-1}. This may generate rotational speeds around 10% higher than the calculated average rotor speed, 17.7 rpm.

The rotor speed at the survival wind speed (roughly 60 ms^{-1}) is hence around 2.4 times the maximum operation rotor speed. Here, the rotor speed was assumed to be proportional to the wind speed after the cut-out wind speed. The minimum rotor speed at the time of detachment is assumed to be 10% less than the average operational wind speed, which is equal to 14.5 rpm.

For risk assessment, the fragment velocity was assumed to follow the Beta distribution with the minimum and maximum rotor speeds and setting the mode to the average rated rotor speed.

Drag Coefficient

The drag coefficient of the fragment depends on its orientation and as it is likely that the fragment will have tumbling flight, the drag coefficient will vary significantly. Macqueen *et al.* [27] considered drag coefficients between 0.6 and 1.0.

In the current work, drag coefficient was assumed to be 1.0. No variation or data distribution was applied to the drag coefficient as the throw distance is the function of C_d x Exposed area. As a data distribution function was already applied to exposed area, it is not appropriate also to apply a distribution to drag coefficient.

Blade Angle at Detachment

The fragment was assumed to detach at any instant in time, i.e., there was no preferential location in the rotor's cycle for detachment to occur.

A Uniform distribution is appropriate with limits 0° and 360^o.

Wind Speed

The Weibull distribution is commonly used to model the distribution of wind speed. The distribution contains two parameters: one represents the magnitude (the "scale factor") and other represents the shape of the distribution (the "shape factor"). To estimate these parameters for a specific site, the wind speed record for an entire year is required. As it can be expensive and complex to monitor wind over an entire year it is common to use the Rayleigh distribution, based on the mean 1- minute wind speed. (Note that the Rayleigh distribution is a special case of the Weibull distribution). BS 6399 [32] has been used in the past to provide mean 1-minute wind speed map for the UK. This is now superseded by BS EN 1991-1-4:2005, to which there is a UK national annex[33]. Average wind speeds can also be obtained from Wind Finder [38] although this source should be used with caution as the averaging procedure for the data is not apparent.

An earlier study used the Weibull distribution for wind speed with a shape factor of 1.796 and a scale factor of 16.97. In the absence of data relating the wind speed distribution to wind direction, the wind speed distribution can be assumed to be the same in all wind directions.

Wind Direction

Site specific wind rose data for the UK can be obtained from the Met Office [38] and other sources. Wind Finder [37] may also be a useful source of data but should be used with caution as noted above.

In the current work, rather than assuming a data distribution for the wind direction, the wind rose data is used directly in the risk analysis.

5.4. CASE STUDY

Description

The aim of the case study was to apply the methodology developed to a real incident; and, calculate the contours for probability of impact and fatality due to direct and indirect impact, for full blade and blade fragments throw. HSE provided MMI with data from an incident at wind farm in March 2010 when a blade broke off a utility scale turbine (2.3 MW device). The data provided included a detailed map of the blade debris locations following the failure. However, as the wind conditions and the turbine's operating condition were not known at the time of the incident, these had to be assumed in the case study.

The risk assessment methodology results can be compared with the debris locations map. This does not provide validation of the risk assessment methodology, partly as some of the input data is assumed and also as full validation would require very many "real" data sets, which are not available. However it does provide some indication of whether the methodology produces results which are consistent with data from a real incident.

Case Study Input Data

The details of the turbine and other assumed variables required for the risk analysis methodology in the case study are given in Table 9 and Table 10. The blade is assumed to be fragmented at the locations of root, 1/2, 1/3, 1/4, 1/5 and 1/10th of the distance from the tip. For each fragment, the probabilities of impact and fatality due to direct and indirect impacts were calculated using the proposed model.

Table 9 Variables and corresponding data distributions

Variables	*Value*	*Data Distribution*
Hub height	80 m	Constant
Rotor diameter	93 m	Constant
Length of blade	45 m	Constant
Coefficient of drag	1	Constant
Angle of detachment	0 to 360^o	Uniform
Rotor speed (rpm)	min. = 14.5; mode = 16.1; max. = 38.6	Beta
Wind speed	mean = 24 ms^{-1}	Rayleigh
Air density	1.225 kgm^{-3}	Constant

The methodology uses a wind rose with 8 compass points. Wind rose data for the case study was taken from Wind Finder [37]. Wind finder provides sixteen wind directions, which were adjusted to eight directions by moving half of the frequency of the additional directions to the adjacent points. Table 11 shows the adjusted wind rose data for Glasgow.

Table 10 Details of blade fragments analysed in the case study

Size (fraction of blade length)	*Mass (kg)*	*CG distance from rotor's centre (m)*	*Exposed area*	
			Min. (m^2)	*Max. (m^2)*
1	6667	25.5	9.7	96.8
0.5	3333	36.8	3.3	33.2
0.333	2222	40.5	1.9	18.8
0.25	1667	42.4	1.3	12.8
0.2	1333	43.5	0.96	9.6
0.1	667	45.8	0.42	4.2

Table 11 Wind rose for Glasgow

Direction	*Frequency of Occurrence*	*Direction*	*Frequency of Occurrence*
N	0.04	S	0.095
NE	0.105	SW	0.315
E	0.105	W	0.245
SE	0.025	NW	0.07

Case Study Results

The trajectory of the different sizes of blade fragments, indicated in Table 10 were calculated and used to assemble the probabilities for blade fragments landing at specific locations. For this case study the grid of locations around the wind turbine used 5 x 5 m cells for probability of impact or fatality due to indirect impact as these events would typically be associated with large debris. (An individual suffers "indirect impact" when they are within a building which is struck by a blade with sufficient energy to cause the building to collapse.)

A 1 x 1 m grid was used for the probability of fatality due to direct impact as this related better to the area occupied by a person.

Basic contours for each blade fragment considered are shown in Figure 14 to Figure 19. The contours plotted for each case are: (i) probability of impact, (ii) probability of fatality due to direct impact, and (iii) probability of fatality due to indirect impact. The contours are shown as log of probability to provide clarity at the lower probability scale.

The probability contours produced can be considered as Location Specific Individual Risk (LSIR) values, conditional on the failure occurring. If the failure rate of the wind turbine is known then LSIR can be determined by multiplying that rate by the probabilities determined by calculation.

Case Study Results – Discussion

The contour plots shown in Figure 14 to Figure 19 were produced using MATLAB. This incorporates the 0.5H, 1.0H, 1.5H, 2.0H contour lines marking distances from the wind turbine tower location in terms of the hub height, H.

A general point to note is that, depending on the grid size used, the results may appear to be more or less uniform. For example, the probability of fatality by direct impact plots appear more "speckled" because there are 25x more grid points, and some locations receive no "hit" and consequently remain white on the plot.

Importantly, this highlights the point that the calculated risk or a blade or fragment strike at any particular location is dependent on the grid size selected – i.e. 5 m by 5 m cells are more likely to be hit than 1 m by 1 m cells.

Probability of Impact

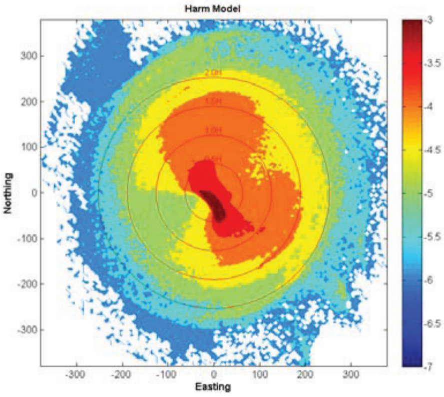
Comparing the probability of impact (i.e. "harm model") results for different fragment sizes, the contours appear more circular for the full blade and larger fragment sizes. This implies that for the large fragments, there is less influence due to the wind direction. Large fragments also tend to have higher probability of impact close to the tower and lower probability of impact further away. For example, the whole blade has the 10^{-4} contour extending beyond 1.5H and the 10^{-5} contour extending to around 2.0H (downwind). Compare this with the 20% blade fragment, where the 10^{-4} contour lies within 1.0H and the 10^{-5} contour extends to 2.5H (downwind) and > 3.0H (in the plane of the rotor).

Still considering the probability of impact, there appears to be a departure from the general trend of probability decreasing monotonically with distance from the tower. This is best shown by the 0.25 blade fragment results in Figure 17 and half blade fragment results shown in Figure 15. (There is also evidence of this effect for other fragment sizes, but it does not show up so well in the contour levels selected.

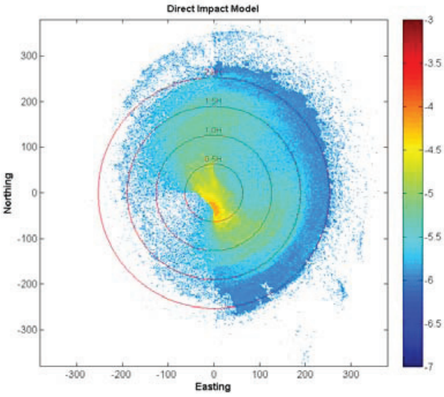
For the 0.25 blade fragment, there are regions of relatively high probability $>10^{-4}$ around 2.0H and outside of the general 10^{-4} contour which is generally limited to 1.0H. This is most likely not due to an aberration in the Monte Carlo method as the additional high probability regions are roughly symmetrical about a vertical plane along the axis of the rotor. It may be due to the particular mass and dimension of the 0.25 fragment responding to the inherent non-linearity of the harm transmission model – e.g. if all other factors are equal, one would expect that fragments released at 45° from the horizontal would travel the furthest distance.

Probability of Fatality by Direct Impact

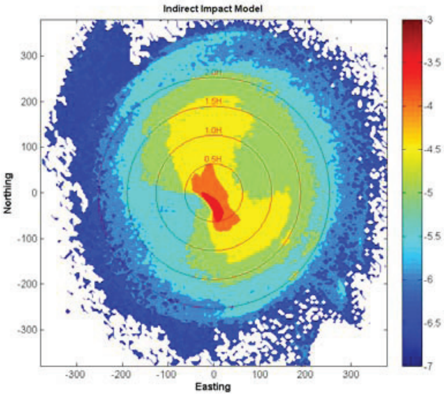
The probability of fatality by direct impact results indicate the expected trend, that as the fragment size deceases, so does the probability of fatality. Both the probability footprint and value decrease: there is a definite region of 10^{-4} probability adjacent to the wind turbine for the whole blade failure, and large $10^{-5.5}$ (3.162×10^{-6}) footprint extending to around 1.75H. However, for a 33% blade fragment the 10^{-4} probability contour has disappeared and the $10^{-5.5}$ probability contour is drastically reduced in size to within 1.0H.



Probability of impact in a 5m x 5m cell

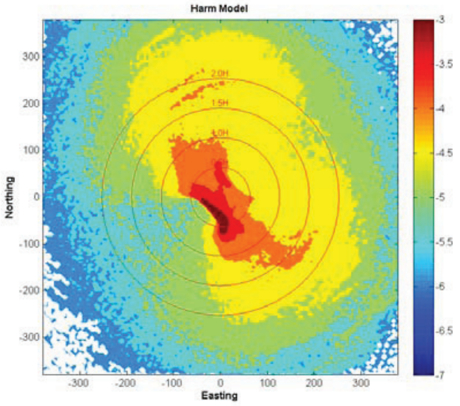


Probability of fatality by direct impact in a 1m x 1m cell

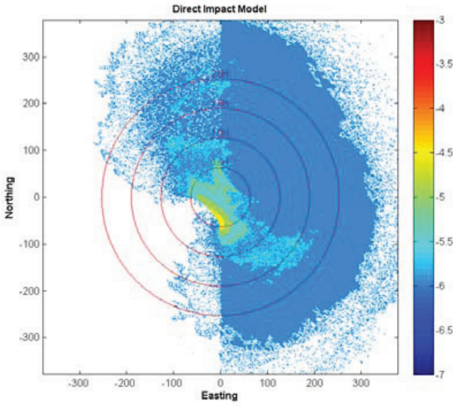


Probability of fatality by indirect impact in a 5m x 5m cell

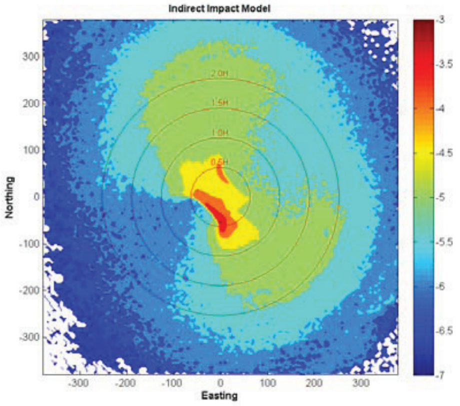
Figure 14 Probability contour plots for whole blade failure



Probability of impact in a 5m x 5m cell

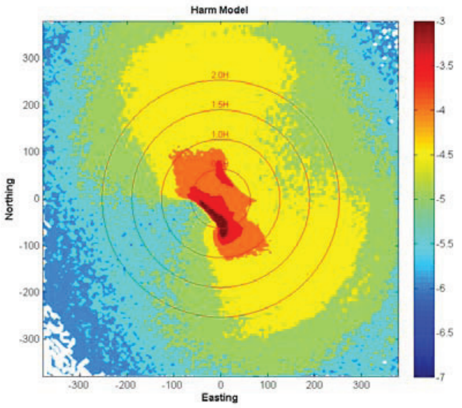


Probability of fatality by direct impact in a 1m x 1m cell

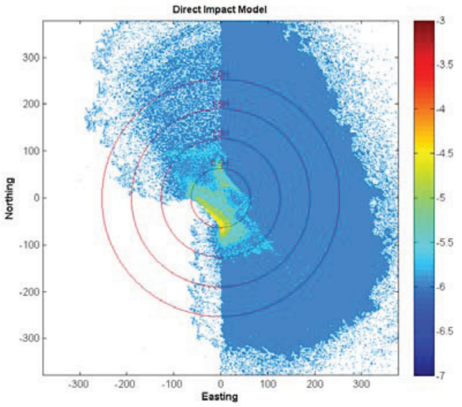


Probability of fatality by indirect impact in a 5m x 5m cell

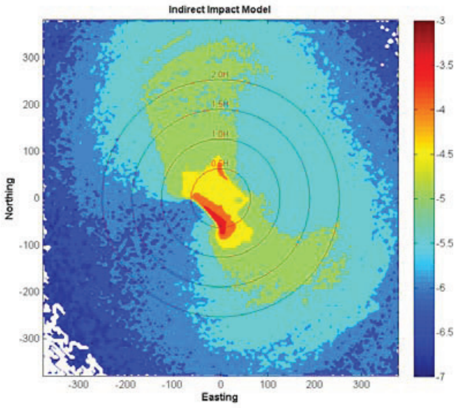
Figure 15 Probability contour plots for 0.5 blade length fragment



Probability of impact in a 5m x 5m cell

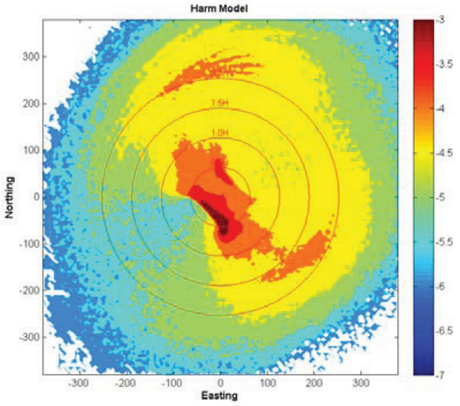


Probability of fatality by direct impact in a 1m x 1m cell

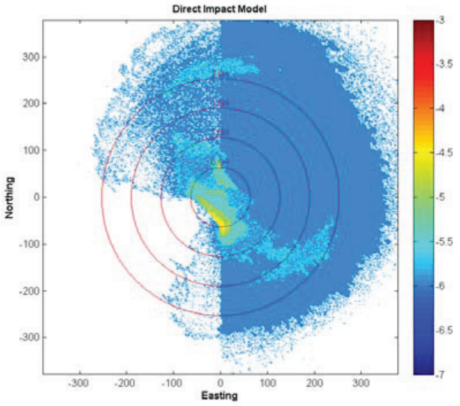


Probability of fatality by indirect impact in a 5m x 5m cell

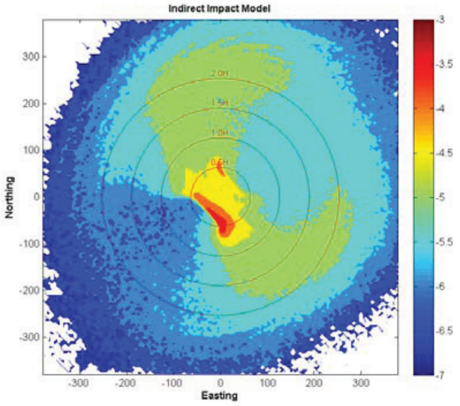
Figure 16 Probability contour plots for 0.333 blade length fragment



Probability of impact in a 5m x 5m cell

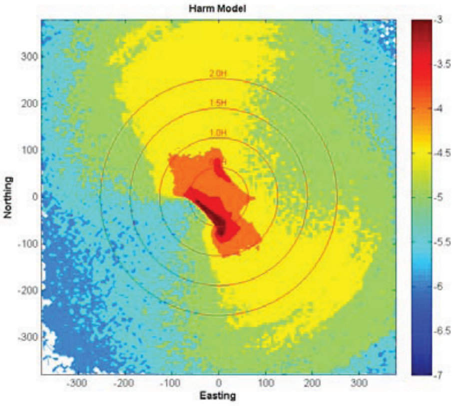


Probability of fatality by direct impact in a 1m x 1m cell

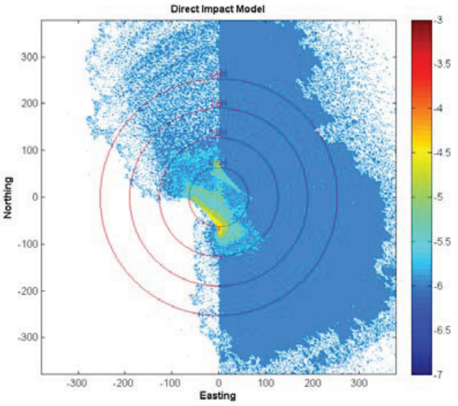


Probability of fatality by indirect impact in a 5m x 5m cell

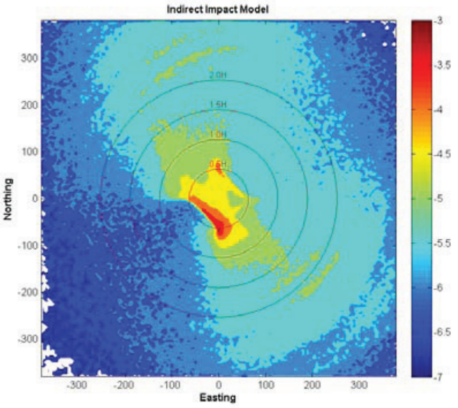
Figure 17 Probability contour plots for 0.25 blade length fragment



Probability of impact in a 5m x 5m cell

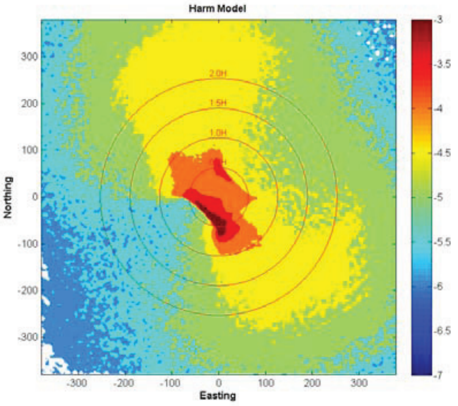


Probability of fatality by direct impact in a 1m x 1m cell

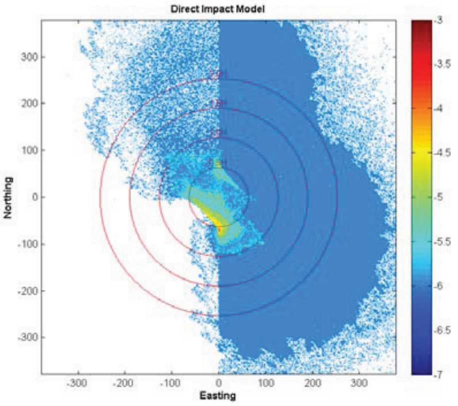


Probability of fatality by indirect impact in a 5m x 5m cell

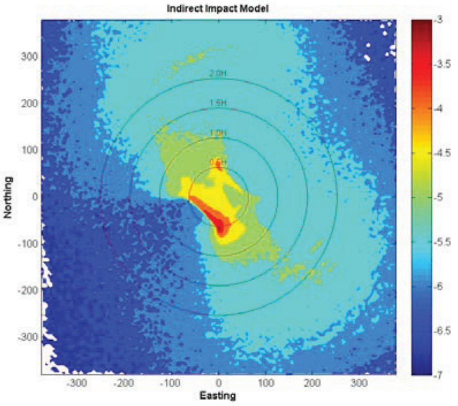
Figure 18 Probability contour plots for 0.20 blade length fragment



Probability of impact in a 5m x 5m cell



Probability of fatality by direct impact in a 1m x 1m cell



Probability of fatality by indirect impact in a 5m x 5m cell

Figure 19 Probability contour plots for 0.10 blade length fragment

Probability of Fatality by Indirect Impact

The results for probability of fatality by indirect impact results are similar in essence to the direct impact results. However, the overall probabilities are significantly higher due to the larger grid cell size used (5 m by 5 m) to represent impact with buildings. For a large wind turbine in an upland moorland location, such as used in this case study, the likelihood of there being building present near the wind turbine is low. (There may also be vehicles present on roads close to the turbine).

Case Study Results – Sensitivity Study

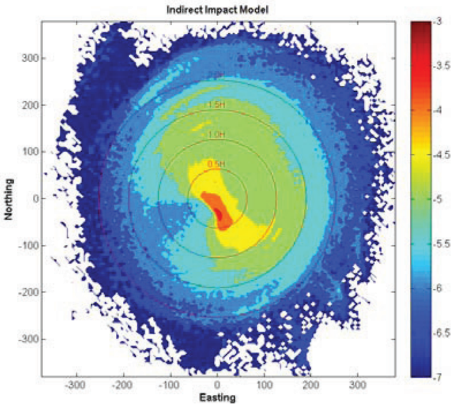
In Section 3.3 it was noted that the sparse nature of the data for fatality due to indirect impact results in a degree of subjectivity. This has been tested in a sensitivity study to determine the influence of 2.0x and 0.5x the probability of fatality per building occupant for the same impact impulse. The results are presented in Figure 20 to Figure 22.

(The notation 0.5xPF, 2.0xPF refers to 0.5x the probability of fatality and 2.0x the probability of fatality defined in the original function described in Section 3.3, Figure 10; whereas, 1.0xPF refers to the original probability of fatality function.)

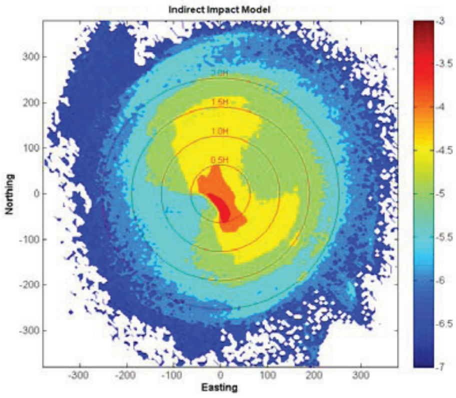
For the whole blade failure the general trend is observed that as the probability of fatality function increases from 0.5xPF to 2.0xPF, the probability contours move outwards from the turbine position. However, this is mitigated somewhat as the higher risks remain relatively close to the turbine tower. For example, the 10^{-5} contour typically lies within 1.5H of the tower for 0.5xPF; this only moves out to 2.0H when the probability of fatality function is increased to 2.0xPF.

A different situation occurs when considering the half and quarter blade fragments. Here the size of the 10^{-5} contour calculated with 0.5xPF is considerably smaller than when calculated with 1.0xPF. However, when calculated with the 2.0xPF function, the contours do not extend very much further than when calculated with 1.0xPF. Typically the limit of the 10^{-5} contour is 2.5H for 1.0xPF and 3.0H for 2.0xPF.

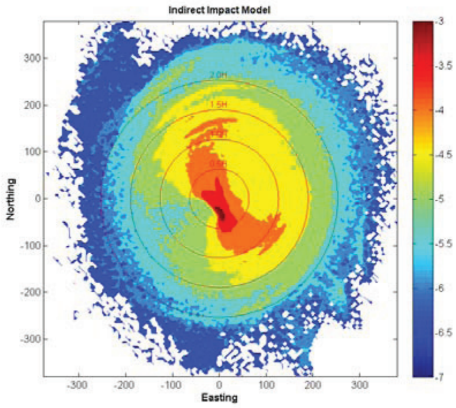
It is concluded that the model is sensitive to changes in the definition of the probability of fatality by indirect impact function. However, there is not a great variation in the results and the function originally defined in Section 3.3 appears reasonable; although the 2.0xPF function could be used if more conservatism was required in a particular calculation.



Probability of fatality by indirect impact in a 5m x 5m cell – 0.5xPF sensitivity

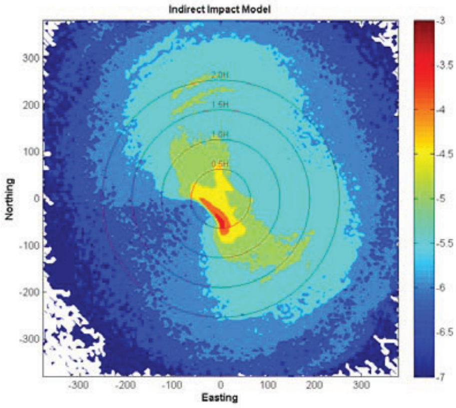


Probability of fatality by indirect impact in a 5m x 5m cell – 1.0xPF original

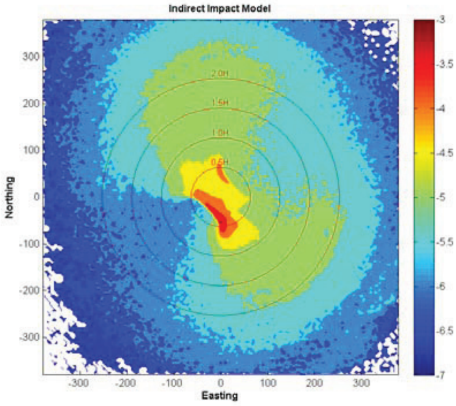


Probability of fatality by indirect impact in a 5m x 5m cell – 2.0xPF sensitivity

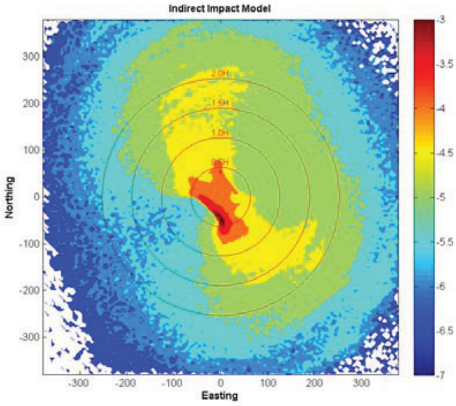
Figure 20 Indirect impact sensitivity test - whole blade length fragment



Probability of fatality by indirect impact in a 5m x 5m cell – 0.5xPF sensitivity

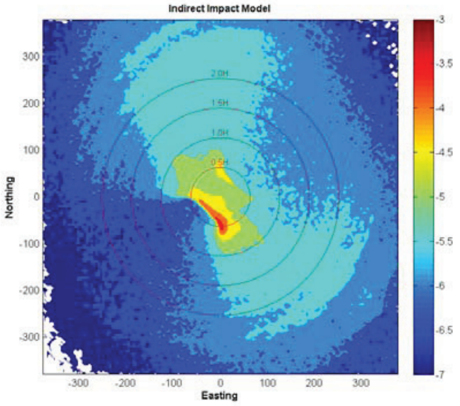


Probability of fatality by indirect impact in a 5m x 5m cell – 1.0xPF original

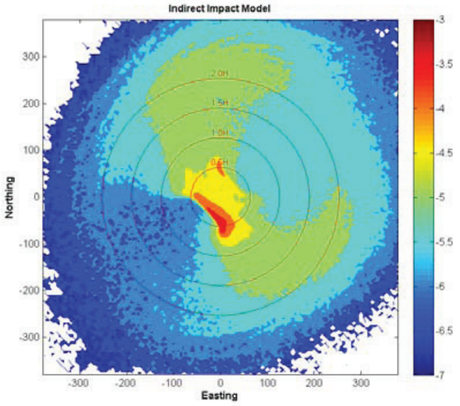


Probability of fatality by indirect impact in a 5m x 5m cell – 2.0xPF sensitivity

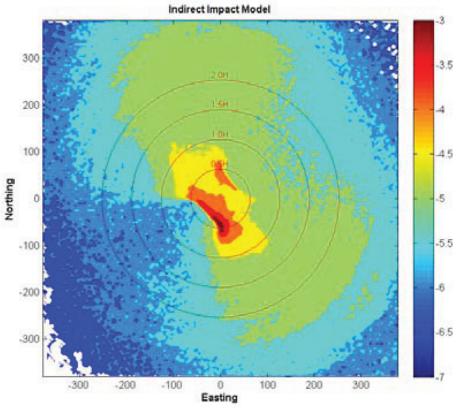
Figure 21 Indirect impact sensitivity test – 0.5x blade length fragment



Probability of fatality by indirect impact in a 5m x 5m cell – 0.5xPF sensitivity



Probability of fatality by indirect impact in a 5m x 5m cell – 1.0xPF original



Probability of fatality by indirect impact in a 5m x 5m cell – 2.0xPF sensitivity

Figure 22 Indirect impact sensitivity test – 0.25x blade length fragment

Case Study Results – Comparison with Societal Risks

To help interpretation of the results of the case study, a comparison is made with other risks commonly experienced in society. The HSE's "Reducing Risks, Protecting People" guidelines [40] (also known as "R2P2") provide detail of a range of risks experienced in day-to-day life. These are stated relative to the particular situation in which the risk is experienced – i.e. transport risks are stated per passenger mile or per passenger journey. For the current comparison, these have been converted to annual risks and the assumptions used in this conversion are stated below in Table 12.

The risks calculated for fatality from direct and indirect impact are *conditional* Location Specific Individual Risks (LSIR) where the condition is that failure has already occurred. The methodology has been deliberately formulated in this fashion to allow the user discretion over the failure rate of a specific wind turbine design. To convert these conditional LSIR values to LSIR the calculated risk values must simply be multiplied by the frequency of failure.

In Appendix A (Section 7), a method is presented to estimate annual frequency of failure of wind turbine blades. This was assessed as between 10^{-3} and 10^{-4} blade failures per turbine per year. For conservatism the higher value is used in the following comparison.

The risks stated for fatality by direct and indirect impact are all taken from Figure 14 to Figure 19. They are stated at distance 2.0H from the turbine location where H is the height of the turbine hub. The risks are stated as the order of magnitude indicated on the Figures; any more detailed analysis would mis-represent the uncertainties inherent in the method.

The data in Table 12 indicates that the risk of fatality from wind turbines (at 2 hub heights or greater from the turbine) is low in comparison to other societal risks. It is roughly equivalent to the risk of fatality from taking two aircraft flights per annum.

Table 12. Estimated annual risk of fatality due to impact from a blade/fragment of a large 2.3 MW wind turbine compared with other societal risks

Source of Fatality	*Annual Risk*	*Assumptions*
Wind turbine - Direct impact by blade/fragment	10^{-9}	At 2x hub height from wind turbine
Wind turbine - Indirect impact by blade/fragment	10^{-8}	At 2x hub height from wind turbine
Cancer	2.58×10^{-3}	Averaged over population. England & Wales 1999
Lightning	5.35×10^{-8}	England & Wales 1995-1999
Mining Industry	1.09×10^{-4}	GB 1996-2001
Construction Industry	5.88×10^{-5}	GB 1996-2001
Agriculture	5.81×10^{-5}	GB 1996-2001
Service Industry	3.00×10^{-6}	GB 1996-2001
Fairground Rides	4.79×10^{-9}	Assumes 4x rides per annum. UK 1996-2000
Road Accidents (all forms)	5.95×10^{-5}	UK 1999
Rail Travel Accidents (per passenger journeys)	2.32×10^{-8}	Fatality per passenger journeys GB 1996-1997
Rail Travel Accidents (annual risk - commuter)	1.05×10^{-5}	Annual risk of fatality: 2 daily journeys, 45 weeks per year
Aircraft Accident (per passenger journeys)	8.00×10^{-9}	Fatality per passenger journeys UK 1991-2000
Aircraft Accident (annual risk – holidaymaker)	1.60×10^{-8}	Annual risk of fatality: 2 flights per annum

6. CONCLUSION

MMI Engineering has carried out a wide ranging study to investigate the issues surrounding the potential for harm to persons in the vicinity of onshore wind turbines and to develop a methodology to estimate the risk to persons.

A literature survey has been carried out to investigate the current status of available data for wind turbine failure rates. This has confirmed that there is little publicly available failure data for wind turbine failures. Where databases have been compiled, the data are typically held in confidence by manufactures or industrial bodies, or are compiled by pressure groups and the source data cannot be verified. A number of recent wind turbine incidents in the UK involving blade throw have had more thorough investigation and the results, although not available publicly, are available to HSE. The UK trade and professional body for wind power, RenewableUK, has maintained a "lessons learnt" database since 2006 which has the potential to become an important resource for wind turbine failure rates.

The US National Renewable Energy Laboratory has contributed to this project in providing detail on wind turbine design, manufacture and failure modes. This highlights the range of safety features installed on most modern utility scale wind turbines which have the potential to detect incipient problems and take the wind turbine out of service before blade detachment or fragmentation occurs. There is the potential that this information may reduce the failure rate in any root-cause analysis undertaken for failure rates (which has been outside the scope of this project).

To develop the methodology for the assessment of risk to persons in the vicinity of wind turbines MMI has adopted a "cautious best estimate" approach under the guidance of HSE. This approach has been necessary as there is insufficient data on wind turbine failures to fully validate the model produced.

MMI has developed models for human vulnerability to direct and indirect impact by wind turbine blades and fragments. These models have been combined with a harm transmission model – essentially a calculation of thrown blade or fragment trajectory. In combination these models provide the methodology for the assessment of risk to persons in the vicinity of wind turbines.

The methodology has been coded in Microsoft Excel using VBA scripts. The code uses a Monte Carlo algorithm to calculate a large sample of failure events, which are analysed to provide: probability of a blade or fragment landing at a particular location; probability of fatality due to direct impact on individuals in the open and probability of fatality due to indirect impact on individuals within buildings. These probabilities of fatality can be considered as *conditional* Location Specific Individual Risk (LSIR), where the condition is that blade failure has already occurred. If multiplied by a known or estimated blade frequency of failure, the probabilities of fatality can then be interpreted as Location Specific Individual Risk.

A single case study was carried out with the risk assessment methodology to determine typical risks associated with wind turbines and to compare the results with other societal risks. This has used the example of a 2.3 MW utility scale wind turbine. The analysis has indicated that the risks of fatality associated with this wind turbine are low relative to other risks commonly experienced.

Although this low level might be considered acceptable, it should be borne in mind that it represents a single large, horizontal axis, utility-scale device. Smaller wind-turbines are more likely to be used in populated areas. If their frequency of failure is significantly different, then so too will be the LSIR. In this current work, no analysis has been carried out on such wind turbines.

Similarly where turbines are to be placed in proximity with hazardous installations, the potential for wind turbine fragments causing incidents on the hazardous plant should be considered. Whilst based on normal separations distances the case for allowing such developments could most likely be made it would be prudent for this to be considered.

7. **APPENDIX A**
METHOD TO ESTIMATE BLADE FAILURE FREQUENCY

Foreword

To provide an order of magnitude estimate of the blade failure frequency per turbine per year, it is necessary to compile a database of turbine failures. As no such validated database has been found to be freely available the following method is based on information from a wind farm information forum available on the internet.

It is strongly advised that the number of failures is treated with caution as it cannot be validated from the information available. There is the risk of double-counting information and exaggerating incidents which may increase the total number of failures. In the main these should add conservatism to the estimate. On the contrary, any incidents which are not included in the database due to lack of awareness or commercial sensitivities will reduce the conservatism in the estimate.

Due to these concerns over the veracity of the data, the source is not referenced. Hence the following method is provided as an illustration only and not a recommendation of a particular blade failure frequency

Estimation Method

As a conservative estimate reported blade failures are all assumed to be from European sources only. 32 blade failures are reported for the period 1995-1999; 53 blade failures for 2000-2004 and 95 blade failures for 2005-2009.

The European Wind Energy Association reports the European total power of installations in MW for the period 1995 to 2009 [23]. Taking the simplifying assumption that the average wind turbines rating is 1 MW, an estimate can be made for the blade failure frequency per mega-Watt per year.

Note that this approach cannot be used to identify the blade failure frequency as a function of WT power rating; also any users of this method should review the average wind turbine rating.

The blade failure frequency per turbine per year can be determined by: (reported number of blade failures in Europe over five year period) divided by (5 x European wind power installation MW for a defined year)

For example:

For the 2005-2009 period, there are 95 reported blade failures; EWEA data gives the total WT power output across Europe as 40500 MW (2005), rising to 74767 MW (for 2009), with an average value of 56907 MW over the 5 year period. Taking the European wind turbine power output for 2005 as a conservative assumption for 2005 - 2009, the following calculation can be made:

Failure frequency per 1MW turbine per year = 95/(5 x 40500) = 5×10^{-4} blade failures/turbine/year

By taking the same approach for the periods 1995 - 1999 and 2000 - 2004, and using both the individual year and averaged values for European wind turbine power outputs, it can be estimated that the failure frequency lies in the range 10^{-3} to 10^{-4} blade failures/turbine/year.

This range is in general agreement with the data presented by Larwood [26] presented in Table 5 (Section 4.2).

8. APPENDIX B

SUMMARY OF DATA FROM THE WIND ENERGY MARKET [31]

Table 13: Wind Turbines – Control and Protection Systems

Manufacturer	*Model*	*Rated Power (kW)*	*Nacelle Design*	*Rotor Type*	*Material*[1]	*Control and Protection System*			
						Gear Type[2]	*Gear Stages*	*Speed Control*[3]	*Breaking System*[4]
Acciona	AW 1500	1500	separated	34	2	2	3	1	1
Acciona	AW 3000	3000	separated	48.8	2	6	3	1	2
Avantis	AV1010	2300	integrated	Avantis AB100	4	1	-	1	2
Avantis	AV928	2500	integrated	Avantis AB92	4	1	-	1	2
DeWind	D8 2000	2000	separated	-	6	2	3	2	1
DeWind	D8.2	2000	separated	-	6	5	2	2	1
DeWind	D9.0	2000	separated	-	6	2	3	2	2
DeWind	D9.1	2000	separated	-	6	2	3	2	2
DeWind	D9.2	2000	separated	-	6	4	2	2	2
Enercon	E101	3000	integrated	E-101	4	1	-	2	2

Manufacturer	**Model**	**Rated Power (kW)**	**Nacelle Design**	**Rotor Type**	**Material**[1]	**Control and Protection System**			
						Gear Type[2]	**Gear Stages**	**Speed Control**[3]	**Breaking System**[4]
Enercon	E33	330	integrated	E-33	4	1	-	2	2
Enercon	E44	900	integrated	E-44	4	1	-	2	2
Enercon	E48	800	integrated	E-48	4	1	-	2	2
Enercon	E53	800	integrated	E-53	4	1	-	2	2
Enercon	E70	2300	integrated	E-70	4	1	-	2	2
Enercon	E-82 E2	2300	integrated	E-82	4	1	-	2	2
Enercon	E-82 E3	3000	integrated	E-83	4	1	-	2	2
e.n.o.energy systems	e.n.o.82-2.0	2000	semi-integrated	LM 40.0 P	3	2	3	2	2
e.n.o.energy systems	e.n.o.92-2.2	2200	semi-integrated	LM 45.3 P	3	3	4	2	2
Alstom	Ecotecnia 100	3000	separated	-	3	2	-	2	2
Alstom	Ecotecnia 74 1.67	1670	separated	-	3	2	3	2	1
Altom	Ecotecnia 80 1.67	1670	separated	-	3	2	3	2	1
Alstom	Ecotecnia 80 2.0	2000	separated	-	3	2	3	2	1

Manufacturer	Model	Rated Power (kW)	Nacelle Design	Rotor Type	Material[1]	Control and Protection System			
						Gear Type[2]	**Gear Stages**	**Speed Control[3]**	**Breaking System[4]**
Eviag	ev100	2500	semi-integrated	-	3	2	3	2	2
Eviag	ev2.93	2050	semi-integrated	-	3	2	3	2	2
Eviag	ev90	2500	semi-integrated	-	3	2	3	2	2
Innovtive Windpower	Falcon 1.25 MW	1250	integrated	-	4	7	2	1	1
Fuhrländer	FL 2500-100	2500	semi-integrated	LM 48.8	3	2	3	2	1
Fuhrländer	FL 2500-90	2500	semi-integrated	M 43.8	3	2	3	2	1
Fuhrländer	FL MD 77	1500	semi-integrated	LM 34	4	2	3	2	1
Gamesa	G52-850 kW	850	separated	-	4	2	3	2	1
Gamesa	G58-851 kW	850	separated	-	4	2	3	2	1
Gamesa	G80-2.0 MW	2000	separated	-	4	2	3	2	2
Gamesa	G87-2.0 MW	2100	separated	-	5	2	3	2	2
Gamesa	G90-2.0 MW	2000	separated	-	5	2	3	2	2
GE Energy	GE 1.5sle	1500	separated	-	3	2	3	2	2
GE Energy	GE 1.5xle	1500	separated	-	3	2	3	2	2

Manufacturer	***Model***	***Rated Power (kW)***	***Nacelle Design***	***Rotor Type***	***Material*[1]**	***Control and Protection System***			
						***Gear Type*[2]**	***Gear Stages***	***Speed Control*[3]**	***Breaking System*[4]**
GE Energy	GE 2.5xl	2500	separated	LM 487	3	2	3	2	2
GE Energy	GE 4.0-110	4000	integrated	-	3	1	-	2	2
Kenersys	K 100 - 2.5 MW	2500	separated	K 100 - 2.5 MW	3	2	3	1	1
Kenersys	K 82 - 2.0 MW	2000	separated	K 82 - 2.0	3	2	3	1	1
Lanco Wind Power	L93	2050	separated	-	3	2	3	2	1
Leitwind	LTW70	1700-2000	separated	-	3	1	-	4	2
Leitwind	LTW77	1000-1500	integrated	-	3	1	-	4	2
Leitwind	LTW80	1500	integrated	-	1	1	-	4	2
Areva / Multibrid	Multibrid M5000	5000	integrated	-	6	8	-	3	1
Nordex	N100/2500	2500	separated	NR 50, LM 48.8	3	3	3	3	2
Nordex	N80/2500	2500	separated	LM 38.8	3	3	3	3	2
Nordex	N90/2500 HS	2500	separated	NR 45, LM 43.8	3	3	3	3	2
Nordex	N90/2500 LS	2500	separated	NR 45, LM 43.8	3	3	3	3	2
PowerWind	56	900	separated	C-27	3	2	3	1	2

Manufacturer	***Model***	***Rated Power (kW)***	***Nacelle Design***	***Rotor Type***	***Material[1]***	***Control and Protection System***			
						Gear Type[2]	***Gear Stages***	***Speed Control[3]***	***Breaking System[4]***
PowerWind	90	2500	separated	-	3	2	3	1	2
RE Power Systems	3.2M114	3200	separated	-	4	2	3	3	2
RE Power Systems	3.4M104	3400	separated	-	4	2	3	3	2
RE Power Systems	5M	5075	separated	-	3	2	3	3	3
RE Power Systems	6M	6150	separated	-	3	2	3	3	3
RE Power Systems	MM82	2050	separated	various	4	2	3	3	2
RE Power Systems	MM92	2050	separated	various	4	2	3	3	2
Schuler	SDD100	2700	integrated	-	4	1	-	-	4
Siemens	SWT-2.3-101	2300	separated	B49	3	2	3	1	1
Siemens	SWT-2.3-82 VS	2300	separated	B40	3	2	3	1	1
Siemens	SWT-2.3-93	2300	separated	B45	3	2	3	1	1

Manufacturer	*Model*	*Rated Power (kW)*	*Nacelle Design*	*Rotor Type*	*Material*[1]	*Control and Protection System*			
						Gear Type[2]	*Gear Stages*	*Speed Control*[3]	*Breaking System*[4]
Siemens	SWT-3.6-107	3600	separated	B52	3	2	3	1	1
Siemens	SWT-3.6-120	3600	separated	B58	3	2	3	1	1
Vensys	100	2500	integrated	LM 48.8	3	1	-	2	2
Vensys	77	1500	integrated	LM 37.3P	3	1	-	2	2
Vensys	82	1500	integrated	LM 40.3	3	1	-	2	2
Vensys	90	2500	integrated	LM 43.8	3	1	-	2	2
Vestas	V100-1.8 MW	1800	integrated	-	3	2	1	3	1
Vestas	V112-3.0 MW	3000	integrated	-	3	2	4	3	3
Vestas	V52-850 kW	850	separated	-	4	2	3	3	1
Vestas	V80-2.0 MW	2000	separated	NACA 63 + FFA-W3	3	2	3	3	1
Vestas	V90-2.0 MW	2000	separated	RISÖP + FFA-W3	3	2	3	2	1
Vestas	V90-3.0 MW	3000	integrated	RISÖP + FFA-W3	3	2	3	2	1

Key for Table 13:

[1] Material column indicates:

1 – Epoxy resin
2 – Carbon fibre reinforced plastic
3 – Glass fibre reinforced plastic
4 – Glass fibre reinforced plastic, epoxy resin
5 – Glass fibre reinforced plastic, carbon fibre reinforced plastic, epoxy resin
6 – Glass fibre reinforced plastic, carbon fibre reinforced plastic

[2] Gear type column indicates

1 – Gearless
2 – Combined spur / planetary gear
3 – Combined spur / planetary gear differential
4 – Combined spur / planetary gear, hydrodynamic WinDrive
5 – Combined spur / planetary gear WinDrive hydrodynamic (variable)
6 – Combined spur/planetary gear 2 planetary / helical
7 – Planetary
8 – Planetary One-step-planetary gear, helical

[3] Speed control column indicates:

1 – Active blade pitch control
2 – Variable via microprocessor
3 – Variable via microprocessor, active blade pitch control
4 –Variable via microprocessor, active blade pitch control, electronic power limiter

[3] Breaking system control column indicates:

1 – Blade pitch control
2 – Individual blade pitch control
3 – Blade pitch control, individual blade pitch control
4 – Blade pitch control 3 individual blade pitch control systems

Table 14: Wind Turbines – Rotor Specification

Manufacturer	*Model*	*Min. Hub Height (m)*	*Diameter (m)*	*Rated Rotor Speed (RPM)*	*Blade Mass (kg)*	*Survival wind speed (m/s)*	*Rated wind speed (m/s)*	*Cut-in wind speed (m/s)*	*Cut-out wind speed (m/s)*
Acciona	AW 1500		70.06	20.2	5160	-	11.6	4	25
Acciona	AW 3000	100	100	14.2	10400	-	11.7	4	25
Avantis	AV1010	99	100.6	16	-	52.5	11.1	3	25
Avantis	AV928	80	93.2	16	-	59.5/70	11.3	3	25
DeWind	D8 2000	80	80	18	5600	57.4	13.5	3	25
DeWind	D8.2	100	80	18	5600	57.4	15	4.9	25
DeWind	D9.0	80	93	15.7	-	-	12	3	25
DeWind	D9.1	80	93	15.7	-	-	12	3	25
DeWind	D9.2	80	93	15.7	-	-	12	4.9	25
Enercon	E101	99	101	4-14.5 (v)	-	-	-	-	28-34 (v)
Enercon	E33	37	33.4	18-45 (v)	-	-	-	-	28-34 (v)
Enercon	E44	45	44	12-34 (v)	-	-	-	-	28-34 (v)
Enercon	E48	50	48	16-31 (v)	-	-	-	-	28-34 (v)
Enercon	E53	60	52.9	12-28.3 (v)	-	-	-	-	28-34 (v)

Manufacturer	***Model***	***Min. Hub Height (m)***	***Diameter (m)***	***Rated Rotor Speed (RPM)***	***Blade Mass (kg)***	***Survival wind speed (m/s)***	***Rated wind speed (m/s)***	***Cut-in wind speed (m/s)***	***Cut-out wind speed (m/s)***
Enercon	E70	57	70	6-21.5 (v)	-	-	-	-	28-34 (v)
Enercon	E-82 E2	78	82	6-18 (v)	-	-	-	-	28-34 (v)
Enercon	E-82 E3	78	82	6-18.5 (v)	-	-	-	-	28-34 (v)
e.n.o.energy systems	e.n.o.82-2.0	58.6	82.4	9.8-18.7	6290	-	13	3	25
e.n.o.energy systems	e.n.o.92-2.2	80	92.8	14.8	8150	-	13	3	25
Alstom	Ecotecnia 100	90	100	7.94-14.3	-	-	-	3	25
Alstom	Ecotecnia 74 1.67	60	74	10-19 (v)	5600	59.5	-	3	25
Altom	Ecotecnia 80 1.67	60	80	9.7-18.4	6000	52.5	-	3	25
Alstom	Ecotecnia 80 2.0	70	80	10-18.4	5600	60	-	3	25
Eviag	ev100	85	100	9.4-16.5	-	-	11.5	3.5	25
Eviag	ev2.93	85	93.2	8.5-17.7	-	-	12	3.5	25
Eviag	ev90	85	90	10.4-18.1	-	-	13	4	25
Innovtive Windpower	Falcon 1.25 MW	60	64	25	4000	-	13	3	25
Fuhrländer	FL 2500-100	85	100	9.4-17.1	-	-	11.5	3.5	25

Manufacturer	***Model***	***Min. Hub Height (m)***	***Diameter (m)***	***Rated Rotor Speed (RPM)***	***Blade Mass (kg)***	***Survival wind speed (m/s)***	***Rated wind speed (m/s)***	***Cut-in wind speed (m/s)***	***Cut-out wind speed (m/s)***
Fuhrländer	FL 2500-90	85	90	10.4-18.1	-	-	13	4	25
Fuhrländer	FL MD 77	61.5	77	9.7-18.3	-	51.6	13	3	20
Gamesa	G52-850 kW	44	52	14.6-30.8	1900	46.6	15	4	28
Gamesa	G58-851 kW	44	58	14.6-30.8	2400	52.5	12	3	23
Gamesa	G80-2.0 MW	60	80	9.0-19.0	6500	55.8	15	4	25
Gamesa	G87-2.0 MW	67	87	9.0-19.1	6150	49	15	4	25
Gamesa	G90-2.0 MW	67	90	9.0-19.0	5800	49	14	3	25
GE Energy	GE 1.5sle	61.4	77	18.4	-	-	14	3	25
GE Energy	GE 1.5xle	80	82.5	16.8	-	-	12	3	20
GE Energy	GE 2.5xl	75	100	14.1	-	-	12	3	25
GE Energy	GE 4.0-110		110	variable	-	-	14	3	25
Kenersys	K 100 - 2.5 MW	85	100	14.1	-	59.5	13	3	25
Kenersys	K 82 - 2.0 MW	80	82	17.1	-	59.5	14	3.5	25
Lanco Wind Power	L93	85	93.2	15.9	8230	59.5	11.5	3.5	25

Manufacturer	*Model*	*Min. Hub Height (m)*	*Diameter (m)*	*Rated Rotor Speed (RPM)*	*Blade Mass (kg)*	*Survival wind speed (m/s)*	*Rated wind speed (m/s)*	*Cut-in wind speed (m/s)*	*Cut-out wind speed (m/s)*
Leitwind	LTW70	60	70.1	6.0-24.0	-	-	13	3	25
Leitwind	LTW77	65	76.8	6-20.9	-	-	12	3	25
Leitwind	LTW80	60	80.3	6-20.9	-	-	10.5	3	25
Areva / Multibrid	Multibrid M5000	90	116	5.9-14.8	16500	-	12.5	4	25
Nordex	N100/2500	100	100	9.6-14.9	9800	52.5	12.5	3	20
Nordex	N80/2500	60	80	10.8-18.9	8600	70	15	3	25
Nordex	N90/2500 HS	70	90	10.3-18.1	10200	70	13	3	25
Nordex	N90/2500 LS	80	90	9.6-16.8	10200	59.5	14	3	25
PowerWind	56	59	56	6.0-27.8	2800	59.5	12	3	25
PowerWind	90	98	90	4.0-16.0	-	-	12.5	3	25
RE Power Systems	3.2M114	93	114	12.6	15000	-	12	3	22
RE Power Systems	3.4M104	80	104	7.1-13.8	11000	-	13.5	3.5	25
RE Power Systems	5M	85	126	12.1	19500	60	13	3.5	25
RE Power Systems	6M	85	126	12.1	21500	70	14	3.5	25

Manufacturer	*Model*	*Min. Hub Height (m)*	*Diameter (m)*	*Rated Rotor Speed (RPM)*	*Blade Mass (kg)*	*Survival wind speed (m/s)*	*Rated wind speed (m/s)*	*Cut-in wind speed (m/s)*	*Cut-out wind speed (m/s)*
RE Power Systems	MM82	59	82	8.5-17.1	6400	-	14.5	3.5	25
RE Power Systems	MM92	68.5	92.5	7.8-15.0	7900	-	12.5	3	24
Schuler	SDD100	100	100	6-14.5	-	42	11.5	3	25
Siemens	SWT-2.3-101	80	101	6.0-16.0	-	-	12.5	4	25
Siemens	SWT-2.3-82 VS	58.5	82.4	6.0-18.0	-	-	13.5	5	25
Siemens	SWT-2.3-93	80	93	6.0-16.0	-	-	13.5	4	25
Siemens	SWT-3.6-107	80	107	5.0-13.0	-	-	13.5	4	25
Siemens	SWT-3.6-120	90	120	5.0-13.0	-	-	12.5	4	25
Vensys	100	100	99.8	6.5-14.5	-	-	13.5	3	25
Vensys	77	61.5	76.84	9-17.3	-	-	13	3	22
Vensys	82	85	82.34	9-17.3	-	-	12.5	3	22
Vensys	90	80	90	8.5-16	-	-	15	3	25
Vestas	V100-1.8 MW	80	100	9.3-16.6	-	-	12	4	20
Vestas	V112-3.0 MW	84	112	4.4-17.7	11900	-	12	3	25

Manufacturer	***Model***	***Min. Hub Height (m)***	***Diameter (m)***	***Rated Rotor Speed (RPM)***	***Blade Mass (kg)***	***Survival wind speed (m/s)***	***Rated wind speed (m/s)***	***Cut-in wind speed (m/s)***	***Cut-out wind speed (m/s)***
Vestas	V52-850 kW	49	52	14-31.4	-	-	15	4	25
Vestas	V80-2.0 MW	60	80	9.0-19.0	-	-	15	4	25
Vestas	V90-2.0 MW	95	90	9-14.9	-	50.7	14	4	23
Vestas	V90-3.0 MW	80	90	8.6-18.4	-	-	16	4	25

9. **APPENDIX C**
VALIDATION OF THE BLADE THROW MODEL

Validation of the model

The following case studies are carried out to validate the proposed blade throw model. In first case study, the equation of projectile motion is developed based on the kinematic theory in which the drag force is ignored; the result obtained from the proposed model, considering zero drag, is compared with that of the model based on the kinetic theory. In second case study, the air resistance is included without any wind. The proposed model is used to simulate the ball throw problem which is available in the literature and the trajectory, presented in the literature is compared with that calculated by the model. In addition to this, the trend in the trajectory and variation of velocity and acceleration are compared for different coefficients of drag. In the final validation case, a wind velocity is applied in addition to air resistance.

Case 1: Test without air resistance, i.e. no drag force.

When aerodynamic body forces are ignored the drag coefficient is equal to zero and the trajectory of the blade/fragment's motion can be obtained using kinematic theory:

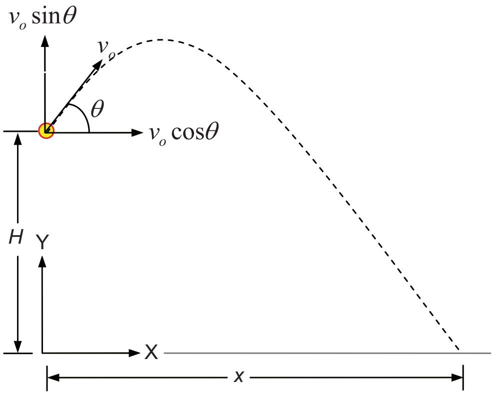


Figure 23. Trajectory of projectile motion

From Newton's laws of motion the position of the fragment at time, *t* can be expressed as follows,

$$x = x_o + v_{xo}t + \frac{1}{2}a_x t^2 \tag{B.1}$$

$$y = y_o + v_{yo}t + \frac{1}{2}a_y t^2 \tag{B.2}$$

Where, v_o is the initial velocity of fragment; v_{xo} is the initial velocity of fragment along the *x*-direction (equal to $v_o \cos\theta$); v_{yo} is the initial velocity of fragment along *y*-direction (equal to $v_o \sin\theta$);

(x_o, y_o) is the initial position of the fragment; a_x and a_y are the acceleration along *x* and *y*-directions respectively; and, θ is the throw angle.

The acceleration in the *x*-direction is zero ($a_{xo} = 0$) and the acceleration in the *y*-direction, a_{yo} is -9.81 m/sec^2. Equations (B.1) and (B.2) can be combined by solving the first equation for *t* and then substituting it into the second equation. x_o is assumed as zero and y_o is the height of the turbine, *H*. The combined equation is:

$$y = H + x\tan\theta - \frac{x^2 g}{2(v_o\cos\theta)^2} \tag{B.3}$$

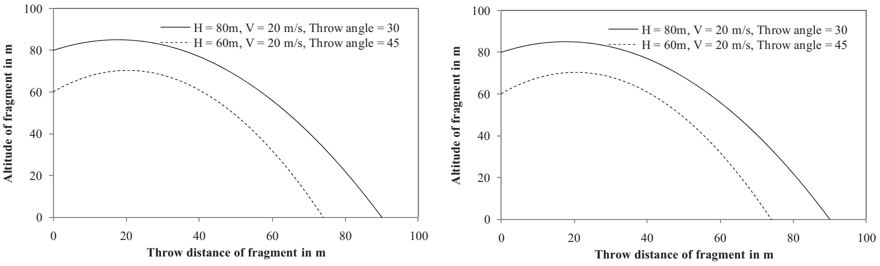
The throw distance, *x* is obtained by solving Equation (B.3) for the boundary condition of y = 0 and is expressed as:

$$x = \frac{v_o^2}{g}\cos\theta\left[\sin\theta \pm \sqrt{\sin^2\theta + \frac{2gH}{v_o^2}}\right] \tag{B.4}$$

Using the proposed model described in Section 4 which has been coded in Excel macros, and the kinematic equation of projectile motion described in this Appendix, distances were calculated for different blade throws. These are presented in Table 15 where it is shown the blade throw model coded in Excel macros gives same result as that of the equation of projectile motion. Also, the trajectories are identical as shown in Figure 24. Given that both the model developed in Section 4 at the equations used here are based on the same formulation of Newton's laws of motion, this does not provide true "validation" but some degree of "verification" that the kinematic aspect of the blade throw model has been coded without errors.

Table 15. Throw distance model verification

Turbine Height (m)	*Throw Angle (°)*	*Velocity of Fragment (m/s)*	*Throw Distance*	
			Blade Throw Model	*Equation of Projectile Motion (Appendix B)*
60	*45*	*20*	*73.89*	*73.89*
80	*30*	*20*	*89.80*	*89.80*



(a) Trajectories obtained using blade throw model

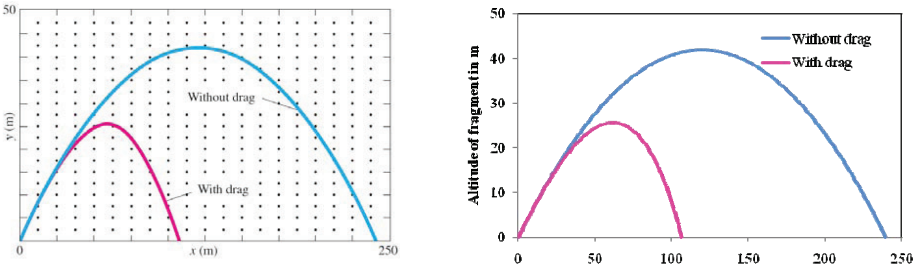
(b) Trajectories obtained using equation of projectile motion

Figure 24. Fragment trajectories obtained using the coded blade throw model and equations of particle motion

Case 2: Test with air resistance, no wind

In this case, the effect of air resistance is included in the equation of the projectile motion. The following test case [40] is considered to check the calculation of the blade throw model. It considers a baseball with radius 0.0366 m and exposed area of 4.208 x 10^{-3} m^2. It has a mass of 0.145 kg, the drag coefficient is taken as 0.5, and the air density as 1.2 kg/m^3. A throw angle of 35^o from the horizontal and an initial velocity of 50 m/s are considered. Figure 25 shows the trajectory, reported in the literature and the trajectory obtained from the coded version of the MMI methodology; both "with" and "without drag" trajectories are identical.

It should be noted that the test case in [40] and the MMI methodology are built on the same equation set and hence this comparison does not provide "validation", but some degree of "verification" of MMI's methodology.



(a) Trajectory from literature [38]

(b) Trajectory from the MMI blade throw model

Figure 25. Comparison of projectile trajectories from literature and MMI model

The effect of air drag on blade throw is also explored through this case study. Zero wind speed is used in this part of the verification. (In practice, when there is no wind, the wind turbine stays idle, and there is no chance of blade throw.) Conditions for the test are: turbine height 60 m; throw angle of zero; fragment's

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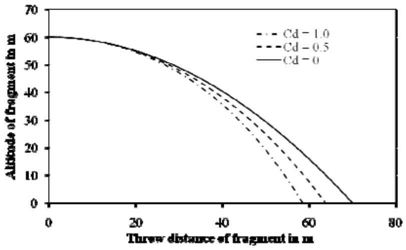
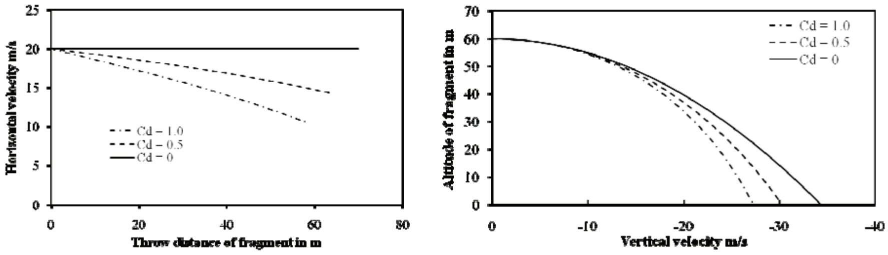
mass 6600 kg; exposed area 80 m^2; initial velocity of 20 ms^{-1}; and air density of 1.2 kg /m^3. Different drag coefficients were tested to check their influence on the trajectory.

The trajectory and the variation of velocity and acceleration of the fragment are plotted and shown in Figure 26. As expected, the throw distance, horizontal and vertical velocities all decrease with increasing drag coefficient, Figure 26 (a-c) . If there is no drag, there will not be any change in the horizontal velocity, i.e., no horizontal acceleration, which is observed in Figs. 4(b) and 4(d). Similarly, there will not be any change in the vertical acceleration, if there is no drag which is observed in Fig. 4 (e).

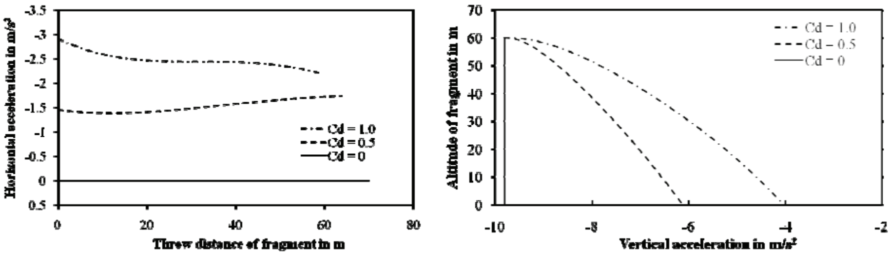


(a) Trajectory of fragment



(b) Horizontal velocity

(c) Vertical velocity



(d) Horizontal acceleration

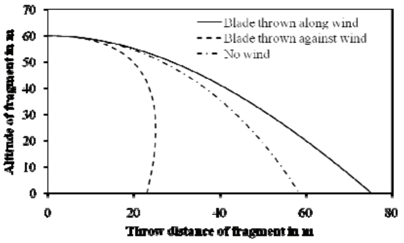
(e) Vertical acceleration

Figure 26 Effect of drag on blade flow trajectory in zero wind

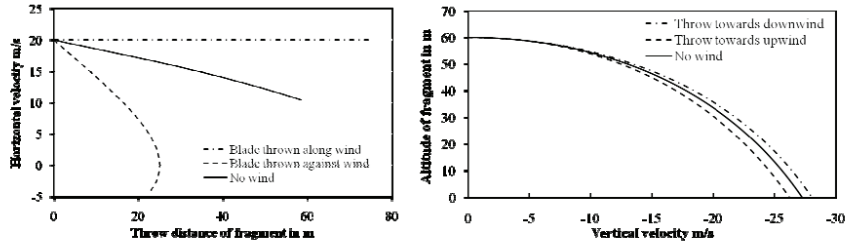
Case 3: With air resistance and wind

The same blade throw problem is considered with the wind speed set to 20 ms^{-1} and the drag coefficient C_d =1. In normal operation, the wind turbine should point towards the upwind direction, i.e., the rotor plan is perpendicular to the wind direction. However, in this test the blade throws are considered along upwind and downwind directions. This would only be possible, either if wind turbine was out of service or if the active yaw control had failed.

The trajectory and the variation of velocity and acceleration of the fragment are plotted and shown in Figure 27. Generally the horizontal velocity and throw distance increases if the fragment travels along the wind direction and vice versa. These are observed in Figure 27 (a) and 5(b). When the initial velocity of the fragment is equal to the wind speed and opposite to each other, there will not be any horizontal acceleration, i.e., no change in the horizontal velocity, which shown in (b) and (d). There is not much change in velocity and acceleration in vertical direction as shown in Figs. 5(c) and 5(e).

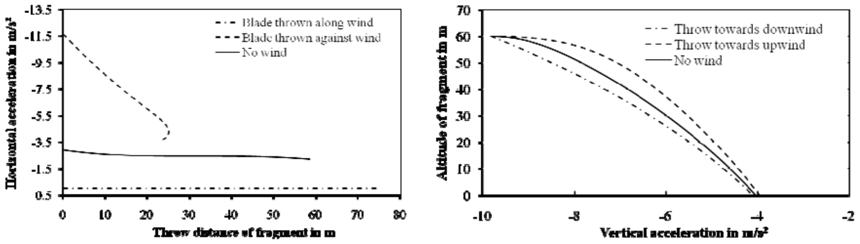


(a) Trajectory of fragment



(b) Horizontal velocity

(c) Vertical velocity



(d) Horizontal acceleration

(e) Vertical acceleration

Figure 27 Effect of air drag and wind on blade throw trajectory

Sensitivity analysis for time step

As an explicit method is used to solve the equations of the blade throw analysis the accuracy of the result is dependent on the time step selected for calculation. Using a small time step to get an accurate result can lead to long computational run times especially in a Monte Carlo simulation.

To determine a typical, acceptable time step, a sensitivity study on the time step was carried out. In this study, the throw distances for various blade throws are estimated considering different time incremental and presented in Table 16. For all cases in the study the following data were assigned: coefficient of drag set to zero; air density 1.2 kg/m^3; fragment mass 6600 kg; fragment initial velocity 16.2 ms^{-1}; exposed area 80 m^2; wind speed 15 ms^{-1}.

The errors in the throw distances for time increment of 0.01 sec are less than 0.1 percent. Using 0.01 s as a time increment increased the speed of computation by 100 times when compared with the time step of 0.0001 s.

Table 16. Sensitivity analysis on time step

Case	*Turbine Height (m)*	*Detach Angle (°)*	*Throw Distance (m)*			
			Δt=0.1 s	*Δt=0.01 s*	*Δt=0.001 s*	*Δt=0000.1 s*
a	30	0	15.66	15.66	15.66	15.66
b	30	45	37.56	37.76	37.78	37.78
c	30	90	35.67	35.82	35.83	35.84
d	80	0	29.78	29.83	29.84	29.84
e	80	45	52.99	53.23	53.25	53.26
f	80	90	55.76	55.99	56.01	56.01

10. **APPENDIX D**
DATA DISTRIBUTIONS USED IN THE RISK METHODOLOGY

Uniform distribution

If x is a uniform random variable between x_l and x_u, and u is a unit uniform random number between 0 and 1, then random number, x is:

$$x = x_l + (x_u - x_l)u \tag{C.1}$$

Beta distribution

If x is a random variable with a minimum of x_l, maximum of x_u and mode of x_m, then the normal random number is:

$$x = \varphi^{-1}(u, \alpha, \beta, x_l, x_u) \tag{C.2}$$

Where α, β are shape factors

$$\alpha = \frac{(\mu - x_l)(2x_m - x_l - x_u)}{(x_m - \mu)(x_u - x_l)} \tag{C.3}$$

$$\beta = \frac{\alpha(x_u - \mu)}{(\mu - x_l)} \tag{C.4}$$

$$\mu = \frac{1}{6}(x_l + x_u + 4x_m) \tag{C.5}$$

Weibull distribution

The cumulative distributions function for a Weibull distribution with characteristic life, α and shape parameter, β is,

$$F(t) = 1 - e^{-\left(x/\alpha\right)^{\beta}} \tag{C.6}$$

Where, *F(t)* is the probability of failure by time, t. The inverse expression is,

$$x = F^{-1} = \alpha(-\ln(1 - F))^{1/\beta} \tag{C.7}$$

Substitute the unit uniform random variable, u_i in the inverse express to provide the random variable conforming to the distribution, x.

$$x = F^{-1}(u) = \alpha(-\ln(1 - u))^{1/\beta} \tag{C.8}$$

Rayleigh distribution

The Rayleigh distribution is a special case of the Weibull distribution with a shape factor of 2. The Rayleigh distribution is given by:

$$p(t) = \frac{\pi}{2}\left(\frac{v}{v_m^2}\right) e^{-\frac{\pi}{4}\left(v/_{v_m}\right)^2} \tag{C.9}$$

The Weibull distribution is,

$$p(t) = \frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1} e^{-\left(v/_{\alpha}\right)^{\beta}} \tag{C.10}$$

In order to use the Weibull distribution instead of the Rayleigh distribution, the following scale factor is used:

$$\alpha = \frac{2v_m}{\sqrt{\pi}} \tag{C.11}$$

Where, α is the scale factor; β is the shape factor and v_m is the annual mean wind speed.

Normal distribution

If x is a normal random variable with a mean of μ and a standard deviation of σ, then normal random number x corresponding to a uniform number u can be shown to be

$$x = \mu + \sigma\varphi^{-1}(u) \tag{C.12}$$

Where, φ^{-1} is the inverse of the cumulative distribution function of standard normal variable.

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HSE
Health and Safety
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Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines

Wind power is becoming an increasingly significant contributor to the UK energy mix and a significant proportion of this is onshore. Onshore wind power generation ranges from large utility scale wind farms, through medium size brownfield type developments, to the small end domestic wind power generation. Although HSE is only a statutory consultee for developments of 50 MW or larger, HSE is often approached for advice on new wind developments at all scales. A number of organisations have previously provided risk assessments for wind power developments, but these are normally bespoke to a particular application.

The work presented in this report has two main components. Firstly, research has been carried out to determine publicly available data for wind turbine failures and failure rates. Data has been drawn from a number of sources, including: HSE incident reports, a trade association, a renewable energy research organisation, web-based literature and published papers. The second component to the work has been to develop a 'standard' methodology for the risk assessment of harm to people from wind turbine failures. This methodology produces contours of probability of harm, and fatality by direct and indirect impact of thrown wind turbine blades or blades fragments. The contours produced by the methodology may be assessed as Location Specific Individual Risk when they are combined with the frequency of failure of the wind turbine.

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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Northern Ireland
Assembly

Committee for the Environment

OFFICIAL REPORT
(Hansard)

Briefing by West Tyrone Against Wind Turbines

27 June 2013

Please note that Official Report (Hansard) staff were not present at this meeting and that this report has been retrospectively compiled without the benefit of contemporary notes and details of the sequence of speakers.

NORTHERN IRELAND ASSEMBLY

Committee for the Environment

Briefing by West Tyrone Against Wind Turbines

27 June 2013

Please note that Official Report (Hansard) staff were not present at this meeting and that this report has been retrospectively compiled without the benefit of contemporary notes and details of the sequence of speakers.

Members present for all or part of the proceedings:
Ms Anna Lo (Chairperson)
Mr Sydney Anderson
Mr Cathal Boylan
Mr Tom Elliott
Mr Barry McElduff
Mr Peter Weir

Witnesses:

Professor Alun Evans	Wind Watch
Dr Dan Kane	Wind Watch
Mr John Peacocke	Wind Watch
Mr Peter Sweetman	Wind Watch

The Chairperson: I welcome Dr Dan Kane, Professor Alun Evans, Mr John Peacocke and Mr Peter Sweetman from West Tyrone Against Wind Turbines.

Dr Dan Kane (Wind Watch): Chairperson, thank you very much for giving us the opportunity to address the Committee.

The Chairperson: You are very welcome. I am sorry that we did not bring sunshine to Omagh today.

Dr Kane: I have to tell you that I am voice-activated. If you want to make a sign to me that I am, perhaps, taking too long to speak or you are pointing at a watch or something, just rattle something at me and I will know.

The Chairperson: I am glad that you made that point because we are running behind time. Some of our members have to be back in Belfast by around 2.00 pm for a Committee this afternoon. We have already received your written submission. Perhaps, you could make a brief, 10-minute presentation, which would allow members to ask you questions afterwards. Would that be OK? We will keep you straight to 10 minutes.

Dr Kane: OK. We are a bit unhappy about the industry not having appeared. The decisions will continue between now and September. We are unhappy that that will be the situation, and we will not have had the issued examined.

Perhaps, I have the advantage over Committee members in that I can remember Omagh as it was up here. What you are seeing now is the despoliation of the area. In the past five years, around 250 applications for wind farms and turbines in this area, west Tyrone, have been approved. At present, there are over 200 additional ones in the system. What you will see is a continuing bank of turbines around Omagh. That will form the backdrop to the Ulster American Folk Park. It is interesting that you were turned away from the wind farm at Bessy Bell this morning. People tell an interesting old joke, which is, "Why is the wind industry so popular? Because it brings its own fans." I think that that is very much the case. We have been told for years that wind farms would be great tourist attractions, educational facilities, and so on. If you look at the original applications, you will see that Bessy Bell and the other wind farms in the area were sold on that basis. I am sure that you were stopped there this morning by the crowds trying to get a look at the turbines. Of course, that does not happen.

The issues that we want to look at in particular are separation distances and noise. There are many more. We could look at jobs, electricity supply, and so on. I want to give Peter an opportunity to speak because he has come here from Dublin. Representatives of the industry could not come here from Belfast. I do not believe that they have only one speaker. The standard that is used to decide separation distances in Northern Ireland is based on one document, which has the snappy title of 'ETSU-R-97'. We will just call it "ET" for short because it really is the type of document that an extra-terrestrial dropped on us. That document was written in 1996. It stated that the minimum separation distance of 300 metres to 400 metres would not be adequate even for small single turbines. At that time, turbines were no higher than around 32 metres. It was out of date. It was a bit like somebody walking in front of your bus this morning with a green or red flag. That is out of date. We know that it is out of date because the document itself says so. It says that it should be reviewed within two years. That has never been done. However, members of the group who wrote it, from the British wind industry and the Department of Trade and Industry, eventually, did presentations. In 2004, they decided that the distance of 300 metres to 400 metres should be doubled. So, according to Andrew Bullmore, who was one of the authors, and others, the minimum separation distance should now be 700 metres.

What is the situation in Northern Ireland? There is an image in the slides of a turbine beside a house. We could take you to homes around Northern Ireland where turbines have been placed as close as 100 metres to them. According to PPS 18, which is the standard that is supposed to be applied by Planning Service, the minimum separation distance is 500 metres. It is now trying to claim that it is not: it is ten times the rotor diameter. However, PPS 18 is quite explicit that it is 500 metres or 10 times the rotor diameter; whichever is the greater. It is quite simple. That is not being applied to single turbines and, in many cases, not even being applied properly to wind farms themselves.

There is a big issue here that is important for a number of reasons. In one way, we are glad that you did not get into Bessy Bell because, as you have, probably, never been told, the top fell off one of those turbines and rolled down the hill. The Health and Safety Executive does not even collect information on such accidents. We know that the accident rate among wind turbines is that, on average, every single wind turbine will have an accident every 10 years. So, if there are 500 turbines, there will be 500 accidents over 10 years. That will be around 50 accidents each year. That rate is increasing, particularly as turbines get older. That is one aspect.

The separation distance issue is very important. It is not being dealt with properly. Other jurisdictions are moving further and further away. They are saying that the minimum separation distance should now be at least two kilometres for a wind farm. Turbines are now much bigger. They are making noise of a different character. That is another issue that we think needs to be looked at. Recently, within the past week, we have submitted two papers to the Committee for Health, Social Services and Public Safety showing the impact of low-frequency noise. That noise is the main pollution that comes from the bigger turbines. How do we know that? The chief executive of Vestas Wind Systems, the biggest turbine manufacturer in the world, has stated that clearly to the Danish environment minister. We know that the low-frequency noise is present and that it travels much greater distances than ordinary audible tones. What we are finding is that people are becoming sick through the effects of sleeplessness and other aspects of low-frequency noise. The research is now there that shows that that is happening. What are we doing? The Environment Minister hides behind the Public Health Agency. He says that it says that there is no problem. However, it has never, ever looked at it. It has never measured anything or gone out and done any testing. Basically, the view that is being taken is that, if you cannot hear it, it does not hurt you. Well, I cannot hear radiation and neither can you, but I can assure you that it hurts you. So, that argument does not stand at all.

With regard to the standards that are being used, it is supposed to protect amenity, among other things. PPS 18 asked for protection of amenity — residential amenity and, obviously, health and safety and all the rest of it. ETSU-R-97, or "ET" as we were calling it, which is the standard that was used, does not protect amenity. It actually states that itself.

The Chairperson: Sorry.

Dr Kane: Do you want me to stop?

The Chairperson: It is OK; I just missed that word "amenity".

Dr Kane: So, ETSU-R-97 does not protect amenity. It states so itself. It does not protect amenity because it states that to set the noise level to one that is required to protect amenity would have too much impact on wind energy. So, there is a problem right away. With regard to the actual method that is used, ETSU-R-97 does not satisfy European requirements under the environmental assessment regulations which have to describe the impact on people who live near a wind-energy operation and what the impact on them will be of shadow flicker, noise and any other emissions. It does not satisfy that at all. It is still being used. It should have been reviewed a long time ago. As I said, ETSU-R-97 was written in 1996. It said itself that it should have been reviewed within two years. To give you an example of how out of date it is, the World Health Organization standard for night noise, which is the noise level to permit you to return to sleep if you wake at night, was originally 43 decibels. Therefore, when ET was written, it was set at 43 decibels. It is the only standard in the entire world that has a higher night-time noise than during the day, which is crazy. Not only that, but the World Health Organization has reduced the level from 43 to 38 decibels. We have not followed suit in Northern Ireland. Therefore, the whole policy is completely out of step. It does not protect the public. It does not properly describe the noise that is affecting people, particularly low-frequency noise, which it does not measure at all. It uses a particular scale, which is called the A-weighting scale, which does not measure low-frequency noise. Therefore, when the wind industry tells you that there are no noise impacts from wind turbines, it does not know that because it is not measuring it. It is not looking at that at all. The thing about low-frequency noise is that, when it reaches your home, it goes through the structure of the building. Insulation, double glazing and so on does not stop it. It actually resonates more loudly inside the home than it does outside. So, there is a big issue with low-frequency noise.

There are many other health impacts that we could talk about. The whole issue of 10 times the rotor diameter as a safe separation distance for noise just does not stand up. It was actually created for a totally different purpose; that of shadow flicker. It was wrong when it was created. It has no application to noise whatsoever. So, we have many concerns about the whole issue of separation distances. Why is it two kilometres in Scotland as a general rule of thumb? Many organisations, such as the French Academy of Medicine, UK Noise Association and the Society for Wind Vigilance, are saying that there should be a minimum separation distance of at least two kilometres. So, we are not going to sit here and argue about whether to have wind energy: the people in the countryside who have to live with the effects of the decisions are the ones who will suffer. They will suffer a reduction in the value of their properties and so on.

David Cameron has talked a great deal about giving power back to the people and the Localism Bill. However, we do not have a localism Bill here. Communities in England can stop applications for turbines and wind-farm developments. We are not being given that right here. We are not being given the right to say no. Now, attempts are being made to bribe us. People who have just lost £100,000 off the value of their home are not going to be greatly tempted by a £200 a year payment off their electricity bill. We need to be clear about that. Also, the benefits of that so-called energy source have to be looked at, such as employment, among others, and the actual number of jobs that are lost for every green job that is created. The big issue is health and safety. We ask the Committee to consider that issue.

At this point, I would like to bring in Peter Sweetman to talk about his view. He has come the whole way up from Dublin to talk about the issue.

The Chairperson: Peter, can you be very brief?

Mr Peter Sweetman (Wind Watch): I will be very brief.

I am a European. I am one of the few people who have taken a case the whole way to the European Court. At present, until now, I have worked only in the South. I have had a recent look at the Northern implementation of the EU environmental impact assessment directive, the habitats directive and the strategic environmental assessment directive. Northern Ireland legislation is completely out of line with the decisions of the European Court. I can give you a few figures. The first case that is relevant to the environmental impact assessment is C-50/09, which is the Commission versus Ireland. It states clearly that article 3 of the directive is that the assessment is carried out by the regulatory authority, not the developer. The decision was made in March 2011. It does not seem to have filtered through to the North because, with regard to all of those wind farms, people are saying that their environment impact statement is the assessment. According to the law, it is not.

We still rely on the 1999 regulations here. There was a directive in 2003 — 2003/35 — which was to implement the relevance of the Aarhus convention into European law. That has recently been tested in the European Court, to a certain extent, by an English case — the Edwards case, reference C-260/11. The actual wording of the directive is that a review shall not be prohibitively expensive. The implementation of that here is that you have now made a ruling that the maximum cost that can be awarded is £5,000 against an individual or £10,000 against a group and that the maximum costs that can be awarded to you in a High Court case are £35,000. Basically, adding all of that up, it is still prohibitively expensive. It costs, in real terms, around £100,000 to take a case to the High Court in Northern Ireland and around €200,000 in Southern Ireland. We are now allowing a cost level of £35,000. That is not in compliance. The Edwards judgement needs a little bit more interpretation. However, it does not come along with that.

We then move on quietly to the habitats directive. The judgement in my case, which is C-258/11, made two very important points, which I will deal with quickly. The first was that there was a mistranslation of article 6 of the habitats directive whereby we assessed the necessity for an appropriate assessment to be carried out if it were not going to have a significant effect on the habitat. It was a mistranslation. The judgement now interprets that there must be an appropriate assessment if a development could have an effect on a habitat. There is an awful lot of difference between "have a significant effect" and "could have a significant effect". We are still going down the road here of not even having a significant effect. We are removing massive amounts of peat for wind farms and draining into protected rivers and suchlike. We are having no assessment at all. That will have to be sorted out.

The other point in my judgement is that when you perform an appropriate assessment on that — of the Narrow Water bridge, for example — the level is that there shall not be any lacuna. In the Narrow Water bridge situation, permission was granted despite the actual design of the bridge not being completed yet. That is a lacuna.

I will just make one final point on the strategic environmental impact assessment directive. What is proposed by your policy document, which was not strategically environmentally assessed, but should be — taking it down directly to Omagh — is being interpreted so that a ring of steel is being put around Omagh with no strategic environmental assessment. Northern Ireland is way outside European law. It is time that you came into compliance like everybody else. Thank you.

The Chairperson: Thank you, Peter. Thank you very much for your presentation. Obviously, we are hearing your concerns about distance. That is the main concern. Certainly, we have two very thick research papers here saying that noise has never been proven to be detrimental. We have two very thick research papers that say that noise has never been proven as being detrimental. How close in distance are wind farms to houses in Omagh? You said that there is one about only 100 metres away. Is that the worst-case scenario? How many of them are 500 metres or more away?

Dr Kane: The policies on single turbines have been handed down to the divisional planning offices. There is no consistency. There should be a minimum of 500 metres. There are many turbines, but we do not know the exact number. Many people are coming to me saying that they have one at 90 metres, 100 metres, 200 metres and 300 metres, all of which are well within the minimum separation distance. That separation distance was set in 1996 for a turbine that was only 32 metres high. Now they are 180 metres or 210 metres high. The turbines that are used as single turbines are, in many cases, bigger than the turbines used in the wind farms. Why should there be any difference in how people living beside them are treated? There are a lot of problems. Alun, would you like to comment on the health aspects?

Professor Alun Evans (Wind Watch): Yes. A 2009 report highlighted the major growing public health problems of night-time noise. Noise is the problem. It may be noise, as Dan told you, that you cannot hear. There are considerable health concerns. My colleague Chris Hanning and I wrote an editorial in the British Medical Journal (BMJ) last year. We have been criticised for not having a systematic review. In an editorial, you are allowed only 800 words, so it is very difficult to do a systematic review. We are well aware of the literature. There are no studies that show that wind farms are safe. That is a simple statement.

The problem with the noise that wind farms generate is that it is a form of noise pollution. It is particularly irritating because it is impulsive, intrusive and incessant. Noise pollution is a real problem. It may not be the noise that you hear, as Dan pointed out. The major problem with it is sleep disturbance and deprivation, which predisposes to a number of conditions. Unfortunately, old people, like me, and the very young are most affected. I would be most affected because I have lost my upper registers of hearing, and so the low registers are more prominent. Children have better hearing. Remember that sleep deprivation was used by the British Army as a form of torture in the early 1970s in this Province. It has been known that it is pretty nasty to deprive people of sleep. It leads to poor memory and possibly cognitive changes in old people and poor memory in the young. There are also disturbing associations between sleep deprivation in children and increased bodyweight. A host of diseases, some more strongly than others, are associated with sleeplessness. There is a relationship to cancer. My background is in cardiovascular epidemiology, where the term "risk factor" is originally said to have been coined. It was actually "factors of risk" that was coined; "risk factor" emanated from the aerospace industry around about 1952. The problem with risk factor — what we know from epidemiology — is that they tend to be continuously distributed. The more you have of it, the more the risk. It is artificial where you have a risk factor to have a cut-off point and say that there is no risk below that; there is a gradation of risk. That is a point to remember about the wind farm noise limits.

There is a big study and a small study this year. The big one is a Norwegian study that shows a very large association between symptoms of sleep deprivation and heart failure. We are swapping heart failure as a cause of death for myocardial infarction. This country used to lead the world in that respect. We have now, thankfully, dropped back, but we are getting more heart failure. There is a strong association with heart failure. The other thing is that a recently published study of sleep deprivation in volunteers showed surprising changes in a vast number of genes' expression: the genes are there, but it is the amount of music that they are playing. Some are increasing and others decreasing, so you explain the —

The Chairperson: That is not directly related to wind farms.

Professor Evans: I am talking about noise and sleep deprivation. This is the major thing that we have to worry about, and that is to do with the set-back distances, which are insufficient.

The Chairperson: According to our research paper, there has never been any medical evidence that wind farms cause sleep deprivation cause·

Professor Evans: We are talking about arguments of nuance, the problem being that the sorts of studies to indubitably prove associations that these things kill you have to be very large and are very slow to accrue. Therefore, we have a problem and have to take our evidence where we can find it. I conclude that there is sufficient evidence to be very worried about these things.

The Chairperson: OK. I will bring other members in.

Mr Sweetman: Sorry, may I just add one point? The report that you are relying on states that there is no evidence —

The Chairperson: It is based on a number of research studies.

Mr Sweetman: I quite agree with that, and it is not problem. The fact is that under European environmental law, the precautionary principle must hold sway. It is not up to them to say that there is no research; it is up to them to prove that there is no damage. It is not for us to prove that there is damage; it is up to the developer to prove that there is no damage. They cannot do that.

Professor Evans: That is the "primum non nocere" principle, which is enshrined in medicine, and I am surprised that our Public Health Agency does not wake up a bit.

The Chairperson: We can ask the Department what the criteria and guidance is for the set back distance and what distance it recommends between turbines and neighbours.

Mr McElduff: It is good that we are having this engagement, and we need more of it. I am struck by the fact that health-related and energy output issues are being raised. We are the Environment Committee and probably concentrate on the planning dimension, but it tells me that government needs to be joined up in how it looks at the whole are of wind energy. There may need to be some interaction between the Environment Committee, Health Committee and Enterprise, Trade and Investment Committee. I think that this is a possible area to look at having a cross-Committee inquiry. However, we are in west Tyrone, which is made up of the Omagh and Strabane districts. In answer to a recent question that I posed in the Assembly, I was told that of nearly half of the North's wind energy infrastructure — I think that it is 48% — is located in this area. That begs the question of whether we have reached or exceeded saturation level in this area. The local campaign group sent us copies of draft questions and areas for consideration.

I will zone in on suggested question 15, which tells us that three major planning applications for this area are in or entering the system. They are described as "Slieveard" wind farm; "Lisnaharney", near Gortin glen in the Sperrins; and the Bessy Bell extension. Earlier, you asked me what type of shoes you should wear, Chair, on the site visit. Well, you did not need to change your shoes because we were denied access to the site. However, each of those sites —

The Chairperson: I brought my trainers.

Mr McElduff: — are within a five-mile radius of each other. So, will the panel perhaps make the case as to why those three planning applications should nearly be considered as one because of their cumulative effect? Will the delegation make a point that we can take to Planning Service about why they should be treated as one big application as opposed to three individual ones?

Mr Sweetman: I can answer that. It comes back to the point that there is a requirement under European law for a strategic environmental impact assessment. This is project-splitting. It is trying to minimise the overall effects by bringing three applications. What I referred to as the "ring of steel" around Omagh is technically one project and should be treated as such.

Professor Evans: From a noise aspect, the positioning of turbines on hilltops is worse because complex terrain makes the sound worse, which is bad news for people who live in the basin below.

Mr Elliott: Thanks very much for your presentation, folks. I am not exactly sure whether you are indicating that there should be no wind turbines or wind farms at all or whether you feel that they would be acceptable under the right and proper conditions.

Mr Sweetman: I feel that they have to be assessed under the right and proper law. Until such time as we have the right and proper law, we cannot answer that question.

Mr Elliott: If you were writing the law —

Mr Sweetman: The law is already written.

Mr Elliott: No, but, if you were starting with —

Mr Sweetman: It is just not being complied with.

Mr Elliott: If you were starting with a blank page and you wanted to write law that would allow wind farms, are you saying that you do not believe that you could write a law that would protect everyone from wind farms? Or, are you saying that there is a possibility that you could have enough safeguards to allow wind farms?

Mr Sweetman: It is possible.

Mr Elliott: What conditions would those be?

Dr Kane: You would need to assess the impacts accurately and honestly. That has not been done. For example, we are told in PPS 18 that a separation distance of 10 times rotor diameter would resolve the issue of shadow flicker. It would not. The original piece of research that that was based on says that it would not, so that is a misquote from the original research.

Mr Elliott: Forgive me, but, forgetting about PPS 18 and the law as it is written at the moment, what do you believe should be put in there that would protect people from wind farms or wind turbines?

Dr Kane: At this stage of our knowledge from the research that has been done, a separation distance of at least 2 kilometres is required.

Professor Evans: Some countries are going for more now. Some are going for 5 kilometres.

Mr Elliott: Do you believe that that would protect people?

Dr Kane: If we were wrong on that, you could always move the turbines closer later. You can never move them further away. That is the issue. So, that is being precautionary about it. A lot of the issues that come up in environmental impact assessments are never gone back on to be tested after the thing is up and running. In the case of wind farms that are causing noise problems, people are not reporting noise problems, because that affects their property value if they are trying to sell their house. Also, the Minister has told us that there is a penalty on the developer that prevents the developer from turning the turbines off so that you can assess the original background noise and so on. Therefore, they are basically saying that they cannot police the noise and cannot enforce anything against the noise. Therefore, if they do not get it right, by the time the applications have gone up, it is too bad and they are stuck with it. That is what we are being told.

Mr Elliott: So, you do believe that there could be opportunities for wind farms but only under very specific conditions, one of which is that it is at least 2 kilometres away from households.

Dr Kane: Yes, turbines are changing. There are now new types of turbines with the vortex inside them and things like this, which have a totally different principle and do not have the same impacts. We have to move on. That is old technology now, and the impact on people is more and more proven.

Mr Elliott: Finally, if there were opportunities for wind farms, do you believe that they would be better congregated in one site, with perhaps 50 turbines together, or do you believe that they would be better separated a few miles apart if that were possible?

Dr Kane: It is a pity that the slides did not work. I have a photograph of the Horns Rev wind farm. It is an offshore one. One of the things that you get with wind turbines is a vortex from the back of them, and that vortex affects the turbines in the next row and the next row and so on. So, there are major issues there about how you distribute turbines around the landscape, and it is now emerging from the research that is being done that turbines need to be scattered everywhere in groups that are quite disparate from each other, because this is how this vortex effect is reduced. In answer to your question, from the point of view of economy of landscape, you would put them all together, but that would mean that the largest proportion of the turbines would not perform properly at all.

Mr Boylan: Thanks for your presentation. To be honest, I think that the number of wind turbines and wind farms that are proposed is alarming. My colleague outlined the three planning applications.

I want to try to break it down into two or three issues and maybe try to get some answers. We have the new proposals; the adaptation, refurbishment or increase of existing wind farms; and I want to go into the noise and health issues. Those are the three main issues that you highlighted. When the professor was talking about "ET", I thought that that was a movie from the 1980s. That is a new meaning for us. I will come back to that point when I speak about the noise issues. Do you believe that with the new proposals in the area mean that we have reached saturation point for wind turbines?

Dr Kane: Yes.

Mr Boylan: Let us go back to the policy. If we are to look at it we need to look at the policy. Do you agree with that as far as the wind energy element of PPS 18 is concerned?

Mr Sweetman: Any strategic environmental assessment would find that we have reached saturation point in the Omagh area.

Mr Boylan: No problem. That is why we are here and that is what we want to hear. We can come here and talk about it or we can come here, take the evidence and come back and look at what we can do with the policy.

The policy states that the maximum size of a wind farm is 500 m for wind farms and 10 times the rotor diameter for single turbines. I am experiencing that in Armagh at the minute; that is what they are using. That is what they say. It clearly does not outline it. Somebody could put in an application for turbines with rotor diameters of 50 m, knowing rightly that they could get away with 300 m. They will then come back and say that they will reduce the rotor diameter to 30 m. We want to look at that. I do not know what the rotor diameter will be on the new wind farm that we did not see this morning. Will it be 30 m, 40 m or 50 m? Does anybody know what the rotor diameter will be for the proposed Bessy Bell wind farm?

Mr Sweetman: I do not know about Bessy Bell, but we have other ones that are up to 60 m.

Mr Boylan: So, that would allow for a maximum wind farm size of 600 m. Is it correct that the policy clearly states that the maxim wind farm size should be 500 m?

Mr Sweetman: There is a conflict.

Mr Boylan: That is grand. The main point that I want to make is that you have a problem with the new proposals, which there will obviously be a challenge to. Your second issue is with existing wind farms. I can only use the following example: as you know, if people put in applications for extending or refurbishing existing businesses, a principle has been established. I do not know how that works and you may have different issues —

Mr Sweetman: An application was made to extend a wind farm — I think it is called Lisnaharney — to make it bigger and have more turbines. The planning authority found that no environmental impact statement was required. It has not been built yet, but it is going to be bigger and higher, and there will be more of them —

Professor Evans: And noisier.

Mr Sweetman: Yes. And they decided that no assessment was required. That is absolutely contrary to a recent European Court judgement C-244/12 on an Austrian case. That decision was that, even on threshold, if a wind farm comes into an EIA process it must be assessed. A line from the planner than no EIA is required is not an assessment. It is a statement of non-fact.

Mr Boylan: OK. Going through all that raises a couple of simple questions. Do you believe that a threshold should be set at the number of wind turbines that are established at the minute?

Mr Sweetman: I think that we have too many.

Mr Boylan: OK. What about a challenge to the policy? There are established wind farms and proposals for new ones. What is your intention? In any debate that we have on this issue, would you like us to ask whether a threshold should be set at the level that exists now?

Mr Sweetman: My attitude is that the strategic environmental assessment directive is there and should have been used to assess this.

Mr Boylan: No. I am asking about established wind turbines. Are you saying that we have reached the threshold?

Mr Sweetman: It has reached saturation.

Mr Boylan: OK. That is your word for it. That is grand. The other issue is —

The Chairperson: Cathal, I am afraid that —

Mr Boylan: I know Chair. I only have two more questions. This is important.

The Chairperson: OK. Well —

Mr Boylan: They have come down here for this. I do not want them to have to come back to the Assembly. Let us deal with it while they are here. I have two more questions.

You said that the ETSU is outdated, so it is time that we looked at that again. Is that basically what you are saying about that?

Mr Sweetman: Yes. By its own admission, it is out of date.

Dr Kane: The noise levels are completely out of date.

Mr Boylan: It is obviously up to local councils to deal with environmental issues. What contribution has been made by councils to the assessment of wind farms, given that you are talking about the ETSU?

Mr Sweetman: The assessments that I have looked at do not comply with European law.

Dr Kane: Usually, the environmental health people are not equipped to look at this. They follow the industry's guidance. The developer tells them what they mean by what they are going to do. They do not have the equipment to measure compliance or low-frequency noise. They also not have the training to look at the landscape impacts and so on.

I am sure that you have been a councillor. If you had a noise issue, you would have sent your environmental health officer, who would have done an assessment in the quietest part of the night and added five decibels to that. That is what you do under what is called BS4142. ETSU does not do that. From the very start, it assumes a minimum noise level for wind turbines of 35 decibels and 43 decibels at night. That means that it cannot protect amenity and you have an increase, particularly in a quiet areas like this, of 20-plus decibels. That does not sound a lot, but it is two, three or four times the noise that is being heard in the area. Under BS4142, that would be a statutory nuisance right away. However, wind turbines get a special dispensation — by the way, no other renewable energy gets, and all the rest have to play by the rules — and are allowed to be noisier at night. If environmental health ever come out to look at the problems they come out during the day. Even if we had got on to Bessy Bell today, the time to hear Bessy Bell's real nose impact is in the middle of the night.

Mr Boylan: OK. Finally, finally, Chair, I promise, you said that there is a separation distance of 2 km for single wind turbines and wind farms. Is that for both?

Dr Kane: Originally, there was supposed to be a difference for turbines with rotor diameters of up to 15 m. That was supposed to be permitted development, but that did not happen and it was then included in PPS18.

You could probably make the case for single turbines that are domestic or farm-related having a closer distance, in other words, those that are in scale with the buildings around them. That is particularly and obviously the case if it owned by the landowner. However, industrial-scale turbines of 100 m-plus are being built on farms. Those are not farm-related and are being built to attract subsidies. Therefore, they should have the same separation distance as wind farms. Those turbines are wind farms of one turbine.

We could talk through it. If we look at the noise aspect in particular, we could come up with a set of robust rules that would deal with that issue very easily. At the moment, we have a rule that there must be a minimum of 500 m and it is being breached left, right and centre.

Mr Boylan: Thank you very much. Thank you, Chair.

The Chairperson: Peter, if possible, could you just ask one question or certainly two?

Mr Weir: I will maybe ask one question, but I want to preface it slightly. As the Environment Committee, we are looking at the planning side of this issue. There seems to be three points. First, I think that a very valid point has been made about overall cumulative applications. One of the weaknesses in the system, whether it is wind farms or other bits, is when piecemeal applications are put in in the knowledge that that will get a particular part over the line. The intention is then to put another one in etc. That also applies to other areas of planning. Secondly, there is the issue that you have raised about what you feel the panning guidance should be, particular as far as separation distances are concerned. Then there is the third issue of the current guidelines. You mentioned that a number of wind turbines are in a position in which the distance is a lot less than the guidance recommends. I assume that, in those cases, housing has predated the wind turbine?

Dr Kane: Yes.

Mr Weir: From the point of view of implementation or enforcement, do you feel that the reason for that is that the guidelines are not strong enough for Planning Service? Is it simply one of a number of factors to be taken into account, and then rolled into an in-the-round position? Or is it that a blind eye has been turned to the guidance and Planning Service is simply happy to drive a coach and four through it? Why do you think that the guidance requirements, even as it is at present, are not followed through? I appreciate that you consider the distance to be inadequate.

Dr Kane: You have pointed out several of them. One is that the planners seem to be too intent on chasing the targets and, therefore, they are putting through applications. A 90%-plus approval rate is not a selection system. It is not really a policing system at all. They are putting them through. The cumulative impact of that comes out very well. I can take you to a situation in Northern Ireland where there are two existing wind farms, a third developer has come along and wants to have a wind farm nearby and his application is based on the assumption that the existing two wind farms comply with the noise standard. They do not, but the planners will not measure it. They say that it is not their job to measure it and they cannot do it. Environmental health officers say that they cannot measure it.

Mr Weir: I am sorry to interrupt. I appreciate that noise is a separate issue, but I am very specifically asking about the separation distance.

Dr Kane: There seems to be a misunderstanding, in the divisional planning offices in particular, over the minimal separation distance. However, it is quite clear. I have been in correspondence over several years with them over this, but the minimum distance is 500 m. There should not be a single turbine in Northern Ireland, which you do not own, less than 500 m from your property. With the exception, possibly, of turbines under 15 m in height.

Professor Evans: Small ones.

Dr Kane: Small ones, yes.

Mr Anderson: Thank you for your presentation. Tom asked some questions and I am trying to get my head around the answers. I am not clear about the answer that you gave to Tom's question as to whether you would be happy with certain conditions, or more wind farms here. I also picked up from a reply that this area had reached saturation point, when Tom asked about the way distances and clusters were done. Would you be happy, or would you say it was OK, if those conditions were met, as regards distances and clustering? Or do you really think that we have gone beyond saturation point, in this area, in relation to the number of wind turbines?

Mr Sweetman: It is not for us to come to an opinion on that. It is for the strategic environmental assessment of the issue to be addressed. We are — certainly, I am — of the opinion that we have reached saturation point, and, under the precautionary principle which is the guiding light under European law, it is up to wind farm developers to prove that we have not reached saturation point, rather than for us to prove that we have. That is what the law says.

Mr Anderson: I am involved in a single wind turbine application at the moment. The applicant has ticked every box to date, and every time he ticks a box, it goes back to the planner's desk because something else keeps coming up. We are trying to find out whether there is a satisfactory solution to the question of whether there is a point at which there is a number of turbines, in this area or any other, that we should not exceed and which should be set in regulations as well — never mind clustering, height or whatever else goes with it. Is that a case that you would argue? Have we reached the point of saturation and can take no more? Are we at that point?

Mr Sweetman: We think —

Mr Anderson: You think. I am trying to tease this out. So it does not really matter now. The case is this: what should the distance be? Should it be 500 metres; 700 metres or 1,000 metres? It does not matter for an applicant or someone trying to bring an application, because you are at a point where it is no more. You say that you think, but are you sure?

Mr Sweetman: If you were to take the existing ones and draw a line at 2 kilometres from them, there is nowhere left to put one. There is saturation.

Mr Anderson: Really, what we are saying today is that it is not a case of distance any more; it is that, in your view, there are too many. Is that what you are saying?

Mr Sweetman: We are not completely looking at this area. We are talking about the general common good. Certainly, in this area, we have reached saturation. However, in any other area, we would say that the 2 kilometre distance should be not affected for public health and safety under the precautionary principle.

Mr Anderson: You are West Tyrone Against Wind Turbines.

Mr Sweetman: We are not totally Nimby. We are looking for the common good across the whole of the country — the whole of the island, actually. That is why I am here.

Mr Anderson: As far as you are concerned, it is beyond the wind turbine situation in west Tyrone.

Dr Kane: I see where you are coming from. I am not going to say that I am anti-wind or pro-wind or anything. I do not think that that is the issue here. However, I do think that we are living with the history of all the bungalows that were built during the direct rule period and so on. We have more than any other part of the UK. It is difficult. Edwin Poots told me that he could not get adequate separation distances and we would have to live with the problem. Therefore, if we cannot get adequate separation distances, do we accept that and move people away? Do we move people? There is no compensation mechanism here. People's homes are being made valueless. I could take you to a family who are living with 111 turbines proposed and in existence around them. Their house is now valueless. In that situation, if a farmer wants to put up his own turbine, the issues that I have with that are whether it will affect me if I am a neighbour and, if it does not affect me, am I going to pay for it? That is another issue that we need to look at. However, other than those things, if he wants to do that to himself, I have no real problem with that at all.

Mr Anderson: What I am trying to find out is this: within regulations, it goes beyond distance and cluster, and it also goes beyond the numbers game in a particular area? Is that what you are trying to say?

Mr Sweetman: The cumulative effect must be assessed, and the cumulative effect is not being assessed under the precautionary principle. That is what we are trying to say.

Mr Anderson: OK. Thank you, Chair.

The Chairperson: Thank you, Sidney. I think that the cumulative effect is an issue for planning, whether it is in my constituency of South Belfast or in other parts.

Mr Sweetman: The law is not being effective.

Mr McElduff: Chair, may I ask one brief question relating to Planning Service? To go back to Planning Service, it has come to my attention that individuals who wish to object to a planning application are given very restrictive, controlled and supervised access to planning application material. Is the delegation aware of the rationale for that? Somebody who has a legitimate stake in either opposing or informing themselves about a particular application is sometimes restricted in how they can view the material and in the number of hours that they can view the material. Am I correct in my understanding of that?

Dr Kane: That is correct.

Mr Sweetman: That is contrary to the Aarhus convention. It is as simple as that. It is a breach of the convention, and we should be making a report to the compliance committee.

The Chairperson: Yes, that should not have happened.

Mr Sweetman: It should not have happened.

The Chairperson: There needs to be transparency. Thank you very much indeed.

Dr Kane: May I finalise that point, if you do not mind, because you have made a very important point? The notification distance is 90 metres. Therefore, most people are never told that a turbine is going to go up near them. That is a crucial issue.

The Chairperson: Knowledge and information are so important. Thank you very much. I am sure that we will be hearing the same argument again.

Good afternoon Sheila,

Please see Addition No.4 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

We want to bring to your attention the comments made by Mr Stephen Hamilton in this NIA Official Report, how the DOE were competent in not being able or qualified to finalise the PPS18 that they invited the wind industry to do it for them. In doing so, 2km setback distances from a wind turbine to a dwelling has been removed from the previous draft copy and a lot of detail relating to LCA's has also been removed, much to the advantage of the wind industry. This was like asking the fox to guard the hen house and this is completely unacceptable and all the requirements of the EIA Directives have been ignored.
This matter has to be investigated as to why this was allowed to happen.

Yours sincerely,

Owen McMullan
Chairman
West Tyrone Against Wind Turbines

In Case C-244/12,

REQUEST for a preliminary ruling under Article 267 TFEU, from the Verwaltungsgerichtshof (Austria), made by decision of 19 April 2012, received at the Court on 21 May 2012, in the proceedings

Salzburger Flughafen GmbH

v

Umweltsenat,

intervening parties:

Landesumweltanwaltschaft Salzburg,

Bundesministerin für Verkehr, Innovation und Technologie,

THE COURT (Fifth Chamber),

composed of T. von Danwitz, President of the Chamber, A. Rosas, E. Juhász (Rapporteur), D. Šváby and C. Vajda, Judges,

Advocate General: N. Wahl,

Registrar: A. Calot Escobar,

having regard to the written procedure,

after considering the observations submitted on behalf of:

– Salzburger Flughafen GmbH, by G. Lebitsch, Rechtsanwalt,

– Landesumweltanwaltschaft Salzburg, by W. Wiener, Landesumweltanwalt,

– the Austrian Government, by C. Pesendorfer, acting as Agent,

– the European Commission, by P. Oliver and D. Düsterhaus, acting as Agents,

having decided, after hearing the Advocate General, to proceed to judgment without an Opinion,

gives the following

Judgment

Grounds

1. This request for a preliminary ruling concerns the interpretation of the relevant provisions of Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (OJ 1985 L 175, p. 40), as amended by Council Directive 97/11/EC of 3 March 1997 (OJ 1997 L 73, p. 5) ('Directive 85/337').

2. The request has been made in proceedings between Salzburger Flughafen GmbH ('Salzburger Flughafen') and the Umweltsenat (Administrative Chamber for Environmental Matters) concerning the obligation to subject certain projects which expand the infrastructure of the airport of Salzburg (Austria) to an environmental impact assessment.

Legal context

European Union law

3. Article 1 of Directive 85/337 provides:

‘1. This Directive shall apply to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment.

2. For the purposes of this Directive:

“project” means:

– the execution of construction works or of other installations or schemes,

– other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources;

…’

4. Article 2(1) of that directive provides:

‘Member States shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue, inter alia, of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects. These projects are defined in Article 4.’

5. Under Article 3 of that directive:

‘The environmental impact assessment will identify, describe and assess in an appropriate manner, in the light of each individual case and in accordance with the Articles 4 to 11, the direct and indirect effects of a project on the following factors:

– human beings, fauna and flora,

– soil, water, air, climate and the landscape,

– material assets and the cultural heritage,

– the interaction between the factors mentioned in the first, second and third indents.’

6. Article 4 of that directive is drafted as follows:

‘1. Subject to Article 2(3), projects listed in Annex I shall be made subject to an assessment in accordance with Articles 5 to 10.

2. Subject to Article 2(3), for projects listed in Annex II, the Member States shall determine through:

(a) a case-by-case examination,

or

(b) thresholds or criteria set by the Member State

whether the project shall be made subject to an assessment in accordance with Articles 5 to 10.

Member States may decide to apply both procedures referred to in (a) and (b).

3. When a case-by-case examination is carried out or thresholds or criteria are set for the purpose of paragraph 2, the relevant selection criteria set out in Annex III shall be taken into account.

…'

7. Annex I to Directive 85/337 lists the projects referred to in Article 4(1) of the directive, which must undergo a compulsory environmental assessment. Point 7(a) of Annex I to the directive refers to the '[c]onstruction … of airports … with a basic runway length of 2 100 m or more'.

8. Annex II to that directive lists the projects referred to in Article 4(2) thereof, in respect of which the Member States retain their discretion, in accordance with the conditions laid down in that article, as regards carrying out an environmental assessment. Point 10(d) of that annex concerns the '[c]onstruction of airfields (projects not included in Annex I)' and the first indent of point 13 of that annex refers to '[a]ny change or extension of projects listed in Annex I or Annex II, already authorised, executed or in the process of being executed, which may have significant adverse effects on the environment'.

9. Annex III to Directive 85/337, which refers to the selection criteria set out in Article 4(3) thereof, provides in point 2, entitled 'Location of projects':

'The environmental sensitivity of geographical areas likely to be affected by projects must be considered, having regard, in particular, to:

…

– the absorption capacity of the natural environment, paying particular attention to the following areas:

…

(g) densely populated areas;

…'

Austrian law

10. Directive 85/337 was transposed into Austrian law by the Environmental Impact Assessment Act 2000 (Umweltverträglichkeitsprüfungsgesetz 2000), in the version applicable to the facts in the main proceedings (BGBl. I, 50/2002; 'the UVPG 2000').

11. Articles 1, 3 and 3a of the UVPG 2000 contain provisions concerning the object and content of environmental impact assessments, the principle in accordance with which the projects listed in Annex I to that Law must be subject to such an assessment, the procedure and the conditions to be followed in that regard and the persons or entities authorised to request an assessment.

12. Thus, the projects which require an assessment are listed in Annex I to the UVPG 2000, in accordance with the principle stated in the provisions referred to above. Where there are changes to those projects, there must be an examination on a case-by-case basis above a certain threshold, with a view to carrying out an assessment. Column 1 of that annex, in point 14(d), refers, in that regard, to the following projects:

‘Modification of airports, if this is expected to increase the number of aircraft movements (motor aircrafts, power gliders in powered flight or helicopters) by 20,000 or more per year…’

13. Operation of a civilian airport and all modifications to the extent of the operation limited by the licence require a ‘civil airport licence’ in accordance with Paragraph 68(1) of the Aviation Law (Luftfahrtgesetz) and an ‘operating licence’ under Paragraph 73(1) of that Law. In addition, the construction, use and substantial modification of civilian ground installations require a licence in accordance with Paragraph 78(1) of that Law.

The dispute in the main proceedings and the questions referred for a preliminary ruling

14. Salzburger Flughafen operates Salzburg Airport, which has a runway of over 2 100 metres in length. On 30 July 2002, it applied for a permit to construct an additional terminal, which it justified on the ground that, in the light of the requirement to ensure full checks on hold luggage, the existing passenger handling facilities were no longer capable of handling peak volumes of passengers. By decision of 2 April 2003, the Landeshauptfrau von Salzburg (Head of Government of the Province of Salzburg), the competent administrative authority, issued the construction permit. The additional terminal was built in 2003/2004. It has been operational ever since.

15. In 2004, Salzburger Flughafen made further applications for expansion of the airport. They concerned, firstly, an area of approximately 90 000 m2 in the south-western part of the present airport site for the construction of ancillary buildings, in particular warehouses, and the extension of vehicle parking areas and aircraft standing areas. Secondly, it applied to incorporate in that expansion further areas of almost 120 000 m2 to the north west of the airport primarily for general aviation, the construction of hangars and vehicle parking and aircraft standing areas. It also sought authorisation to alter taxiways. The application did not involve any changes to the runway itself.

16. The fact that the airport is sited in an urban area, with, in addition, a high level of air pollution, and the expected effects on the environment led the Landesumweltanwaltschaft Salzburg (Provincial Legal Office for the Environment), on 13 March 2006, to request the Amt der Salzburger Landesregierung (Office of the Salzburg Federal Government; ‘the Amt’) to lay down a requirement for an environmental assessment covering both the additional terminal and the expansion works to the airport infrastructure. Since the Amt rejected that request, the Landesumweltanwaltschaft Salzburg appealed against that decision to the Umweltsenat (Environmental Tribunal).

17. In its decision, the Umweltsenat found that both the extension of the airport infrastructure already in existence, following the construction and putting into operation of the additional terminal, and the expansion proposed in the permit applications require an environmental impact assessment, in accordance with the relevant provisions of the UVPG 2000, read in conjunction with Directive 85/337.

18. To justify its decision, that authority noted that if, in the context of the dispute in the main proceedings, the national legislation does not require any environmental impact assessment, since the threshold established, namely an increase in the number of aircraft movements of at least 20 000 per year, is not

exceeded, that legislation only imperfectly transposes Directive 85/337. The UVPG 2000 establishes too high a threshold, so that changes to the infrastructure of small or medium-sized airports ought never, in practice, to give rise to an environmental impact assessment. In addition, the Umweltsenat noted that the national legislation at issue does not list sites requiring specific protection, whereas Directive 85/337 requires, under Annex III(2)(g) thereto, that special attention be paid to densely populated areas. The airport under consideration is near to the city of Salzburg.

19. The Umweltsenat therefore took the view that it was necessary to apply Directive 85/337 directly, because of the fact that the changes to the airport infrastructure can be regarded, in particular by reason of their nature, size and characteristics, as a modification of the airport itself, likely to increase its activity and aircraft traffic.

20. An appeal has been brought against that decision by Salzburger Flughafen before the Verwaltungsgerichtshof (Supreme Administrative Court).

21. The referring court notes that, in accordance with the case-law of the Court following from Cases C-2/07 Abraham and Others [2008] ECR I-1197 and C-275/09 Brussels Hoofdstedelijk Gewest and Others [2011] ECR I-1753, the relevant provisions of Annex II to Directive 85/337, read in conjunction with those of Annex I thereto, also encompass works to change the infrastructure of an existing airport. Furthermore, in order to avoid misuse of the European Union rules by splitting projects which, taken together, are likely to have significant effects on the environment, it is ne cessary to take into account the cumulative effect of such projects which have an objective and chronological link between them. The Verwaltungsgerichtshof is therefore of the opinion that the assessment of the environmental impact of the later project, namely the expansion of the airport area, must also take into account the impact of the earlier project, the construction of the additional terminal.

22. As regards the fact that the project at issue in the main proceedings, taken as a whole, appears to require an environmental impact assessment pursuant to the provisions of Directive 85/337 while the national legislation does not require such an assessment, the Verwaltungsgerichtshof observes that, in accordance with the case-law of the Court, the measure of discretion conferred on Member States by Article 4(2) of Directive 85/337 is limited by the obligation set out in Article 2(1) of the directive to make projects likely to have significant effects on the environment, by virtue, inter alia, of their nature, size or location, subject to an impact assessment. Thus, a Member State which establishes criteria or thresholds without taking into consideration the location of projects or which establishes them at a level which, in practice, means that all of a particular type of projects will be removed in advance from the obligation of carrying out an impact assessment exceeds the discretion which it has (Abraham and Others , paragraph 37; Case C-72/95 Kraaijeveld and Others [1996] ECR I-5403, paragraph 53 and Case C-435/97 WWF and Others [1999] ECR I-5613, paragraph 38).

23. As regards the monitoring of compliance with that discretion and the consequences if it is exceeded, the referring court points out that, in accordance with the case-law of the Court, where that discretion is exceeded by the legislative or administrative authorities of a Member State, individuals may rely on Articles 2(1) and 4(2) of Directive 85/337 before the courts of a Member

State against the national authorities and thus obtain an order that the national rules or measures which are incompatible with those provisions be set aside. In such a case, it follows from the judgments in Kraaijeveld and Others (paragraphs 59 to 61) and WWF and Others (paragraph 5 of the operative part) that it is for the authorities of a Member State to adopt, according to their respective powers, to take all the general or particular measures necessary to ensure that projects are examined in order to determine whether they are likely to have significant effects on the environment and, if so, to ensure that they are subject to an impact assessment.

24. With regard to the direct effect of the relevant provisions of Directive 85/337, the referring court is of the opinion that, from the point of view of their content, those provisions are unconditional. As regards whether they are also sufficiently precise to be capable of direct application, it notes that the selection criteria laid down in Annex III to Directive 85/337 in any event state the limits of the discretion of the Member States under Article 4(2) of that directive. The rules at issue in the main proceedings do not take account of the criterion of location of the projects provided for in point 2(g) of Annex III to Directive 85/337. In addition, the threshold established in those rules means that it is, in practice, highly unlikely that there would be an environmental assessment for medium-sized or small airports. Thus, according to the referring court, not only does the legislation at issue in the main proceedings fail fully to transpose Directive 85/337, but, in addition, it manifestly fails to take account of the clear and sufficiently precise criteria laid down in Annex III to that directive.

25. Having regard to those considerations and to the fact that it rules at final instance, the Verwaltungsgerichtshof decided to stay the proceedings and to refer the following questions to the Court of Justice for a preliminary ruling:

‘1. Does … Directive 85/337/EEC … preclude a national rule by which it is established that an environmental impact assessment for infrastructure works (not concerning the runway) at an airport, that is the construction of a terminal and the extension of the airport site to construct further facilities (in particular hangars, equipment buildings and parking areas), shall only be carried out if the annual number of aircraft movements is anticipated to increase by no less than 20 000?

In the event that Question 1 is answered in the affirmative:

2. In the absence of relevant national provisions, does Directive 85/337 require and allow for the direct application of its provisions to assess (taking due account of the objectives thereby pursued and the criteria set out in Annex III thereto) the environmental impact of a project – specified in Question 1 – which is covered by Annex II?’

Consideration of the questions referred

The first question

26. By its first question, the referring court asks, in essence, whether the provisions of Directive 85/337 preclude national legislation which makes projects which change the infrastructure of an airport and fall within the scope of Annex II to that directive subject to an environmental impact assessment only if those projects are likely to increase the number of aircraft movements by at least 20 000 per year.

27. In order to respond to that question, it is necessary to note that, as follows from the combined provisions of Article 4(2) of Directive 85/337 and the first indent of point 13 of Annex II thereto, any change or extension of projects listed in Annex I or Annex II, already authorised, executed or in the process of being executed, which may have significant adverse effects on the environment, the Member States must determine on the basis of a case-by-case examination or of thresholds or criteria which they establish, whether such a project must be made subject to an environmental impact assessment.

28. In that regard, it must be borne in mind that, in accordance with the settled case-law of the Court, works to change the infrastructure of an existing airport, without extension of the runway, are likely to be covered by point 13 of Annex II to Directive 85/337, where they may be regarded, in particular because of their nature, extent and characteristics, as an alteration of the airport itself (see, to that effect, Brussels Hoofdstedelijk Gewest , paragraph 35 and the case-law cited).

29. As regards the establishment of thresholds or criteria to determine whether such a project must be made subject to an environmental impact assessment, it must be borne in mind that, indeed, Article 4(2)(b) of Directive 85/337 confers a measure of discretion on the Member States in that regard. However, that discretion is limited by the obligation set out in Article 2(1) of the directive to make projects likely, by virtue inter alia of their nature, size or location, to have significant effects on the environment subject to an impact assessment (see, to that effect, WWF and Others , paragraph 36 and the case-law cited).

30. Thus, the criteria and/or thresholds mentioned in Article 4(2)(b) of Directive 85/337 are designed to facilitate examination of the actual characteristics of any given project in order to determine whether it is subject to the requirement to carry out an assessment, and not to exempt in advance from that obligation certain whole classes of projects listed in Annex II to that directive which may be envisaged on the territory of a Member State (see, to that effect, WWF and Others , paragraph 37 and the case-law cited).

31. The Court has already held that a Member State which established criteria or thresholds at a level such that, in practice, an entire class of projects would be exempted in advance from the requirement of an impact assessment would exceed the limits of its discretion under Articles 2(1) and 4(2) of Directive 85/337 unless all projects excluded could, when viewed as a whole, be regarded as not being likely to have significant effects on the environment (see, to that effect, WWF and Others , paragraph 38 and the case-law cited).

32. Finally, it is apparent from Article 4(3) of Directive 85/337 that for the establishment of thresholds or criteria under Article 4(2)(b), regard must be had to the relevant selection criteria established in Annex III to the directive. Those criteria include the absorption capacity of the natural environment and, in that regard, particular attention must be paid to densely populated areas.

33. It must be noted that a threshold such as that at issue in the main proceedings is incompatible with the general obligation laid down in Article 2(1) of that directive for the purposes of correct identification of projects likely to have significant effects on the environment.

34. As the referring court points out, the establishment of such a high threshold means that changes to the infrastructure of small or medium-sized airports can

never, in practice, give rise to an environmental impact assessment, despite the fact, as the observation from the European Commission pertinently states, it cannot be excluded that such works may have significant effects on the environment.

35. Furthermore, by establishing such a threshold in order to decide on the need for an environmental assessment of projects such as those at issue in the main proceedings, the national legislation concerned, despite the obligation placed on Member States by Article 4(3) of Directive 85/337, takes into consideration only the quantitative aspect of the consequences of a project, without taking account of the other selection criteria in Annex III to that directive, particularly that laid down in point 2(g) of that annex, namely the population density of the area affected by the project. It is not in dispute that the airport whose infrastructure is affected by the changes at issue in the main proceedings is located near to the city of Salzburg.

36. Moreover, the referring court observes that, in the circumstances of the main proceedings, with a view to deciding whether an environmental assessment must be carried out, it is necessary to take account of the effects on the environment of both the earlier project concerning the construction of the additional terminal and the later project concerning the expansion of the airport area.

37. In that regard, in accordance with the case-law of the Court, it can be necessary to take account of the cumulative effect of projects in order to avoid a circumvention of the objective of the European Union legislation by the splitting of projects which, taken together, are likely to have significant effects on the environment (see, to that effect, Brussels Hoofdstedelijk Gewest and Others , paragraph 36 and the case-law cited). It is for the referring court to examine, in the light of that case-law, whether and to what extent the effects on the environment of the projects referred to in paragraph 15 of this judgment and the projects already carried out during 2003 and 2004 must be assessed as a whole.

38. Consequently, the answer to the first question is that Articles 2(1) and 4(2)(b) and (3) of Directive 85/337 preclude national legislation which makes projects which change the infrastructure of an airport and fall within the scope of Annex II to that directive subject to an environmental impact assessment only if those projects are likely to increase the number of aircraft movements by at least 20 000 per year.

The second question

39. By its second question, the referring court asks, in essence, whether, when a Member State makes an incorrect transposition of Directive 85/337, that directive requires an environmental impact assessment of projects such as those at issue in the main proceedings, which fall within the scope of Annex II thereto.

40. The question referred must be understood as asking whether, when a Member State, pursuant to Article 4(2)(b) of Directive 85/337, with regard to projects falling within the scope of Annex II thereto, establishes a threshold which is incompatible with the obligations laid down in Articles 2(1) and 4(3) of that directive, the provisions of Articles 2(1) and 4(2)(a) and (3) of the directive have direct effect, which means that the competent national authorities must

ensure that it is first examined whether the projects concerned are likely to have significant effects on the environment and, if so, that an assessment of those effects is then undertaken.

41. In accordance with the case-law of the Court, if the discretion conferred on Member States by Article 4(2) of Directive 85/337, read in conjunction with Article 2(1) thereof has been exceeded, it is for the authorities of the Member State to take, according to their relevant powers, all the general or particular measures necessary to ensure that projects are examined in order to determine whether they are likely to have significant effects on the environment and, if so, to ensure that they are subject to an impact assessment (see, to that effect, Kraaijeveld and Others , paragraph 61, and WWF and Others , paragraphs 70 and 71).

42. The same conclusion applies to a situation such as that of the main proceedings, equivalent from the point of view of its effects to that described in the preceding paragraph of this judgment, in which the threshold established by the national legislation results in an incorrect transposition of Article 4(2)(b), read in conjunction with Articles 2(1) and 4(3) of Directive 85/337.

43. Consequently, in a situation such as that of the main proceedings, as the Commission rightly points out, when a Member State, on the basis of Article 4(2)(b) of Directive 85/337, has established a threshold which is likely to exempt in advance entire classes of projects from an environmental assessment, the national authorities are obliged to ensure, in accordance with Article 2(1) and Article 4(2)(a) and (3) of that directive, that it is determined, in each individual case, whether such an assessment must be undertaken and if so, to undertake that assessment.

44. However, the Austrian Government and Salzburger Flughafen dispute that conclusion, referring to Case C-201/02 Wells [2004] ECR I-723, in accordance with which the principle of legal certainty preludes an individual from relying on a directive against a Member State where it is a matter of a State obligation directly linked to the performance of another obligation falling, pursuant to that directive, on a third party.

45. That objection cannot be accepted.

46. In the case which gave rise to the Wells judgment, the Court held, firstly, that it had to be recognised that it is possible for an individual to rely on the provisions of Directive 85/337 and, secondly, that the owners of the land at issue had to bear the consequences of the belated performance of the obligations of the Member State concerned which follow from that directive.

47. Thus, in the main proceedings, in the event that a decision finds that an environmental study is necessary, Salzburger Flughafen, as the user of the land in question, must also bear the consequences of such a decision.

48. Accordingly, the answer to the second question is that, when a Member State, pursuant to Article 4(2)(b) of Directive 85/337, with regard to projects falling within the scope of Annex II thereto, establishes a threshold which is incompatible with the obligations laid down in Articles 2(1) and 4(3) of that directive, the provisions of Articles 2(1) and 4(2)(a) and (3) of the directive have direct effect, which means that the competent national authorities must ensure that it is first examined whether the projects concerned are likely to

have significant effects on the environment and, if so, that an assessment of those effects is then undertaken.

Costs

49. Since these proceedings are, for the parties to the main proceedings, a step in the action pending before the referring court, the decision on costs is a matter for that court. Costs incurred in submitting observations to the Court, other than the costs of those parties, are not recoverable.

Operative part

On those grounds, the Court (Fifth Chamber) hereby rules:

1. Articles 2(1) and 4(2)(b) and (3) of Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment, as amended by Council Directive 97/11/EC of 3 March 1997, preclude national legislation which makes projects which change the infrastructure of an airport and fall within the scope of Annex II to that directive subject to an environmental impact assessment only if those projects are likely to increase the number of aircraft movements by at least 20 000 per year;

2. When a Member State, pursuant to Article 4(2)(b) of Directive 85/337, as amended by Directive 97/11, with regard to projects falling within the scope of Annex II thereto, establishes a threshold which is incompatible with the obligations laid down in Articles 2(1) and 4(3) of that directive, the provisions of Articles 2(1) and 4(2)(a) and (3) of the directive have direct effect, which means that the competent national authorities must ensure that it is first examined whether the projects concerned are likely to have significant effects on the environment and, if so, that an assessment of those effects is then undertaken.

62009C0050j C v Ireland EIA

Title and reference

Judgment of the Court (First Chamber) of 3 March 2011.

European Commission v Ireland.

Failure of a Member State to fulfil obligations - Directive 85/337/EEC - Obligation of the competent environmental authority to carry out an assessment of the effects of certain projects on the environment - More than one competent authority - Need to ensure an assessment of the interaction between factors likely to be directly or indirectly affected - Application of the directive to demolition works.

Case C-50/09.

Parties

In Case C-50/09,

ACTION under Article 226 EC for failure to fulfil obligations, brought on 4 February 2009,

European Commission, represented by P. Oliver, C. Clyne and J.-B. Laignelot, acting as Agents, with an address for service in Luxembourg,

applicant,

v

Ireland, represented by D. O'Hagan, acting as Agent, assisted by G. Simons SC and D. McGrath BL, with an address for service in Luxembourg,

defendant,

THE COURT (First Chamber),

composed of A. Tizzano, President of the Chamber, J.-J. Kasel, A. Borg Barthet, M. Ilešič and M. Berger (Rapporteur), Judges,

Advocate General: J. Mazák,

Registrar: N. Nanchev, Administrator,

having regard to the written procedure and further to the hearing on 24 June 2010,

having decided, after hearing the Advocate General, to proceed to judgment without an Opinion,

gives the following

Judgment

Grounds

1. By its action, the Commission of the European Communities requested the Court to declare that:

– by failing to transpose Article 3 of Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (OJ 1985 L 175, p. 40), as amended by Council Directive 97/11/EC of 3 March 1997 (OJ 1997 L 73, p. 5) and by Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 (OJ 2003 L 156, p. 17; 'Directive 85/337');

– by failing to ensure that, where Irish planning authorities and the Environmental Protection Agency ('the Agency') both have decision-making powers on a project, there will be complete fulfilment of the requirements of Articles 2 to 4 of that directive; and

– by excluding demolition works from the scope of its legislation transposing that directive,

Ireland has failed to fulfil its obligations under that directive.

Legal context

European Union legislation

2. Article 1(2) and (3) of Directive 85/337 provide:

'(2) For the purposes of this Directive:

"project" means:

– the execution of construction works or of other installations or schemes,

– other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources;

...

"development consent" means:

the decision of the competent authority or authorities which entitles the developer to proceed with the project.

(3) The competent authority or authorities shall be that or those which the Member States designate as responsible for performing the duties arising from this Directive.'

3. Under Article 2(1) to (2a) of Directive 85/337:

'(1) Member States shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue inter alia, of their nature, size or location are made subject to an assessment with regard to their effects. These projects are defined in Article 4.

(2) The environmental impact assessment may be integrated into the existing procedures for consent to projects in the Member States, or, failing this, into other procedures or into procedures to be established to comply with the aims of this Directive.

(2a) Member States may provide for a single procedure in order to fulfil the requirements of this Directive and the requirements of Council Directive 96/61/EC of 24 September 1996 on integrated pollution prevention and control …'

4. Article 3 of Directive 85/337 provides:

'The environmental impact assessment will identify, describe and assess in an appropriate manner, in the light of each individual case and in accordance with Articles 4 to 11, the direct and indirect effects of a project on the following factors:

– human beings, fauna and flora,

– soil, water, air, climate and the landscape,

– material assets and the cultural heritage,

– the interaction between the factors mentioned in the first, second and third indents.'

5. Article 4(1) and (2) of Directive 85/337 are worded as follows:

'1. Subject to Article 2(3), projects listed in Annex I shall be made subject to an assessment in accordance with Articles 5 to 10.

2. Subject to Article 2(3), for projects listed in Annex II, the Member States shall determine through:

(a) a case-by-case examination,

or

(b) thresholds or criteria set by the Member State

whether the project shall be made subject to an assessment in accordance with Articles 5 to 10.

Member States may decide to apply both procedures referred to in (a) and (b).'

6. Articles 5 to 7 of Directive 85/337 concern the information which must be gathered and the consultations which must be undertaken for the purposes of the assessment procedure. Article 5 deals with the information which the developer must supply, Article 6 deals with the obligation to consult, on the one hand, authorities with specific environmental responsibilities and the public, on the other, and Article 7 covers the obligation, in the case of a cross-border project, to inform the other Member State concerned. Article 8 of the directive states that the results of those consultations and the information gathered must be taken into consideration in the development consent procedure.

7. Articles 9 to 11 of Directive 85/337, relating to the decision taken at the conclusion of the consent procedure, cover, respectively, informing the public and the Member States concerned, respect for commercial and industrial confidentiality, the right of members of the public to bring proceedings before a court and the exchange of information between Member States and the Commission.

8. Under Article 12(1) of Directive 85/337, in its original version, the Member States were obliged to comply with that directive's provisions by 3 July 1988 at the latest. With regard to the amendments made to it by Directives 97/11 and 2003/35, the Member States were obliged to bring them into force at the latest by 14 March 1999 and 25 June 2005 respectively.

National legislation

The Planning and Development Act 2000

9. The Planning and Development Act 2000, as amended by the Strategic Infrastructure Act 2006 ('the PDA'), lays down the legal framework for issuing development consent for most of the project categories listed in Annexes I and II to Directive 85/337. For some projects, development consent under the PDA, which is termed 'planning permission' and granted, as a rule, by a local authority, is the only form of consent required for a project to proceed. In such cases, the PDA provides that the decisions taken by local authorities may be appealed against to An Bord Pleanála (The Planning Appeals Board; 'the Board').

10. Part X of the PDA, comprising sections 172 to 177, is devoted to environmental impact assessments. Section 176 provides for ministerial regulations to identify projects requiring such an assessment. Section 172 provides that, for projects covered by regulations made under section 176, applications for planning permission are to be accompanied by an environmental impact statement. Under section 173, where a planning authority receives an application for planning permission accompanied by an environmental impact statement, that authority and, on appeal, the Board must have regard to that statement. Section 177 provides that the information to be included in such a statement is to be prescribed by ministerial regulation.

11. Detailed measures for the implementation of the PDA are set out in the Planning and Development Regulations 2001, as amended by the Planning and Development Regulations 2008 ('the PDR'), which were adopted pursuant to, among others, sections 176 and 177 of the PDA.

12. Part 2 of the PDR concerns projects which are exempt from an environmental impact assessment. Article 6 thereof refers in that regard to Part 1 of Schedule 2 to the PDR, which, in Category 50, refers to 'the demolition of a building or other structure'. Articles 9 and 10 of the PDR lay down the conditions under which a project as a rule exempted must none the less be made subject to a consent procedure.

13. Part 10 of the PDR is devoted to environmental impact assessments. Article 93 thereof, in combination with Schedule 5 thereto, defines the categories of projects for which such an assessment is required. Article 94 of the PDR, which lists the information that should be found in an environmental impact statement, is worded as follows:

'An environmental impact statement shall contain:

(a) the information specified in paragraph 1 of Schedule 6,

(b) the information specified in paragraph 2 of Schedule 6 to the extent that

(i) such information is relevant to a given stage of the consent procedure and to the specific characteristics of the development or type of development concerned and of the environmental features likely to be affected, and

(ii) the person or persons preparing the statement may reasonably be required to compile such information having regard, among other things, to current knowledge and methods of assessment, and,

(c) a summary in non-technical language of the information required under paragraphs (a) and (b).'

14. Schedule 6 to the PDR specifies the information to be contained in an environmental impact statement. Paragraph 2(b) of Schedule 6 stipulates that it must contain:

'A description of the aspects of the environment likely to be significantly affected by the proposed development, including in particular:

– human beings, fauna and flora,

– soil, water, air, climatic factors and the landscape,

– material assets, including the architectural and archaeological heritage, and the cultural heritage,

– the inter-relationship between the above factors.'

15. Under Article 108 of the PDR, the competent planning authority is obliged to establish whether the information contained in an environmental impact statement complies with the requirements laid down in the PDR.

The Environmental Protection Agency Act 1992

16. The Environmental Protection Agency Act 1992 ('the EPAA') introduced, among other things, a new system of integrated pollution control under which many industrial activities require a licence granted by the Agency. Where the activity is new and/or involves new construction, it must also obtain planning permission as provided for by the PDA.

17. Section 98 of the EPAA, which precluded planning authorities from taking into consideration aspects connected with pollution risks in considering an application for planning permission, was amended by section 256 of the PDA to the effect that, whilst it precluded planning authorities from including any pollution control conditions in planning permissions for activities also requiring a licence from the Agency, they could nevertheless, where appropriate, refuse to grant planning permission on environmental grounds. Section 98 of the EPAA, as amended, provides that planning authorities may ask the Agency for an opinion, in particular on an environmental impact statement. However, the Agency is not required to respond to such a request.

18. Under the Environmental Protection Agency (Licensing) Regulations 1994 ('the EPAR'), the Agency may notify a planning authority of a licence application. There is, however, no obligation on the planning authority to respond to such a notification.

The National Monuments Act 1930

19. The National Monuments Act 1930 ('the NMA') governs the protection of Ireland's most culturally significant archaeological remains, which are classed as 'national monuments'. It was amended by the National Monuments (Amendment) Act 2004, to relax the constraints imposed under earlier legislation concerning proposals to alter or remove national monuments.

20. Section 14 of the NMA confers on the Irish Minister for the Environment, Heritage and Local Government ('the Minister') discretion to consent to the destruction of a national monument. Where a national monument is discovered during the carrying out of a road development which has been subject to an environmental impact assessment, section 14A of the NMA provides that it is, in principle, prohibited to carry out any works on the monument pending directions by the Minister. Those directions can relate to 'the doing to the monument of [various] matters', including its demolition. There is no provision for any assessment to be made, for the adoption of such directions, of the effects on the environment. However, section 14B of the NMA provides that the Minister's

directions must be notified to the Board. If those directions envisage an alteration to the approved road development, the Board must consider whether or not that alteration is likely to have significant adverse effects on the environment. If it is of that opinion, it must require the submission of an environmental impact statement.

Pre-litigation procedure

21. Following the examination of a complaint regarding Ireland's transposition of Directive 85/337, the Commission took the view that Ireland had failed to ensure its full and correct transposition and, by letter of 19 November 1998, gave Ireland formal notice, to submit its observations, in accordance with the procedure for failure to fulfil Treaty obligations. A further letter of formal notice was sent to Ireland on 9 February 2001.

22. After examining the observations received in response to those letters, the Commission, on 6 August 2001, sent the Irish authorities a reasoned opinion in which it claimed that Ireland had not correctly transposed Articles 2 to 6, 8 and 9 of Directive 85/337. In reply, Ireland stated that the legislative amendments necessary to bring about the transposition were being adopted and requested that the proceedings be stayed.

23. Following further complaints, the Commission, on 2 May 2006, sent an additional letter of formal notice to Ireland.

24. As the Commission was not satisfied with the replies received, on 29 June 2007 it addressed an additional reasoned opinion to Ireland in which it claimed that Ireland had not correctly transposed Directive 85/337, in particular Articles 2 to 4 thereof, and called upon it to comply with that reasoned opinion within a period of two months from the date of its receipt. In reply, Ireland maintained its position that the Irish legislation in force now constitutes adequate transposition of that directive.

25. The Commission then brought the present action.

The action

The first complaint, alleging failure to transpose Article 3 of Directive 85/337

Arguments of the parties

26. According to the Commission, Article 3 of Directive 85/337 is of pivotal importance, since it sets out what constitutes an environmental impact assessment and must therefore be transposed explicitly. The provisions relied upon by Ireland as adequate transposition of Article 3 of the directive are insufficient.

27. Thus, section 173 of the PDA, which requires planning authorities to have regard to the information contained in an environmental impact statement submitted by a developer, relates to the obligation, under Article 8 of Directive 85/337, to take into consideration the information gathered pursuant to Articles 5 to 7 thereof. By contrast, section 173 does not correspond to the wider obligation, imposed by Article 3 of Directive 85/337 on the competent authority, to ensure that there is carried out an environmental impact assessment which identifies, describes and assesses all the matters referred to in that article.

28. As for Articles 94, 108 and 111 of, and Schedule 6 to, the PDR, the Commission observes that they are confined, first, to setting out the matters on which the developer must supply information in its environmental impact statement and, second, to specifying the obligation on the competent authorities to establish that the information is complete. The obligations laid down by those provisions are different from that, imposed by Article 3 of Directive 85/337 on the competent authority, of carrying out a full environmental impact assessment

29. With regard to the relevance of the Irish courts' case-law on the application of the provisions of national law at issue, the Commission points out that while those courts may interpret ambiguous provisions so as to ensure their compatibility with a directive; they cannot plug legal gaps in the national legislation. Moreover, the extracts from the decisions cited by Ireland concern, in the Commission's submission, not the interpretation of that legislation but the interpretation of Directive 85/337 itself.

30. Ireland disputes the significance which the Commission attaches to Article 3 of that directive. It submits that that provision, drafted in general terms, is confined to stating that an environmental impact assessment must be made in accordance with Articles 4 to 11 of the directive. By transposing Articles 4 to 11 into national law, a Member State thereby, in Ireland's submission, ensures the transposition of Article 3.

31. Ireland maintains that Article 3 of Directive 85/337 is fully transposed by sections 172(1) and 173 of the PDA and Articles 94 and 108 of, and Schedule 6 to, the PDR. It points out that the Supreme Court (Ireland) has confirmed, in two separate judgments of 2003 and 2007, namely O'Connell v Environmental Protection Agency and Martin v An Bord Pleanála , that Irish law requires planning authorities and the Agency to assess the factors referred to in Article 3 and the interaction between them. Those judgments, which, Ireland submits, should be taken into account when assessing the scope of the national provisions at issue, do not fill a legal gap but are confined to holding that the applicable national legislation imposes an obligation on the competent authorities to carry out an environmental impact assessment of a development in the light of the criteria laid down in Article 3 of Directive 85/337.

32. In the alternative, Ireland refers to the concept of 'proper planning and sustainable development' referred to in section 34 of the PDA. It is, in Ireland's submission, the principal criterion which must be taken into consideration by any planning authority when deciding on an application for planning permission. That concept is in addition to all the criteria referred to in section 34 of the PDA, as well as in other provisions of that Act, including section 173, the application of which it reinforces.

33. Finally, Ireland submits that the Commission does not respect the discretion which a Member State enjoys under Article 249 EC as to the form and methods for transposing a directive. By requiring the literal transposition of Article 3 of Directive 85/337, the Commission is disregarding the body of legislation and case-law built up in Ireland over 45 years surrounding the concepts of 'proper planning' and 'sustainable development'.

Findings of the Court

34. At the outset, it is to be noted that the Commission and Ireland give a different reading to Article 3 of Directive 85/337 and a different analysis of its relationship with Articles 4 to 11 thereof. The Commission maintains that Article 3 lays down obligations which go beyond those required by Articles 4 to 11, whereas Ireland submits that it is merely a provision drafted in general terms and that the details of the process of environmental impact assessment are specified in Articles 4 to 11.

35. In that regard, whilst Article 3 of Directive 85/337 provides that the environmental impact assessment is to take place 'in accordance with Articles 4 to 11' thereof, the obligations referred to by those articles differ from that under Article 3 itself.

36. Article 3 of Directive 85/337 makes the competent environmental authority responsible for carrying out an environmental impact assessment which must include a description of a project's direct and indirect effects on the factors set out in the first three indents of that article and the interaction between those factors (judgment of 16 March 2006 in Case C-332/04 Commission v Spain , paragraph 33). As stated in Article 2(1) of the directive, that assessment is to be carried out before the consent applied for to proceed with a project is given.

37. In order to satisfy the obligation imposed on it by Article 3, the competent environmental authority may not confine itself to identifying and describing a project’s direct and indirect effects on certain factors, but must also assess them in an appropriate manner, in the light of each individual case.

38. That assessment obligation is distinct from the obligations laid down in Articles 4 to 7, 10 and 11 of Directive 85/337, which are, essentially, obligations to collect and exchange information, consult, publicise and guarantee the possibility of challenge before the courts. They are procedural provisions which do not concern the implementation of the substantial obligation laid down in Article 3 of that directive.

39. Admittedly, Article 8 of Directive 85/337 provides that the results of the consultations and the information gathered pursuant to Articles 5 to 7 must be taken into consideration in the development consent procedure.

40. However, that obligation to take into consideration, at the conclusion of the decision-making process, information gathered by the competent environmental authority must not be confused with the assessment obligation laid down in Article 3 of Directive 85/337. Indeed, that assessment, which must be carried out before the decision-making process (Case C-508/03 Commission v United Kingdom [2006] ECR I-3969, paragraph 103), involves an examination of the substance of the information gathered as well as a consideration of the expediency of supplementing it, if appropriate, with additional data. That competent environmental authority must thus undertake both an investigation and an analysis to reach as complete an assessment as possible of the direct and indirect effects of the project concerned on the factors set out in the first three indents of Article 3 and the interaction between those factors.

41. It follows therefore both from the wording of the provisions at issue of Directive 85/337 and from its general scheme that Article 3 is a fundamental provision. The transposition of Articles 4 to 11 alone cannot be regarded as automatically transposing Article 3.

42. It is in the light of those considerations that the Court must consider whether the national provisions upon which Ireland relies constitute proper transposition of Article 3 of Directive 85/337.

43. It can be seen from the wording of section 172 of the PDA and of Article 94 of, and Schedule 6 to, the PDR that those provisions relate to the developer’s obligation to supply an environmental impact statement, which corresponds, as the Commission correctly claims, to the obligation imposed upon the developer by Article 5 of Directive 85/337. Article 108 of the PDR imposes no obligation on the planning authority other than that of establishing the completeness of that information.

44. As regards section 173 of the PDA, according to which the planning authority, where it receives an application for planning permission accompanied by an environmental impact statement, must take that statement into account as well as any additional information provided to it, it is clear from the very wording of that article that it is confined to laying down an obligation similar to that provided for in Article 8 of Directive 85/337, namely that of taking the results of the consultations and the information gathered for the purposes of the consent procedure into consideration. That obligation does not correspond to the broader one, imposed by Article 3 of Directive 85/337 on the competent environmental authority, to carry out itself an environmental impact assessment in the light of the factors set out in that provision.

45. In those circumstances, it must be held that the national provisions invoked by Ireland cannot attain the result pursued by Article 3 of Directive 85/337.

46. Whilst it is true that, according to settled case-law, the transposition of a directive into domestic law does not necessarily require the provisions of the directive to be enacted in precisely the same words in a specific, express provision of national law and a general legal context may be sufficient if it actually ensures the full application of the directive in a sufficiently clear and precise manner (see, in

particular, Case C-427/07 Commission v Ireland [2009] ECR I-6277, paragraph 54 and the case-law cited), the fact remains that, according to equally settled case-law, the provisions of a directive must be implemented with unquestionable binding force and with the specificity, precision and clarity required in order to satisfy the need for legal certainty, which requires that, in the case of a directive intended to confer rights on individuals, the persons concerned must be enabled to ascertain the full extent of their rights (see, in particular, Commission v Ireland , paragraph 55 and the case-law cited).

47. In that regard, the judgment of the Supreme Court in O'Connell v Environmental Protection Agency gives, admittedly, in the passage upon which Ireland relies, an interpretation of the provisions of domestic law consistent with Directive 85/337. However, according to the Court's settled case-law, such a consistent interpretation of the provisions of domestic law cannot in itself achieve the clarity and precision needed to meet the requirement of legal certainty (see, in particular, Case C-508/04 Commission v Austria [2007] ECR I-3787, paragraph 79 and the case-law cited). The passage in the judgment of the same court in Martin v An Bord Pleanála , to which Ireland also refers, concerns the question of whether all the factors referred to in Article 3 of Directive 85/337 are mentioned in the consent procedures put in place by the Irish legislation. By contrast, it has no bearing on the question, which is decisive for the purposes of determining the first complaint, of what the examination of those factors by the competent national authorities should comprise.

48. As regards the concepts of 'proper planning' and 'sustainable development' to which Ireland also refers, it must be held that, even if those concepts encompass the criteria referred to in Article 3 of Directive 85/337, it is not established that they require that those criteria be taken into account in all cases for which an environmental impact assessment is required.

49. It follows that neither the national case-law nor the concepts of 'proper planning' and 'sustainable development' can be invoked to remedy the failure to transpose into the Irish legal order Article 3 of Directive 85/337.

50. The Commission's first complaint in support of its action must therefore be held to be well founded.

The second complaint, alleging failure to ensure full compliance with Articles 2 to 4 of Directive 85/337 where several authorities are involved in the decision-making process

Arguments of the parties

51. For the Commission, it is of the essence that the environmental impact assessment be carried out as part of a holistic process. In Ireland, following the Agency's creation, certain projects requiring such an assessment are subject to two separate decision-making processes: one process involves decision-making on land-use aspects by planning authorities, while the other involves decision-making by the Agency on pollution aspects. The Commission accepts that planning permission and an Agency licence may be regarded, as has been held in Irish case-law (Martin v An Bord Pleanála), as together constituting 'development consent' within the meaning of Article 1(2) of Directive 85/337 and it does not object to such consent being given in two successive stages. However, the Commission criticises the fact that the Irish legislation fails to impose any obligation on planning authorities and the Agency to coordinate their activities. In the Commission's submission, that situation is contrary to Articles 2 to 4 of Directive 85/337.

52. As regards Article 2 of Directive 85/337, the Commission notes that it requires an environmental impact assessment to be undertaken for a project covered by Article 4 'before consent is given'. The Commission submits that there is a possibility under the Irish legislation that part of the decision-making process will take place in disregard of that requirement. First, the Irish legislation does not require that an application for planning permission be lodged with the planning authorities before a licence application is submitted to the Agency, which is not empowered to undertake an environmental impact assessment. Second, the planning authorities are not obliged to take into account, in their assessment, the impact of pollution, which might not be assessed at all.

53. Referring to the Court's case-law (see, in particular, judgment of 20 November 2008 in Case C-66/06 Commission v Ireland , paragraph 59), the Commission states that it is not obliged to wait until the application of the transposing legislation produces harmful effects or to establish that it does so, where the wording of the legislation itself is insufficient or defective.

54. As regards Article 3 of Directive 85/337, the Commission submits that where there is more than one competent body, the procedures followed by each of them must, when taken together, ensure that the assessment required by Article 3 is fully carried out. The strict demarcation of the separate roles of the planning authorities on the one hand and the Agency on the other, as laid down by the Irish legislation, fails to take formally into account the concept of 'environment' in the decision-making. None of the bodies involved in the consent process is responsible for assessing and taking into consideration the interaction between the factors referred to in the first to third indents of Article 3, which fall respectively within the separate spheres of the powers of each of those authorities.

55. In that regard, the Commission, referring to section 98 of the EPAA, as amended, and to the EPAR, observes that there is no formal link, in the form of an obligation, for the competent authorities, to consult each other between the process of planning permission followed by the planning authority and the licensing process followed by the Agency.

56. In order to illustrate its analysis, the Commission refers to the projects relating to the installation of an incinerator at Duleek, in County Meath, and to the wood-processing factory at Leap, in County Offaly.

57. Referring to Case C-98/04 Commission v United Kingdom [2006] ECR I-4003, Ireland contests the admissibility of the Commission's second complaint in support of its action, on the ground that, in Ireland's submission, the Commission has failed to indicate precisely the reason why Ireland's designation of two competent authorities infringes the requirements of Directive 85/337. Ireland submits that the failure has interfered with the preparation of its defence.

58. On the substance, Ireland contends that the consequence of involving a number of different competent authorities in the decision-making process, which is permitted by Articles 1(3) and 2(2) of Directive 85/337, is that their involvement and their obligations will be different and will occur at different stages prior to 'development consent' being given. Relying on Martin v An Bord Pleanála , Ireland contends that nowhere in that directive is it in any sense suggested that a single competent body must carry out a 'global assessment' of the impact on the environment.

59. Ireland denies that there is a strict demarcation between the powers of the two decision-making bodies and submits that there is, rather, overlap between them. The concept of 'proper planning and sustainable development', to which the PDA refers, is a very broad one, which includes, in particular, environmental pollution. Planning authorities are required to assess environmental pollution in the context of a decision relating to planning permission. They are moreover empowered under various provisions to refuse planning permission on environmental grounds.

60. Replying to the Commission's argument that it is possible for a licence application to be made to the Agency before an application for planning permission has been made to the planning authority, and thus before an environmental impact assessment has been carried out, Ireland contends that under Irish law 'development consent' requires both planning permission from the competent planning authority and a licence from the Agency. In those circumstances, there is no practical benefit in the developer applying for a licence from the Agency without making a contemporaneous application to the planning authority; such separate applications do not therefore occur in practice.

61. In addition, Ireland argues that, contrary to the Commission's assertion that the Agency cannot undertake an environmental impact assessment, there is in several instances an obligation, particularly for waste recovery or waste disposal licence applications and for applications for integrated pollution control and prevention licences, to submit an environmental impact statement to the Agency independently of any earlier application for planning permission lodged with a planning

authority. In addition, in such cases the Agency is expressly empowered to request further information from an applicant and may therefore request information which is substantially similar to that contained in an environmental impact statement.

62. Ireland submits that an obligation on the planning authority and the Agency to consult in every case would be inappropriate. It would be more appropriate to allow such consultation whilst affording a discretion to the relevant decision-makers as to whether, in each particular case, to undertake such consultation.

63. Finally, the judgment in Case C-66/06 Commission v Ireland , to which the Commission refers in order to avoid having to adduce proof of its allegations, is not relevant to the present case. In Ireland's submission, the alleged infringement, in that case, concerned the manner in which Directive 85/337 had been transposed into Irish domestic law, whereas the present case concerns the application of the legislation transposing that directive. Whilst a comprehensive scheme has been put in place by the Irish legislation on the environmental impact assessment, the Commission claims that that legislation may not always be applied properly in practice. In that regard, the onus of proof lies with the Commission, which has failed to discharge it. The references to the projects at Duleek and Leap offer no support whatsoever for the Commission's allegations.

Findings of the Court

– Admissibility of the second complaint

64. It is settled case-law that, in the context of an action brought on the basis of Article 226 EC, the reasoned opinion and the action must set out the Commission's complaints coherently and precisely in order that the Member State and the Court may appreciate exactly the scope of the infringement of European Union law complained of, a condition which is necessary in order to enable the Member State to avail itself of its right to defend itself and the Court to determine whether there is a breach of obligations as alleged (see, in particular, Commission v United Kingdom , paragraph 18, and Case C-66/06 Commission v Ireland , paragraph 31).

65. In this case, it is apparent from the documents in the court file that, in the pre-litigation procedure, both paragraphs 3.2.2 to 3.2.5 of the reasoned opinion of 6 August 2001 and paragraphs 2.17 and 2.18 of the additional reasoned opinion of 29 June 2007 set forth the reason for which the strict demarcation between the separate roles assigned to the planning authorities, on the one hand, and the Agency, on the other, does not satisfy, in the Commission's submission, the requirements of Directive 85/337. It is there explained that such sharing of powers is incompatible with the fact that the concept of 'environment', as it must be taken into account in the decision-making process laid down by that directive, involves taking into consideration the interaction between the factors falling within the separate spheres of responsibility of each of those decision-making authorities.

66. That complaint is set out in identical or similar terms in paragraphs 55 et seq. of the application in this action which, in addition, contains, in its paragraphs 9 to 20, a summary of the relevant provisions of the Irish legislation.

67. It follows from those findings that the Commission's allegations in the course of the pre-litigation procedure and the proceedings before the Court were sufficiently clear to enable Ireland properly to defend itself.

68. Accordingly, Ireland's plea of inadmissibility in respect of the Commission's second complaint must be rejected.

– Substance

69. At the outset, it is to be noted that, by its second complaint, the Commission is criticising the transposition by the Irish legislation at issue of Articles 2 to 4 of Directive 85/337, on the ground that

the procedures put in place by that legislation do not ensure full compliance with those articles where several national authorities take part in the decision-making process.

70. Consequently, Ireland's line of argument that the Commission has not adequately established the factual basis for its action must immediately be rejected. As the Commission claimed, since its action for failure to fulfil obligations is concerned with the way in which Directive 85/337 has been transposed, and not with the actual result of the application of the national legislation relating to that transposition, it must be determined whether that legislation itself harbours the insufficiencies or defects in the transposition of the directive which the Commission alleges, without any need to establish the actual effects of the national legislation effecting that transposition with regard to specific projects (see Case C-66/06 Commission v Ireland , paragraph 59).

71. Article 1(2) of Directive 85/337 defines the term 'development consent' as 'the decision of the competent authority or authorities which entitles the developer to proceed with the project'. Article 1(3) states that the competent authorities are to be that or those which the Member States designate as responsible for performing the duties arising from that directive.

72. For the purposes of the freedom thus left to them to determine the competent authorities for giving development consent, for the purposes of that directive, the Member States may decide to entrust that task to several entities, as the Commission has moreover expressly accepted.

73. Article 2(2) of Directive 85/337 adds that the environmental impact statement may be integrated into the existing procedures for consent to projects or failing that, into other procedures or into procedures to be established to comply with the aims of that directive.

74. That provision means that the liberty left to the Member States extends to the determination of the rules of procedure and requirements for the grant of the development consent in question.

75. However, that freedom may be exercised only within the limits imposed by that directive and provided that the choices made by the Member States ensure full compliance with its aims.

76. Article 2(1) of Directive 85/337 thus states that the environmental impact assessment must take place 'before the giving of consent'. That entails that the examination of a project's direct and indirect effects on the factors referred to in Article 3 of that directive and on the interaction between those factors be fully carried out before consent is given.

77. In those circumstances, while nothing precludes Ireland's choice to entrust the attainment of that directive's aims to two different authorities, namely planning authorities on the one hand and the Agency on the other, that is subject to those authorities' respective powers and the rules governing their implementation ensuring that an environmental impact assessment is carried out fully and in good time, that is to say before the giving of consent, within the meaning of that directive.

78. In that regard, the Commission maintains that it has identified, in the Irish legislation, a gap arising from the combination of two factors. The first is the lack of any right on the part of the Agency, where it receives an application for a licence for a project as regards pollution aspects, to require an environmental impact assessment. The second is the possibility that the Agency might receive an application and decide on questions of pollution before an application is made to the planning authority, which alone can require the developer to make an environmental impact statement.

79. In its defence, Ireland, which does not deny that, generally, the Agency is not empowered to require a developer to produce such a statement, contends that there is no practical benefit for a developer in seeking a licence from the Agency without simultaneously making an application for planning permission to the planning authority, since he needs a consent from both those authorities. However, Ireland has neither established, nor even alleged, that it is legally impossible for a

developer to obtain a decision from the Agency where he has not applied to the planning authority for permission.

80. Admittedly, the EPAR give the Agency the right to notify a licence application to the planning authority. However, it is common ground between the parties that it is not an obligation and, moreover, an authority which has received such notification is not bound to reply to it.

81. It is therefore not inconceivable that the Agency, as the authority responsible for licensing a project as regards pollution aspects, may make its decision without an environmental impact assessment being carried out in accordance with Articles 2 to 4 of Directive 85/337.

82. Ireland contends that, in certain cases, relating particularly to licences for the recovery or disposal of waste and integrated pollution control and prevention licences, the Agency is empowered to require an environmental impact statement, which it must take into account. However, such specific rules cannot fill the gap in the Irish legislation identified in the preceding paragraph.

83. Ireland submits also that planning authorities are empowered, since the amendment of the EPAA by section 256 of the PDA, to refuse, where appropriate, planning permission on environmental grounds and that the concepts of 'proper planning' and 'sustainable development' confer on those authorities, generally, such power.

84. Such an extension of the planning authority's powers may, as Ireland argues, create in certain cases an overlap of the respective powers of the authorities responsible for environmental matters. None the less, it must be held that such an overlap cannot fill the gap pointed out in paragraph 81 of the present judgment, which leaves open the possibility that the Agency will alone decide, without an environmental impact assessment complying with Articles 2 to 4 of Directive 85/337, on a project as regards pollution aspects.

85. In those circumstances, it must be held that the Commission's second complaint in support of its action for failure to fulfil obligations is well founded.

The third complaint, alleging failure to apply Directive 85/337 to demolition works

Arguments of the parties

86. In the Commission's submission, demolition works may constitute a 'project' within the meaning of Article 1(2) of Directive 85/337, since they fall within the concept of 'other interventions in the natural surroundings and landscape'. However, in the PDR, Ireland purported to exempt nearly all demolition works from the obligation to carry out an environmental impact assessment. After the end of the two-month period laid down in the additional reasoned opinion of 29 June 2007, Ireland admittedly notified the Commission of new legislation, which amended the PDR by significantly narrowing the scope of the exemption for demolition works. However, that legislation cannot, the Commission submits, be taken into account in the present infringement action.

87. The Commission claims that Ireland's interpretation that demolition works fall outside the scope of the directive is reflected in the NMA, and refers in that regard to sections 14, 14A and 14B of that Act which relate to the demolition of a national monument.

88. By way of illustration of how, in contravention of Directive 85/337, the exclusion of demolition works allowed, by virtue of section 14A of the NMA, a national monument to be demolished without an environmental impact assessment being undertaken, the Commission cites the ministerial decision of 13 June 2007 ordering the destruction of a national monument in order to permit the M3 motorway project to proceed.

89. As a preliminary point, Ireland objects that the Commission's third complaint is, in so far as it concerns section 14 of the NMA, inadmissible, since that provision was not mentioned in the additional reasoned opinion of 29 June 2007.

90. In Ireland's submission, demolition works do not fall within the scope of Directive 85/337, since they are not mentioned in Annex I or II thereto. In addition, Ireland submits that section 10 of the PDA and Article 9 of the PDR, when read together, make clear that the exemption from the obligation to obtain planning permission in respect of demolition works can apply only if the project is unlikely to have significant effects on the environment.

91. As regards the obligation to carry out further assessments, Ireland argues that the essence of Directive 85/337 is that the environmental impact assessment be carried out at the earliest possible stage, before the development starts. The only occasion when it is ever necessary to carry out a fresh assessment is, in accordance with the first indent of point 13 in Annex II to the directive, where the development project has been changed or extended.

92. With regard to the scope of ministerial directions issued under section 14A of the NMA, Ireland states that that provision applies only in the context of a road development previously approved by the Board, on the basis of an environmental impact assessment. Only the Board may authorise an alteration to a road development and it must in such a case assess whether that alteration is likely to have adverse environmental consequences. In those circumstances, the Minister's power to issue ministerial directions cannot be equated with the giving of consent for the motorway project. Those directions are issued only, if at all, following the commencement of the development works and the discovery of a new national monument and are designed only to regulate how the newly discovered national monument is to be dealt with. Also, Ireland denies that a ministerial decision was taken ordering the destruction of a national monument in order to allow the M3 motorway project to proceed.

Findings of the Court

– Admissibility of the third complaint

93. According to the Court's settled case-law, the subject-matter of proceedings brought under Article 226 EC is delimited by the administrative pre-litigation procedure governed by that article and the application must be founded on the same grounds and pleas as those stated in the reasoned opinion (see, in particular, Case C-340/02 Commission v France [2004] ECR I-9845, paragraph 26 and the case-law cited).

94. In this case, it is clear from the wording of the additional reasoned opinion of 29 June 2007 that the Commission, in paragraphs 2.34 to 2.38 thereof, complained that Ireland had excluded demolition works from the scope of the national legislation transposing Directive 85/337. In paragraphs 2.39 and 2.40 of the same opinion, the Commission stated that Ireland's interpretation of that directive was reflected not only in the PDA, but also in other more specific legislative provisions, such as the NMA, and it took as an example the carrying-out of the M3 motorway project.

95. It follows that, while the Commission did not expressly refer to section 14 of the NMA in that reasoned opinion, it none the less referred clearly to the decision-making mechanism laid down by that section as part of its analysis of the deficiencies which, in its submission, that Act entails.

96. In those circumstances, Ireland's plea of inadmissibility against the Commission's third complaint must be rejected.

– Substance

97. As regards the question whether demolition works come within the scope of Directive 85/337, as the Commission maintains in its pleadings, or whether, as Ireland contends, they are excluded, it is

appropriate to note, at the outset, that the definition of the word 'project' in Article 1(2) of that directive cannot lead to the conclusion that demolition works could not satisfy the criteria of that definition. Such works can, indeed, be described as 'other interventions in the natural surroundings and landscape'.

98. That interpretation is supported by the fact that, if demolition works were excluded from the scope of that directive, the references to 'the cultural heritage' in Article 3 thereof, to 'landscapes of historical, cultural or archaeological significance' in point 2(h) of Annex III to that directive and to 'the architectural and archaeological heritage' in point 3 of Annex IV thereto would have no purpose.

99. It is true that, under Article 4 of Directive 85/337, for a project to require an environmental impact assessment, it must come within one of the categories in Annexes I and II to that directive. However, as Ireland contends, they make no express reference to demolition works except, irrelevantly for the purposes of the present action, the dismantling of nuclear power stations and other nuclear reactors, referred to in point 2 of Annex I.

100. However, it must be borne in mind that those annexes refer rather to sectoral categories of projects, without describing the precise nature of the works provided for. As an illustration it may be noted, as did the Commission, that 'urban development projects' referred to in point 10(b) of Annex II often involve the demolition of existing structures.

101. It follows that demolition works come within the scope of Directive 85/337 and, in that respect, may constitute a 'project' within the meaning of Article 1(2) thereof.

102. According to settled case-law, the question whether a Member State has failed to fulfil its obligations must be determined by reference to the situation in that Member State as it stood at the end of the period laid down in the reasoned opinion (see, in particular, Case C-427/07 Commission v Ireland , paragraph 64 and the case-law cited).

103. Ireland does not deny that, under the national legislation in force at the date of the additional reasoned opinion, demolition works were not subject, as a general rule, to an environmental impact assessment but, on the contrary, were entitled to an exemption in principle.

104. It is clear from the rules laid down in sections 14 to 14B of the NMA as regards the demolition of a national monument that, as the Commission claims, they take no account of the possibility that such demolition works might constitute, in themselves, a 'project' within the meaning of Articles 1 and 4 of Directive 85/337 and, in that respect, require a prior environmental impact assessment. However, since the insufficiency of that directive's transposition into the Irish legal order has been established, there is no need to consider what that legislation's actual effects are in the light of the carrying-out of specific projects, such as that of the M3 motorway.

105. As regards the legislative changes subsequent to the action for failure to fulfil obligations being brought, they cannot be taken into consideration by the Court (see, in particular, Case C-427/07 Commission v Ireland , paragraph 65 and the case-law cited).

106. In those circumstances, the Commission's third complaint in support of its action must be held to be well founded.

107. Accordingly, it must be declared that:

– by failing to transpose Article 3 of Directive 85/337;

– by failing to ensure that, where planning authorities and the Agency both have decision-making powers concerning a project, there will be complete fulfilment of the requirements of Articles 2 to 4 of that directive; and

– by excluding demolition works from the scope of its legislation transposing that directive,

Ireland has failed to fulfil its obligations under that directive.

Costs

108. Under Article 69(2) of the Rules of Procedure, the unsuccessful party is to be ordered to pay the costs if they have been applied for in the successful party's pleadings. Since the Commission has applied for costs and Ireland has been unsuccessful the latter must be ordered to pay the costs.

Operative part

On those grounds, the Court (First Chamber) hereby:

1. Declares that:

– by failing to transpose Article 3 of Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment, as amended by Council Directive 97/11/EC of 3 March 1997 and by Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003;

– by failing to ensure that, where Irish planning authorities and the Environmental Protection Agency both have decision-making powers concerning a project, there will be complete fulfilment of the requirements of Articles 2 to 4 of Directive 85/337, as amended by Directive 2003/35; and

– by excluding demolition works from the scope of its legislation transposing Directive 85/337, as amended by Directive 2003/35,

Ireland has failed to fulfil its obligations under that directive;

2. Orders Ireland to pay the costs.

From: Owen Mcmullan
Sent: 28 February 2014 13:42
To: +Comm Environment Public Email
Subject: Fwd: French wind industry in disarray following ECJ conclusion | Windpower Monthly

Good afternoon Sheila,

Please see below Addition No.5 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

The French wind industry is in disarray following ECJ conclusion.
Yours sincerely,

Owen McMullan
Chairman
West Tyrone Against Wind Turbines

Subject: Re: French wind industry in disarray following ECJ conclusion

OPINION OF ADVOCATE GENERAL
Mr Niilo Jääskinen
on 11 July 2013 (1)

Case C-262/12

Wind Association Of Anger! National Federation,
Alain Bruguier,
Jean-Pierre Gorgeu,
Marie-Christine Piot,
Eric ERREC,
Didier Wirth,
Daniel Steinbach,
Sabine Servan-Schreiber,
Philippe Rusch
Peter Recher,
Jean-Louis Moret,
Didier Jocteur Monrozier
against
Minister of Ecology, Sustainable Development, Transport and Housing,
Minister of Economy, Finance and Industry

[Request for a preliminary ruling from the Conseil d'État (France)]

"State aid - Article 107, paragraph 1, TFEU - Definition of government intervention or through State resources - Electricity from wind - Obligation to purchase at a price above the market price - full compensation - Jurisprudence 'PreussenElektra' - Contributions of final electricity consumers "

1. This question, asked by the Council of State (France) on the interpretation of one of the constitutive elements of the concept of State aid, namely the notion of state intervention or through State resources within the meaning of Article 107, paragraph 1, TFEU, and in the context of the internal electricity market. The dispute in the main origin for the application submitted to the State Council by the Association of Wind Go! - National Federation and eleven other applicants (hereinafter "Wind of Anger and Others') against two ministerial orders laying down the conditions of purchase of the electricity produced by plants using the mechanical energy of the wind (hereinafter" arrested issue ") (2).

2. The main issue before the Court concerns the method of financing the compensation for additional costs imposed on distributors of wind power in France because of the obligation to purchase the electricity at a higher price than the market. Distributors are subject to the obligation under Law No. 2000-108 of 10 February 2000 on the modernization and development of the public electricity service (3). Under this law, the additional costs resulting from the purchase obligation were being compensated by the "public service fund electricity generation, managed by the Caisse des Dépôts and Consignations (hereinafter CDC ") and by contributions payable by producers, suppliers and distributors listed in the Act.

3. However, the mechanism in question before the court, resulting in the amendment of the Act No. 2000-108 (hereinafter "Law No. 2000-108 as amended ') (4) now provides that additional costs arising from the purchase obligation above are subject to full compensation, financed by contributions payable by the final consumers of electricity installed in the country. The appellants consider that this is a State aid within the meaning of Article 107, paragraph 1, TFEU.

4. Consequently, it is in the light of the case law on both mechanisms granted indirectly through the creation of funds or agencies managing the flow may constitute aid within the meaning of Article 107, paragraph 1, TFEU (5), on the measures financed by means of quasi-taxes or compulsory contributions (6) that the Court should answer the question. It is also worth noting the line of jurisprudence inspired by the approach taken by the Court in PreussenElektra solution (7) in which, as was pointed out by Advocate General Jacobs, the amounts used to finance the system support in the area of renewable energy were at no time available to a public authority. In fact, these amounts never left the private sector (8).

I - Legal framework

5. financing system in question before the Council of State may be summarized as follows.

A - *The purchase obligation for the benefit of facilities using mechanical wind energy*

6. Pursuant to Article 10 of Law No. 2000-108 as amended, those who produce, on the national territory of electricity from, including facilities producing electricity using mechanical energy wind that are located within the perimeter of an area of wind power development (9) have, if they so request and on satisfying themselves to certain obligations (10), a requirement to purchase of electricity produced.

7. Debtors of the obligation to purchase are the distributors operating the network is connected to the system, namely Electricité de France (EDF) and non-nationalized distributors (11), who sell the electricity in their respective service areas . The implementation of these provisions leads to the conclusion of a purchase contract which is subject to conditions laid down in the law (12). The method of calculating this rate resulting from a formula set by order of the Ministers of Economy and Energy, made under Article 8 of Decree No. 2001-410 of 10 May 2001, after opinion of the Supreme Energy Council and after consulting the Commission of Energy Regulation (hereinafter the "CRE"). Article 10 of Law No. 2000-108 as amended, provides otherwise in his fifth paragraph a repurchase obligation by EDF of surplus electricity to the same conditions as for the conclusion of a binding purchase agreement, provided that the takeover by EDF also entitles you to compensation in favor of the latter.

B - *Clearing the benefit of electric operators subject to the obligation to buy*

8. As a result of the penultimate paragraph of Article 10 of Law No. 2000-108 as amended, that the additional costs arising for the electricity distributors, the implementation of the obligation to purchase can be fully compensated under Article 5, paragraph I, of Law No. 2000-108 as amended, as "the expenses for public service tasks assigned to the grid operators."

9. According to that provision, the incremental cost compensable considers "costs avoided or EDF, if any, [of] those avoided the non-nationalized distributors [...] by reference to the market price of the electricity or for non-nationalized by reference to the rates of transfer referred to in Article 4 of the Law distributors [2000-108 modified] in proportion to the share of electricity purchased at these rates in their total supply net of amounts acquired under Articles 8 and 10 [of the Act], "including" when any facility operated by [EDF] or a non-nationalized "distributor.

10. The amount of expenses incurred by the operators concerned shall be calculated on the basis of a proper accounting by the above operators, established according to rules defined by the CRE and under the control of the latter. The Minister of Energy determines the amount of charge on a proposal from the CRE conducted annually. As was stated at the hearing, only the difference between the

cost associated with the purchase obligation and contributions received from its customers is subject to a payment on account of the specific CDC .

11. The corresponding expenses are compensable to the operators concerned are paid four times a year by the CDC, which provides for this purpose a specific account, powered by the contributions due by the final consumer, where it traces the different operations.

C - *The contribution paid by the final consumers*

12. Finally, the compensation for the benefit of operators subject to the obligation to purchase is passed on to final consumers of electricity installed in the country in the manner provided in Article 5 of Law No. 2000-108 as amended .

13. The amount of this contribution, adopted annually by the Minister of Energy on a proposal from the CRE is "prorated the amount consumed" and "so that the contributions cover all costs [...] as well as the management costs incurred by the CDC [...] and the budget of the National Energy Ombudsman "within two limits (13). In principle, the amounts collected during a year must cover all expenses related to this exercise, but the adjustment mechanism allows to charge the amount of the contribution due for the following year no charge collected for the current year.

14. The amount of the contribution is paid by the consumer in the settlement of the electricity bill or using networks based on the amount of electricity it was delivered. Special provisions are made for the purchase of electricity as well as cross-border to consumers producing their own energy or that generated by a producer to whom they are directly connected.

II - The dispute in the main proceedings, the question and the procedure before the Court

15. By application dated 6 February 2009, Wind anger Others brought before the Council of State an application for judicial review to set aside the orders in question.

16. According to the court, the purchase of electricity generated by plants using mechanical energy from the wind more than its market value is an advantage likely to affect trade between Member States and impact on competition. Regarding the criterion of government intervention or through State resources, the State Council recalls that, in a decision UNIDEN dated 21 May 2003 (14), it has applied the PreussenElektra, supra, in holding that the financial burden of the obligation to purchase the facilities enjoyed using mechanical wind energy was divided between a number of companies without public funds contributed, directly or indirectly, funding assistance and considering when the mechanism prior to purchase electricity produced by plants using mechanical energy from wind does not constitute State aid within the meaning of Article 107, paragraph 1 TFEU.

17. The court, however, questioned the impact of the change in the law No. 2000-108, especially in light of the judgment Essent Netwerk Noord and Others, in which the Court held that a financing a surcharge imposed by the state to

purchasers of electricity, constitutes a tax, the remaining funds also under the control of the State, should be regarded as a state intervention through resources of State.

. 18 It is in this context that, by decision of 15 May 2012, the State Council has stayed the proceedings and referred to the Court the following question:

"Given the changing nature of the funding of full compensation for the additional costs imposed on [EDF] and non-nationalized distributors mentioned in Article 23 of Law No. 46-628 of 8 April 1946 on the nationalization of electricity and gas, because of the obligation to purchase electricity produced by plants using mechanical wind energy at a higher market price that electricity resulting from Law No. 2003-8, January 3, 2003, this mechanism should it now be regarded as an intervention by the State or through State resources within the meaning and application of the provisions of Article [107, paragraph 1, TFEU]? "

19. The present preliminary ruling was lodged at the Court on 29 May 2012. Written observations were submitted by Wind Anger Others the Renewable Energy Association (15), the French and Greek Governments and the European Commission.

20. At the hearing held on April 24, 2013 Wind Anger Others, the Renewable Energy Association, the French and Greek Governments and the Commission were heard governments.

III - Analysis

A - *On the treatment of the question*

21. At the outset, I note that some parties which submitted written observations to the Court is invited to reformulate or to complete the scope of the question posed by the State Council.

22. Indeed, Vent Anger others proposes, firstly, to include the Altmark Trans and Regierungspräsidium (16) in the analysis to determine whether a purchase obligation at a fixed price such as that at the main proceedings meets the requirements of this law. On the other hand, wind Anger Others raises an issue concerning Directive 2003/54/EC (17) and suggests that the Court should decide the question of whether the directive requires the national court to disapply national bond measure power purchase adopted in contradiction with the opinion of the national regulatory authority, namely the CRE.

23. For its part, the Commission proposes to rephrase the question, arguing that the changing nature of the funding is not decisive in terms of the response to this case. It proposes, therefore, that the Court rule on the national legislation as a whole and ab initio in that it provides full compensation for the additional costs imposed on network operators within the meaning of Article 2 of Directive 2009/72 .

24. , it should be recalled that when the Court for a preliminary ruling, its function is to provide the national court on the scope of EU rules to allow it to make

in this regard proper application of these rules to the facts before that court and not to conduct itself in such an application, and all that the Court does not necessarily have all of the essential elements in this regard (18).

25. In this case, since, on the one hand, this record does not contain sufficient information to determine whether the compensation obligation of purchase could fall because the service concept of economic general interest (SGEI) within the meaning of the Altmark Trans and Regierungspräsidium Magdeburg, and, on the other hand, neither the problem nor the SGEI of Directive 2003/54 have been debated between the parties this proceeding, the Court does not rule in this regard.

26. Moreover, I recall that, as part of the procedure for cooperation between national courts and the Court, it is for the latter to provide the national court with an answer which would enable it to decide the case before it (19). The choice of the wording of the question made by the national court must, in principle, benefit from a presumption of relevance and a "presumption of use" for the solution of the main proceedings.

27. Consequently, since the formulation of the question seems to me clear and well defined, it is not returned to the Court to extend the scope of the debate.

B - *Qualification challenged under the case law on the concept of intervention by the State or through State resources within the meaning of Article 107, paragraph 1 measure TFEU*

28. Firstly, it should be noted that the parties to this proceeding exhibit diametrically opposed views regarding the answer to the question asked. The Commission and wind Anger Others share the view that the funding mechanism because the intervention of state resources is no doubt. However, the French government and the Renewable Energy Association defending the opposite view. As the Greek government, it suggests leaving the national judge to make the final classification of the measure.

29. In this regard, it should be recalled that, according to settled case-law, the qualification of "state aid" within the meaning of Article 107, paragraph 1, TFEU requires that all the conditions laid down in that provision are met (20). Thus, for a national measure as State aid, it must be, first, an intervention by the State or through State resources, second, the intervention must be liable affect trade between Member States and third, it must confer an advantage on the recipient and, fourth, it must distort or threaten to distort competition (21).

30. The present question concerning only the first of these conditions, it should be noted that for the benefits to be classified as aid within the meaning of Article 107 paragraph 1 TFEU, they should, as a first, be granted directly or indirectly through State resources and, second, be imputable to the State (22). Case law has established the cumulative nature of these two conditions (23).

1. The accountability measure

31. Regarding accountability to the state, the concept in question includes aid both directly by the state at large (24) than by public or private bodies established or appointed for manage aid (25). It should be noted that the case law has evolved from an institutional approach to accountability (26) approaching that accountability can not be presumed and therefore inferred from the fact that the measure was adopted by a public company (27). However, it is clear that such a test state control does not apply to public authorities when they are pure disintegration of the State itself.

32. In this case, the evidence show that the attachment of the contested was the result of a due to the French state behavior. Indeed, since the contribution levied on final consumers was established by Law No. 2000-108 as amended, it is justified to consider that it is the government that is causing the impugned scheme.

2. The condition of the state origin of resources

33. Regarding the condition relating to the state origin of resources, I recall that the distinction between aid granted by the State and aid granted through State resources is intended to include in the concept of using non- only aid granted directly by the State, but also aid granted by public or private bodies designated or established by the State (28).

34. Article 107 TFEU includes all the financial means that the state can actually support businesses. The fact that these resources are constantly under public control, and therefore available to the competent national authorities, is sufficient for them to be categorized as State resources and that they are able to finance fall within the scope of application of Article 107, paragraph 1, TFEU (29).

35. Such seems to be the case here. Indeed, as reflected in the record, pursuant to Law No. 2000-108 as amended, the obligation to purchase electricity is offset by contributions payable by all electricity end-users located in France (30). The amount of the contribution is determined through a ministerial decree. The management of funds collected is entrusted to the CDC has for this purpose a specific account by contributions due by the final consumer, where it traces these operations. The sums to finance the additional costs accruing to EDF and other distributors, the obligation to purchase wind energy are paid to the operators concerned by the CDC four times a year. The contribution amount is calculated in proportion to the amount of electricity consumed, while being subject to a ceiling of EUR 500 000 per consumption site.

a) The control exercised by the State

36. In this regard, in the case of direct or indirect control as the state has the resources used (31), it should be noted, first, the role of the organs within the sphere of law public in the mechanism established by Law No. 2000-108 as amended.

37. Indeed, as is apparent from the record, the amount of the tax to which each final consumer of electricity in France is subject set annually by way of an order of the Minister of Energy on a proposal CRE, which is an independent administrative authority to ensure the proper functioning of markets for electricity and gas in

France (32). As was explained at the hearing, in the absence of ministerial decree, the amount of the contribution is increased for the following year up to 3 euros per megawatt hour. Furthermore, although, as has been pointed out at the hearing, this mechanism does not actually provide an exact equivalence between the costs borne by the distributors and the amount of the contribution donated to the latter, the Law No. 2000 -108 modified enshrines the principle of full coverage of the purchase obligation in question, which in itself prove that the State shall guarantee the system as a whole.

38. Moreover, Law No. 2000-108 as amended, provides mechanisms for administrative penalties for non-payment of contributions (33). In accordance with Article 5 of Law No. 2000-108 as amended, in case of failure of payment by a debtor, the Minister of Energy delivers an administrative penalty in accordance with Article 41 of the Act (34).

39. However, under the law, the funds which are financed through compulsory contributions imposed by the legislation of the Member State and are managed and distributed in accordance with this legislation are to be regarded as State resources within the meaning of Article 107 paragraph 1 TFEU, even if they are administered by different institutions of public authority (35).

40. This finding is not challenged by the recently reasoning adopted by the Court in the case which gave rise to the judgment Soft Livestock and Agricultural Cooperative UKL-ARREE, supra, regarding the legality of a decision a national authority extends to all professionals in the agricultural sector of production and breeding turkeys an interprofessional agreement which established a mandatory fee, in order to allow the implementation of some actions of interest this sector. Indeed, in that case, public authorities have acted only as an "instrument" to make compulsory contributions imposed by private organizations (36).

b) The status of the body involved in the transfer of funds

41. Secondly, as regards the mechanism of transfer of funds for financing the aid measure between subjects and recipients accountable subjects, it should be noted that the resources made available by the loads imposed on all consumers go through the public body specifically mandated by the State, namely the CDC.

42. In this regard, I wish to clarify that it is only if the benefit is provided by a private entity as appropriate, to assess the state of the resources implemented to examine in detail whether the state entrusted the management of the scheme to the private body. This assumes that the State should directly or indirectly resources to aid management in the provision of private body designated (37).

43. Such was the case, especially in the case of Essent Netwerk Noord and Others, in which the beneficiary of the tax and the fund manager was contested for by law (ie, MS) society.However, that company was a joint venture of four domestic generating electricity companies that operated in the domestic market before liberalization and were also responsible for the importation and transmission of electricity. Therefore, the Court analyzed the degree of autonomy that airline company, which turned out to be strictly controlled in the task of managing the funds, since it was required to be certified by an accountant counting

are collected and transferred and could not use it for assignments required by law (38).

44. However, in this case, since the organization was given the accounting and financial allocation of funds is a public institution of choice (39) and especially when the funds in question are entirely left to the discretion of national authorities (40), the analysis of details of how the CDC is, in my opinion, irrelevant to the criterion of the state origin of resources (41).

45. In this regard, I note that, with regard to the funding mechanism, the present case is distinguishable from the case explicitly Pearle and Others, which concerned a funding an advertising campaign for companies optical industry. In that case, the funds were actually collected by a professional body of public law with its affiliates, beneficiaries of the campaign by a mandatory contribution affected the organization of the campaign. According to the Court, it was not a burden on the state or funds remain under the control of the State (42). However, the Court stressed that the initiative for the organization and the pursuit of that year came from a private opticians association, said non professional public body. Therefore, unlike the mechanism involved in this case, the decisive factor in the case of Pearle and Others, was the lack of accountability to the Dutch State (43). Indeed, said public body only instrument used for the collection and allocation of resources collected for a purely commercial purpose previously determined by the relevant workplace and had nothing to do in the context of defined by the Dutch government policy (44).

46. Consequently, given the peculiarities of the above Essent Netwerk Noord and Others Pearle business, I can not share a general assertion that the public nature of an organization does not imply that the resources available must be qualified State resources (45).

47. The role assigned in this case to the CDC supports the thesis of the presence of public resources despite the fact, stated at the hearing that the CDC does not receive a portion of the funds channeled to the beneficiaries of the contribution. Indeed, in the event that, on the one hand, accountability to the state no doubt and, on the other hand, intermediary organizations involved in the management of resources to finance the measure are public bodies, the criterion of State resources is deemed completed.

c) The nature of the resources involved

48. Thirdly, with regard to the origin and extent of resources to finance a measure may constitute State aid, it should be noted that, contrary to the arguments advanced by the parties for the thesis of the lack of state resources in this case, this case is certainly not considered to be assimilated in PreussenElektra mechanism in which the Court held that the device in question involved no transfer of resources State to electricity generating companies (46).

49. In this case, the Court examined the obligation imposed on private electricity supply undertakings to purchase electricity in their area of supply higher minimum price the real economic value of this type electricity. The mechanism in question also provided that the resulting financial burden would be distributed

between said supply companies and private operators of electricity networks. In addition, companies were not mandated by the State to manage a State resource, but were required to purchase a bond through their own financial resources (47), the resources from individual payments n were not combined in a global resource, separate business assets involved and managed by a separate organization and end users did not support funding mechanism involved through a load uniformly defined and generally applicable (48).

50. The main feature that distinguishes the present case considered by the Court in PreussenElektra (cited mechanism 49), lies in the fact that the burden to fund the purchase obligation of wind electricity higher than the market price applies to all electricity consumers in France, regardless of whether or not they buy green power, knowing that in the liberalized electricity market, which completion is one of the primary objectives of the Union (50), there is competition between producers and energy suppliers.

51. While admitting that, physically, the energy from different sources in the background grid, I note that, in the framework of the mechanism at issue, the suppliers do not have the ability to differentiate prices between different categories of consumers and that consumers are deprived of the possibility to opt for or against the purchase of renewable energy. However, the rules in the liberalized internal market in electricity designed to offer consumers a real fair and competitive price range, boost clean energy production and enhance security of supply. Indeed, the purpose of the disclosure of information on energy sources for electricity production was already pointed out in Directive 2003/54 (51).

52. Thus, contrary to the funding system put in place by the Rural Code, analyzed by the Court in Sweet Livestock and Agricultural Cooperative UKL-ARREE, supra, and considered by the Advocate General Wathelet as a "system closed "in the sense that the sums involved were all the time managed and controlled by private entities (52), the system established by Law No. 2000-108 as amended could be described as "open."

53. I note that in the case Soft Livestock and Agricultural Cooperative UKL-ARREE, supra, which is clearly in line with the jurisprudence Pearle and Others, contributions came from private traders, members or non members the interbranch organization involved, but engaged in an economic activity in the markets concerned. Moreover, no transit through the state budget or other public entity was expected, which led the Court to hold that the funds retained their private nature all throughout their career (53).

54. Having regard to all the foregoing considerations, it must be concluded that the system established by Law No. 2000-108 as amended introduces a tax on the consumption of electricity, which is fed by a general contribution according to the rules uniformly by the state and hit all consumers of electricity in the country. The configuration of this contribution fully exclude its classification as a device confined to a class of business, which would be imposed, administered and controlled by private operators.

55. Finally, I recall that the objective pursued by State measures is not sufficient to make them outright from classification as aid. Indeed, Article 107,

paragraph 1, TFEU does not distinguish between the causes or the objectives of State aid, but defines them in relation to their effects (54).

56. So I can not share the position of the French government, while stressing that the obligation to purchase is budget neutral for the State that the State does not waive collect revenue (55) argued that the contribution of final consumers is merely a method of organizing the impact of additional costs incurred by the debtors of the purchase of wind power requirement. Finally, the appointment of CDC as an operating entity to centralize contributions and distribute the funds collected would, according to him, motivated by practical considerations related to the number of companies subject to the obligation to purchase. These arguments explain the motivations of the national legislature can not support the view of the lack of state resources in the funding mechanism involved. Moreover, even though the role of the CDC appears to be technical and accounting, as the distribution of income that the determination of costs in the system depend on the decisions taken by the French government in the form of decrees of the competent minister.

57. Having regard to all the foregoing, I consider that the answer to the question as a result of Law No. 2000-108 modified mechanism is the notion of state intervention or through State resources within the meaning of Article 107, paragraph 1, TFEU.

IV - On Demand limit the temporal effects

58. Assuming that the Court should consider that method of financing, such as that provided by the national legislation at issue in the main proceedings constitutes an intervention through State resources, the French government asked the Court to limit the temporal effects of its judgment. At the hearing, said government has stated that it believes the court considers that the other conditions of the concept of State aid are fulfilled, which leads to a qualification of the contested scheme as State aid which, in the absence of notification to the Commission will be considered illegal.

59. , the request for limitation of the temporal effects of the judgment of the Court seems unfounded from the outset for two reasons.

60. Firstly, such a request does not succeed under the scope of the question, the Court in this case is asked to rule on a single element of the concept of State aid.

61. It is true that the Council of State appears to have analyzed the criteria set out in Article 107, paragraph 1, TFEU. However, a possible conclusion of a national court as to the qualification of the measure as State aid is only part of the complex procedure of control of State aid.

62. Moreover, it seems from the file that the issue of service of general economic interest was not decided by the State Council.

63. In this regard, it is worth remembering that, as regards the monitoring of compliance by Member States of obligations applicable to them under Articles 107 and 108 TFEU, it is necessary to consider complementary and separate roles filled

by national and Commission (court 56). While assessing the compatibility within the exclusive competence of the Commission, acting under the supervision of the Court, to ensure the protection of the rights of individuals in the event of breach of the obligation of prior notification of aid national courts State to the Commission pursuant to Article 108, paragraph 3, TFEU. As such, a national court may be called upon to interpret the concept of aid (57).

64. Indeed, national courts must, in principle, be entitled to a refund of aid paid in breach of Article 108, paragraph 3, TFEU (58). They must therefore ensure that all the consequences of a violation of Article 108, paragraph 3, last sentence TFEU will be drawn in accordance with their national law, as regards both the validity of the acts of execution of measures aid the recovery of financial support granted in disregard of that provision (59).

65. However, it should be noted that the finding of the State Council that the resulting law No. 2000-108 modified system is the concept of State aid does not, in the case of review plan following the notification, a positive decision of the Commission.

66. It is clear however that, under penalty of violating the direct effect of Article 108, paragraph 3, last sentence TFEU, the final decision of the Commission is not the consequence of regularizing ex post the implementing acts were invalid because they had been taken in breach of the prohibition referred to in that article. Any other interpretation would encourage non-compliance by the Member State concerned, this provision and would deprive it of its effectiveness (60).

67. Finally, the Court ruled in the CELF case (61), where an application based on Article 108, paragraph 3, last sentence TFEU is examined after the Commission adopted a positive decision, the national court, notwithstanding the finding of compatibility with the common market of the aid must rule on the validity of enforcement actions and the recovery of financial support granted. However, EU law does not require in such a case the national court an obligation of full recovery of unlawful aid (62), but requires that directs the recipient of aid compatible development work illegally in the payment of interest in respect of the period of illegality (63).

68. Secondly, I recall that the interpretation the Court gives to a rule of EU law, in the exercise of its jurisdiction under Article 267 TFEU clarifies and defines the meaning of it and the scope of that rule as it must be or ought to be understood and applied from the time of its entry into force. It follows that the rule as thus interpreted may, and must be applied by the courts even to legal relationships arising and established before the judgment ruling on the request for interpretation, moreover, the conditions for bringing before the courts a dispute concerning the application of that rule are satisfied (64).

69. It is only in quite exceptional, the Court may, in application of a general principle of legal certainty inherent in the legal order of the Union, be moved to restrict the opportunity for interested parties invoke a provision it has interpreted with a view to calling in question legal relationships established in good faith. For such a limitation can be imposed, it is necessary that two essential criteria are met, namely the good faith of interest groups and the risk of serious disorders (65).

70. More specifically, the Court has used this solution in specific circumstances, such as where there was a risk of serious economic repercussions owing in particular to the large number of legal relationships entered into in good faith on the basis of rules considered to be validly in force and it appeared that individuals and national authorities had been encouraged to adopt a non-compliant behavior in EU law because of objective, significant uncertainty regarding the scope of the provisions of EU law, uncertainty that had possibly contributed the same behaviors adopted by other Member States or the Commission (66).

71. Even though I could hypothetically that the criterion relating to the large number of legal relationships within the ambit of the impugned legislation is met in this case, the provisions of Union law applicable in the field of aid State, especially with regard to the notification requirement under Article 108 paragraph 3 TFEU, can under no circumstances be regarded as tainted by any uncertainty (67).

72. Having regard to all the foregoing, I propose that the Court dismiss the application to limit the effects of its judgment in time.

V - Conclusion

. 73 In light of the foregoing considerations, I propose that the Court reply as follows to the question referred by the Council of State:

A funding mechanism of the obligation to purchase electricity produced by plants using mechanical wind energy, based on a tax on all final electricity consumers in the country, such as that resulting of Law No. 2000-108 of 10 February 2000 on the modernization and development of the public electricity service, as amended, is the notion of state intervention or through resources of State within the meaning of Article 107, paragraph 1, TFEU.

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1 - Original language: French.

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2 - Order of 17 November 2008 the Minister of Ecology, Energy, Sustainable Development and Spatial Planning, supplemented by an Order of 23 December 2008 of the Minister of Economy, Industry and Employment (Official Gazette of 13 December 2008, p. 19032).

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3 - The legal basis of the mechanism in question result in a cascade of Law No. 2000-108 of 10 February 2000 on the modernization and development of the public electricity service (Official Journal of 11 February 2000, p . 2143). Pursuant to Article 10 of the said Act, Decree No. 2001-410 (Official Journal of 12 May 2001, p. 7543) empowers particular by Article 8, the competent ministers to set purchase prices of the electricity they have therefore adopted the contested orders.

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4 - Act No. 2000-108 was notably amended by Law No. 2003-8 of 3 January 2003 (Official Gazette of 4 January 2003, p 265.) and by Law No. 2005-781 of 13 July 2005 (Official Journal of 14 July 2005, p. 11570).

[5] - See, inter alia, on 2 February 1988, van der Kooy / Commission (67/85, 68/85 and 70/85 ECR 219..) on the preferential tariff applied natural gas in the Netherlands for horticulture in heated greenhouses of 22 March 1977, Steinike & Weinlig (78/76 ECR 595..), on the implementation of a state policy to promote agriculture, forestry and the national food industry on 16 May 2002, France / Commission, said "Stardust Marine" (C-482/99, ECR I-4397..) on support of the textile and clothing; November 20, 2003, ITF (C-126/01, ECR I-13769..) on the system of financing of public service rendered by a tax on meat purchases, 17 July 2008 Essent Netwerk Noord and Others (C-206/06, Rec. p. I-5497) on the funding mechanism for stranded costs in the electricity market in the Netherlands.

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[6] - Case 2 July 1974, Italy / Commission (173/73 ECR 709...)

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[7] - Judgment of 13 March 2001 (C-379/98, ECR I-2099..) relating to the requirement for private companies to buy renewable electricity. See also judgment of 15 July 2004, Pearle (C-345/02, Rec. P. I-7139), for the financing of the campaign decided by the members of a professional body, and May 30, 2013 , Soft Livestock and Agricultural Cooperative UKL-ARREE (C-677/11, not yet published), on the decision of a national authority extends to all members of a state-recognized interbranch organization a agreement establishes a mandatory contribution to fund the promotion and defense of the interests of the sector in question.

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[8] - See paragraph 166 of the Opinion in PreussenElektra, supra.

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[9] - As defined in Article 10-1 of Law No. 2000-108 (repealed), unlimited power.

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[10] - Resulting In particular, Decree No. 410-2001, dated 10 May 2001, and orders made under section 8 of this decree, which orders that are the subject of this proceeding.

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[11] - Namely, the distribution companies mixed economy in which the state or public authorities have the majority of boards made by local communities, user cooperatives and societies of collective interest agricultural dealers electricity as defined in Article 23 of the Act of 8 April 1946 on the nationalization of electricity and gas (repealed).

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[12] - The principles governing the determination of the purchase price of electricity are set out in Article 10 of Law No. 2000-108 as amended. The duration of the purchase contract was fifteen or twenty years in 2008, provided that the eligible facilities could benefit once (see issue decrees).

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[13] - Under Article 5 of Law No. 2000-108 as amended, the amount of the contribution due by site consumption by final consumers mentioned in the first paragraph of section I of Article 22 may not exceed 500,000 euros and the applicable contribution for each kilowatt-hour shall not exceed 7% of the sales price per kilowatt-hour, non-subscription and duty corresponding to a subscription with a capacity of 6 kWh without erasing or horosaisonnalité.

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14 - Decision No. 237466, May 21, 2003, Uniden.

15 - Having been admitted to appear before the court with respect to its interest in maintaining the orders in question.

16 - Judgment of 24 July 2003 (C-280/00, ECR I-7747...)

17 - Directive of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC (OJ L 176, p 37.), repealed by Directive 2009 / 72/CE the European Parliament and of the Council of 13 July 2009 concerning common rules for the electricity market (OJ L 211, p. 55).

18 - Judgment of 21 June 2007, Omni Metal Service (C-259/05, ECR I-4945, paragraph 15...)

19 - Judgment of 8 March 2007, Campina (C-45/06, ECR I-2089, paragraph 30...)

20 - See, inter alia, judgment of 2 September 2010, Commission / Deutsche Post (C-399/08 P, ECR I-7831, paragraph 38...)

21 - See, to that effect, judgment of 17 November 2009, Presidente del Consiglio dei Ministri (C-169/08, ECR I-10821, paragraph 52 and cases cited therein.)..

22 ˉ Judgments of March 21, 1991, Italy / Commission (C-303/88, ECR I-1433, paragraph 11..) ITF (paragraph 24) and Pearle (paragraph 35 and case-law cited).

23 ˉ Stop Stardust Marine (paragraph 24).

24 - Judgment of 14 October 1987, Germany / Commission (248/84, ECR 4013, paragraphs 17 and 18...)

25 - Stop Steinike & Weinlig (paragraph 21).

26 - Judgment of 21 March 1991, Italy / Commission (C-303/88, ECR 1991 ECR I-1433, paragraph 12.)., and March 21, 1991, Italy / Commission (C-305/89, ECR. . I-1603, paragraph 14). See Dony, M.,*Control of State aid* Publishing University of Brussels in 2006, 3^{e} ed., p. 26 et seq.

27 - Stop Stardust Marine (paragraph 52): the mere fact that a public undertaking is under State control is not sufficient to impute actions thereof, such as financial

support measures in question, the State. It is still necessary to consider whether the public authorities must be regarded as having been involved, in one way or another, in the adoption of these measures.

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[28] - Judgment of 30 January 1985, Commission / France (290/83 ECR 439..), and March 17, 1993, Sloman Neptun (C-72/91 and C-73/91, ECR I-.. 887, paragraph 19).

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[29] - Judgment of 29 April 2004 Greece / Commission (C-278/00, ECR I-3997, paragraph 52...)

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[30] - During the period between 2000 and 2003, contributions were made by operators who delivered electricity to live in France, by auto-producers and end customers as guests end that mattered or who performed intra-Community acquisitions of electricity.

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[31] - See Stardust Marine (paragraph 37).

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[32] - The CRE is the national regulator within the meaning of Article 23 of Directive 2003/54, which requires Member States must appoint one or more competent bodies with the function of regulatory authorities. These authorities shall be wholly independent of the electricity sector. However, since the law provides a cap on increases in the absence of a ministerial order, the role of the CRE seems affected.

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[33] - See, in contrast, Soft stop farming and agricultural cooperative UKL-ARREE (paragraph 32).

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[34] - Certainly, under Article 4 of Ordinance No. 2011-504, 9 May 2011, Article 41 of Law No. 2000-108 as amended was repealed. However, under Article 6 of the Ordinance, the repeal has not yet taken effect.

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[35] - Off Italy / Commission 173/73 (paragraph 35).

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[36] - See point 90 of the Opinion of Advocate General in the case Wathelet Sweet Livestock and Agricultural cooperative UKL-ARREE, supra.

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[37] - See, to that effect, the judgments Italy / Commission 173/73 (paragraphs 33 to 35) and Steinike & Weinlig (paragraph 22).

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[38] - Stop Essent Netwerk Noord and Others (paragraphs 68-70).

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[39] - For a detailed description of the CDC, see the judgment of 12 December 1996, Air France / Commission (T-358/94, ECR II-2109...)

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40 - See, in contrast, Pearle and Others (paragraph 36).

41 - In contrast, I remember, in particular, in the case of van der Kooy, supra, the parties argued before the Court that the company had imposed the price may constitute State aid was a company private law in which the Dutch State had only 50% of capital and, secondly, that the rate was the result of a private law agreement concluded between operators and which the Dutch State was abroad. The Court has therefore been forced to analyze said elements have also led to conclude that the State was fully involved in the imposition of the tariff at issue.

42 - Stop Essent Netwerk Noord and Others (paragraph 72).

43 - See also paragraph 110 of the Opinion in Essent Netwerk Noord and Others.

44 - See point 76 of the Opinion of Advocate General in the case of Pearle and Others.

45 - Paragraph 104 of the Opinion of Advocate General Mengozzi in the case of Essent Netwerk Noord and Others.

46 - Cited above (paragraph 59).

47 - See Essent Netwerk Noord and Others (paragraph 74).

48 - See, in contrast, Pearle and Others (paragraph 36).

49 - In addition, another aspect that illustrates the difference between the two mechanisms lies in the establishment of a body such as the CDC, which is responsible for administering and managing the funds from the tax.

50 - The internal energy market has been gradually introduced initially by Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal electricity market (OJ 1997 L 27, p. 20), which was replaced by Directive 2003/54. Given the objective of further liberalization of the internal electricity market, the / 72 Directive 2009 repealing Directive 2003/54 was adopted. Its transposition deadline expired in March 2011.

51 - While acknowledging that the / 72 Directive 2009 is not applicable to this case temporal, I note that, under Article 3, paragraph 9 thereof, Member States shall ensure that the electricity suppliers specify in or with the bills sent to final customers the contribution of each energy source to all the sources used by the supplier.

52 - See point 66 of the Opinion in Sweet Livestock and Agricultural cooperative ARREE UKL-cited case.

53 - See Case Soft Livestock and Agricultural Cooperative UKL-ARREE (paragraph 32).

54 - Judgment of 22 December 2008, British Aggregates / Commission (C-487/06 P, ECR I-10515, paragraphs 84 and 85 and case-law cited...)

55 - See, in that regard, paragraph 162 of the Opinion of Advocate General Jacobs in PreussenElektra, supra.

56 - As they were recalled by the Court in its judgment of 11 July 1996, SFEI (C-39/94, ECR I-3547, paragraph 41 et seq....)

57 - See, to that effect, SFEI (paragraphs 49-51).

58 - See, in particular, SFEI (paragraph 70).

59 - Judgments SFEI (paragraph 40) and of 21 October 2003, van Calster (C-261/01 and C-262/01, ECR I-12249, paragraph 64..), and 5 October 2006 Transalpine Ölleitung in Österreich (C-368/04, p. I-9957, paragraph 47 Rec.).

60 - Stop van Calster (paragraph 63).

61 - Judgment of 12 February 2008, CELF and the Minister of Culture and Communication (C-199/06, ECR I-469...)

62 - Stop CELF and the Minister of Culture and Communication (paragraph 46).

63 - See, to that effect, the judgments SFEI (paragraph 75), and Transalpine Ölleitung in Österreich (paragraph 56). However, the Court stated that, under its national law, the national court may, if appropriate, also order the recovery of unlawful aid, without prejudice to the right of the Member State to put it to execution again later. It may also be required to uphold claims for compensation for damage caused by reason of the unlawful nature of the aid.

64 - See, inter alia, of 3 October 2002, Barreira Pérez (.. C-347/00, ECR I-8191, paragraph 44) of 17 February 2005 Linneweber and Akritidis (C-453/02 and C-462/02, Rec. p. I-1131, paragraph 41), and on 6 March 2007, Meilicke (C-292/04, p. I-1835, paragraph 34) Rec..

65 - See, inter alia, 10 January 2006, Skov and Bilka (C-402/03, ECR I-199, paragraph 51..) and June 3, 2010, Kalinchev (C-2/09, ECR . p. I-4939, paragraph 50).

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66 - See, inter alia, of 27 April 2006, Richards (C-423/04, ECR I-3585, paragraph 42.).; Kalinchev (paragraph 51), and May 10, 2012, Santander Asset Management SGIIC (C-338/11 to C-347/11, not yet published in the ECR, paragraphs 59 and 60).

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67 - I note, in this regard, a well-established administrative practice related in the comments of the Commission, which was discussed in the last decade a large number of comparable support systems in other Member States. See, among others, as an example of a final decision has

On Sat, Jul 13, 2013 at 3:16 AM, Owen Mcmullan <omcmullan@me.com> wrote:

http://www.windpowermonthly.com/article/1190402/french-wind-industry-disarray-following-ecj-conclusion

Sent from my iPad

--
Peter Sweetman

>> Good afternoon Sheila
>>
>> Please see Addition No.6 to our Submission by West Tyrone Against Wind Turbines on Wind Energy. This story on the link below from the Guardian confirms my earlier comments about the increase in fossil fuels.
>>
>> As the wind does not blow all the time these industrial wind turbines require back up from power stations to keep the blades on the wind turbines turning in order to prevent the blades of the wind turbines from warping, thus defeating the purpose of which they were intended and therefore INCREASING our dependancy on fossil fuels by more than 30%.
>>
>> European countries like Germany for example and building more power stations at present to help meet with their increasing demand as their huge investment in wind power is proving to be a massive failure and even the UK government is getting the French to build two nuclear power plants to provide a constant and reliable source of power at a fraction of the cost of their investment in their failing wind energy programme.
>>
>> This use of electricity to the wind turbines is unmetered with the cost passed on to the consumer in hidden charges on their electric bill. A major selling point by the wind industry was that these wind turbines and wind farms would reduce our dependancy on fossil fuels and therefore reduce our electricity bills. Where is the evidence of this? No home or business in Northern Ireland is getting cheaper electricity as a result of wind energy but thousands of homes are being driven into fuel poverty while jobs in the manufacturing sector in oarticular are being jeopardised as they are struggling to compete with their competitors overseas in the export market.
>>
>> The wind industry also claim that the use of wind energy reduces carbon emissions.
>>
>> This is another false claim.
>>
>> Something the wind industry is very good at is making false claims, increasing energy costs and delivering empty promises.
>>
>> Withdraw their substantial subsidies and then we can see how good and efficient the wind industry is.
>>
>> Yours sincerely,
>>
>> Owen McMullan

SERI/TP-217-3261
UC Category: 60
DE88001113

A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions

N.D. Kelley

November 1987

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A PROPOSED METRIC FOR ASSESSING THE POTENTIAL OF COMMUNITY ANNOYANCE FROM WIND TURBINE LOW-FREQUENCY NOISE EMISSIONS

N.D. Kelley
Solar Energy Research Institute
Golden, Colorado 80401

ABSTRACT

Given our initial experience with the low-frequency, impulsive noise emissions from the MOD-1 wind turbine and their impact on the surrounding community, the ability to assess the potential of interior low-frequency annoyance in homes located near wind turbine installations may be important. Since there are currently no universally accepted metrics or descriptors for low-frequency community annoyance, we performed a limited program using volunteers to see if we could identify a method suitable for wind turbine noise applications. We electronically simulated three interior environments resulting from low-frequency acoustical loads radiated from both individual turbines and groups of upwind and downwind turbines. The written comments of the volunteers exposed to these interior stimuli were correlated with a number of descriptors which have been proposed for predicting low-frequency annoyance. The results are presented in this paper. We discuss our modifications of the highest correlated predictor to include the internal dynamic pressure effects associated with the response of residential structures to low-frequency acoustic loads. Finally, we outline a proposed procedure for establishing both a low-frequency "figure of merit" for a particular wind turbine design and, using actual measurements, estimate the potential for annoyance to nearby communities.

INTRODUCTION

Experience with wind turbines has shown that it is possible, under the right circumstances, for low-frequency (LF) acoustic noise radiated from the turbine rotor to interact with residential structures of nearby communities and annoy the occupants. Currently there are no universally accepted metrics or descriptors for community annoyance from low levels of LF noise. It is important from both a design and an operational perspective that the potential for such annoyance from wind turbines be quantified as much as possible. This is not a straightforward task, given the highly subjective nature of human response to noise in this frequency range. Given the lack of guidance in this area, we performed a limited experiment in which several volunteers were asked to describe their impressions of three electronically simulated, interior, LF noise environments related to the operation of wind turbines. We correlated the volunteers' responses with a series of currently available LF noise descriptors and identified two that we believe to be the most efficient. The spectral definitions of these descriptors were then modified to include the influence of an intervening residential structure and the levels adjusted for a reference propagation distance.

BACKGROUND

The modern wind turbine radiates its *peak* sound power (energy) in the very low frequency (VLF) range, typically between 1 and 10 Hz. This is a direct consequence of its small rotor solidity and relatively low rotational (shaft) speed (17.5-300 rpm). Other common rotating machinery employing lifting blades (such as the large fans and blowers associated with forced-draft cooling towers and ventilation systems) generally radiate their peak sound powers at frequencies greater than 60 Hz. This higher frequency is due to a combination of high rotor solidity and much faster shaft speeds.

Our experience with the low-frequency noise emissions from a single, 2-MW MOD-1 wind turbine demonstrated that, under the right circumstances, it was possible to cause annoyance within homes in the surrounding community with relatively low levels of LF-range acoustic noise. An extensive investigation of the MOD-1 situation [1,2] revealed that this annoyance was the result of a coupling of the turbine's impulsive LF acoustic energy into the structures of some of the surrounding homes. This often created an annoyance environment that was frequently confined to ***within the home itself***.

LOADING OF RESIDENTIAL STRUCTURES BY LOW-FREQUENCY ACOUSTIC EMISSIONS

Impulsive Loading

A significant amount of scientific investigation has gone into documenting the response of residential structures (and resulting community annoyance) to high-energy noise events such as aircraft flyovers and short-duration, impulsive events such as sonic booms and quarrying and mining explosions [3,4]. We found that the periodic loading by the MOD-1 impulses excited a range of structural resonances within the homes measured. Figure 1 schematically illustrates the radiated acoustic frequency spectrum associated with the various types of wind turbine emission characteristics. If there was no small-scale turbulence in the turbine inflow, the acoustic spectrum would resemble the monotonic falloff in the blade passage harmonics indicated by the "steady and long-period loading curve." The curve then rises again as the processes

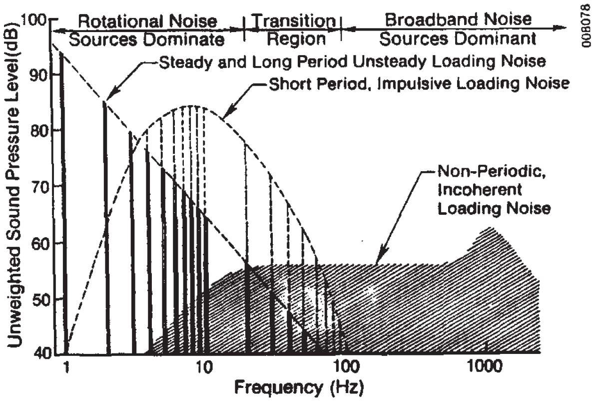


Figure 1. SCHEMATIC REPRESENTATION OF AN AVERAGED RADIATED SOUND PRESSURE SPECTRUM FROM A WIND TURBINE

responsible for the nonperiodic, incoherent, or broadband (high-frequency) radiation become dominant above 100 Hz. However, there are always some short-period aerodynamic load fluctuations as a result of the rotor encountering atmospheric turbulence, indicated by the dashed region of Figure 1. This region can expand to higher frequencies and contain considerable energy if impulses are present. A blade passing through the downstream wake of the support tower or intersecting its own wake can result in repetitive, transient aerodynamic loads that can produce LF impulsive radiation that is *periodic at the blade passage frequency* (BPF).

The acoustic-mechanical response of a residential structure to acoustic loads is schematically diagramed in Figure 2. The ranges of the various structural and acoustic resonances and the typical wind turbine acoustic spectrum have been superimposed. The dashed region, corresponding to the short-period and impulsive radiation range, overlaps with the structural resonances almost perfectly. Figure 2, therefore, illustrates the coupling mechanisms between the structure and the LF noise excitation. The temporal dynamics of this coupling are shown in Figure 3. The upper curve traces the outdoor acoustic pressure field and the lower one the internal one, as we see in the 31.5-Hz octave frequency band. The pair of turbine-generated impulses, about 8 ms in duration each, produce a strongly resonant pressure field in the house oscillating at the room fundamental of 14 Hz, lasting about 1.8 s. Thus, the action of the house has been to stretch the initial impulse duration over 100 times. The auditory time constant has been estimated to be on the order of 70-100 ms, thus, at least in theory, raising the possibility of audible detection inside the home but not necessarily outside. Hubbard and Shepherd [5] have isolated the Helmholtz response and measured enhancements up to 5 dB. They also found significant sound pressure level variations up to 20 dB when acoustic interactions were present. We have determined a typical indoor/outdoor LF acoustic transfer function using measurements from two homes near the MOD-1 turbine. The impulsive-source curve of Figure 4 illustrates this empirically derived function.

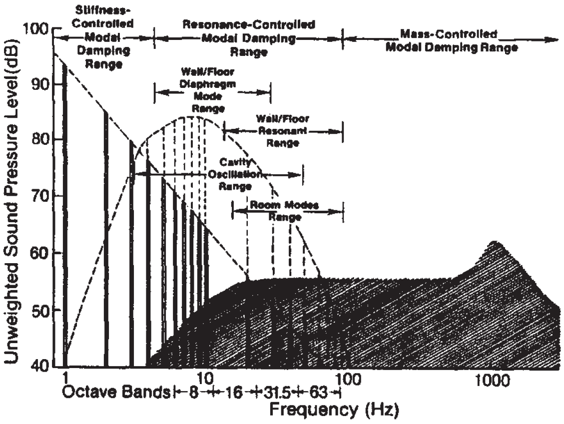


Figure 2. SCHEMATIC SOUND SPECTRUM OF FIGURE 1, WITH RESIDENTIAL VIBRATION AND ACOUSTIC MODES ADDED

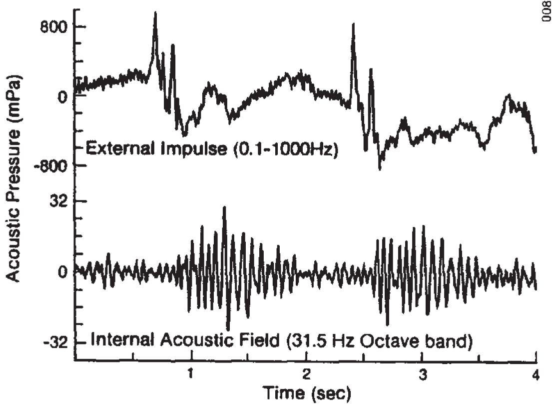


Figure 3. TRANSIENT RESPONSE OF AN INTERNAL PRESSURE FIELD TO EXTERNAL IMPULSIVE EXCITATION

Nonimpulsive Acoustic Loads

Even when an impulsive-type emission characteristic is not present (the MOD-1 did not always generate impulses), a varying level of LF acoustic energy is emitted (see the dashed region of Figure 1) as a result of the turbulent inflow. Because of the low damping present in residential structural modes in the 5-100 Hz range of Figure 1, we needed to find a well-documented source of nonimpulsive, LF acoustic excitation and indoor response for comparison. We were fortunate to obtain a series of measurements made simultaneously inside and outside five homes within a few kilometers of a gas turbine peaking generator [6]. The homes were acoustically excited by broadband LF emissions from a resonating exhaust stack. The nonimpulsive curve of Figure 4 traces the mean of the measured indoor/outdoor response for several rooms of the homes. The two curves of Figure 4 indicate that internal overpressures up to 10 dB can be expected in the 3-10 Hz

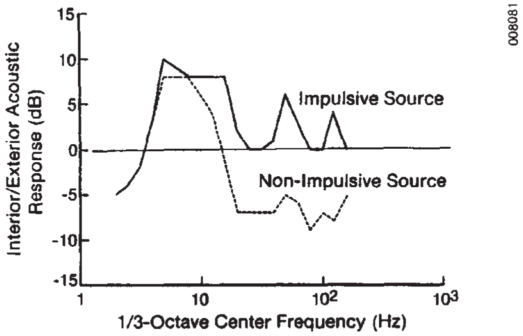


Figure 4. A TYPICAL INDOOR/OUTDOOR ACOUSTIC TRANSFER FUNCTION MAGNITUDE FOR IMPULSIVE AND NONIMPULSIVE LF ACOUSTIC LOADS

range for both impulsive and nonimpulsive acoustic loads. Above 10 Hz, significant overpressures occur in the 40-63 Hz and 80-125 Hz 1/3-octave bands under impulsive loads. Typically, 5-7 dB of attenuation occurs in the 10-160 Hz band range for a nonimpulsive source excitation.

EXPERIMENTAL PROCEDURE

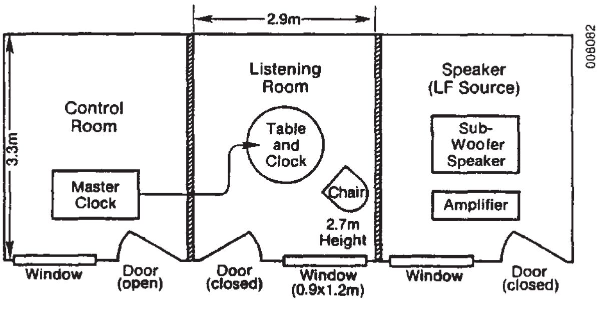
Our objective in the limited experiment reported on here was to simulate a series of LF noise environments that would be likely to exist within a small room of a home (a small bedroom, for example) as a result of the LF acoustic loading caused by wind turbine emissions. Our experience has shown that interior LF annoyance is more likely to occur and be more severe in rooms with small dimensions and at least one outside wall facing the wind turbine. This was also true of the annoyance related to the gas turbine peaking generator; i.e., the most serious annoyance occurred near the sides of the houses facing the LF source. We synthesized three interior LF noise environments that would be expected as a result of the acoustic loading of a residential structure from the following kinds of emissions:

- A single, large, multimegawatt turbine or an array of smaller turbines that *are not* producing periodic impulses *(a periodic random source)*;
- A nearby single turbine operating at a shaft speed of 30 rpm and producing impulses at the blade passage frequency *(a periodic impulsive source)*;
- An upwind *array* of turbines that are individually producing unsynchronized impulses at their blade passage frequencies *(a random impulsive source)*.

In addition to these three basic environments or *stimuli classes*, the periodic random source was repeated but with a "pink" noise masking level of 40 dBA.

Physical Setup

The physical layout of the testing environment is diagramed in Figure 5. A very low frequency or subwoofer speaker system and its high-powered amplifier were placed in a room adjoining the listening area. The subwoofer had a minimum frequency cutoff of about 5 Hz. This arrangement allowed only the dominant LF noise to be transmitted to the listening-room environment via the walls. It also filtered out the higher frequency sounds associated with the nonlinear response of the speaker cone (a "whooshing" sound), which was particularly evident during large excursions. The electronic equipment responsible for developing the subwoofer's "drive" signals was located in the control room. A master time code generator was also located here, and a repeater or slave unit was placed on the table in the listening room for the evaluator to time-index his or her comments. Table 1 lists the physical and acoustic properties of the listening room. The concrete slab floor minimized tactile (feeling) transmission of LF vibration to the evaluator. Since we were trying to simulate the quiet environment typical of a family home, we did not ask the staff on the other side of the partition to refrain from talking during the evaluation process. As a result, the evaluators occasionally noted hearing conversations from the offices adjacent to the rear wall of the listening room. The background noise was dominated by the sound of air moving through the ventilation system which produced an average background noise level of 35 dBA, typical of a quiet home.



Concrete Slab Floors Covered with 1.6cm Resilient Carpeting

Figure 5. PLAN VIEW SCHEMATIC OF PHYSICAL ARRANGEMENT OF TESTING FACILITIES

Table 1. PHYSICAL AND ACOUSTIC PROPERTIES OF LISTENING-ROOM ENVIRONMENT

Dimensions	2.9 x 3.3 x 2.7 m (25.8 m^3 or 254 ft^3)
Walls	Movable partitions, composition material, nominally supported
Floor	Concrete slab covered with 1.6 cm of resilient carpet
Background Noise Level	35 dBA dominated by ventilation system noise; no attempt to reduce or mask voices generated on other side of rear wall

Evaluation Procedure

A series of sequences was developed for each type of LF noise environment in which the levels and intensities were systematically varied. We found that the corresponding, unweighted acoustic 1/3-octave band pressure levels over the range of 2-160 Hz could be repeated to better than 0.3 dB for each test level. The three simulated characteristic wind-turbine-emission environments are *schematically* diagramed in Figure 6. The averaged 1/3-octave band pressure level spectra for each of the source characteristics, and the incremental level changes are shown in Figures 7, 8, and 9. The room background spectra are indicated with dashed lines.

Seven volunteer evaluators took part in the experiment. The group consisted of three women and four men who ranged in age from the early twenties to the early sixties. All claimed to have an adequate hearing acuity. In this choice of a very limited number of participants, we attempted to obtain what we believed to be a small, random sample of the general population.

During the evaluation, the evaluator sat at the table indicated in Figure 5 on which a record log was furnished. The evaluators were asked to write down their impressions of what they were currently experiencing along with the time indicated on the clock. The evaluation sequence began with the periodic random simulation, stepped up through the six intermediate levels, and then back down again to the background level. No indication was given to the evaluators of the stimuli classes or their incremental steps. The initiation and completion times of each incremental step in a simulation were logged for later comparison with the evaluator's opinions. The dwell or integration time at each incremental stimuli step was held at 2 minutes plus or minus a 20% *random* variation to prevent the evaluator from anticipating changes in the testing sequence. The five levels of the periodic impulsive simulation were then sequenced, and this was followed by the five levels of the random impulsive stimuli. Finally, 2 minutes after the conclusion of the random impulsive simulation, the 40 dBA pink noise masking was activated from two speakers in the room's ceiling and the random periodic stimuli sequence was repeated. The entire four-pass process required about 45 minutes to complete.

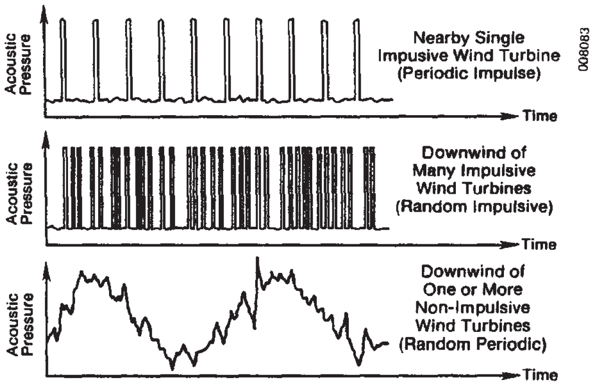


Figure 6. SIMULATED ACOUSTIC EMISSION CHARACTERISTICS OF WIND TURBINES

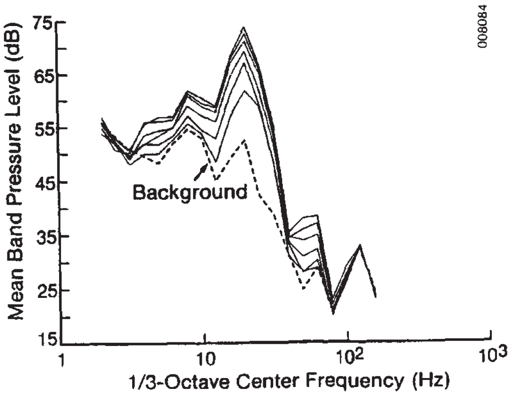


Figure 7. PERIODIC RANDOM STIMULI SPECTRA

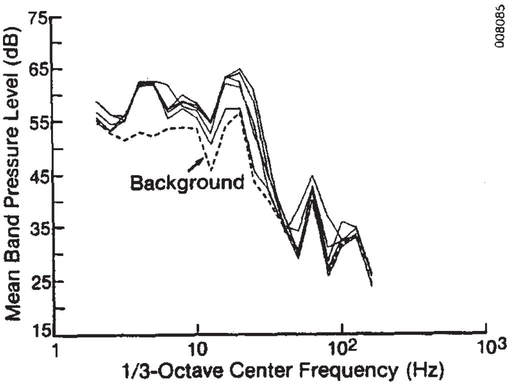


Figure 8. PERIODIC IMPULSE STIMULI SPECTRA

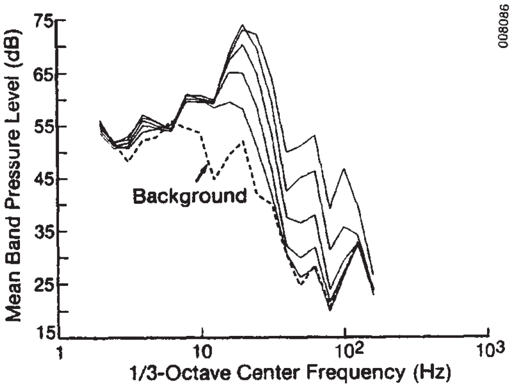


Figure 9. RANDOM IMPULSIVE STIMULI SPECTRA

Data Reduction

The evaluators' responses were quantified by means of a six-level ranking in terms of the following four annoyance categories:

(1) Loudness or noise level

4

(2) Overall degree of annoyance and displeasure

(3) Any sensations of vibration or pressure

(4) The sensing of any pulsations.

Table 2 lists the subjective ranking criteria. The ranked responses were then correlated by linear regression with a series of low-frequency noise descriptors or metrics. These particular metrics or spectral weighting factors have been suggested as measures of LF annoyance by a number of investigators, and they include the following:

- The ISO (International Organization for Standardization) proposed G$_1$ weighting [7]
- The ISO proposed G$_2$ weighting [7]
- The LSPL or low-frequency sound pressure level weighting [8]
- The LSL or low-frequency sound level weighting [8]
- The ISO/ANSI (American National Standards Institute) C-weighting [9]
- The ISO/ANSI A weighting [9].

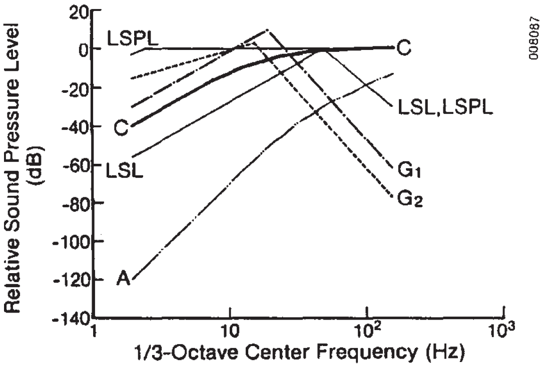


Figure 10. LOW-FREQUENCY NOISE METRICS SPECTRAL WEIGHTINGS

Figure 10 plots these weighting windows over a frequency range of 2-100 Hz. The ISO G$_1$ and G$_2$ curves have been proposed for assessing subjective human responses to acoustic noise in the infrasonic range (less than 20 Hz). The ISO/ANSI A- and (usually) C-weighting curves are standard on sound level measuring equipment. As Figure 10 shows, the C-weighting passes much lower frequencies than does the most common noise description, the A-weighting scale. The LSL and LSPL metrics have been proposed by Tokita et al. [8] for assessing residential interior environments. The LSL metric "reflects three low-frequency noise influences: structural, physiological, and psychological complaint stimuli" [8]. The LSL metric has been proposed as an appropriate descriptor for evaluating residential interior environments that contain both infra- and low-frequency audible acoustic components.

RESULTS

The ranked responses to the four annoyance categories were correlated with the four stimuli sequences by regression and are summarized in Table 3. Immediately

Table 2. SUBJECTIVE RANKING CRITERIA FOR LOW-FREQUENCY (LF) NOISE ENVIRONMENTS

			Stimuli Response Rating			
Rank	**0**	**1**	**2**	**3**	**4**	**5**
			Perception			
Noise level (loudness)	Can't hear	Barely can here	Weak, but definitely audible	Moderate loudness	High noise level, loud	Very high noise level, very loud
Annoyance/ displeasure	None	Barely aware of presence	Definitely aware of presence	Moderate distraction/ some irritation	Very annoying, irritating	Extremely annoying, uncomfortable
Vibration/ pressure	None	Feel presence	Definitely feel vibration/ pressure	Moderate vibration/ pressure feeling	Very noticeable	Severe vibration
Pulsations	None	Barely feel pulses	Definite pulses or bumping	Moderate booming or thumping	Heavy booming or thumps	Very heavy pulses, booms, thumps
	Acceptable		???????		Clearly unacceptable	

Table 3. CORRELATION COEFFICIENTS OF EVALUATOR ANNOYANCE RATINGS OF LF NOISE STIMULI VERSUS SIX NOISE METRICS

Metric	Noise Level	Annoyance/ Displeasure	Vibration/ Pressure	Pulsations	Mean
G_1	0.898 *(0.033)*	0.933 *(0.018)*	0.709 *(0.170)*	0.819 *(0.115)*	0.840 *(0.084)*
G_2	0.873 *(0.071)*	0.879 *(0.053)*	0.701 *(0.157)*	0.769 *(0.148)*	0.806 *(0.107)*
LSPL	0.898 *(0.035)*	0.924 *(0.034)*	0.711 *(0.155)*	0.831 *(0.107)*	0.841 *(0.083)*
LSL	0.935 *(0.021)*	0.958 *(0.014)*	0.732 *(0.174)*	0.860 *(0.097)*	0.871 *(0.077)*
C	0.940 *(0.030)*	0.947 *(0.008)*	0.725 *(0.167)*	0.841 *(0.098)*	0.863 *(0.076)*
A	0.384 *(0.464)*	0.269 *(0.413)*	0.413 *(0.137)*	-0.077 *(0.719)*	0.247 *(0.433)*

obvious is the superiority of the five metrics that pass significant low frequencies in comparison with the A-weighted scale. These results, limited as they are, seem to confirm that (1) people do indeed react to a low-frequency noise environment and (2) A-weighted measurements are not an adequate indicator of annoyance when ***low frequencies are dominant.*** Table 4 ranks the efficiency of each metric for the stimuli population in terms of the correlation coefficient and stimuli-to-stimuli class standard deviation. These rankings, with the exception of the last two, contain two of the six metrics. We simply do not have a sufficient number of statistical degrees of freedom to differentiate further. Actually, the only statistically significant difference is between the five LF metrics and the A-weighted scale. This experiment would have to be repeated with a much larger number of evaluators (population) to confirm Tables 3 and 4 in terms of their individual matrix elements.

ESTABLISHING AN INTERIOR ANNOYANCE SCALE

The rankings of the evaluators' comments were summarized for each of the four stimuli, and three annoyance-level classes were determined for each. The perception-threshold level is defined as the corresponding LSL- and C-weighted band levels for an evaluation ranking of 1. The annoyance-threshold level classification was arbitrarily assigned a ranking of 2.5, and the unacceptable-annoyance level classification was given a value of 4 or greater. The LSL- and C-weighted metrics corresponding to the annoyance classification rankings are listed in Table 5 for the four stimuli evaluated. As the table shows, three of the four stimuli have similar threshold-perception LSL- and C-weighted values. It is interesting to note that, even though many individual impulsive sources are present, the net effect of a ***random summing*** of these contributions invokes a response similar to that from a periodic random source. It is also evident that the threshold is considerably lower for a single or a few distinct impulsive sources. This is reflected by the general source characteristics listed at the bottom of Table 5. For all practical purposes, the annoyance level criteria for the C-weighted scale are 10 dB higher than those for the LSL-weighted band pressure level (BPL).

PREDICTING AN INTERIOR LSL OR C LEVEL

To assess the potential of interior LF noise annoyance in nearby communities, we must estimate the LSL or C metric levels from available acoustic measurements of the turbine design. Generally, this will be an averaged, unweighted (linear) 1/3-octave band spectrum over a 5-100 Hz range and, when adjusted for propagation losses, it can be considered representative of the external acoustic load present at the home being evaluated. We noted earlier that the structural dynamic response of houses alters both the temporal and spectral characteristics of the external acoustic excitation and that the alteration characteristics depend on whether the source is impulsive or not. To predict an interior LSL- or C-level (PLSL or PC), we must ***spectrally*** apply the appropriate

Table 4. APPROXIMATE EFFICIENCY RANKING OF THE SIX METRICS AS DESCRIPTORS OF INTERIOR, LF NOISE ANNOYANCE

Rank	Metric	$r^{(a)}$	Stimuli Class Variance Coefficient
1	LSL	0.871	8.8%
1	C	0.863	8.8%
2	LSPL	0.841	9.8%
2	G_1	0.840	10.0%
3	G_2	0.806	13.3%
4	A	0.247	175%

[a] Correlation coefficient.

indoor/outdoor acoustic transfer function magnitudes plotted in Figure 4 to the measured 1/3-octave band spectrum. Using these functions, we have replotted the original frequency weighting characteristics of the LSL and C metrics in Figure 11 for both impulsive and non-impulsive sources. Table 6 lists the corresponding weighting factors for the transfer function magnitudes of Figure 4.

A limited verification of this procedure is shown in Figure 12. The predicted or PLSL values are plotted against the measured value for a bedroom excited by the MOD-1 impulses. The remaining rooms were in various homes excited by the gas turbine for which annoyance was reported. Figure 13 plots the observed interior LSL values in relation to the LSL annoyance criteria thresholds. While complaints were received from the residents of all four homes in which these rooms were located, we do not have sufficient information to completely verify the vertical stratification other than that it was above the perception level.

ESTABLISHING A REFERENCE EXTERNAL ACOUSTIC LOADING

The method of estimating a representative internal PLSL or PC value requires a suitable measure of the external acoustic loading spectrum. Since most homes are located

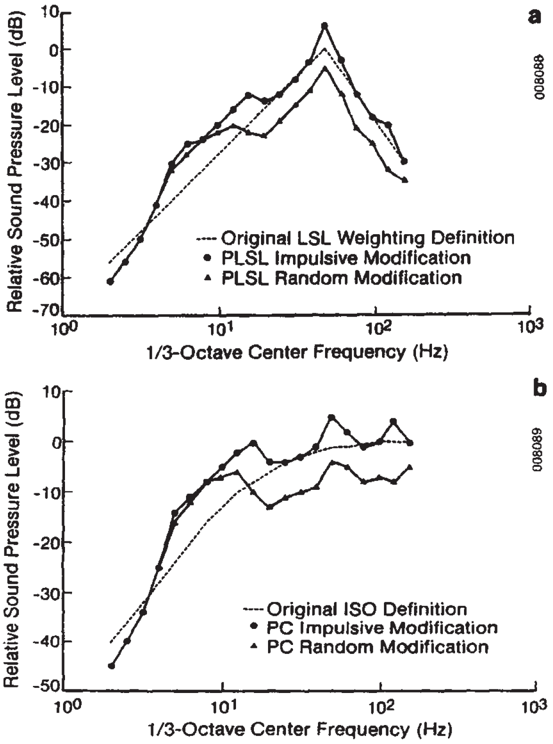


Figure 11. (a) PLSL SPECTRAL WEIGHTING; (b) ISO AND MODIFIED C SPECTRAL WEIGHTING

Table 5. INTERIOR LF ANNOYANCE-LEVEL CRITERIA EMPLOYING THE LSL AND C METRICS

Stimuli Class	Threshold Perception LSL (dB)	Threshold Perception C (dB)	Annoyance Threshold LSL (dB)	Annoyance Threshold C (dB)	Unacceptable Annoyance LSL (dB)	Unacceptable Annoyance C (dB)
Nonimpulsive, periodic random	58	68	65	75	68	77
Periodic impulsive source	53	63	57	67	60	68
Random periodic source	59	67	68	76	70	78
Periodic random w/40 dBA mask	59	68	65	75	67	79
Considering Only General Source Characteristics						
Nonimpulsive source	58	68	65	75	68	78
Impulsive source	53	63	57	67	60	68

Table 6. INDOOR/OUTDOOR TRANSFER FUNCTION WEIGHTING FACTORS

1/3-Octave Band Center Frequency (Hz)	Impulsive Transfer Function Magnitude LSL (dB)	Impulsive Transfer Function Magnitude C (dB)	Nonimpulsive Transfer Function Magnitude LSL (dB)	Nonimpulsive Transfer Function Magnitude C (dB)
2.0	-61	-45	-61	-45
2.5	-56	-40	-56	-40
3.15	-50	-34	-50	-34
4.0	-41	-25	-41	-25[a]
5.0	-30	-14	-32	-16
6.3	-25	-11	-28	-12
8.0	-24	- 8	-24	- 8
10.0	-20	- 5	-22	- 7
12.5	-16	- 2	-20	- 6
16.0	-12	0	-22	-10
20.0	-14	- 4	-23	-13
25.0	-12	- 4	-19	-11
31.5	- 8	- 3	-15	-10
40.0	- 3	- 1	-11	- 9
50.0	+ 6	+ 5	- 5	- 4
63.0	- 3	+ 2	-12	- 5
80.0	-12	- 1	-21	- 8
100	-18	0	-25	- 7
125	-20	+ 4	-32	- 8
160	-30	0	-35	- 5

[a] Recommended minimum 1/3-octave spectral range.

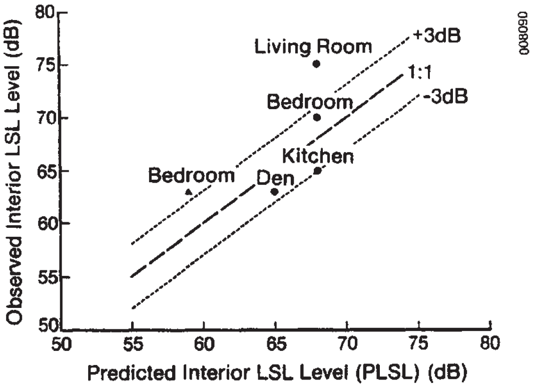


Figure 12. PREDICTED VS. OBSERVED INTERIOR LSL LEVEL COMPARISON

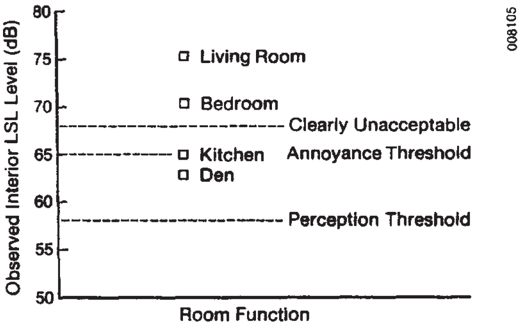


Figure 13. OBSERVED INTERIOR LSL VALUES FOR NONIMPULSIVE SOURCE

some distance from the nearest wind turbine(s), a method must be devised to provide a reference spectrum that takes into account situations in which atmospheric refraction and terrain reflection increase the acoustic levels above those expected from spherical divergence alone. We recommend using a reference distance of 1 km (0.6 mile) for calculating a "figure of merit" PLSL or PC level for a given wind turbine installation. To account for worst-case terrain/atmospheric focusing, we also recommend that 15 dB be added to the PLSL or PC values calculated at the 1 km distance. As an example, Table 7 lists the predicted or PLSL values for a home located 1 km from the MOD-1 and MOD-2 wind turbines [10].

Table 7. PREDICTED INTERIOR LSL (PLSL) VALUES AT 1 km FROM THE MOD-1 AND MOD-2 WIND TURBINES

Turbine	PLSL (dB)	PLSL+15 (dB)
MOD-1 Turbine (Severe impulsive characteristic)		
35 rpm operation	65	80
23 rpm operation	54	69
MOD-2 Turbine (Nonimpulsive characteristic)		
17.5 rpm operation	41	56

SUGGESTED PROCEDURE FOR ESTIMATING THE INTERIOR LF ANNOYANCE POTENTIAL OF A GIVEN TURBINE DESIGN

The results of this paper are summarized below as a recommended procedure for establishing a low-frequency figure of merit for a given wind turbine design.

(1) Obtain a series of representative, unweighted, averaged 1/3-octave band pressure spectra over a range of 5-100 Hz for a range of operating conditions. Make the measurements at a distance from the turbine where a sufficient signal-to-noise ratio for this frequency range can be reasonably obtained. Use recording periods of at least 2 minutes but not more than 10 minutes.

(2) Establish whether the turbine exhibits impulsive radiation characteristics.

(3) Determine the equivalent near-field PLSL- or PC-weighted level by using the contents of Table 6 for impulsive or nonimpulsive sources to weight the linear 1/3-octave band spectra.

(4) Calculate the equivalent PLSL or PC levels at the reference distance of 1 km by assuming spherical divergence (-6 dB per doubling of distance).

(5) Add 15 dB to the results of step (4). This result is the figure of merit for the worst-case, low-frequency-range acoustic emissions associated with the wind turbine design. This level or these levels can now be compared with Table 5 to assess the interior annoyance potential.

ACKNOWLEDGEMENTS

This work has been supported by the U.S. Department of Energy under contract no. DE-AC02-83CH10093. The author wishes to thank the seven SERI staff members who took the time to serve as evaluators for this project. Acknowledgment is also given for the excellent technical support rendered by Ed McKenna, David Jager, James Pruett, and Richard Garrelts. Engineering Dynamics, Inc., was responsible for the design and construction of the very low frequency (subwoofer) speaker system.

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Hi Sheila,

Please see below Addition No.7 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

These attachments refer to Acoustic Noise From Wind Turbines. The government has been directly mislead by the wind industry on this issue of Acoustic Noise and this makes very interesting reading.

Yours sincerely,

Owen McMullan
Chairman

SERI/TR-635-1166
UC Category: 60
DE85002947

Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control

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H. E. McKenna
R. R. Hemphill
C. L. Etter
R. L. Garrelts
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February 1985

Prepared under Task Nos. 1066.70 and 4803.10
WPA No. 171A

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
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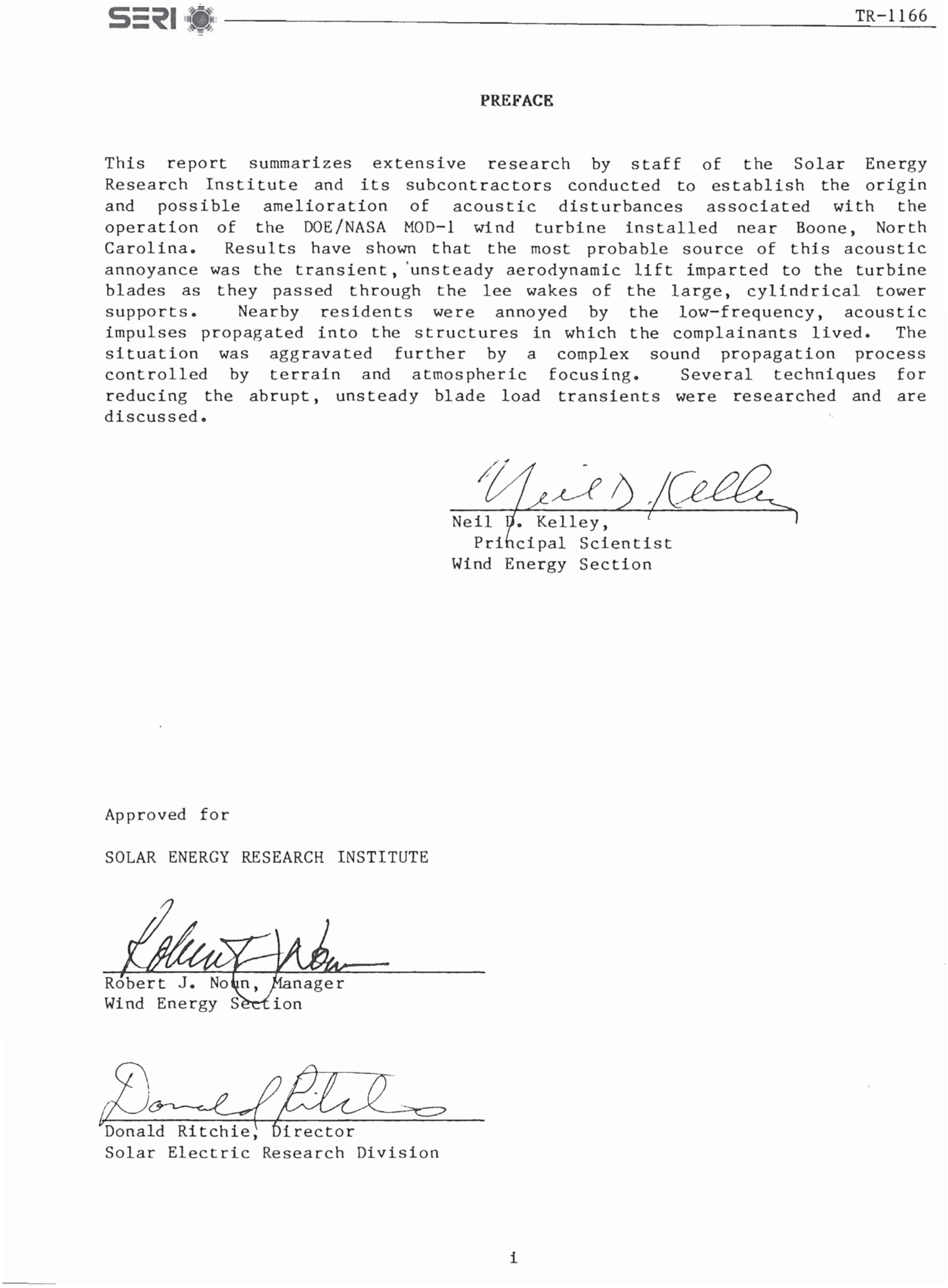

PREFACE

This report summarizes extensive research by staff of the Solar Energy Research Institute and its subcontractors conducted to establish the origin and possible amelioration of acoustic disturbances associated with the operation of the DOE/NASA MOD-1 wind turbine installed near Boone, North Carolina. Results have shown that the most probable source of this acoustic annoyance was the transient, unsteady aerodynamic lift imparted to the turbine blades as they passed through the lee wakes of the large, cylindrical tower supports. Nearby residents were annoyed by the low-frequency, acoustic impulses propagated into the structures in which the complainants lived. The situation was aggravated further by a complex sound propagation process controlled by terrain and atmospheric focusing. Several techniques for reducing the abrupt, unsteady blade load transients were researched and are discussed.

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- Pennsylvania State University, Departments of Meteorology and Mechanical Engineering
- The Portland General Electric Company
- Rocky Flats Wind Energy Research Center
- University of Colorado-Boulder, Departments of Mechanical and Aerospace Engineering
- University of Virginia, Department of Environmental Sciences

Special thanks are extended to the residents of Boone, North Carolina, particularly those near the MOD-1 site who aided us in this investigation. Some parts of the program could not have been accomplished without the help of SERI staff members Stan Thues, Bob McConnell, and Jane Ullman. Benjamin Bell was responsible for developing much of the computerized, time-domain analysis technique. University of Colorado-Boulder (UCB) engineering undergraduates Robert Wooten, David Dill, and Daniel Schell were responsible for supporting the testing at the Rocky Flats Research Center and provided the bulk of the support and planning for the testing in the UCB wind tunnel. This work was supported by the DOE Wind Energy Technology Division under contracts EG-77-C-01-4042 and DE-AC02-83CH10093.

SUMMARY

This document summarizes the results of an extensive investigation into the physical factors surrounding noise complaints related to the DOE/NASA MOD-1 wind turbine operating near Boone, North Carolina. The work reported here presents the results of investigative efforts of staff members of the Solar Energy Research Institute (SERI) and its subcontractors: the Fluid Dynamics Research Laboratory of the Massachusetts Institute of Technology (MIT), the Departments of Meteorology and Mechanical Engineering of Pennsylvania State University, and the Departments of Mechanical and Aerospace Engineering of the University of Colorado-Boulder.

Complaints of noise emanating from the operating MOD-1 were confined to about a dozen families living within a 3-km radius of the turbine, about half of whom were annoyed frequently. These families represented a very small fraction of the total households within this radial distance, a number exceeding 1000 homes, including most of the town of Boone itself. In summary, the complaints centered on the following perceptions:

- The annoyance was described as an intermittent "thumping" sound accompanied by vibrations.
- A "feeling" or "presence" was described, felt rather than heard, accompanied by sensations of uneasiness and personal disturbance.
- The "sounds" were louder and more annoying inside the affected homes.
- Some rattling of loose objects occurred.
- In one or two instances, structural vibrations were great enough to cause loose dust to fall from high ceilings and create an additional nuisance.

The primary objectives of SERI's investigation have been (1) to identify the physical mechanisms responsible for the generation, propagation, and human response (impact) of the annoying "sounds" related to the operation of the MOD-1 turbine and (2) to develop suggestions for its amelioration.

A definitive set of physical measurements that document the characteristics of the MOD-1 acoustic emissions, the vertical structure of the atmospheric velocity and thermal fields controlling the sound propagation, and the internal acoustic pressure variations and structural vibrations of two of the affected homes has been obtained through a series of field surveys. In addition, a number of supporting wind tunnel and full-scale tests using a small, downwind turbine have been conducted to enhance our basic understanding of the suspected physical processes involved. To aid in the investigation, a numerical model of the noise generation process has also been developed. These field measurements and model results allowed us to conclude the following:

- The annoyance was real and not imagined.

- The source of the annoyance was aerodynamic and involved the passage of the turbine blades through the lee wakes of the large, 0.5-m cylindrical tower legs.

- The coherent characteristics of the radiated acoustic impulses (produced by the leg wake-blade interaction) were responsible for the annoyance of the complaining residents.

- The responsible acoustic impulses were being propagated through the air and, in some instances, being focused on the complainants' homes as a consequence of ground reflection and refraction by the atmosphere.

Using a SERI-developed impulse waveform/energy analysis technique, we tested significant differences in the generation processes associated with the wakes from two of the support legs in the data taken during the June 1980 field survey. The impulses produced during this period were far more intense than those observed during our earlier survey in March-April 1980. The impulse analysis demonstrated that the severity of the intermittent impulses was not a unique function of the leg wake momentum deficit and that other factors were also involved. The analysis further demonstrated that slowing the rotor rotational speed from 35 to 23 rpm would reduce but not eliminate the annoyance.

Our analysis of field studies conducted at the MOD-1 strongly suggests that the leg wake-blade interaction was the ultimate source of the annoying acoustic impulses and that the physical process responsible was aerodynamic in origin. Through both controlled wind tunnel testing and experiments performed using a small, downwind turbine in the natural airflow, we determined that vortex-dominated circulations in the cylinder wakes can cause transient lift fluctuations and therefore be a source of acoustic impulses. In particular, the leg wake influences the severity of the impulses generated by

- providing a spatial coherency parallel to the cylinder's major axis and the spanwise direction of the rotor blade;

- its lateral dimensions;

- its turbulence characteristics (whether broadband chaotic or narrowband discrete);

- its time-varying (dynamic) properties as opposed to mean quantities.

The wake characteristics are externally influenced by conditions in the freestream that reach the cylindrical tower legs, including embedded perturbations containing turbulent length scales equivalent to the Strouhal shedding frequency. Other important variables are the freestream velocity, the vertical wind shear and hydrodynamic stability of the layer between the surface and hub height, the upwind fetch characteristics, and the wind direction controlling the orientation of the rotor plane with respect to the tower structure.

We have found that a number of turbine design parameters influence the severity of the acoustic impulses, including the rotor airfoil shape (close to stall), the operating angle of attack, and the leg-to-blade distance downwind of the tower. The airfoil shape may be a primary contributor to the impulse generation, particularly when the incidence approaches the stall angle. Factors in the impulse generation at the intersection of the blade and wake are spatially organized turbulent perturbations that simultaneously affect the lift generating portion of the blade span and incorporate length scales ranging from less than a chordwidth to several chords.

Perturbation pressure distributions, resulting from vortex core pressure deficits in the leg wakes, have been shown to adversely influence the blade leading edge pressure gradient, resulting in a transient separation of the blade boundary layer as it passes through the wakes. This is a consequence of the characteristic chordwise pressure distribution of the 44xx-series airfoil shape. Because of a forward shift (towards the stagnation point) in the peak negative pressure with an increasing quasi-steady incidence angle, transient leading edge separation and reattachment, as well as airfoil hysteresis, apparently become more severe when the upwash circulation and core pressure deficits created by the embedded vortices in the leg wakes are encountered. Wind tunnel tests have shown, and comparisons of full-scale field data have confirmed, the existence of a critical turbulent scale defined by the reduced frequency parameter k and covering the range $0.5 \leqslant k \leqslant \pi$ or, expressed in terms of a perturbation length scale, $2\pi c \geqslant \lambda_p' \geqslant c$ (where c is the chord dimension at 80% span). Turbulent structures in these ranges that are spatially coherent in a direction parallel to the span impart the most severe lift fluctuations through an interaction with the blade and account for not only the intense, impulsive acoustic radiation but the generation of strong aeroelastic stresses in the blade structure as well. Critical, unsteady aerodynamic parameters, which have been identified as exerting control over these unsteady processes, include the reduced frequency k (or, equivalently, the perturbation wavelength λ_p'), the quasi-steady incidence angle $\overline{\alpha}$, the perturbation spanwise coherence (with respect to the blade span), and possibly the vortex core pressure deficit Δp_v , all of which are stochastic with narrowband (critical) sensitivities.

An investigation into the role atmospheric propagation plays in the MOD-1 annoyance has shown that surface and ground propagation are negligible in comparison with a combination of terrain reflection and atmospheric refaction. Strong focusing (25 dB or more) of the emitted MOD-1 acoustic impulses as a result of these processes can account for local, far-field enhancements (caustics).

Acoustic and seismic (vibration) measurements taken in two of the affected homes near the MOD-1 site revealed that the structures had been undergoing transient elastic deformation under the periodic acoustic loadings from the turbine's operation. The excitation of lightly damped structural modes has also been responsible for summarily exciting cavity (Helmholtz) and air volume resonances within the rooms of the homes and producing secondary acoustic emissions from loose objects. Possibly very important, however, are the strongly oscillatory (harmonic), low-frequency pressure fields created within the smaller rooms and their relation to annoyance of the residents. A measurement of the indoor threshold perception (audible stimuli but no sensation of vibration) at one of the homes undergoing excitation by the MOD-1 impulsive noise led us to suggest the design goal of limiting peak coherent emission in the 8, 16, 31.5, and 63 Hz standard octave frequency bands (measured on-axis 1.5 rotor diameters upwind or downwind of the subject turbine) to band intensity levels of 60, 50, 40, and 40 dB (re 1 pW m^{-2}), respectively, under <u>all</u> atmospheric and operating conditions. The sensitivity of these threshold levels measured in a Boone home compares favorably with documented cases of human annoyance known to be associated with industrial sources of low-frequency noise.

A number of ways to ameliorate the MOD-1 impulsive noise were investigated. Because the leg wakes were found to be ultimately responsible, the abatement of coherent noise emissions has been targeted towards techniques that convert the offending 2-D, discrete wakes to 3-D chaotic by minimizing the spatially organized wake energy in the critical turbulent length scales. Three aerodynamic spoiling devices designed to be placed around the large, cylindrical tower legs were investigated in terms of their ability to achieve the desired transformation of the wake characteristics. We found that installing a helical strake or fence or covering the leg's cylindrical surface with square vortex generator elements or turbulators, placed over most of the leg's surface extending above and below the rotor disk, provided the necessary wake modification. Tests of a perforated shroud-type spoiler indicated it is unusable when the blade plane is less than three cylinder diameters downstream, but it may be adequate at distances beyond that (cylinder far wake). Additional analysis and testing of this type of spoiling device will be necessary before it can be considered as a solution to the problem.

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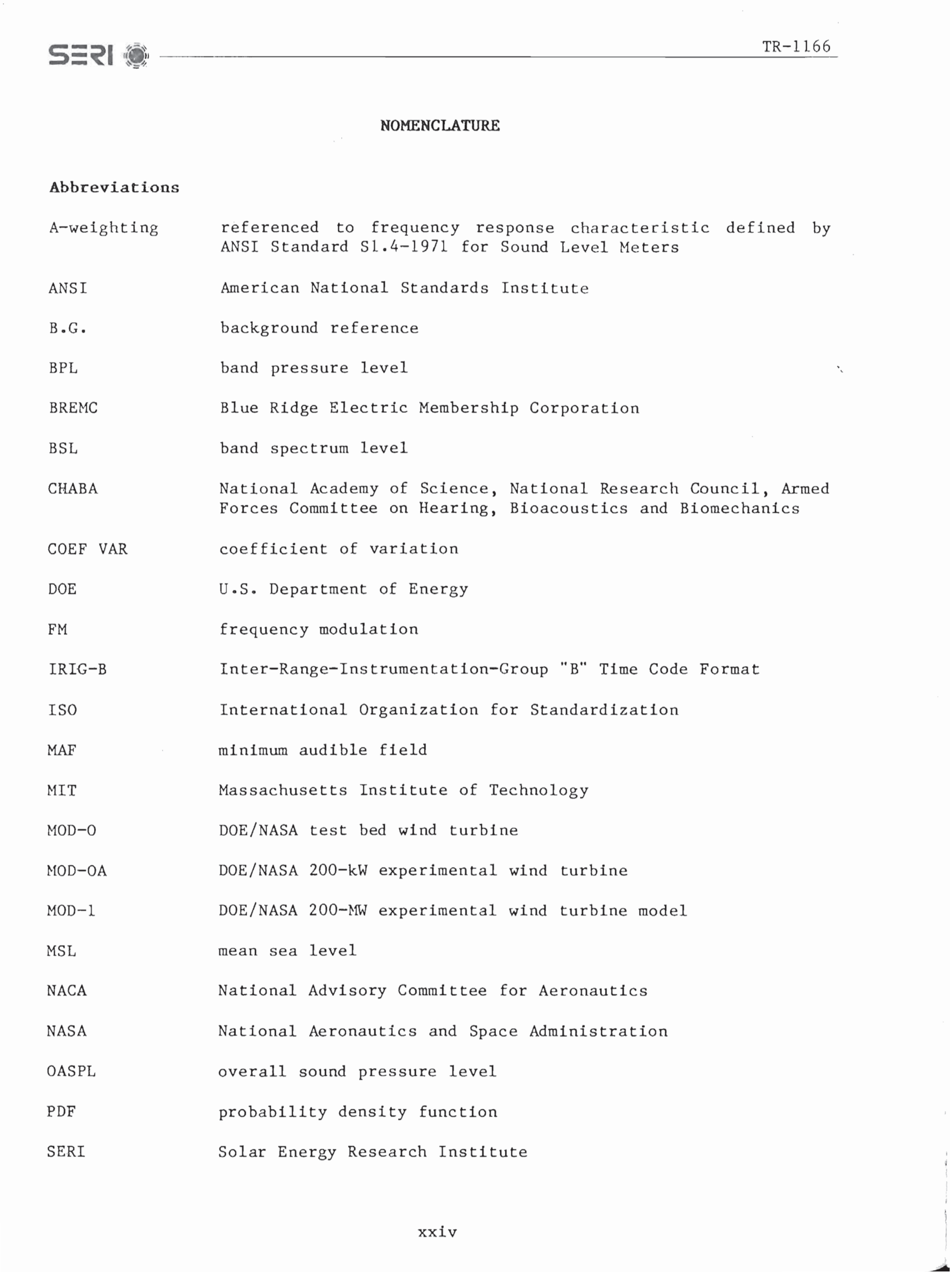
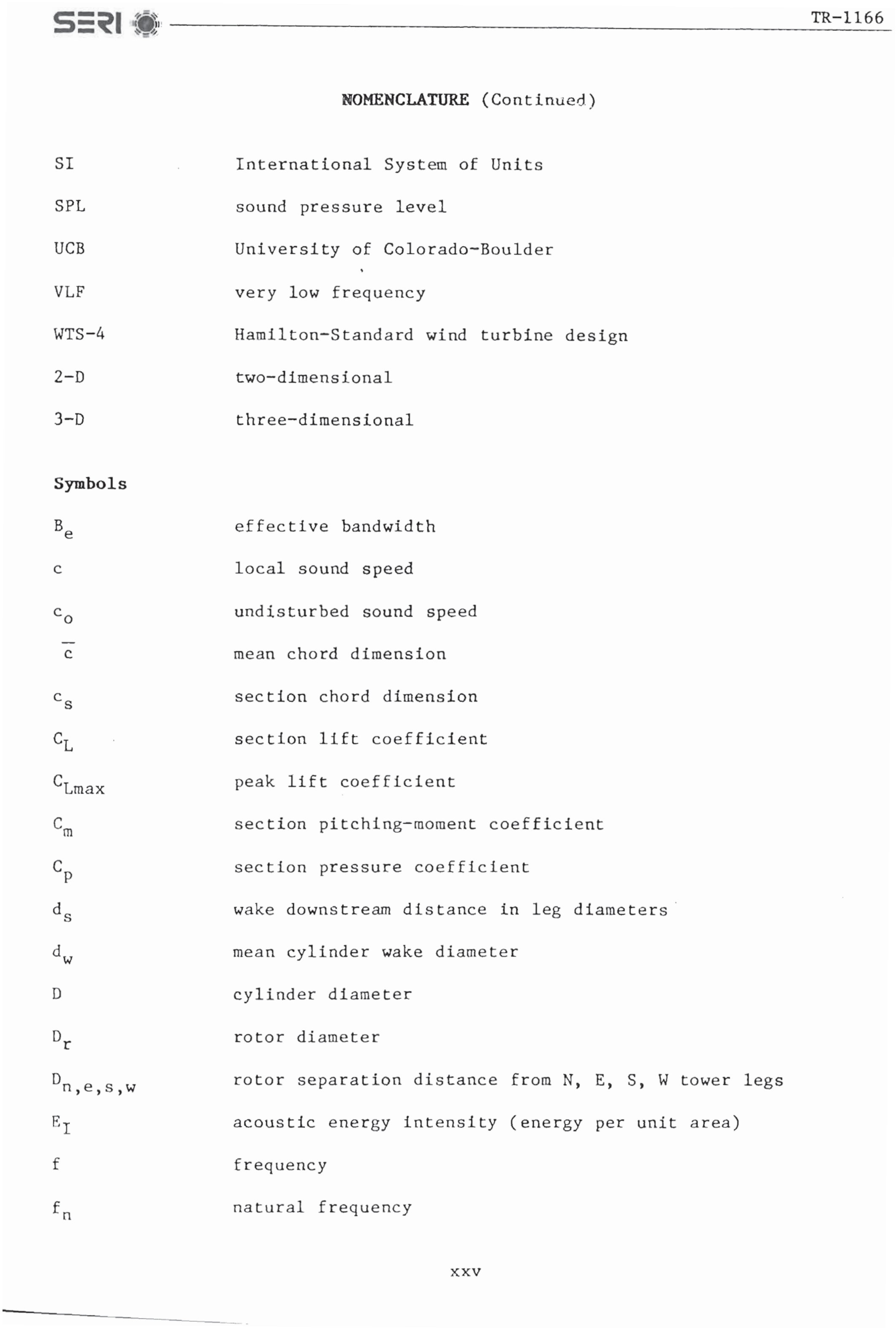


NOMENCLATURE

Abbreviations

A-weighting	referenced to frequency response characteristic defined by ANSI Standard S1.4-1971 for Sound Level Meters
ANSI	American National Standards Institute
B.G.	background reference
BPL	band pressure level
BREMC	Blue Ridge Electric Membership Corporation
BSL	band spectrum level
CHABA	National Academy of Science, National Research Council, Armed Forces Committee on Hearing, Bioacoustics and Biomechanics
COEF VAR	coefficient of variation
DOE	U.S. Department of Energy
FM	frequency modulation
IRIG-B	Inter-Range-Instrumentation-Group "B" Time Code Format
ISO	International Organization for Standardization
MAF	minimum audible field
MIT	Massachusetts Institute of Technology
MOD-0	DOE/NASA test bed wind turbine
MOD-0A	DOE/NASA 200-kW experimental wind turbine
MOD-1	DOE/NASA 200-MW experimental wind turbine model
MSL	mean sea level
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
OASPL	overall sound pressure level
PDF	probability density function
SERI	Solar Energy Research Institute



NOMENCLATURE (Continued)

SI	International System of Units
SPL	sound pressure level
UCB	University of Colorado-Boulder
VLF	very low frequency
WTS-4	Hamilton-Standard wind turbine design
2-D	two-dimensional
3-D	three-dimensional

Symbols

B_e	effective bandwidth
c	local sound speed
c_o	undisturbed sound speed
$\bar{c}$	mean chord dimension
c_s	section chord dimension
C_L	section lift coefficient
C_{Lmax}	peak lift coefficient
C_m	section pitching-moment coefficient
C_p	section pressure coefficient
d_s	wake downstream distance in leg diameters
d_w	mean cylinder wake diameter
D	cylinder diameter
D_r	rotor diameter
$D_{n,e,s,w}$	rotor separation distance from N, E, S, W tower legs
E_I	acoustic energy intensity (energy per unit area)
f	frequency
f_n	natural frequency

NOMENCLATURE (Continued)

f_s	Strouhal shedding frequency
F	force per unit volume
$G_a(f)$	floor/wall acceleration power spectrum
$G_p(f)$	interior acoustic pressure field power spectrum
k	reduced frequency parameter
K	vorticity rate parameter
ℓ_s	blade loading per unit span
L	total span lift
M, M_∞	Mach number
O( )	order of
p	total pressure
p_o	barometric pressure
$\hat{p}$	acoustic (dynamic) pressure, $\hat{p} = p - p_o$
P_o	reference pressure, 100 kPa
P(f)	harmonic acoustic energy spectrum
Q	mass source strength
r	source to observer distance, vortex radius
R	turbine rotor radius
Re	Reynolds number
Re_c	Reynolds number referenced to chord dimension
Re_d	Reynolds number referenced to cylinder diameter
St	Strouhal number
t	time
T	period of time
T_{ij}	Lighthill stress tensor

NOMENCLATURE (Continued)

$t-r/c_o$	retarded time
U	relative blade speed
$\|U_\infty$	freestream velocity magnitude
U_θ	vortex tangential velocity
x_i	distance in i direction
X_n	source dipole coordinates
z	vertical distance
α	incidence angle
$\dot{\alpha}$	rate of change of incidence angle
α_o, α_{ss}	quasi-steady incidence angle
α_{max}	peak incidence angle
α_s	static stall incidence angle
Γ	vortex circulation parameter
δ_c	effective correlated span length
δ_s	blade airload per unit span
$\Delta\alpha_s$	incidence angle excess over static value
Δp_v	vortex core pressure deficit
ζ	damping ratio
θ	potential temperature
κ	fraction of wake containing vortex core
λ	perturbation wavelength
μ	absolute viscosity
ν	kinematic viscosity
ρ	density
σ_{ij}	viscous stress tensor

NOMENCLATURE (Concluded)

$\phi(f)$	phase spectrum
ψ	nacelle yaw angle
ω	radian frequency
Ω	rotor rotation rate

Units

dB	decibels
dBA	decibels referenced to A-weighted scale
Hz	hertz (frequency in cycles per second)
J	joules (SI unit for energy)
k	kilo (10^3 multiplier)
K	kelvins (SI unit for absolute temperature)
m	milli (10^{-3} multiplier), meter
M	mega (10^6 multiplier)
p	pico (10^{-12} multiplier)
Pa	pascals (SI unit for pressure)
rpm	revolutions per minute
s	seconds
W	watts (SI unit for power)

SECTION 1.0

INTRODUCTION

This document summarizes the results of an extensive investigation into the factors surrounding noise complaints related to the operation of the DOE/NASA 2-MW MOD-1 wind turbine installed atop Howard's Knob near Boone, North Carolina. The work reported here primarily represents the efforts of staff members of the Solar Energy Research Institute (SERI). Companion documents include results obtained by the Fluid Dynamics Research Laboratory of the Department of Aeronautics and Astronautics, Massachusetts Institute of Technology (MIT), in the analytical modeling aspects of the investigation (SERI Report No. TR-635-1247). The part of this work related to propagation effects has been excerpted from research performed by a team of staff members of the Departments of Meteorology and Mechanical Engineering and the Noise Control Laboratory of Pennsylvania State University (Penn State), which are summarized in SERI Report No. TR-635-1292.

1.1 CHARACTERISTICS OF THE MOD-1 WIND TURBINE

The subject wind turbine of this study, referred to as the MOD-1, was the fifth DOE/NASA Lewis (U.S. Department of Energy/National Aeronautics and Space Administration, Lewis Research Center) operational wind turbine constructed as part of the Federal Wind Energy Program. It was located atop a small, somewhat isolated peak known as Howard's Knob [elevation: 1348 m (4420 ft) MSL] overlooking the town of Boone in the Blue Ridge Mountains of northwestern North Carolina. Figure 1-1 illustrates the turbine and its surroundings. At the time of its dedication in July 1979, the MOD-1 was the largest wind turbine so far constructed, surpassing the Smith-Putnam machine that operated in the Green Mountains of Vermont in the early 1940s. The MOD-1 had a rotor diameter of 61 m (200 ft) and, as originally installed, was capable of generating 2 MW of power at rated windspeed. The machine was designed and constructed by the General Electric Company under a contract managed by the NASA Lewis Research Center, Wind Energy Program Office. Power generated by the MOD-1 was fed to the local utility grid operated by the Blue Ridge Electric Membership Corporation (BREMC), a nongenerating rural electric cooperative that delivers electrical service in seven northwestern North Carolina counties. The first rotation of the MOD-1 occurred in May 1979, and the first grid synchronization took place in September 1979. The turbine operated until early 1981, when a major mechanical failure occurred, effectively terminating the program. The turbine has since been decommissioned and removed. Table 1-1 summarizes the original design and mechanical specifications of the turbine.

1.2 BACKGROUND

In the fall of 1979, as the MOD-1 turbine was undergoing a series of engineering shakedown tests, a number of sporadic and totally unexpected noise complaints were received from a few homeowners living within a 3-km radius of the installation atop Howard's Knob. These complaints came as a suprise, since a series of earlier sound measurements taken at the 100-kW MOD-0 wind

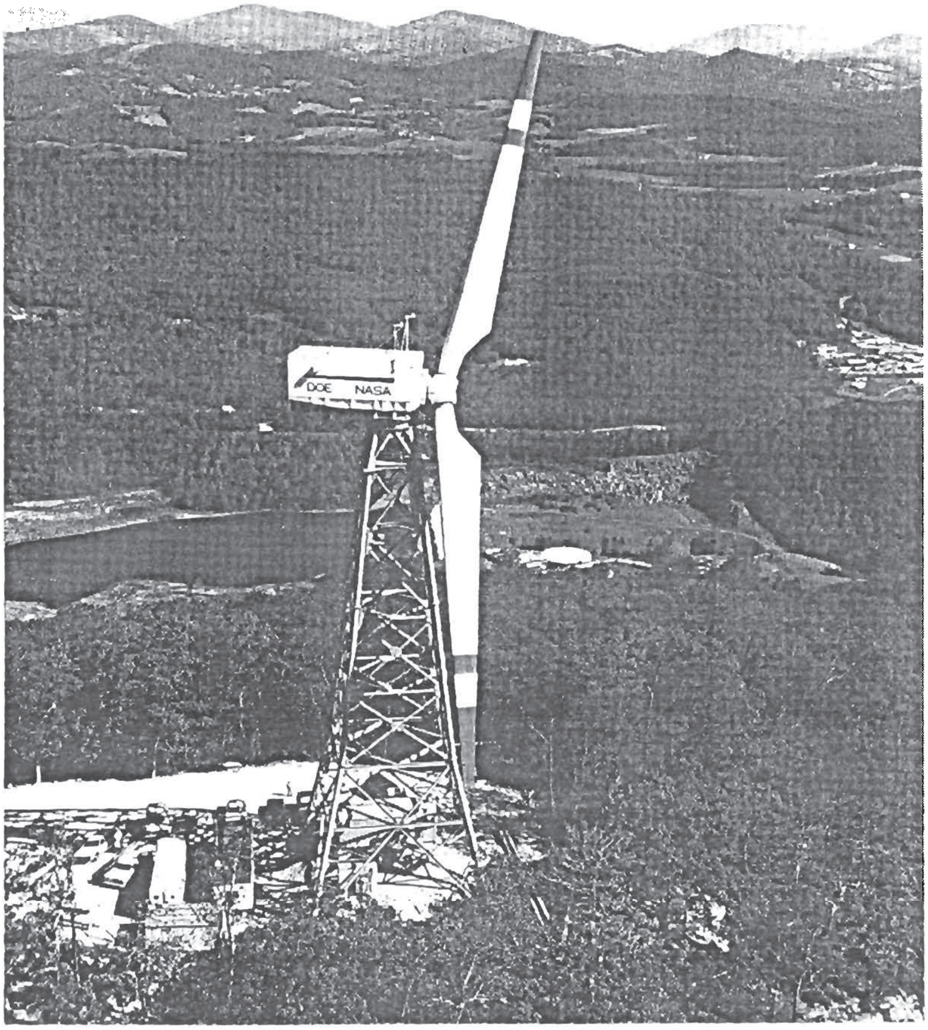


Figure 1-1. DOE/NASA Wind Turbine Installed Atop Howard's Knob near Boone, North Carolina, in 1979

Table 1-1. Original Specifications for the MOD-1 Wind Turbine

Rotor	
Number of blades	2
Diameter [m (ft)]	61 (200)
Speed (rpm)	35
Location relative to tower	Downwind
Type of hub	Rigid
Method of power regulation	Variable pitch
Cone angle (degrees)	9
Tilt angle (degrees)	0

Generator	
Type	Synchronous ac
Rating (kVA)	2225
Power factor	0.8
Voltage	4160 (3-ph)
Speed (rpm)	1800
Frequency (Hz)	60

Blade	
Length [m (ft)]	30 (97)
Material	Steel spar/foam tr. edge
Airfoil shape	NACA 44xx
Twist (deg)	11
Tip chord [m (ft)]	0.9 (2.8)
Chord taper	Linear

Tower	
Type	Pipe truss
Height [m (ft)]	40 (131)
Ground clearance [m (ft)]	12 (40)
Hub height [m (ft)]	43 (140)
Access	Hoist

Peformance	
Rated Power (kW)	2000
Wind speed at 10 m (m/s):	
Cut-in	6
Rated	13
Cut-out	18
Maximum design	64

Control System	
Supervisory	Computer
Pitch actuator	Hydraulic

turbine operating near Sandusky, Ohio, indicated that acoustic emissions associated with the machine's operation were indistinguishable from the wind-dominated background at distances greater than 200 m [1]. These early reports associated with the MOD-1 were also puzzling, because complaints were not received each time the turbine was operated, and attempts to correlate the type and location of the complaints with machine operating modes were inconclusive. So, the NASA Wind Energy Program Office and SERI entered into a cooperative effort to document and establish the source of the noise, ultimately to implement a suitable abatement procedure. Since that time, a number of organizations have made considerable efforts to study the situation in order to discover the exact nature of the noise responsible for annoying the neighbors, its origin and production mechanism, its propagation path, and what could be done to eliminate it or at least reduce it to below perceptible levels. This report summarizes a three-year SERI research effort to develop an understanding of the physical processes responsible for the MOD-1 noise annoyance.

1.2.1 The Nature of the Complaints

It is important, first, to place the MOD-1 noise situation in the proper perspective. The nature of the complaints generally did not change materially from the earliest to the latest reports received, and the total number of families known to be affected did not increase above the dozen identified within the first few months, even though more than 1000 families lived within a 3-km radius of the turbine installation. About a third of those dozen families were annoyed more frequently than the others. Figure 1-2 shows the location of the complainants' homes with respect to the wind turbine and also indicates those reporting a higher frequency of annoyance. Most homeowners described the annoyance as periodic "thumping sounds and vibrations," similar to the sensation of having someone walk heavily across a wooden porch or a heavy truck passing with a flat tire. During our investigation, we visited many of the complainants' households and received descriptions of the annoying sounds. The complaints can be summarized in the following perceptions:

- The annoyance was described as an intermittent "thumping" sound accompanied by the vibrations mentioned above.
- Many persons reported they could "feel" more than hear the "sounds," which created a sensation of uneasiness and personal disturbance.
- The "sounds" were louder and more annoying inside their homes than outside.
- Some people noticed loose glass rattling in picture frames mounted on outside walls, as well as small objects such as miniature perfume bottles on top of furniture in contact with an inside wall.
- In one or two severe situations, structural vibrations were sufficient to cause loose dust to fall from high ceilings, which created an additional nuisance.

The intermittence of the noise and disturbing feelings brought on by the noise were the most objectionable qualities of this annoyance. When visiting a complainants' home, we asked in which room did the residents believe the "sounds" were most noticeable. Without fail, we were shown rooms that had at least one window that faced the turbine. More often than not, the room was a relatively small one, usually a bedroom.

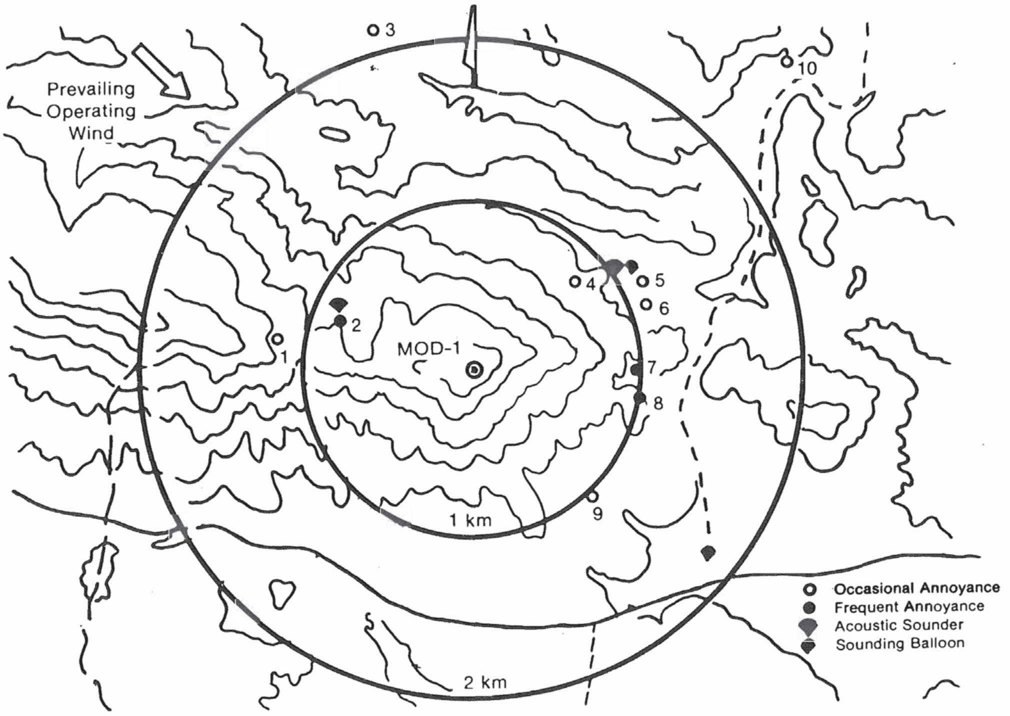


Figure 1-2. Schematic Map Showing MOD-1 Site and Relationship of Complainants' Homes

1.2.2 The SERI Program

In cooperation with NASA, its contractor, the General Electric Company, and BREMC, SERI performed a series of field measurements at and near the MOD-1 installation during five separate sessions including October 1979 (within a week after the initial complaints were received), February 1980, March-April 1980, June 1980, and January 1981. The most comprehensive efforts in March-April and June 1980. The Pacific Northwest Laboratories and their subcontractor, the University of Virginia Department of Environmental Science, supported SERI field efforts at Boone during the March/April experiments. In addition to the measurement programs at the MOD-1, SERI conducted ancillary experimental studies at the NASA Plumbrook Facility using the MOD-0 experimental turbine, the facilities of the DOE Rocky Flats Wind Energy Research Center, the anechoic wind tunnel of MIT's Department of Aeronautics and Astronautics, and the subsonic wind tunnel facilities of the Department of Aerospace Engineering of the University of Colorado-Boulder (UCB). Both analytical and field studies of low-frequency noise propagation in the vicinity of the MOD-1 turbine were conducted by a multidisciplinary group at Penn State and analytical studies of aerodynamic noise generation were performed by staff members of the Fluid Dynamics Research Laboratory of MIT's Department of Aeronautics and Astronautics, both under subcontract to SERI in support of the overall effort. The results of these studies are summarized in this document.

1.3 RELATED STUDIES

In addition to the SERI/MIT/Penn State effort, a number of other organizations have been active in the MOD-1 noise investigation:

- NASA Lewis Research Center--analytical modeling of noise generation by wind turbines [46]
- NASA Langley Research Center--aeroacoustical and psychophysical studies of wind turbine noise [45, 51, 32]
- General Electric Company Corporate Research Center--analytical and statistical studies of the MOD-1 noise situation and wind turbine noise in general [31,47]
- Boeing Vertol Division--wind turbine aeroacoustic studies [48]
- Hamilton-Standard Corporation--analytical studies of wind turbine aeroacoustics [49].

1.4 SERI PROGRAM INVESTIGATION OBJECTIVES

In cooperation with NASA, the SERI Program objectives were to (1) identify the physical mechanisms responsible for the generation of the MOD-1 noise, (2) determine the method of noise propagation to the homes below, (3) determine resulting subjective responses (impacts), and (4) develop suggestions for noise abatement techniques. In addition, the SERI studies attempted to answer the following questions:

1. Why did the noise not reach annoying levels each time the turbine was operated?
2. Why were some families annoyed more often than others, and why did the situation confine itself to such a small fraction of the total population living within 3 km of the machine?
3. Why was the noise more noticeable inside the affected homes and why did it become more persistent and louder during the evening and nighttime hours?

The SERI effort went beyond the specific noise situation associated with the MOD-1 so that the knowledge gained in this study can be applied to understand the acoustic performance and human annoyance potentials of a number of generic wind turbine designs.

SECTION 2.0

THE INVESTIGATIVE PROCEDURE

As a result of the initial assessment of the MOD-1 situation, made during preliminary on-site investigations in October 1979 and February 1980, we recognized the problem had three major components: (1) the actual noise generation process (which was suspected to be aeroacoustic in origin); (2) the propagation of the sound in the surrounding terrain; and (3) the mechanism responsible for producing the impact or annoyance in the affected homes. The Fluid Dynamics Research Laboratory of MIT's Department of Aeronautics and Astronautics and a multidisciplinary group comprising faculty and staff members from the Departments of Meteorology and Mechanical Engineering and the Noise Control Laboratory at Penn State were retained under SERI subcontracts to develop analytical techniques for evaluating the physics of the sound generation process and the propagation aspects of the problem, respectively.

A definitive set of physical measurements was needed that would document (1) the acoustic characteristics of the annoying sounds produced by the turbine, (2) the atmospheric motions and thermodynamic structure controlling the noise propagation, and (3) the structural and ground motions of the affected homes. In addition to the MOD-1 on-site studies, additional limited field experiments were performed using a small wind turbine at the Rocky Flats Wind Energy Research Center during spring and summer 1981. Supporting wind tunnel experiments were conducted in both the MIT anechoic wind tunnel and the UCB subsonic tunnel in May 1981 and February 1982, respectively.

2.1 MOD-1 FIELD STUDIES

SERI performed five field measurements at the MOD-1 site in the course of its investigation. The first two were initial assessments to gather information for planning more extensive measurement efforts at a later date. The third was the first extensive study of many important parameters of the situation. The fourth was a comprehensive effort comprising acoustic measurements of the turbine under various operating conditions, including use with a resistive load bank instead of the utility grid. The last measurement involved evaluating the effectiveness of lowering the turbine rotational speed from 35 to 23 rpm to reduce the noise.

2.1.1 October 1979 Study

The purpose of the study conducted in late October 1979 was to obtain an initial assessment of the noise that had recently been reported. The limited available acoustic data could not furnish any information about the severity of the reported noise problem, because it did not occur while SERI personnel were on site. BREMC personnel canvassed some of the complaining residents later, who indicated that they did not perceive the annoyance during the period of our data collection.

2.1.2 February 1980 Study

BREMC personnel received a number of complaints of a "thumping" noise during November and December 1979 and January 1981, after our initial visit. After our initial analysis of the first data set, we decided to return to Boone to try to obtain data during one of the complaint periods in order to (1) take a closer look at factors related to the annoyance, and (2) collect information needed to plan a larger field measurement effort later in the year. During this period the Penn State Group also installed the two acoustic sounders (SODARS) in the locations shown in Figure 1-2 (see Section 1.0). During the last evening of our visit we were able to obtain a data set representative of a typical annoyance episode.

2.1.3 March/April 1980 Study

This comprehensive study began during the third week of March. Its major objectives included detailed measurements of the vertical atmospheric structure using tethered balloons and SODARs to assess meteorological factors on sound propagation; seismic measurements of at least two homes experiencing actual annoyance episodes to varying degrees including measurements taken in the buildings and in the soil near the foundations; and, of course, detailed simultaneous acoustic data taken near the turbine and at the homes being monitored. The program was a reasonable success in that all three objectives were met. The findings are discussed in Section 4.0.

2.1.4 June 1980 Study

The June 1980 experiment was a combined effort of NASA, General Electric, and SERI to (1) collect more detailed acoustic data under a wide range of operating conditions; (2) evaluate the noise reduction achieved by reducing the rotor rotational speed from 35 to 23 rpm; and (3) assess the effects of treating two of the four major vertical support members of the tower with wire mesh on the severity of the noise measured. To place a load on the turbine at the lower rotational speed, a 1-MW (actual capacity, ~750 kW) resistive load bank was installed in place of the normal utility grid connection, and the operating sequences were altered accordingly to accommodate the maximum available load.

During this experimental series, SERI obtained its most comprehensive data set on the acoustic emissions from the turbine under a wide range of inflow wind speeds. Also during this series, on the evening of June 9th, the most severe instance of acoustic annoyance occurred that we were able to tape record. Unfortunately, during that episode we were not able to simultaneously collect acoustic and structural data at one of the affected homes.

2.1.5 January 1981

The objective of the January 1981 experiment was to evaluate the effectiveness of reducing the permanent rotor speed from 35 to 23 rpm under a full range of load conditions--which could not be accomplished in June because of the capacity limits of the resistive load bank. Because the tests conditions required by the SERI test plan were not present, we supported NASA and General Electric in their specific efforts. Some data were obtained, but the critical turbine operating data were not yet available; therefore, the results have been of limited value. At the conclusion of this set of experiments, a failure occurred in the drive train that made the turbine inoperable.

2.2 INSTRUMENTATION

2.2.1 Acoustic

Special, very-low-frequency (VLF) microphone systems were employed. These instruments can measure acoustic pressures down to a frequency of 0.02 Hz (Bruel & Kjaer Model 2631 FM-carrier preamplifers with Type 4147 microphones). The same preamplifier was also used with a back-sealed, Type 4144 microphone with a minimum frequency response of 0.1 Hz. Although the upper frequency limits of these combinations were 18 kHz and 8 kHz, respectively, in fact the upper frequency responses were limited by the FM tape recording used. In addition to the low-frequency systems, standard ANSI Type-1 Precision Sound Level Meters (Bruel & Kjaer Model 2209) also supplemented the acoustic measuring systems. All microphone calibrations were referenced to a standard pistonphone calibrator (Bruel & Kjaer Model 4220) corrected for the local barometric pressure. The VLF acoustic equipment allowed us to study accurately the time-pressure signatures of the acoustic field radiated from the turbine without the amplitude and phase distortion resulting from highpass characteristics of most microphones and their preamplifiers.

2.2.2 Seismic

Seismic range accelerometers (Bruel & Kjaer Type 8306) with a flat frequency response of 0.08 Hz to 1 kHz and a minimum sensitivity of more than -120 dB (referenced to 1 g_{rms}) measured the structural response of two of the affected homes. The Penn State investigators employed two Hall-Sears Model HS-10-1 seismometers (geophones) to measure any ground-borne component of the MOD-1 noise coupling to the foundations of the homes.

2.2.3 Atmospheric

The vertical wind and thermal structure of the atmosphere near the MOD-1 were measured directly by means of two tethered balloon systems which recorded windspeed and direction, temperature, humidity, and altitude during the March/April 1980 field study. In addition to the direct measurements, a pair of monostatic acoustic sounders (SODARs) were employed to qualitatively map the vertical thermal (and to some extent wind) structure during known annoyance episodes. One of these sounders was equipped with a telephone hookup that sent real-time data to the Penn State Meteorology Department computer at State College, Pennsylvania, for immediate analysis and interpretation. The map in Figure 2-1 shows the location of the tethered balloons and acoustic sounders.

2.2.4 Turbine Operational Information

Several turbine operating parameters that we belived were important were recorded for further analysis. These included the nacelle azimuth angle, Blade No. 1 position and pitch (blade) angles, hub-height wind direction and speed, generator output power, and the flat bending moment at the root of Blade No. 1. Because of the tape recorder's channel limitations, not all of the parameters listed were recorded during each field phase.

2.2.5 Data Recording

All acoustic, seismic, and supporting turbine operating data were recorded on multichannel, analog magnetic tape in FM format. Some of the acoustic data were also recorded in direct (amplitude-modulated) format to achieve a greater dynamic range and higher upper frequency limit. The recorders used in the field programs evolved from one portable, 4-channel machine employed during the initial assessments in October 1979 and February 1980 to three recorders used simultaneously (during the January 1981 experiment) consisting of 14-, 7-, and 4-channel units. In addition to the acoustic data (from as many as four microphone systems) and the turbine operating parameters, an IRIG-B digital time code signal was recorded during the June 1980 and January 1981 field programs to allow us to time-synchronize and reproduce certain time sequences more accurately than we could with footage counters alone. The time code was synchronized with the site data acquisition system for later comparisons with more of the turbine operational information.

2.3 DATA REDUCTION

When they were available, the supporting turbine operating data (e.g., blade pitch and position angles, nacelle azimuth angle, generator output, and hub height wind speed) were digitized, scaled, and stratified into 2- to 3-minute record segments that exhibited relatively stationary statistics. The near- and far-field acoustic data and the structural seismic data taken at the affected homes were analyzed using both time and frequency domain methods through the facilities of a commercial, dual-channel narrowband Fast Fourier Transform (FFT) spectrum analyzer (Nicolet Model 660A). Much of the single parameter data were analyzed using the high resolution (800-line) mode of this instrument. Impulses found in the acoustic signal were analyzed in the single-channel, time domain mode under the control of an external computer to obtain statistical estimates of various waveform parameters. The dual-channel, 400-line mode was used to study the dynamic interaction between the acoustic and elastic, structural responses of the affected homes.

2.4 ANALYTICAL MODELING

To better understand the physics of the noise generation process associated with the MOD-1, an analytical model was developed by MIT's Fluid Dynamics Research Laboratory. The physical basis of this model and the first set of results achieved with it are discussed in SERI report TR-635-1247 [2].

SECTION 3.0

MOD-1 FIELD INVESTIGATION RESULTS

3.1 IDENTIFICATION OF SOURCE OF ACOUSTIC ANNOYANCE

The factors chiefly responsible for the annoyance reported by the dozen residents near the MOD-1 are discussed here in terms of both source and impact. The characteristics of the turbine acoustic emissions that occurred during the annoyance episodes are discussed first, and then the effects of these emissions on the residential structures.

3.1.1 Annoyance-Related Acoustic Emission Characteristics of the Wind Turbine

Our analysis of the near-field acoustic data (measurements taken at 1.5 rotor diameters or 107 m upwind from the turbine rotor hub at ground level) has shown that the averaged frequency spectrum indicates three types of aerodynamic or aeroacoustic sources. The relative contribution of each of these sources, and the resulting distribution of acoustic energy across the frequency spectrum, occur in different proportions depending on the characteristics of the wind blowing through the turbine support tower and the rotor disk. Figure 3-1 illustrates an averaged sound pressure spectrum in which two of the three aeroacoustic sources identified are present. This spectrum is composed chiefly of broadband, incoherent rotor noise with a few discrete tones in evidence out to about 10 Hz. Two distinct tones at 60 and 79 Hz are related to mechanical and electrical equipment in the turbine. The low-frequency tones or rotational noise discretes are the reflection of unsteady aerodynamic loads on the blades as they move around the rotor disk and are brought about by such factors as wind shear, inflow turbulence, and the tower wake. Figure 3-2 depicts the corresponding pressure-time plot of a portion of the record used to obtain the average of Figure 3-1 but contains four blade passages by the tower or two complete rotor revolutions. The windspeed at the hub at that time averaged 9 m s^{-1} (20 mph), was rather steady, and apparently low in turbulence.

Figure 3-3 illustrates the strong, highly energetic impulses recorded during the evening of February 7, 1980, which are imbedded in the normal pressure-time signature similar to that of Figure 3-2. Compare the sharpness and higher peak overpressures of these impulses with those of Figure 3-2. Figure 3-4 plots the corresponding averaged, sound pressure spectrum for the two-minute period from which the time domain plot was taken. Note the many discrete tones extending all the way to 100 Hz. Compare this spectrum with that of Figure 3-3. Figures 3-5 and 3-6 increase the time resolution of the time-pressure plots to include only a single blade passage by the tower, allowing waveforms to be compared in much greater detail. The more gentle traces of Figures 3-2 and 3-5 were made when the rotor was parallel to the southeast-facing side of the tower (SE flat) and those of Figures 3-3 and 3-6 were made as the blade passed slightly closer while perpendicular to the tower north-south (N-S) diagonal. Figure 3-7 illustrates the tower construction arrangement and blade passage distance relationships. The blade came slightly closer to the tower leg (5 leg diameters downstream) near the N-S axis,

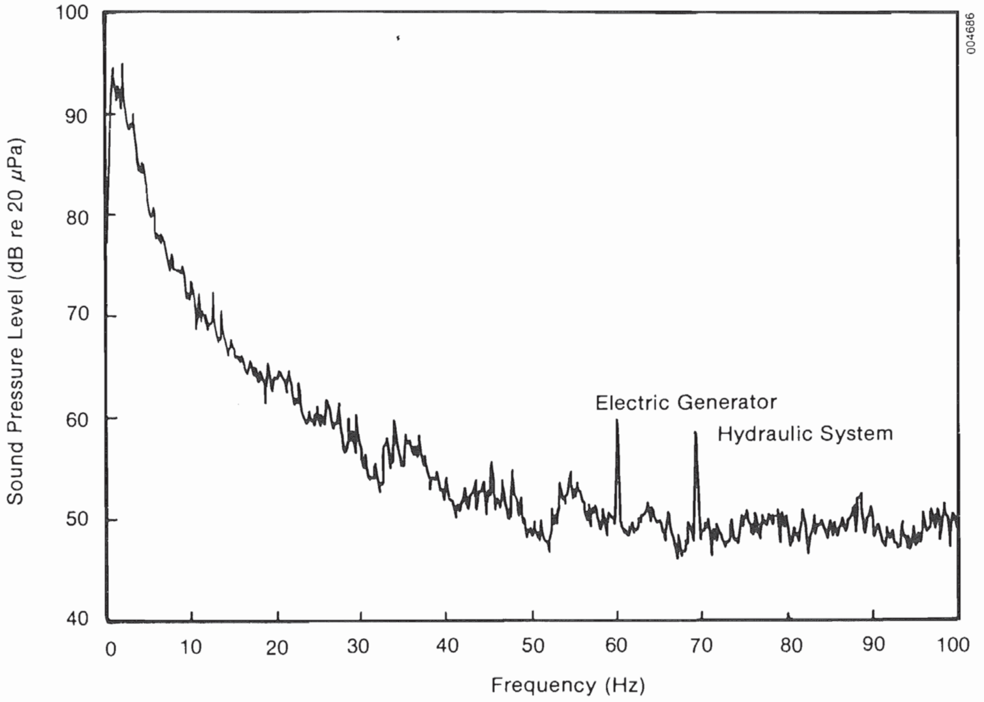


Figure 3-1. Averaged MOD-1 Sound Pressure Spectrum with No Periodic Impulses Present (B_e = 0.25 Hz)

compared with the 7.5 leg diameter spacing while the blade was parallel to the SE flat. The wind speed during the period of intense impulses was 11 m s^{-1} (25 mph).

The pressure-time history of Figure 3-8 is similar to the intense impulse periods illustrated in Figures 3-3 and 3-6 but was recorded on March 31, 1980, in the far-field outside of House #8 shown in Figure 1-2. This 1-1/2 story, frame construction home is located about 1 km to the ESE and 300 m below the turbine. At the time of this recording, the home was experiencing what was described by the SERI personnel in the house as a "very heavy thumping" sensation. Confirmation was provided by two of the residents who were also present. The turbine rotor was oriented at that time slightly closer to one leg but almost parallel to the SE flat of the tower. Examining Figure 3-8 more closely, the time delay between the two major negative-going pulses (81 ms) translates to an equivalent linear distance (for a MOD-1 blade tip velocity of 111 ms^{-1} at 35 rpm) of 9.3 m (30.5 ft). The horizontal spacing of the two vertical members of the tower at tip height on the SE flat is 9.5 m (31.2 ft). The wind at hub height was gusty and averaged 11-13 ms^{-1} (25-30 mph).

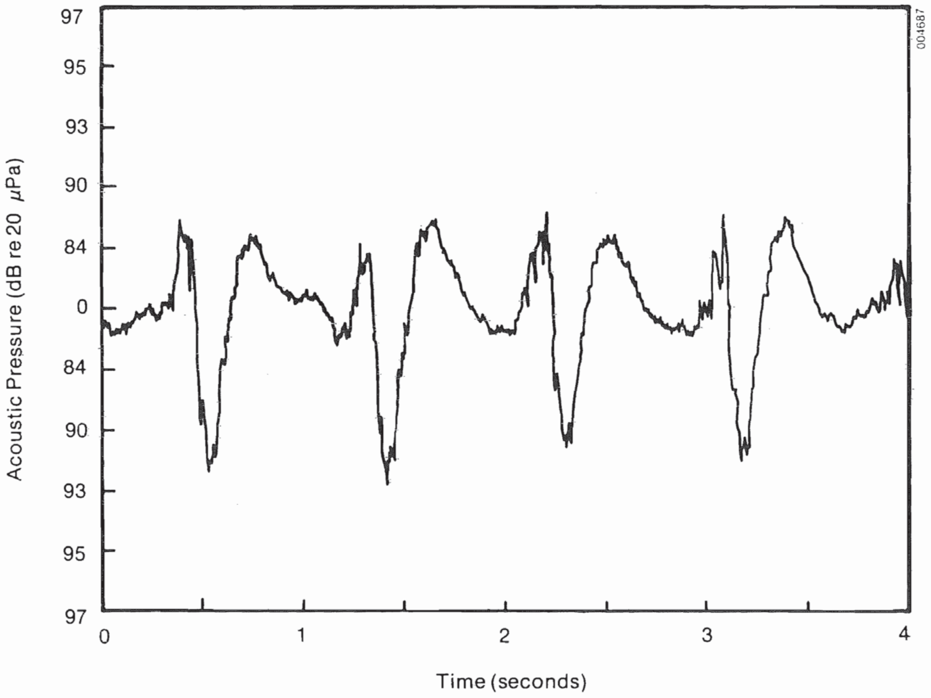


Figure 3-2. Typical Pressure-Time Plot of MOD-1 Acoustic Emissions with No Periodic Impulses Present. (Two complete rotor revolutions and four blade passages)[14]

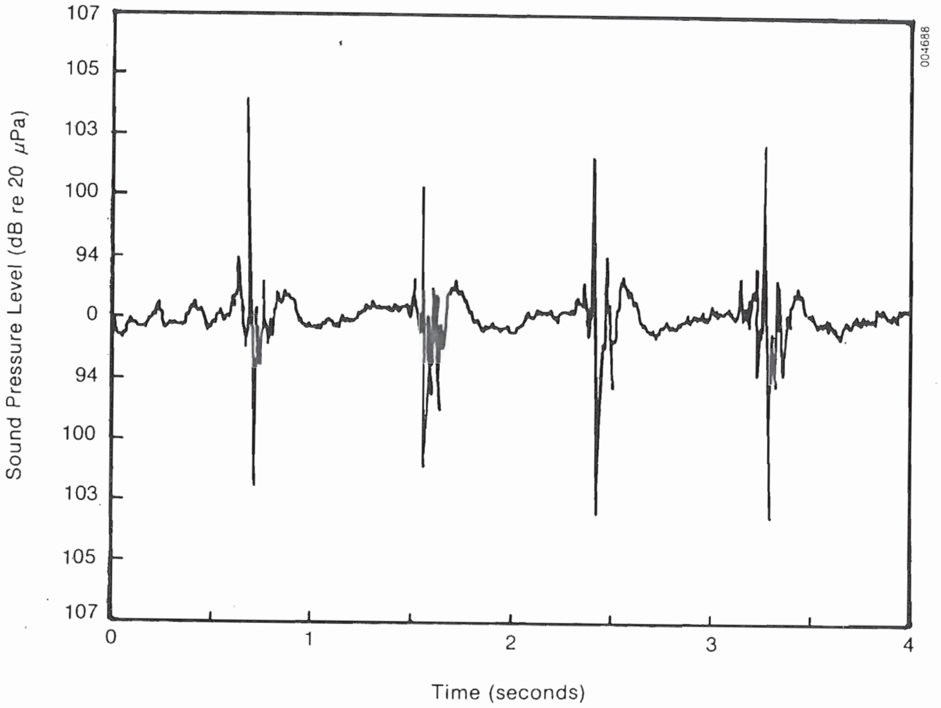


Figure 3-3. Typical Pressure-Time Plot of MOD-1 Acoustic Emissions Containing Strong Period Impulses. (Two complete rotor revolutions and four blade passages)

From this it was clear that whatever was producing these acoustic impulses was taking place in the lee of the 0.5-m-diameter tower legs. Furthermore, the impulses were also the most likely source of the low-frequency "thumping" sounds the residents reported. Impulsive waveforms of this type, when transformed into the frequency domain, generally resemble the (sin x)/x or sinc function shape, as illustrated in Figure 3-9. The characteristic spectral shape of an impulse also indicates the distribution of acoustic energy as a function of frequency in the radiated emission, with the total impulse energy striking a surface defined as the energy intensity E_I (energy per unit area), or

$$E_I = \frac{1}{\rho c} \int_0^T (p(t) - p_0)^2 \, dt = \frac{1}{\rho c} \int_0^T \hat{p}^2(t) dt \;, \qquad (3\text{-}1)$$

where ρ is the air density; c, the sound speed; p_0, the local atmospheric pressure; p, the total pressure; $\hat{p} = p - p_0$, the dynamic (over or under) pressure; and T, the impulse duration (Parseval's Theorem).

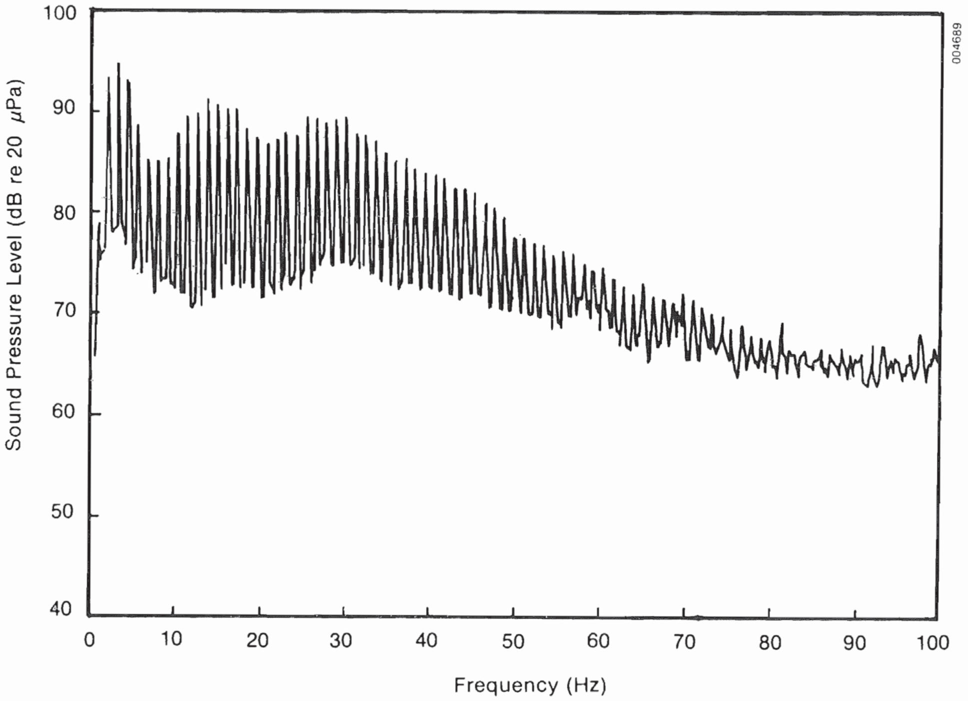


Figure 3-4. Averaged Sound Pressure Spectrum of MOD-1 Acoustic Emissions Containing Strong Periodic Impulses (B_e = 0.25 Hz)

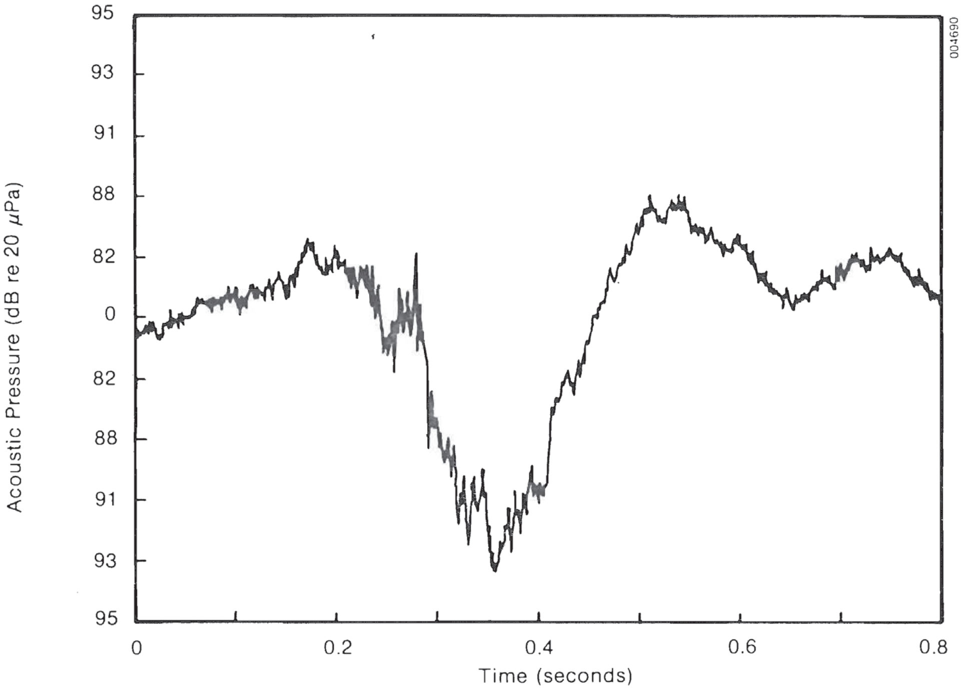


Figure 3-5. Detail of Typical Pressure-Time Plot of MOD-1 Acoustic Emissions with No Periodic Impulse Present. (Single blade passage by tower)

The spectral distribution of the acoustic energy of the impulse shown in Figure 3-9 is given by the Fourier transform of the dynamic acoustic pressure. To describe the energy distribution with frequency, both the magnitude and phase spectra are necessary. The magnitude spectrum shows how the energy is distributed as a function of frequency, and the phase spectrum indicates how energies in the frequency bands are related to each other in time (i.e., does it all appear at the same instant or does the energy in some bands lag or lead others with respect to some time reference?). The phase spectrum of Figure 3-9, which corresponds to the (sin x)/x distribution of the magnitude spectrum, indicates that by the zero phase angle at these frequencies the harmonic energy peaks are in phase with one another; i.e., they occur at the same instant in time. Thus, this type of impulsive acoustic radiation is usually referred to as coherent, a term borrowed from the study of optics, which infers that corresponding points on a propagating wavefront are in phase. This means the harmonic energy from an impulse arrives at the receiver at the same time or with a definite phase relationship, as opposed to an incoherent source which is composed of harmonic energies that are radiated with a random phase (time) relationship. In this regard, an impulsive source may be viewed as a much more efficient radiator in its ability to transfer energy to a receiver than a broadband, incoherent source (for a pure rectangular-shaped impulse, the phase angle is zero across the entire frequency spectrum), compared with the much longer time that is usually necessary to transfer the same total amount of broadband, incoherent energy.

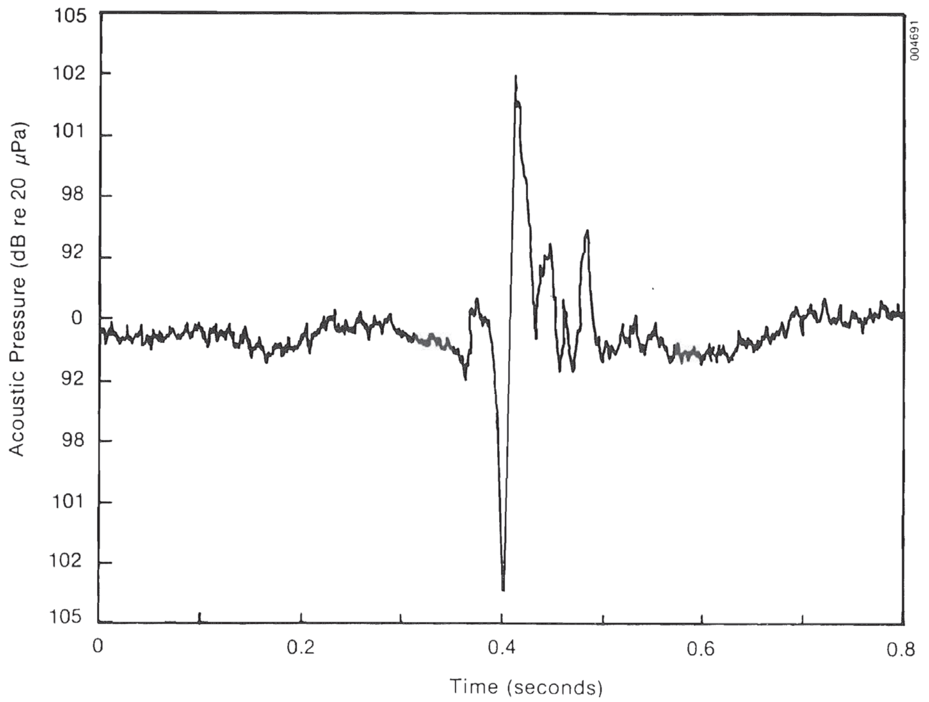


Figure 3-6. Detail of Typical Pressure-Time Plot of MOD-1 Acoustic Emissions Containing Strong Periodic Impulses. (Single blade passage by tower)

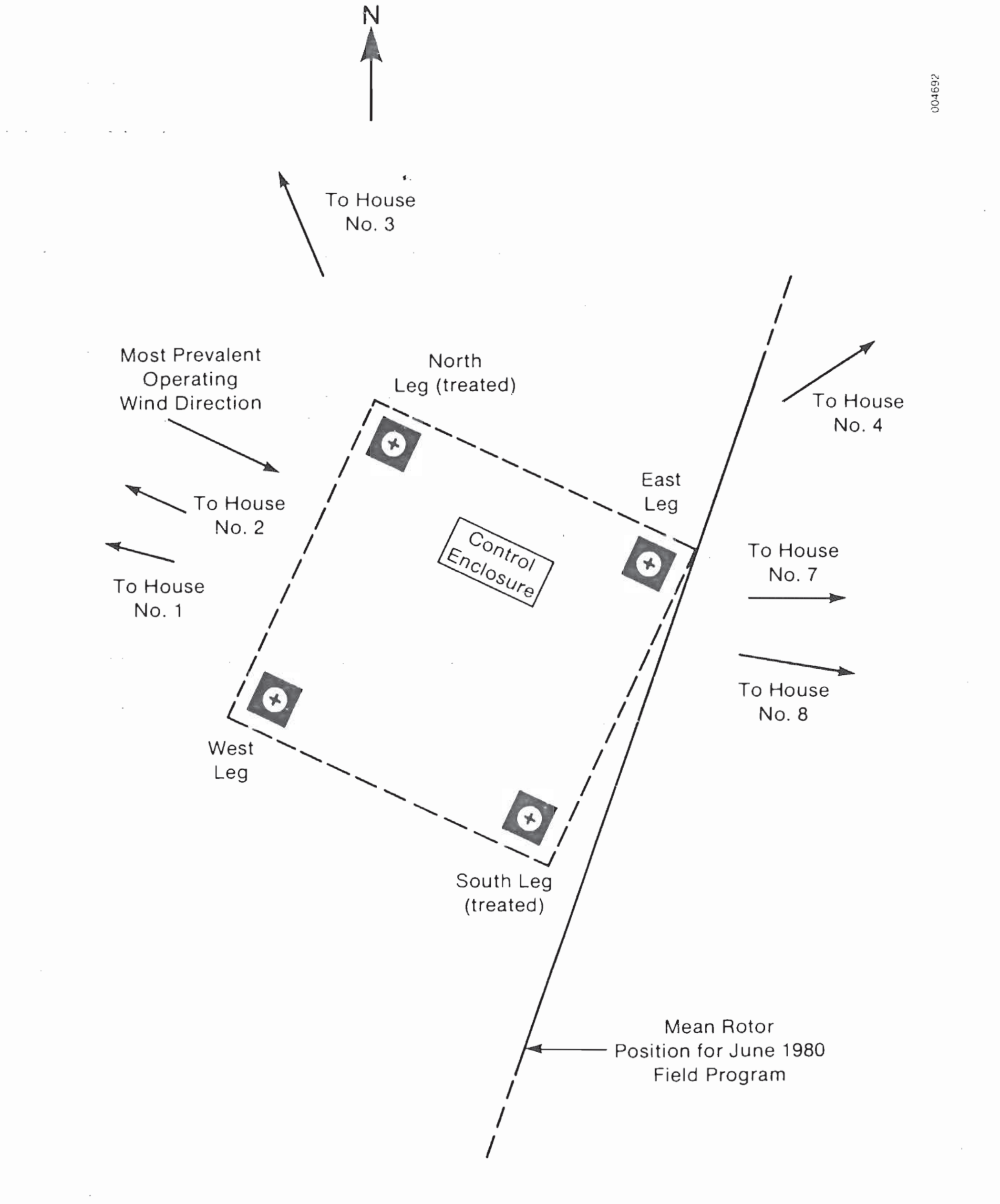


Figure 3-7. MOD-1 Tower Base Layout and Relationships to Rotor Plane, Prevalent Operating Wind Direction, and Orientations of Complainants' Homes

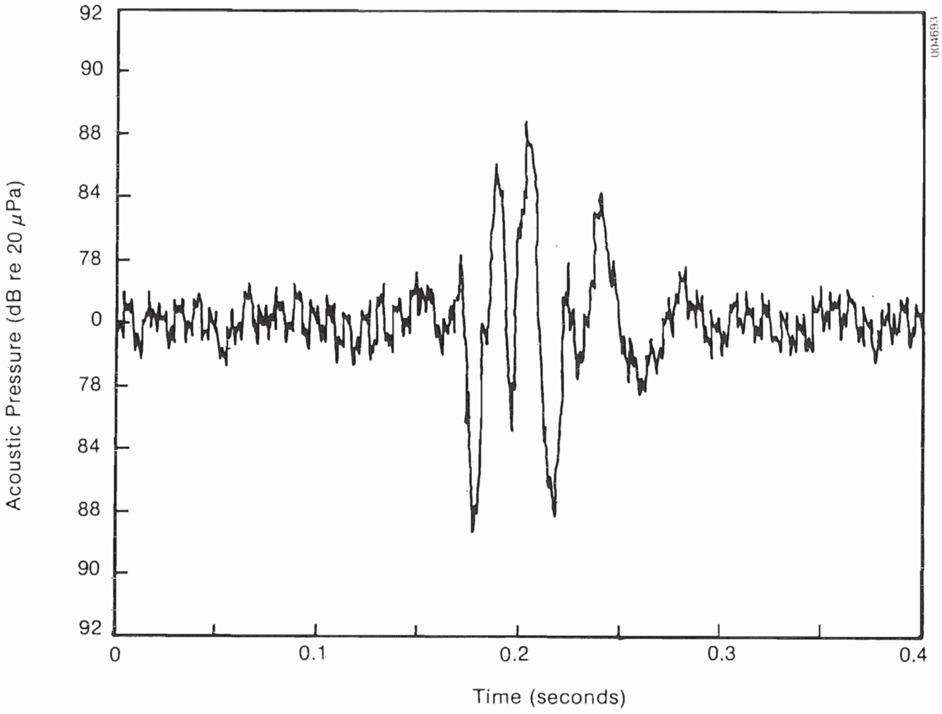


Figure 3-8. Pressure-Time Plot of Moderate-to-Severe MOD-1 Acoustic Impulse Measured Outside House #8. (Single blade passage by tower)

Coherent pulses of the type described above are best evaluated using energy techniques in both the time and frequency domains. The time domain is used to establish important waveform characteristics of the impulses; i.e., the rise time, rise rate, total energy content, and peak overpressure (underpressure or deviations from the local static pressure value). These are discussed more fully in Section 4.0. The frequency domain, through the application of the Fourier transform, provides the spectral or harmonic distribution of the impulse energy. Figure 3-10 plots the energy distribution for the impulse of Figure 3-8.

Thus, we have found that the impulsive character of the MOD-1 acoustic radiation related to the passage of the rotor blades through the downstream wakes of the cylindrical, vertical tower support members or legs is in some way responsible for the annoyance complaints.

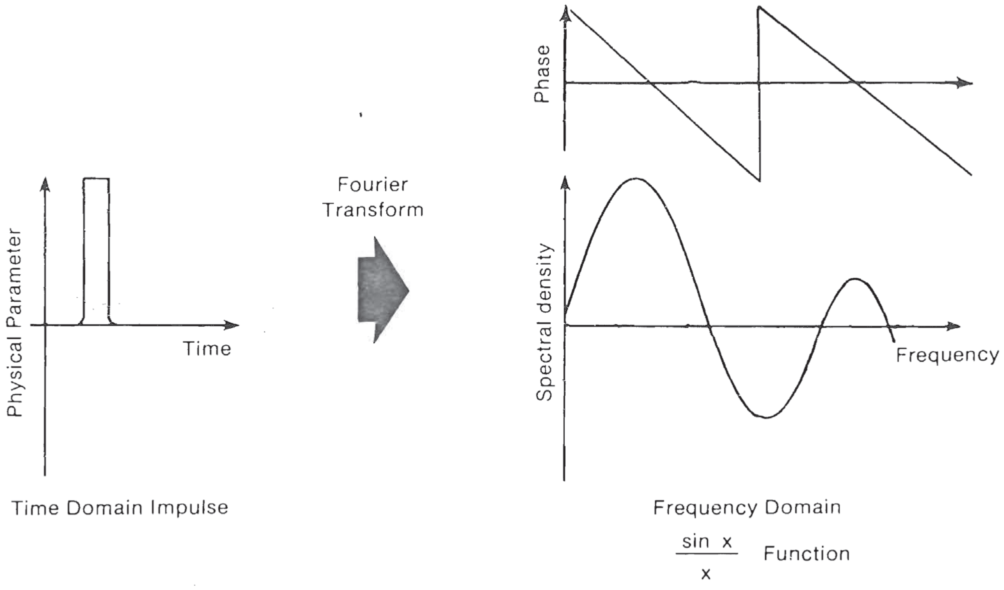


Figure 3-9. Schematic Example of the Transformation of a Time Domain Acoustic Impulse into the Frequency Domain as a (sin x)/x Function

3.1.2 Annoyance and Acoustic-Structural Interaction

After the acoustic impulse was identified as a possible source of the annoyance associated with the MOD-1, it became important to understand the mechanism(s) prompting the noise complaints themselves, particularly because people generally appeared to be more annoyed inside their homes than out. To determine the physical basis of the complaints (i.e., thumping sounds and vibrations inside the affected homes), we instrumented two of the most frequently affectd homes with acoustic and seimsic equipment and recorded the range of severity of the turbine-induced impulsive noises.

3.1.2.1 External/Internal Acoustic Fields Under Turbine-Induced Impulsive Excitation

Houses #7 (a double-wide mobile home) and #8 (a conventional 1-1/2 story frame structure) were instrumented with a pair of our VLF microphone systems, one outside the home and one in the room designated by the owners as the one in which the greatest annoyance occurred. In addition, a precision sound level meter was also installed in the room of the house to better document sounds

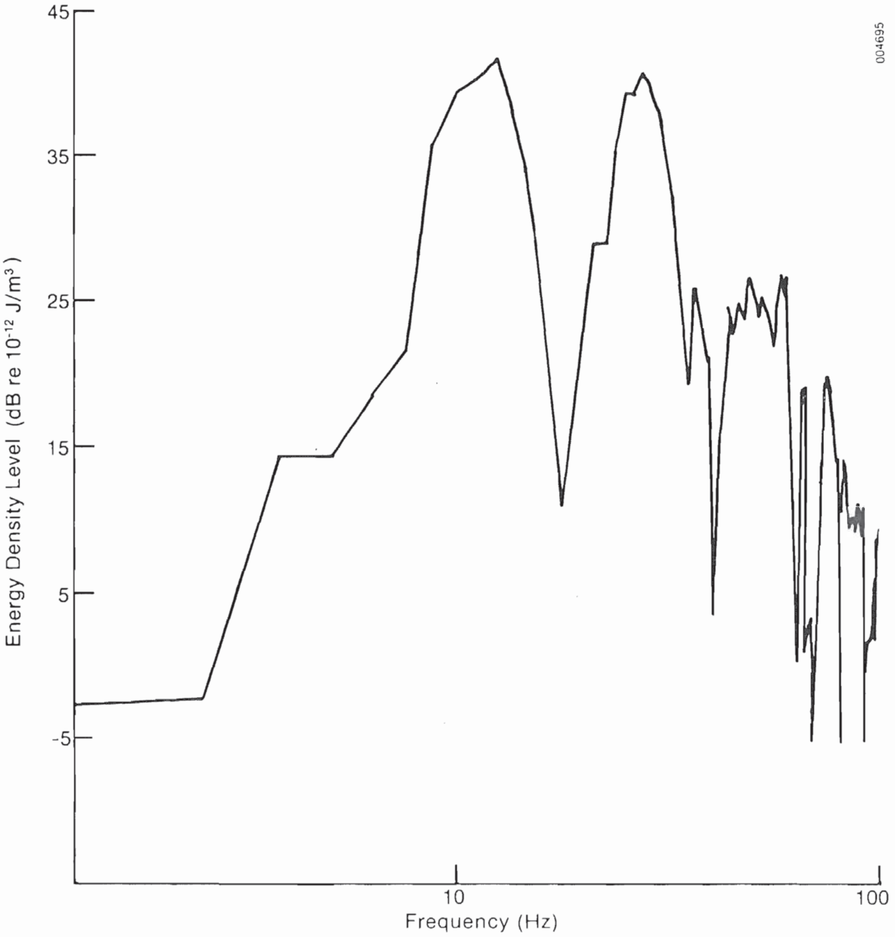


Figure 3-10. **Acoustic Energy Level Distribution of the Single Impulse Shown in Figure 3-8 Received at House #8**

in the normal audible range. We noted that both homes were equipped with storm windows and that the conventional frame house was substantially tighter. Both affected rooms were bedrooms; the room in House #8 has a single window that faces the turbine site. House #7 has two windows that face in the direction of the machine, but it could not be seen because the house was near a steep grade at the base of Howard's Knob.

Figure 3-11 shows the external pressure excitation of the radiated impulse and the resulting indoor pressure trace in the 31.5-Hz octave frequency band in the bedroom of house #8 under moderate-to-severe impulsive annoyance. As shown, the indoor pressure impulse lasted for a period of over a second, in contrast to the two individual impulses outside the house which lasted for only a few milliseconds each (care was taken to ensure that there was no ringing of the filter). Further, there was a time delay between the arrival of the acoustic peak pressure at the outdoor microphone and the initial onset of the internal reaction in the 31.5-Hz band of about 125 ms. The physical separation between the two microphones was about 23 m, and the outdoor one was closer to the wind turbine. The separation at this altitude and air temperature would account for only 73 ms or only about 60%, of the observed delay, which indicated that some form of a dynamic process with storage was involved.

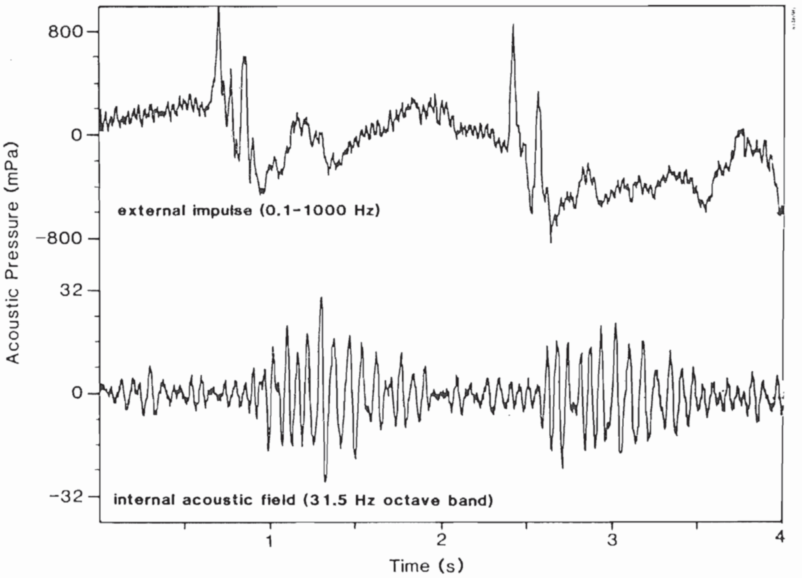


Figure 3-11. Plot Showing Time Delay between Arrival of Outdoor MOD-1 Impulse and Onset of 31.5-Hz Octave Band Acoustic Pressure

The coherent output power* plots of Figures 3-12 and 3-13 for houses #7 and #8, respectively, indicate that the transmission of impulsive acoustic energy into the house was dispersive because of the observed frequency dependency and not simply a pure delay. The spectra of Figures 3-12 and 3-13 contain peaks at the power line frequency of 60 Hz and its harmonics, the source of which were humming transformers near both homes.

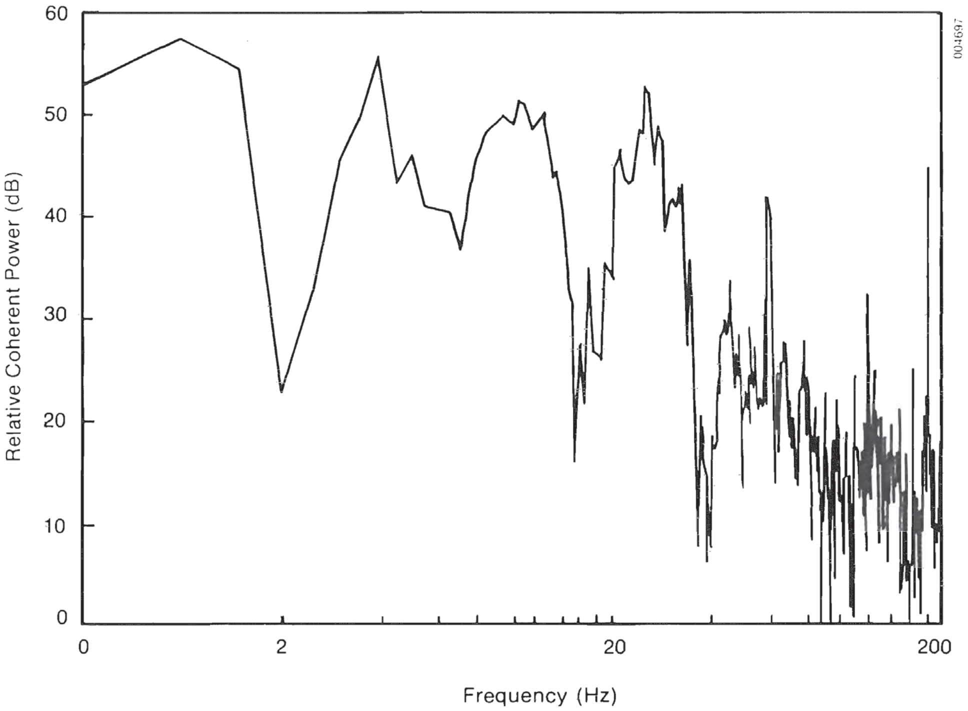


Figure 3-12. External-Internal Acoustic Coupling Modes of House #7 under MOD-1 Impulsive Excitation

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*Coherent output power is derived from the product of the squared coherence function and the measured output power spectrum (in this case the indoor acoustic pressure under the excitation of the external impulse) which is useful for determining dynamic interdependence when the output signal may be contaminated with signals containing energies at similar frequencies; e.g., it is the part of the output signal which is coherent with the excitation.

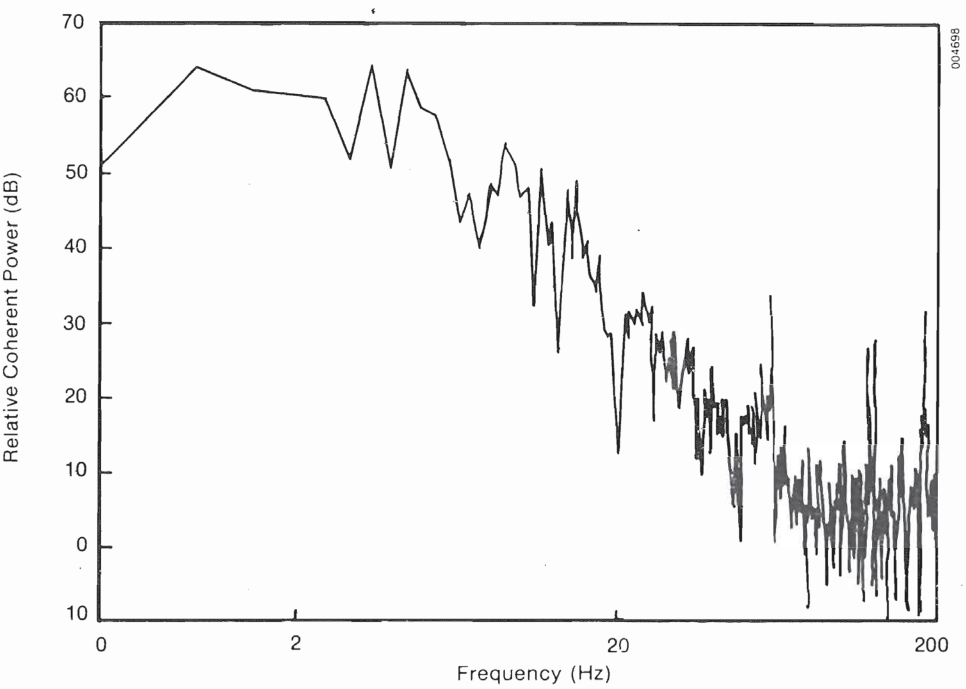

Figure 3-13. External-Inernal Acoustic Coupling Modes of House #8 under MOD-1 Impulsive Excitation

To compare acoustic pressure fields accompanying moderate annoyance epsisodes in house #8 with the threshold perception measured at house #7, we analyzed the differences between indoor and outdoor sound pressure levels and the indoor levels as a function of the existing acoustic environment. These results are presented in Figures 3-14 and 3-15. The interior peak overpressures above background for moderate and threshold excitation levels forcing compared with peak outdoor levels are shown in Figure 3-16. Figure 3-17 presents the energy density level spectrum for a typical impulse striking house #7 that permits threshold perception. See, in comparison, the energy density level spectrum of a moderate-to-severe impulse at house #8 in Figure 3-10.

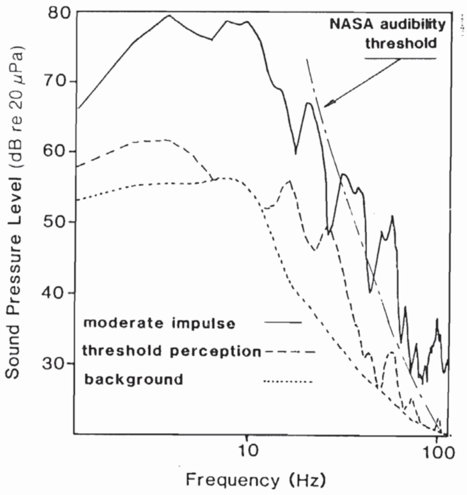

Figure 3-14. Peak Interior South Pressure Levels Observed in Houses #7 and #8 during Threshold Perception and Moderate Impulsive Annoyance Conditions, Respectively ($B_e = 1.25$ Hz)

3.1.2.2 Structural Response in Houses #7 and #8 under Turbine-Induced Impulsive Excitation

Figures 3-18 and 3-19 plot the frequency spectra of the horizontal component of the floor vibration under moderate (house #8) and threshold (house #7) perception. In both cases, the sensitive axis of the accelerometer was parallel to the major floor supports, pointing toward the wind turbine. The relative transmissibility function T_r, defined by

$$T_r = \left\{\frac{1 + [2\zeta f/f_n]^2}{[1 - (f/f_n)^2]^2 + [2\zeta f/f_n]^2}\right\}^{1/2} = \left.\frac{G_p(f)}{G_a(f)}\right]^{1/2} , \qquad (3-2)$$

(where

ζ is the damping ratio of the house mechanical/acoustic/elastic structure given by $c/2\ (km)^{1/2}$ and c, k, and m are the effective damping, stiffness, and mass

f is the cyclic frequency

f_n is the natural frequency of the structure

$G_p(f)$ is the power spectrum of the interior acoustic pressure field and

$G_a(f)$ is the floor/wall acceleration power spectrum),

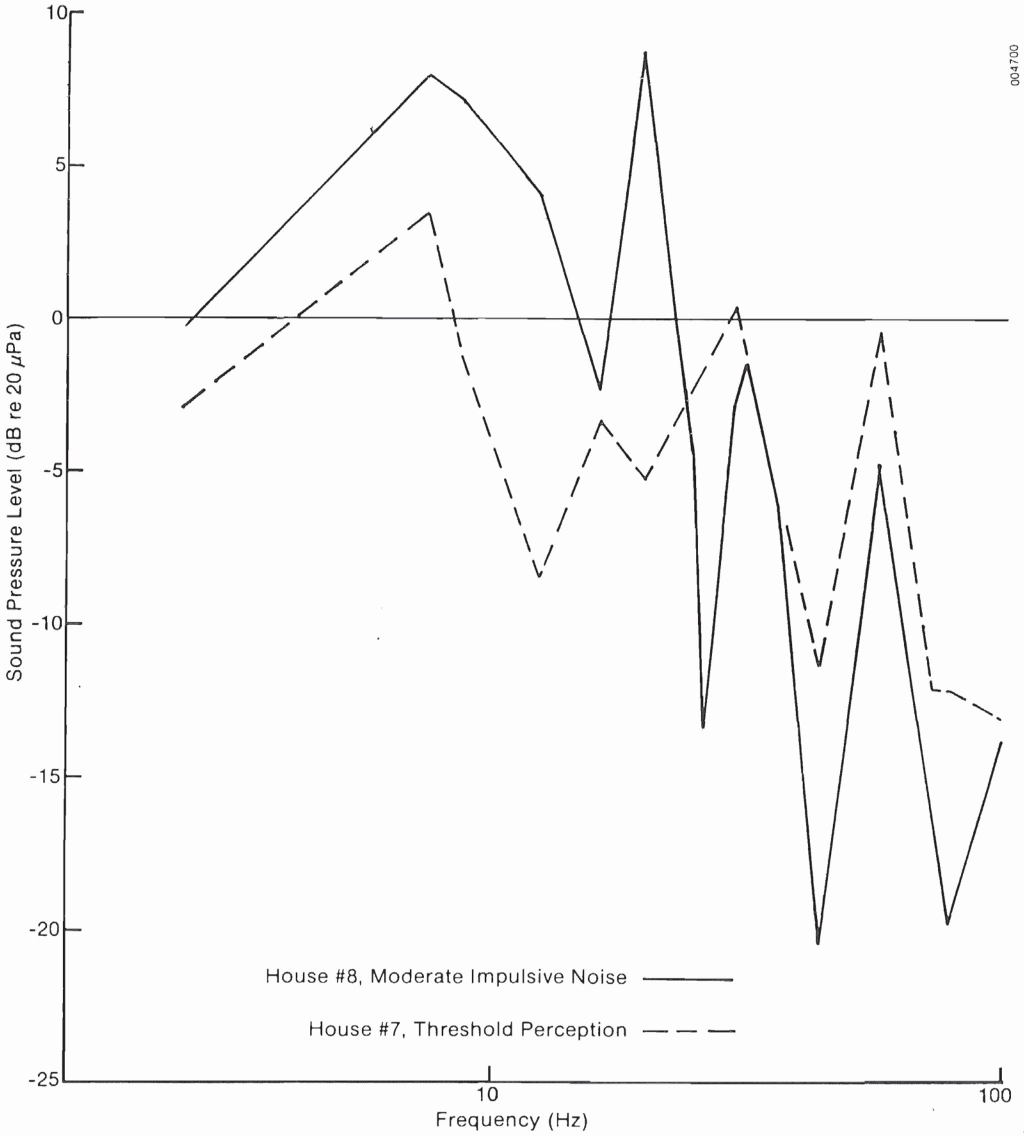

Figure 3-15. Peak Internal-External Sound Pressure Level Differences for Moderate Annoyance and Threshold Perception in Houses #7 and #8 (B_e = 1.25 Hz)

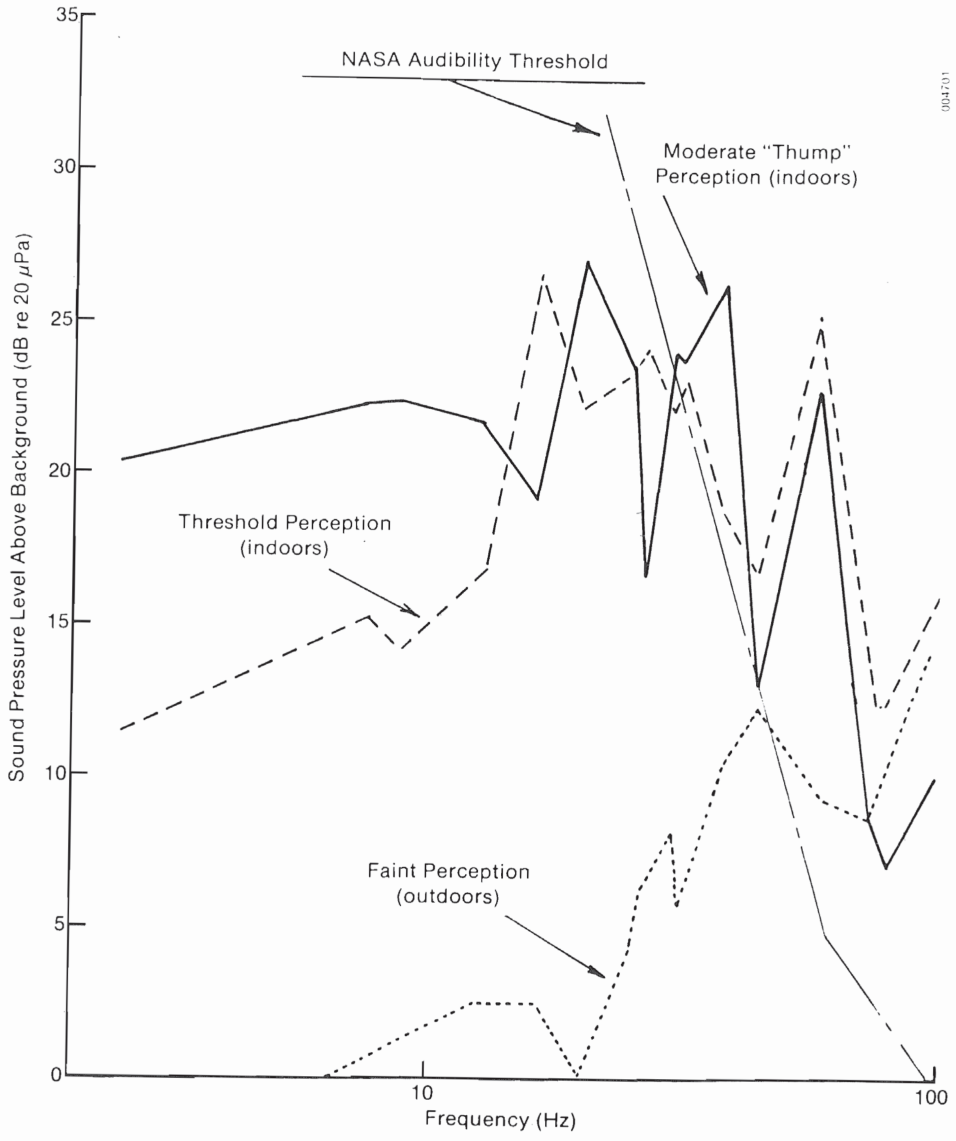

Figure 3-16. **Peak Sound Pressure Levels above Background for Moderate Impulsive Excitation (Outdoors and Indoors, House #8) and Threshold Perception (Indoors, House #7)** (B_e = 1.25 Hz)

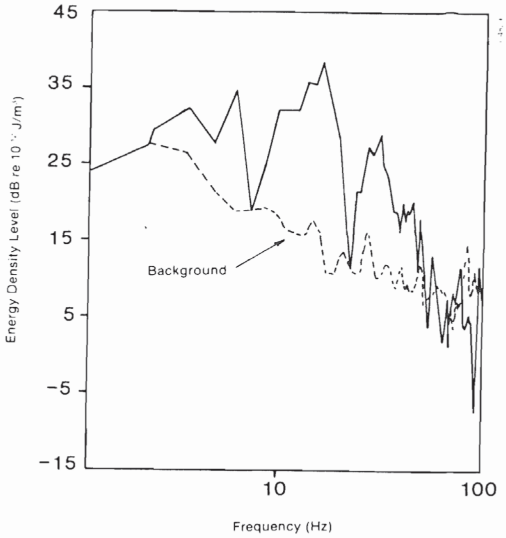

Figure 3-17. External Acoustic Energy Density Level Narrowband Spectrum for Single Impulse Corresponding to Threshold Perception in House #7 (B_e = 1.25 Hz)

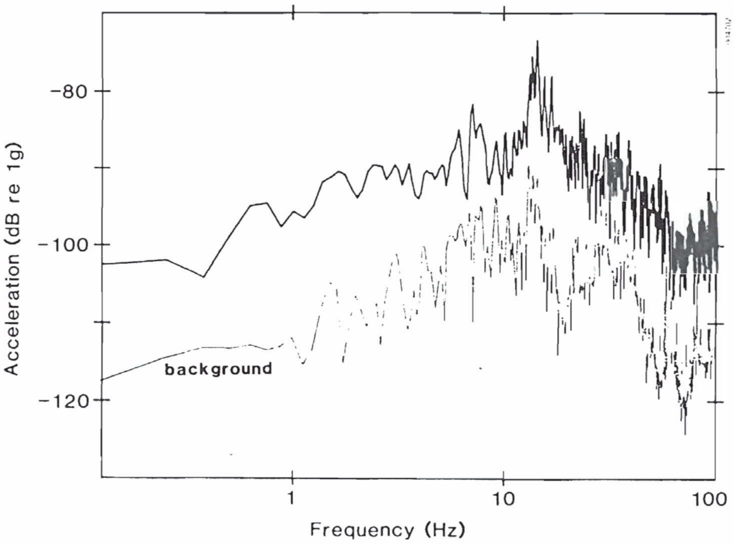

Figure 3-18. Background and Peak Horizontal Floor Acceleration Levels in House #7 during Perception-Level MOD-1 Impulsive Excitation (B_e = 1.25 Hz)

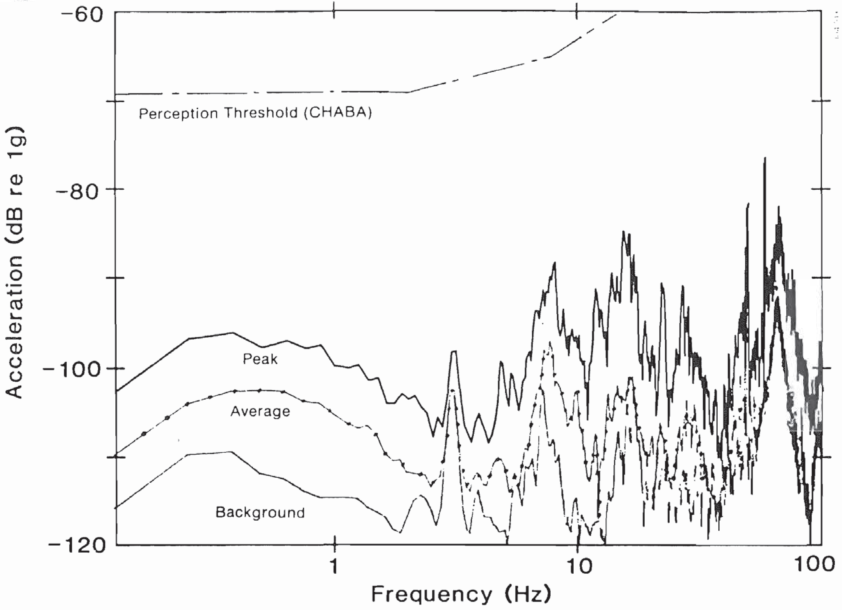

Figure 3-19. Peak, Average, and Background Horizontal Floor Acceleration Levels in House #8 during Moderate Annoyance MOD-1 Impulsive Excitation (B_e = 1.25 Hz perception threshold: see Ref. [50])

is plotted in Figure 3-20 for the acoustic pressure field of the affected room of house #8, using both the vertical and horizontal floor accelerations as the forcing (made relative by setting the levels equal, or 0 dB at f = 0.2 Hz). Equation (3-2) describes the dynamic interaction between the walls and air volume contained within the affected room and, in this case, indicates the level of dynamic coupling between the mechanical forcing of the floor vibration (displacement) and the room acoustic pressure. As shown in Figure 3-20, the horizontal floor motion is coupled more to the pressure field in several frequency bands than the vertical mode is. This agrees with the low acceleration levels measured in the vertical orientation, plotted in Figures 3-18 and 3-19 for houses #7 and #8. Note the dynamic relationship between the external pressure forcing by turbine-generated impulses and the elastic response of the vertical floor acceleration plotted in Figure 3-21; the maximum occurs in the 10-20 Hz frequency band, with less prominent effects in the 20-40 and 40-80 Hz bands.

3.1.2.3 Groundborne (Seismic) Propagation/Excitation by Turbine

At the beginning of the field measurement program, we did not know if groundborne noise propagation from the MOD-1 turbine was a factor in the disturbance of residents living near the base of what was thought to be a solid granite mountain. To answer this question, the Penn State Group installed two Hall-Sears Model HS-10-1 seismometers (geophones) to record any ground excitation by the turbine that might occur near the foundations of houses #7 and #8.

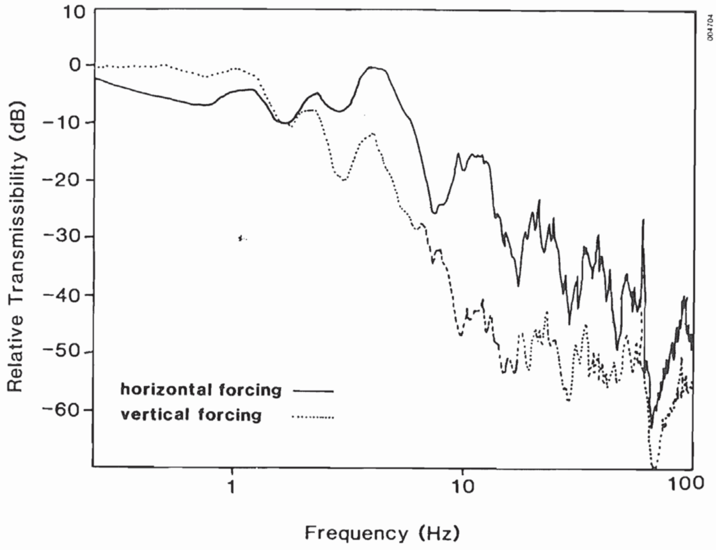

Figure 3-20. Horizontal and Vertical Plane Acceleration (Deformation)-Forced Internal Acoustic Pressure Transmissibility for House #8 under Moderate Impulsive Excitation ($B_e = 1.25$ Hz)

During the recording period, footsteps of persons in the vicinity were much more prominent than the turbine impulses, which indicated that the disturbance was being transmitted by airborne propagation. Ground velocities measured when the turbine was operating and when annoyances were being reported were less than 0.16 μm-s^{-1} (0.4 μ-inch-s^{-1}). Figure 3-22 plots typical ground motion velocity spectra for a period at house #8 when residents were reporting impulsive annoyance [3].

3.2 FACTORS AFFECTING NOISE GENERATION

When we discovered that the annoyance was associated with the strong acoustic pressure impulses produced as the turbine's blades passed behind the large, cylindrical tower legs, we directed our attention to the air flow around the legs, the truss-lattice tower as a whole, and the resulting downstream wakes through which the blades passed. A NASA wind tunnel study of the wake characteristics of a 1/40th-scale model of the MOD-1 [4] showed that pronounced mean velocity deficits existed in the lee of the vertical leg members. The shape and magnitude of the deficits depended in part on the orientation of the wind flow into the turbine tower structure. Unfortunately, the characteristics of these wakes had been measured at an equivalent distance of about 40 leg diameters downstream, but the actual blades can come as close as 4 leg diameters. While the study did provide a basis for more investigation, details about the wake structure could not be ascertained from reported data.

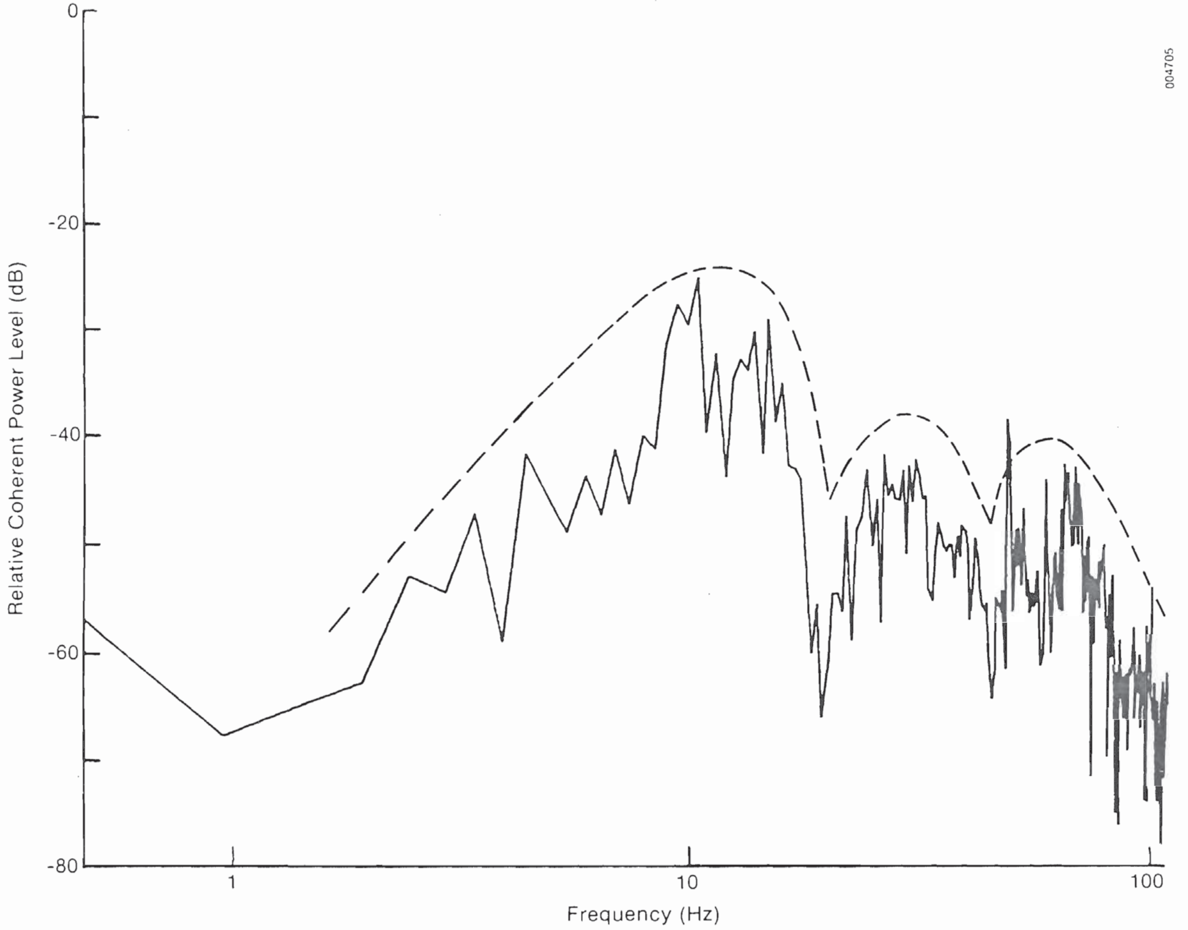

Figure 3-21. **Elastic (Deformation) Response of Floor Vertical Plane in House #8 under Moderate, External Impulsive Acoustic (Pressure) Loading** (B_e = 1.25 Hz)

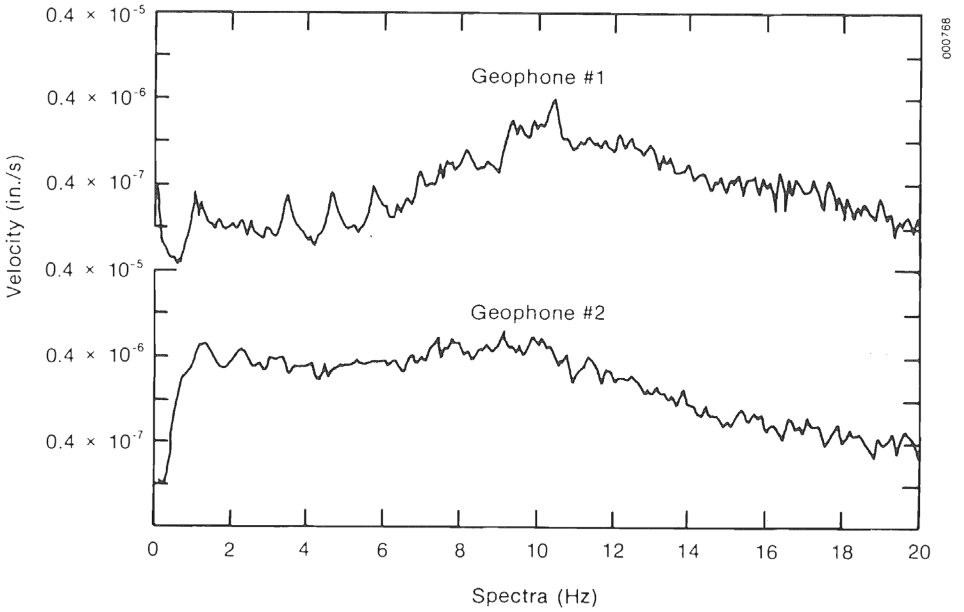

Figure 3-22. Ground Motion Velocity Spectra Measured near House #8 when Undergoing Moderate Impulsive Annoyance (B_e = 1.25 Hz)

The conclusions we drew at this point in the investigation were that (1) the leg wakes were the primary source of the impulsive noise generation; (2) the orientation of the turbine nacelle might be partly responsible (per Ref. [4]) and (3) the actual physical process was aerodynamic (aeroacoustic) because of the variation in lift experienced by the blades passing through the tower leg wakes. The third conclusion helped us to realize that the rotor speed (principally the tip speed, which was known to be a major design parameter in aerodynamic noise generation) and perhaps the commanded electrical load as well were also factors to be considered--particularly the former, since a reduction in tip speed reduced noise output from propeller and fan blades.

3.3 FACTORS AFFECTING THE PROPAGATION OF THE TURBINE NOISE

From our first visit to the MOD-1 site in October 1979, we recognized the role atmospheric propagation could play in annoying the surrounding families. The isolated peak is surrounded by deep valleys that can trap layers of colder, still air, while strong winds were prevalent at the turbine site. Such a situation is highly conducive to strong atmospheric refraction of sound waves from the turbine down into the valleys below. The Penn State Group found that the vertical wind shear, particularly to the east of Howard's Knob, is the primary factor in conjunction with ground reflection in the enhancement of the turbine impulse levels received at houses #7 and #8 [3, 30]. They have also found that the low-frequency components of the impulse could also be propagated upwind of the site, which resulted in frequent annoyance of the residents in house #2 (see Figure 1-2). Thus, the factors controlling the propagation of sound away from the turbine include (1) the complex terrain surrounding the site; (2) the vertical wind shear plus the thermal structure in the layer bounded by the area immediately above the elevation of the turbine to the valley floors below; and (3) the wind direction that prevailed when the turbine was operating.

3.4 INITIAL CONCLUSIONS BASED ON FIELD MEASUREMENTS

After the first three field surveys were completed, we reached the following conclusions about the MOD-1 noise situation:

- The residents' annoyance in several homes near the turbine was real and not imagined.
- Acoustic and vibration measurements supported the residents' observations, at least as to time if not always in terms of accepted annoyance levels.
- The physical mechanism responsible for the impulsive noise generation was related to the dynamic characteristics of the wakes downstream of the large, vertical tower legs and some form of a transient lift fluctuation, and the attendant acoustic pressure impulse radiated as the rotor blades passed downwind of the tower.
- The greater part of the impulse acoustic energy responsible for the annoyance was very low frequency, and the observed peak was generally below the "normally" audible lower limit of 20 Hz.
- The physical mechanism responsible for the complaints, particularly the higher levels observed in the homes, was the considerable energy contained in the impulses, their coherent characteristics, and the dynamic interaction with the building structures discussed in Section 3.1.2.
- The source of the annoyance was the acoustic pressure impulses propagated through the air rather than through the ground.
- Some sort of enhancement of the impulses at homes in the valleys below the turbine was taking place through the mechanism of terrain and atmospheric refraction which depended upon meterorological conditions in the complex terrain surrounding the site.
- Measures had to be taken to reduce the generated impulses below detection levels, given that the source was aerodynamic and that reducing the blade tip speed had met with some success in other cases of propeller or fan noise.

We preferred to begin solving this problem by understanding the physical mechanisms involved in the noise generation, propagation, and resulting subjective impact on the families affected. In that way we could identify the physical parameters responsible, including both important turbine design and critical environmental parameters that needed to be pointed out to planners and designers of second- and third-generation machines. In the following sections, we summarize the results of this effort.

SECTION 4.0

ANALYSIS AND INTERPRETATION

In this section, we discuss the results of our investigation into the physical parameters of the generation, propagation, and impacts of the acoustic noise associated with the operation of the MOD-1 turbine. The conclusions are based on the results of the five field measurement periods undertaken at the MOD-1 site and on supporting experimentation performed with models under controlled conditions in wind tunnels and with full-scale turbines operating in the natural environment. We also briefly discuss the results of analytical modeling done at MIT's Fluid Dynamics Research Laboratory and at Penn State in aerodynamic noise generation and atmospheric sound propagation, respectively.

4.1 AEROACOUSTIC NOISE GENERATION MECHANISMS

As discussed in Section 3.1.1, the source of the residents' complaints was traced to the acoustic impulses being generated as the rotor blades passed through the wakes of the large, cylindrical tower legs. While the NASA wind tunnel study [4] gave some clues as to the physical aeroacoustic mechanisms involved, the far-wake position of the profile measurements and the presentation in terms of averaged quantities were limited in applicability to the situation in Boone, N.C. Examination of the characteristics of the waveshape and the severity of the impulses generated under a range of conditions revealed not only the cases sited in Section 3.1.1 (from no impulses present to the most severe situation) but impulses whose waveforms varied considerably. Closer study revealed that while the impulse waveform shape varies from blade to blade passage in some detail, it also tends to take on a more or less specific shape over a few minutes in a given situation.

4.1.1 Aeroacoustic Mechanism for Impulse Noise Generation

To understand the pertinent physical characteristics present in the tower leg wakes and to determine what is responsible for the severe impulsive action, we need to review the aerodynamic (aeroacoustic) process that is functioning to radiate the acoustic pressure field. Acoustic impulses similar to those found with the MOD-1 have also been observed with the rotors of helicopters in which the physical mechanism is believed to be the interaction of the rotor with a vortex shed by the passage of a previous blade. The impulsive noise from a helicopter rotor can be very annoying and, of course, clearly gives away the aircraft's presence. Fortunately, except for the detectability problem, the period of impulsiveness is generally short and related to certain maneuvers of the aircraft. Understandably, this has been and continues to be an area of considerable research.

4.1.1.1 Rotor Noise Characteristics

Wind turbines exhibit many of the noise generation mechanisms associated with low-speed rotating blades utilizing aerodynamic lift, particularly those using high lift airfoil shapes. Rotating blade noises are generally classified into three major mechanisms that effectively function as acoustic dipoles at low Mach numbers: noises caused by steady forces on the blades, noises emanating from periodic sources, and those coming from random or nonperiodic sources.

Steady Forces. Steady forces of lift and drag produce noise that, as first pointed out by Gutin [52], is modulated in frequency by the motion of the blade at a fixed observer location by the Doppler effect. These sources account for noise that contains relatively high energy at discrete frequencies close to the blade passage frequency (when viewed in terms of an average of several blade passages) but suffers from poor radiation efficiency [5,6]. It is usually impossible to identify the steady load noise, particularly in the case of a full-scale wind turbine, because it is masked by other, more effective sources.

Unsteady Forces. Unsteady forces on the blades as they move around the rotor disk can be classifed as either periodic or non-periodic. Periodic sources arise from fluctuating asymmetric disk loading resulting from blade-to-blade interactions, vortex interactions (helicopter blade slap), etc. These reflect coherent sources (see Section 3.1.1 for a definition of coherency) and are characterized by discrete noise with high energy and moderate radiation efficiency, which results in the extension of the discrete noise to relatively high frequencies in an averaged acoustic spectrum. If sufficiently strong, these can be most annoying. Nonperiodic or random fluctuating loads, in contrast, are brought about by sources such as wind shear, inflow turbulence, and blade vortex shedding. These sources are usually characterized by broadband, incoherent noise having high energy and moderate radiation efficiency. Such sounds are often described as the "swishing" noise associated with the blade passage of a wind turbine. The unsteady forces are usually sufficient to mask noise being created by the steady blade loads. Figures 3-1 and 3-4 illustrate the averaged sound pressure spectra that contain a predominance of periodic or nonperiodic sources.

4.1.1.2 Physical Basis for Impulsive Noise Generation

This discussion follows that of George [7] in which he discusses the physical mechanisms that lead to acoustic radiation from rotor blades employing aerodynamic lift. Lighthill [8] showed that the equations of mass and momentum conservation, while they allow for mass sources and applied forces in the fluid, could be put in the form of wave equation on the left-hand side with all other terms on the right, or

$$\frac{\partial^2 \rho}{\partial t^2} - c_o^2 \frac{\partial^2 \rho}{\partial x_i{}^2} = \frac{\partial Q}{\partial t} - \frac{\partial F_i}{\partial x_i} + \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j} , \tag{4-1}$$

where

ρ = density

c_o = the undisturbed sound speed

Q = mass source strength, mass/volume x time

F_i = force/volume = momentum/volume x time

T_{ij} = Lighthill stress = $\rho u_i u_j + (p - c_o^2 \rho)\delta_{ij} - \sigma_{ij}$

σ_{ij} = viscous stress tensor.

For the wind turbine situation, the operating tip Mach number (~ 0.3) and observed radiated frequency range (i.e., acoustic wavelengths >> rotor blade physical dimensions) may allow mass (thickness) and viscous stress effects to be ignored and the source may be considered a point dipole (compact assumption). By applying the equation of state one can obtain the pressure as the desired dependent variable. Equation (4-1) now becomes, for the acoustic far-field,

$$p - p_o = \hat{p} = \frac{x_i}{4\pi c_o r^2} \frac{\partial F_i}{\partial t} \left(t - \frac{r}{c_o} \right) , \qquad (4-2)$$

where r is the distance to the observer from the compact dipole source and $\partial F_i/\partial t$ is evaluated at $t-r/c_o$, the "retarded time." Following the development of Leverton and Amor [9], we define a blade loading per unit span, ℓ_s (x, t), perpendicular to the plane of rotation, or

$$\delta F_i \equiv \delta F_n = \ell_s \delta x, \qquad (4-3)$$

where δx is a small increment over which ℓ_s acts; then,

$$\delta \hat{p} = \frac{X_n}{4\pi c_o r^2} \frac{\partial \ell_s}{\partial t} (t - r/c_o) \delta x. \qquad (4-4)$$

If we now integrate over the span x = 0 to x = span assuming that the differences in retarded time over the span can be neglected (i.e., either λ >> span or for on-axis noise), then,

$$\hat{p} = \frac{X_n}{4\pi c_o r^2} \frac{d}{dt} \int_o^{span} \ell_s(x,t) \, dx , \qquad (4-5)$$

which shows that the radiated sound depends on the net correlated lift over the span. If ℓ_s(x, t) is of the form L(t) f(x), then,

$$\hat{p} = \frac{X_n}{4\pi c_o r^2} \frac{dL(t)}{dt} \delta_c , \qquad (4-6)$$

where the effective correlated span length is defined as

$$\delta_c \equiv \int_o^{span} f(x) \, dx . \qquad (4-7)$$

This indicates that acoustic pressure radiated from a blade undergoing lift fluctuations is a function of the span length simultaneously involved. Another way to view the concept is as a spanwise (line) source of simple point dipoles radiating in-phase or coherently. From the discussion in Section 3.1.1, we see that this situation corresponds to a very efficient acoustic radiator. Thus, the more spanwise correlated is the lift, the more coherent is the radiated acoustic pressure field. Using Eq. (3-1), we can now write the expression for the energy intensity of the radiated impulse for an observer in a fixed location as

$$E_I(t) = \frac{1}{\rho c_o} \int_o^T \hat{p}^2(t)\ dt = \frac{X_n^2\ \delta_c^2}{16\pi^2 \rho c^3 r^4} \int_o^T \left[\frac{dL(t)}{dt} \right]^2 dt \quad . \qquad (4\text{-}8)$$

Equation (4-8) now directly relates the energy content of the radiated acoustic impulses to the coherent or spanwise correlated lift fluctuations on the blade surface. The blade loading function $\ell_s(t)$ for each increment of the correlated span length can be expressed in terms of a series of loading harmonics through the use of the Fourier Transform, or

$$\tilde{L}(f) = \int_{-\infty}^{\infty} L(t)\ e^{-i2\pi ft}\ dt = \left| \tilde{L}\ (f) \right|\ e^{i\phi(f)} \quad , \qquad (4\text{-}9)$$

where the far right expression relates to the amplitude or magnitude loading spectrum and the phase spectrum $\phi(f)$, both of which are required to completely define L(f). In terms of the time domain utilizing the inverse transform,

$$L(t) = \frac{1}{\pi} \int_o^{\infty} \tilde{L}(f)\ e^{i2\pi ft}\ df \ , \qquad (4\text{-}10)$$

where the integration is carried out over a period T corresponding to an impulsive lift fluctuation for (4-10) and an upper frequency limit of interest for (4-11). Similarly, the same transform may be applied to the square of the dynamic pressure $p^2(t)$ to acquire the harmonic acoustic energy P(f).

With the use of the Fourier Transform, both sides of Eq. (4-8) can be viewed in terms of the frequency domain or observed acoustic pressure harmonics that have their origins in the harmonics of the unsteady blade loads. This relationship is reasonable for impulsive-type noise where Doppler modulation has very little influence due to the very short time periods and small segments of the rotor disk involved. Wright [5,6], for example, has shown that the essence of the blade loading spectrum is carried through to the acoustic spectrum even when the Doppler effect cannot be disregarded. Equations (4-8) and (4-10) now give us a tool for additional insight into the nature of the unsteady lift fluctuations occurring on the blades of the MOD-1 for they allow us to examine both the time-pressure signature (Eq. 4-8) and the instantaneous and averaged frequency spectra (Eq. 4-10).

4.1.1.3 Impulse Waveform Analysis and Interpretation

The discussion of the previous section pointed out that the essence of the lift transients responsible for the impulsive radiation can be interpreted from the acoustic pressure time signature. To see this more clearly, we repeat Eq. (4-6):

$$\hat{p}(t) = \frac{X_n}{4\pi c_o r^2} \frac{dL(t)}{dt} \delta_c \quad .$$

This equation indicates that the dynamic pressure field is proportional to the rate of change of the lift correlated in time over a given portion of the blade. The resulting acoustic pressure wave form can be interpreted in terms of the effect on the radiated frequency spectrum as follows:

1. Impulse rise time (seconds): this is the time required for the pressure to rise (or fall) from 10%-90% of peak pressure change. The smaller the value, the greater the amount of energy present at higher frequencies; i.e., this has a major influence over the radiated spectral shape, the location of spectral band energy.
2. Impulse peak dynamic (over or under) pressure (dB re 20 μPa): this parameter controls the level of impulse energy present across the spectral bands specified by the rise time.
3. Impulse rise rate (rate of change of radiated acoustic pressure, Pa/s): this parameter combines the spectral influences of (1.) and (2.) above (i.e., both the spectral shape and energy content) and is more convenient to measure particularly when the impulse period is very small.
4. Total impulse energy intensity (mJ/m^2): this is defined in Eq. (3-1), which describes the total dynamic pressure energy per unit area contained in the impulse.

In summary, the impulse rise time controls the spectral frequency distribution; the peak dynamic pressure controls the level of energy in the various spectral bands; and the total impulse energy intensity controls the total energy available to be distributed spectrally by the first two. In terms of the unsteady, transient lift on the turbine, Eq. (4-6) tells us that the peak dynamic pressure is determined by the maximum rate of lift change and the rise rate by the period of time in which this change takes place. Equation (4-8) indicates the energy intensity is the area under the impulse pressure curve. Thus, by examining the impulsive waveshapes, quantified in terms of the parameters above, we have a basis for understanding what may be occurring aerodynamically on the blade itself, the severity of the occurrence in terms of energy content and spectral distribution, and we find grounds for comparing different operating conditions and the effectiveness of various amelioration techniques.

4.2 MULTIVARIATE STATISTICAL ANALYSIS OF PARAMETERS RELATED TO IMPULSIVE NOISE GENERATION

In order to isolate the parameters influencing the impulsive noise associated with the MOD-1, a data analysis technique was developed to correlate three of the impulse waveform parameters: peak dynamic (over) pressure, rise rate, and energy intensity (the operational parameters were believed to be in some way responsible). These operational parameters included the hub-height windspeed, nacelle azimuth angle, generator output power, blade attack and pitch angles, and rotor rotational speed. These data, plus one or two additional parameters discussed below, were then synchronized in time with acoustic impulse information and input to a multivariate, linear regression analysis to identify important correlations. The results of this analysis are discussed in Section 4.2.2.

4.2.1 Impulse and Operational Data Reduction

4.2.1.1 Impulse Data Reduction

Data from the March and June 1980 field studies were stratified into about 3-minute records that exhibited relatively stationary statistics. This was necessitated by the fact that the MOD-1 noise situation (including generation, propagation, and impact) was a nonstationary process. Impulses found in the acoustic signal (derived from the on-axis, upwind microphone) were processed with the spectrum analyzer in the time domain mode and under the control of an external computer. Special software was developed to obtain sample estimates of the populations of the three waveform parameters plus a reference nonimpulsive sound pressure level. The sample statistics of these parameters were then assembled for each 2- to 3-minute record of interest including the sample mean, variance, and peak and minimum values, and a frequency distribution was plotted of each. The process could also be synchronized to obtain statistical summaries of the impulses generated in the lee of each tower leg for comparison.

4.2.1.2 Operational Data Reduction

The periods to be analyzed for the impulse data reduction process discussed in the previous section were chosen from one-second samples of turbine operational data that had been digitized and scaled by a specially programmed minicomputer system. After the periods for analysis had been identified, the one-second samples that composed these segments were processed to acquire sample statistics of each. Impulse data and operational sample statistics were then merged into a single data file for each record segment analyzed.

4.2.2 Analysis Results

A series of bivariate correlations were calculated for the master data file. The independent variables included the nacelle azimuth (essentially the mean wind direction), wind speed, rotor rotational speed (rpm), generator output power, and the pitch and attack angles.

We recognized early that the position of the rotor blade in terms of its downstream distance from the tower legs was also a factor to be considered and a function of the nacelle azimuth angle. The closest approach of rotor blades to a tower leg occurred when the nacelle was oriented along the structure's diagonal [about 4 leg diameters, or 2.1 m (see Figure 3-7)]. The following expressions were derived to locate the rotor plane in terms of the downwind distance from each of the tower legs, in leg (cylinder) diameters, identified as the north, east, south, and west legs in Figure 3-7:

$$\begin{aligned} D_n &= 12 \cos(\psi + 315) + 16 \\ D_e &= 12 \cos(\psi + 225) + 16 \\ D_s &= 12 \cos(\psi + 135) + 16 \\ D_w &= 12 \cos(\psi + 45) + 16 \quad , \end{aligned} \tag{4-11}$$

where n, e, s, and w are the distances in leg diameters downstream of the identified tower leg and ψ is the nacelle yaw angle in degrees (differs from the true azimuth (w.r.t. geographic north) by addition of 28 degrees or 0.49 rad).

Figures 4-1 through 4-12 present representative bivariate distributions of the waveform parameters with a range of independent variables, including the nacelle azimuth angle (w.r.t. to true north), hub-height wind speed, blade pitch angle, minimum blade-to-leg distance, generator output power, and blade rotational speed (rpm). With the exception of one or two to be discussed separately, these bivariate distributions generally show little in the way of correlation. Figures 4-1 and 4-2 do indicate the azimuthal preference for impulse generation, but these directions only reflect the site power wind rose as shown in Figure 4-13. Figure 4-5 does demonstrate the blade rotational speed influence on the impulse rise rate versus blade pitch angle plot, however. The peak dynamic or acoustic overpressure is usually the dependent variable, since it is a good reflection of the impulse severity.

The bivariate distributions that indicate a relationship are Figures 4-10, 4-11, and 4-12. Figure 4-10 plots the nonimpulsive or reference sound pressure level as a function of hub-height wind speed which increases montonically. The acoustic signal depicted here contains not only the increase in wind noise at the turbine site but also reflects an overall turbine noise output outside of the rotor disk segment in which the tower structure resides and, in fact, dominates this measurement. Thus, as shown in Figure 4-10, the general noise SPL rises approximately 14 dB (or a factor of 5 in acoustic pressure) from cut-in to normal cut-out windspeed [6.7 ms^{-1} (15 mph) to 15.6 ms^{-1} (35 mph)].

The dependence of impulse severity on windspeed is shown in Figures 4-11 (March 1980) and 4-12; in Figure 4-11, 35 rpm runs for June and March 1980 are plotted. It is clear from Figure 4-11 that for the same wind speed, the impulses generated by the turbine's operation during June were generally much more severe than those recorded in March; in fact, the slopes of the linear regression lines are quite different, though they tend to converge at high wind speeds. Figure 4-14 indicates the relationship of rotor rotational speed to the mean impulse peak dynamic pressure bivariate sample population. As can be seen, the 35-rpm cases generally cluster around the upper regression line

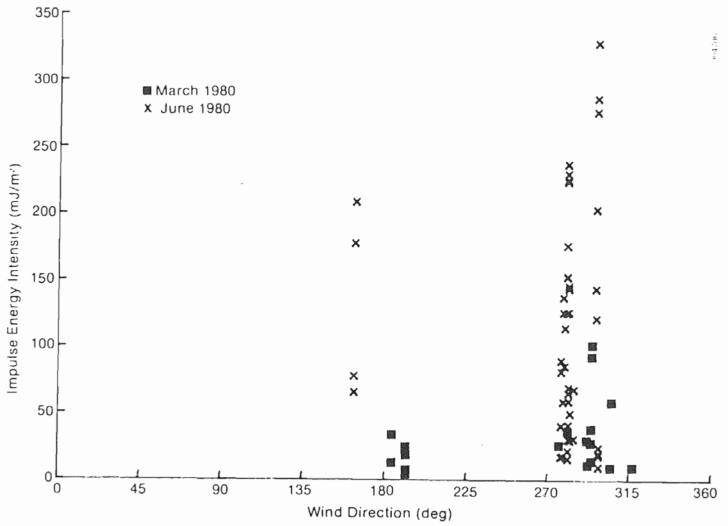

Figure 4-1. Scatter Diagram of Impulse Energy Intensity vs. Hub-Height Wind Direction for March and June 1980 Field Surveys

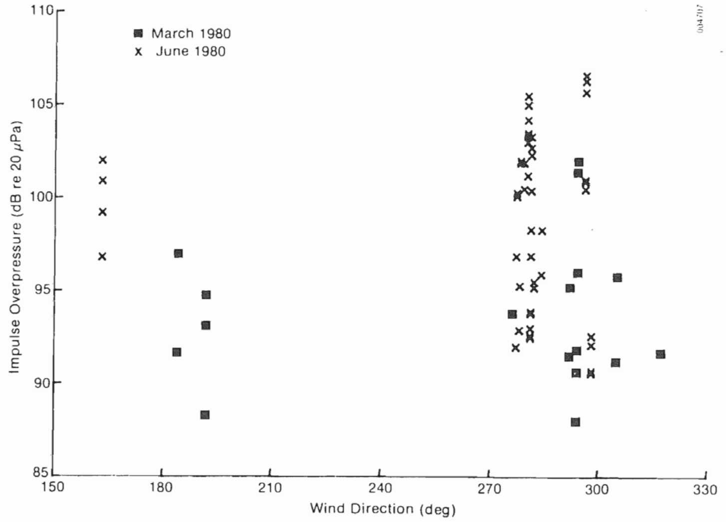

Figure 4-2. Scatter Diagram of Impulse Overpressures vs. Hub-Height Wind Direction for March and June 1980 Field Surveys

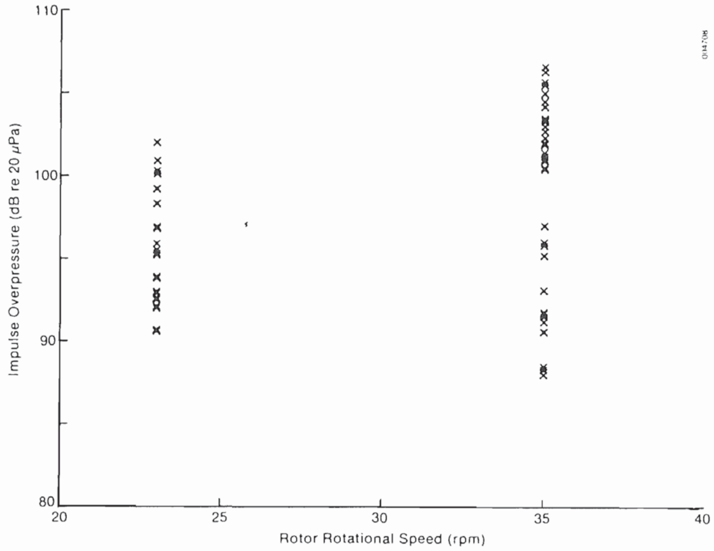

Figure 4-3. Scatter Diagram of Impulse Overpressure vs. Blade Rotational Speed (rpm)

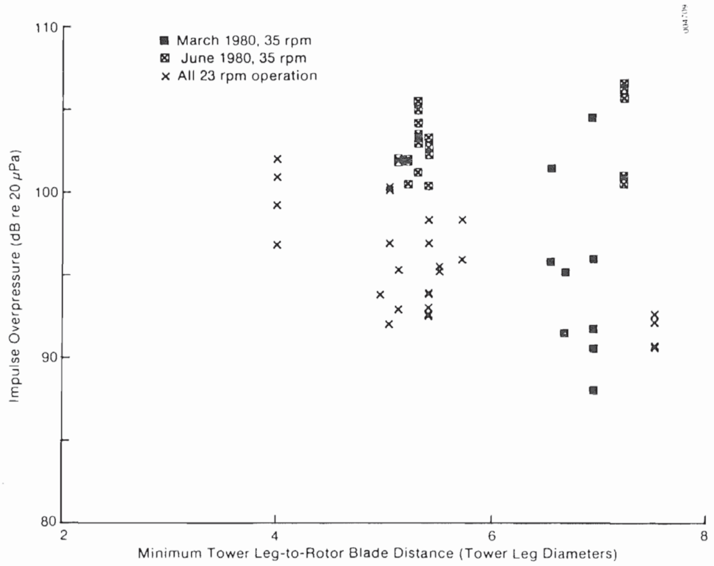

Figure 4-4. Scatter Diagram of Impulse Overpressure vs. Minimum Tower Leg-to-Rotor Blade Distance (in Tower Leg Diameters) as a Function of rpm and Survey Period

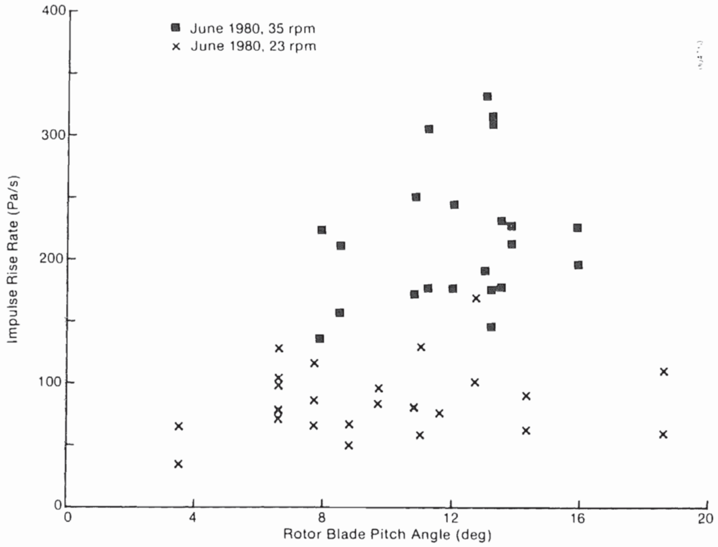

Figure 4-5. Scatter Diagram of Impulse Rise Rate vs. Rotor Blade Pitch Angle as a Function of Blade rpm for June 1980 Survey

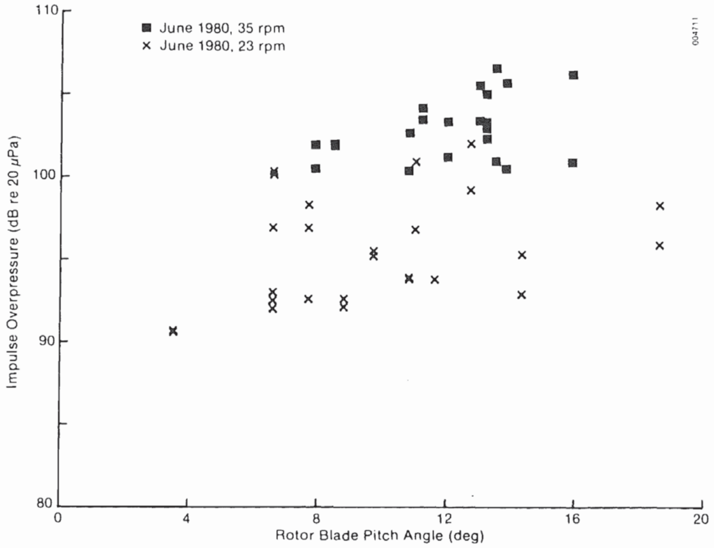

Figure 4-6. Scatter Diagram of Impulse Overpressure vs. Rotor Blade Pitch Angle as a Function of Blade rpm for June 1980 Survey

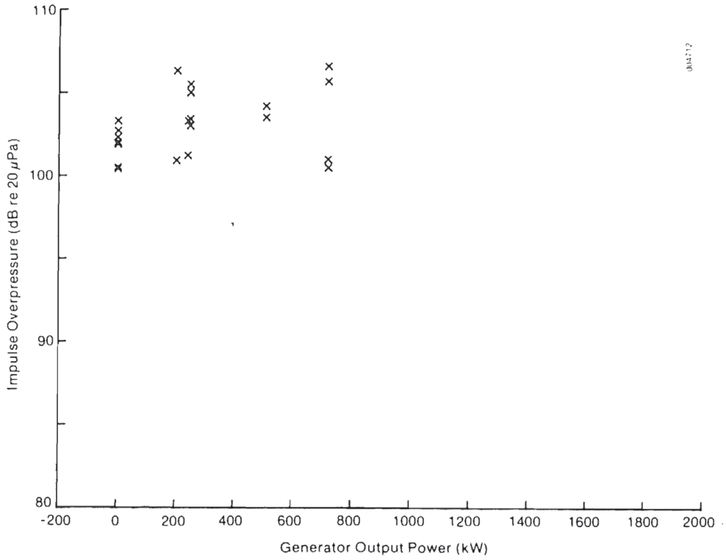

Figure 4-7. Scatter Diagram of Impulse Overpressure vs. Generator Output Power for 35 rpm Operation during June 1980 Survey

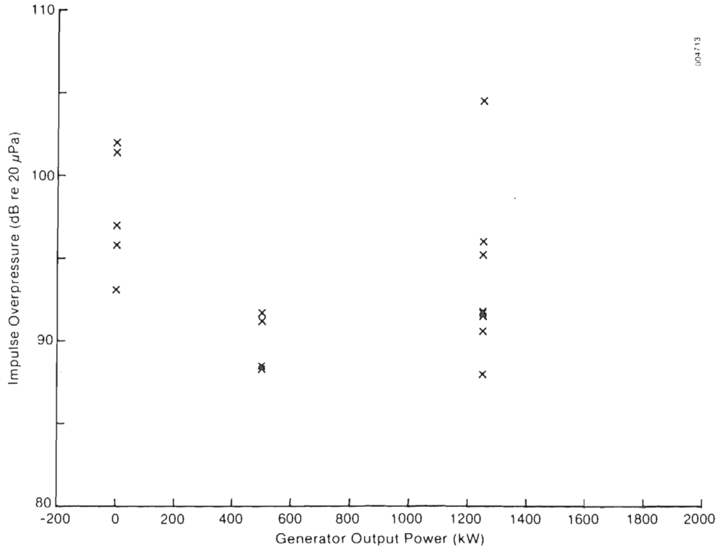

Figure 4-8. Scatter Diagram of Impulse Overpressure vs. Generator Output Power for 35 rpm Operation during March 1980 Survey

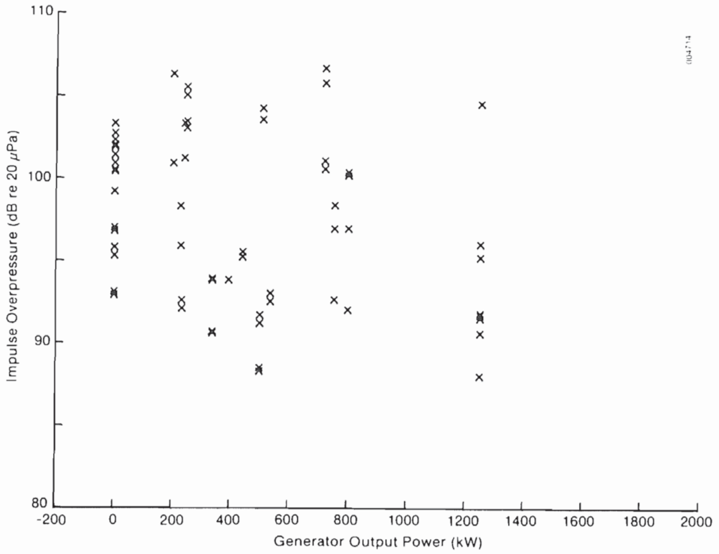

Figure 4-9. **Summary Scatter Diagram of Impulse Overpressure vs. Generator Output Power under 35 rpm Operation for Both March and June 1980 Surveys**

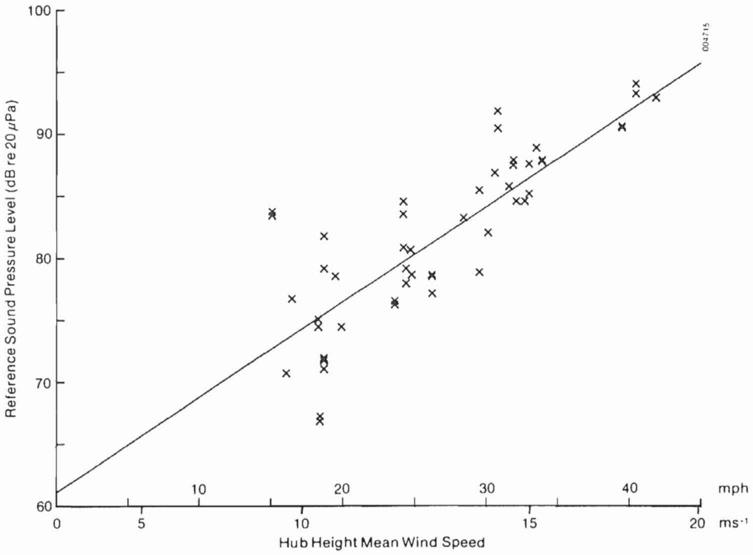

Figure 4-10. **Scatter Diagram with Linear Regression Line of Reference Sound Pressure Level (at 1.5 Rotor Diameters Upwind of Turbine) as a Function of Hub-Height Wind Speed**

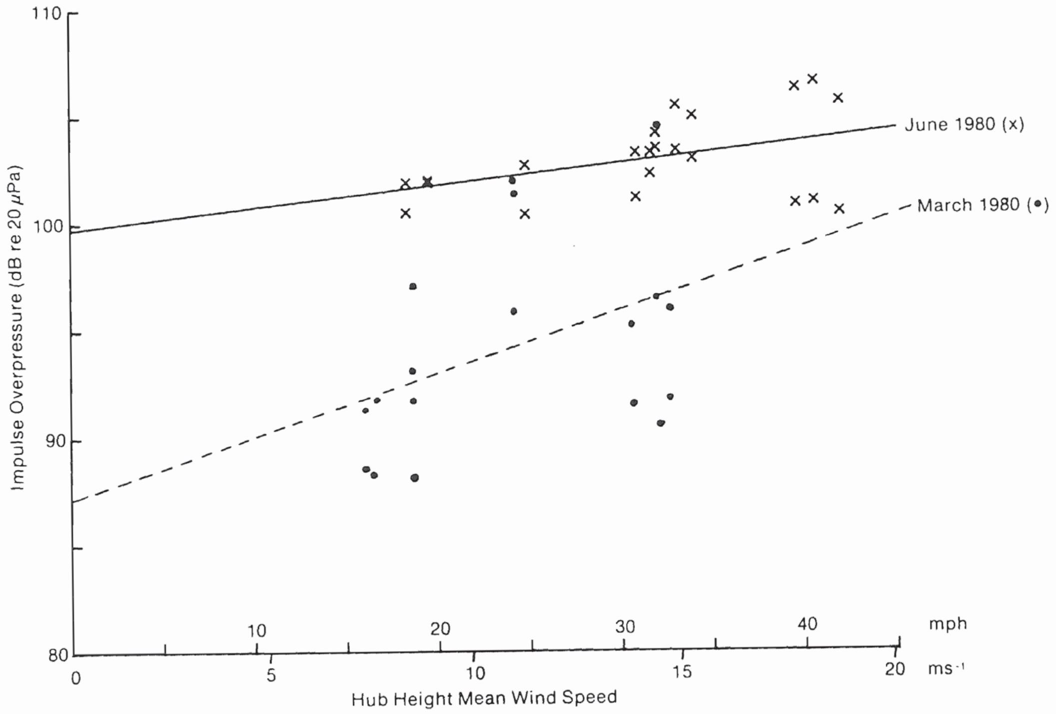

Figure 4-11. Scatter Diagram with Linear Regression Lines for Impulse Overpressure vs. Hub-Height Mean Wind Speed (35 rpm Operation) for March and June 1980 Survey Periods

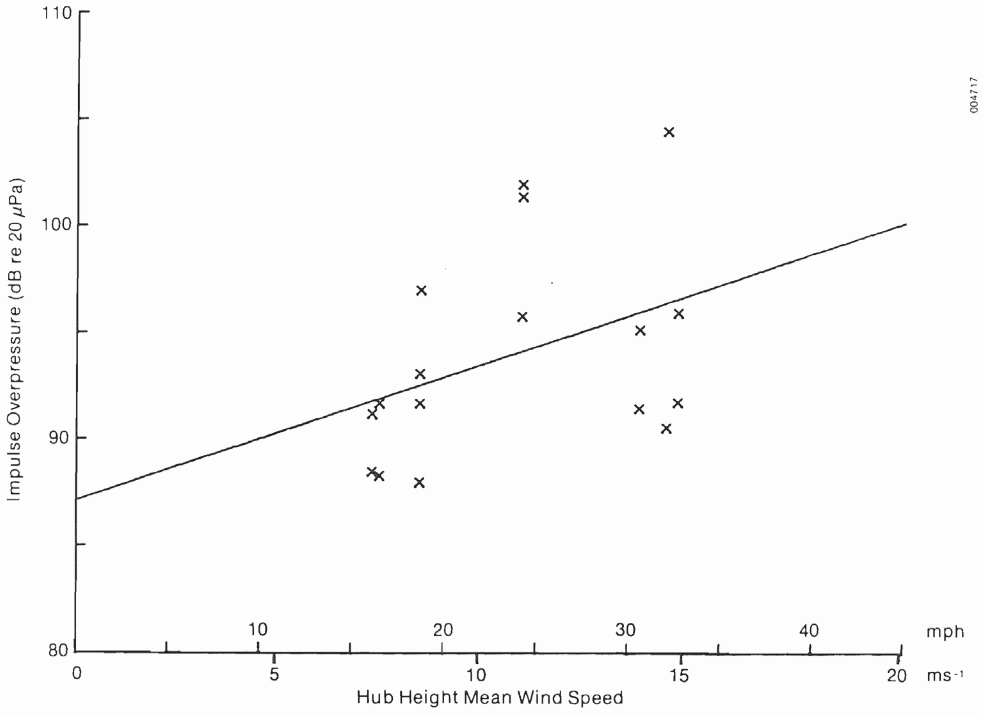

Figure 4-12. **Scatter Diagram with Linear Regression Line of Impulse Overpressure vs. Hub-Height Wind Speed for 35 rpm Operation during March 1980 Survey**

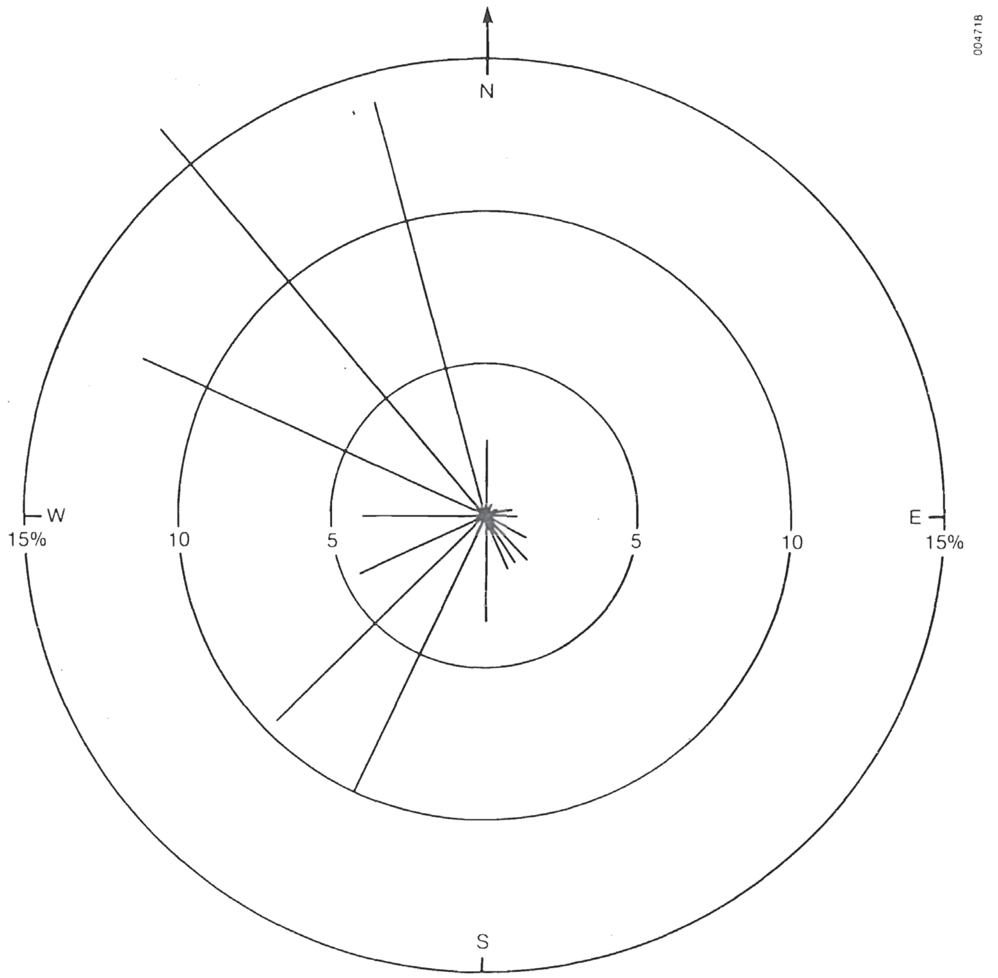

Figure 4-13. "Power" Wind Rose—Directional Probability of Receiving Hub-Height Wind Speeds between Turbine Cut-In and Cut-Out Values—for MOD-1 Site

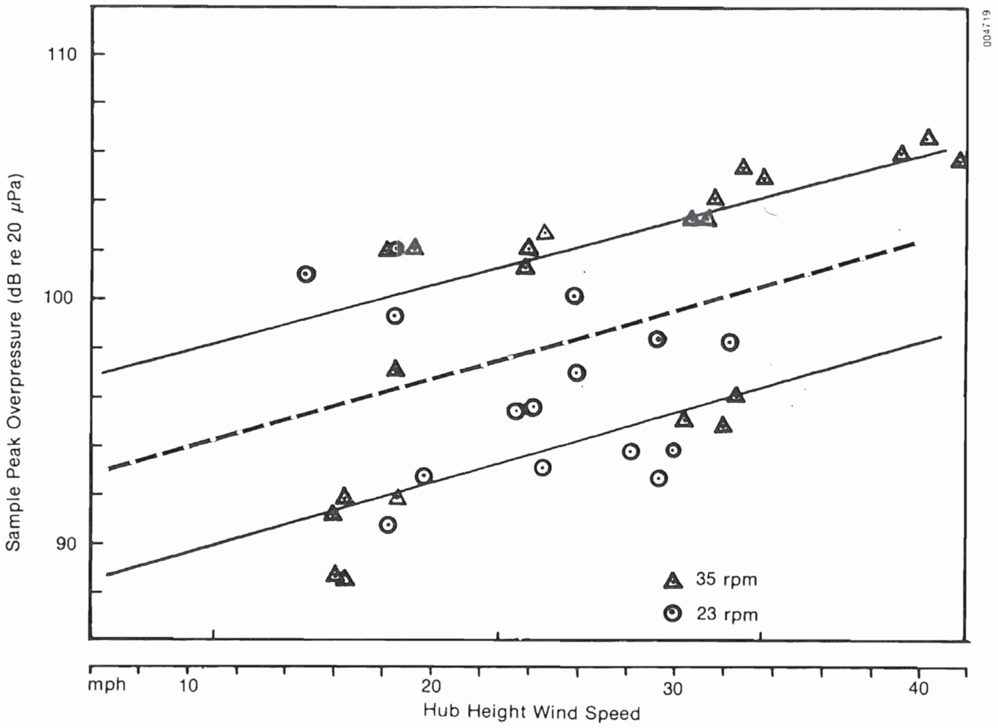

Figure 4-14. Scatter Plot of Impulse Peak Overpressure vs. Hub-Height Wind Speed as a Function of Rotor rpm. (Solid lines represent best fits for upper and lower groups of points and the dashed line was chosen as an approximate divider in between.)

and the 23-rpm cases, around the lower. However, on closer examination, we find that this is not always the case. In this figure, the few 23-rpm data points collected during the January 1981 field survey are included, about half of which cluster around the upper, more severe line.

From an examination of these figures and a number of similar ones, we have reached the following conclusions:

1. More than two parameters are necessary to describe a statistically significant correlation between variables and the observed impulse characteristics.

2. The wind direction in itself is a factor only because of the site wind rose, in which winds sufficient for power generation tend to cluster around two azimuths; i.e., 180 ± 25^{o} and 290 ± 20^{o}. The stronger and more persistent winds blow from the latter.

3. A high sensitivity to the rotational speed of the blade and the hub height wind speed has been shown, but it is not consistent.

4. The impulses generated by the turbine's operation during the June 1980 study were generally more severe than those measured in March 1980.

5. The severity of the few impulses that could be recorded and processed from the January 1981 study at 23 rpm indicated that about half reached levels as severe as those observed in June 1980 at the same rotational speed.

4.2.3 Multivariate Statistical Analysis

The impulse data set described in the previous sections was analyzed using a multivariate, linear regression technique as a response to the obvious interaction between more than two independent variables, which was also discussed in the previous section. The purpose of this analysis was twofold: (1) to establish correlation factors and regression coefficients for the list of operational variables in order to assess the sensitivity of the impulse generation process to these particular parameters; and (2) to establish a statistical model in which different cases could be compared, albeit somewhat crudely. The latter could also serve as a basis for assessing the effectiveness of trying abatement procedures, such as roughening one of the tower legs with wire mesh or reducing the rotor rotational speed.

4.2.3.1 Methodology

As explained earlier, 2- to 3-minute sample periods of both acoustic and operational parameters were selected based on relatively stationary statistics in the latter. The operational data summaries, compiled from samples at one-second intervals, were assembled and merged with the results of the asociated impulse analysis and placed on a computer disk file. This master file then was sorted several times, allowing a subfile structure to be developed which included, as examples, all cases stratified in terms of rotational speed (35 or 23 rpm), survey period (March or June 1980 or January 1981), and the specific tower leg with which the impulse was associated. This stratification allowed details in the statistical distributions to be brought out more clearly.

A standard set of statistical estimates including means, variances, coefficients of variation, skewness, and kurtosis were obtained for the entire data set and many of the subfiles. Correlation matrices and cumulative probability distributions were also obtained and will be discussed in the next section. Both bivariate, polynomial regressions and multivariate, linear regression models were used to compare the stratified data sets.

4.2.3.2 Analysis Results

As discussed above, the data were stratified into different operational categories: the two rotational speeds (35 and 23 rpm); the survey period during which the data were collected (March 1980, June 1980, or January 1981); and whether or not the impulse was associated with either the east or south leg of the support tower. The effect of the various operational parameters, including rotor rotational speed, nacelle azimuth angle, hub-height wind speed, blade pitch and attack angles, the blade downwind distance from a tower leg, and the electrical load (generator output power) are discussed below in terms of the overall data set and for the two major field surveys (March and June 1980) individually.

Effect of Rotor Rotational Speed on Impulse Generation. Table 4-1 presents the correlation matrices for the three mean impulse characteristics of energy intensity, overpressure (peak dynamic pressure), and rise rate for 39 sample periods at 35 rpm and 26 at 23 rpm. Figures 4-15, 4-16, and 4-17 present the cumulative probability distributions for impulse energy intensity, overpressure, and rise rate, respectively, for 35 and 23 rpm operation. Figure 4-16 also displays the reference sound pressure level taken when no impulse was present.

Table 4-1. Correlation Matrix of Mean Impulse Characteristics and Operational Parameters

	Energy Intensity	Overpressure	Rise Rate
35 rpm (39 sets of observations)			
Nacelle azimuth angle	0.258	0.157	0.184
Hub height wind speed	0.654	0.565	0.460
Blade pitch angle	0.515	0.392	0.231
Blade attack angle	0.051	-0.076	-0.084
Blade distance from nearest leg	-0.141	-0.389	-0.434
Generator output power	-0.307	-0.454	-0.521
23 rpm (26 sets of observations)			
Nacelle azimuth angle	-0.750	-0.622	-0.490
Hub height windspeed	-0.330	-0.023	0.008
Blade pitch angle	0.224	0.332	0.188
Blade attack angle	-0.437	-0.364	-0.187
Blade distance from nearest leg	-0.600	-0.680	-0.598
Generator output power	-0.282	-0.072	0.017

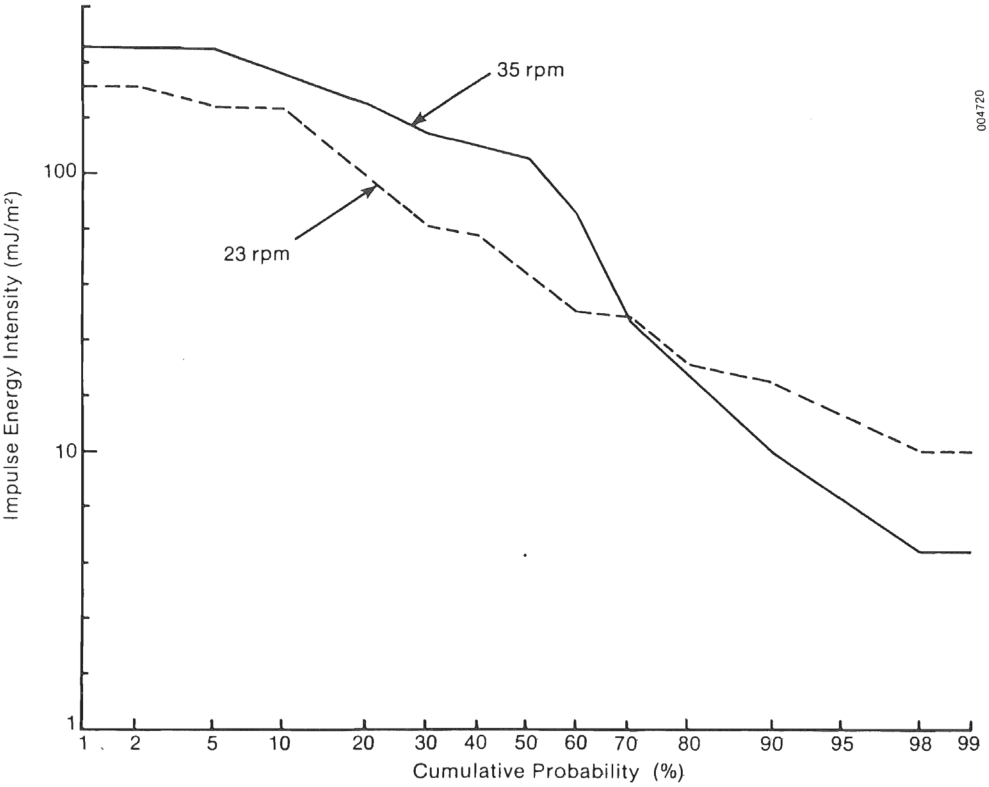

Figure 4-15. Cumulative Probability Plot of Impulse Energy Intensity as a Function of Rotor rpm

The effect of the blade rotation speed is graphically illustrated in the cumulative probability plots. In terms of energy intensity, as shown in Figure 4-15, the 35-rpm-derived impulse contained 25 times more acoustic energy than the 23-rpm operation 10% or less (90th percentile) of the time; i.e., the fraction of time the rotor blades spend in the tower wake. A similar contrast is seen in Figure 4-16 in which the mean impulse overpressure observed at 35 rpm was 106 dB, versus 101.5 dB at 23 rpm for the same percentile. Both Figures 4-15 and 4-16 indicate that the 35-rpm impulses tend to be persistent, as evidenced by the probability of higher levels extending out to the 40th-percentile (60%) level. Figure 4-17 also illustrates the

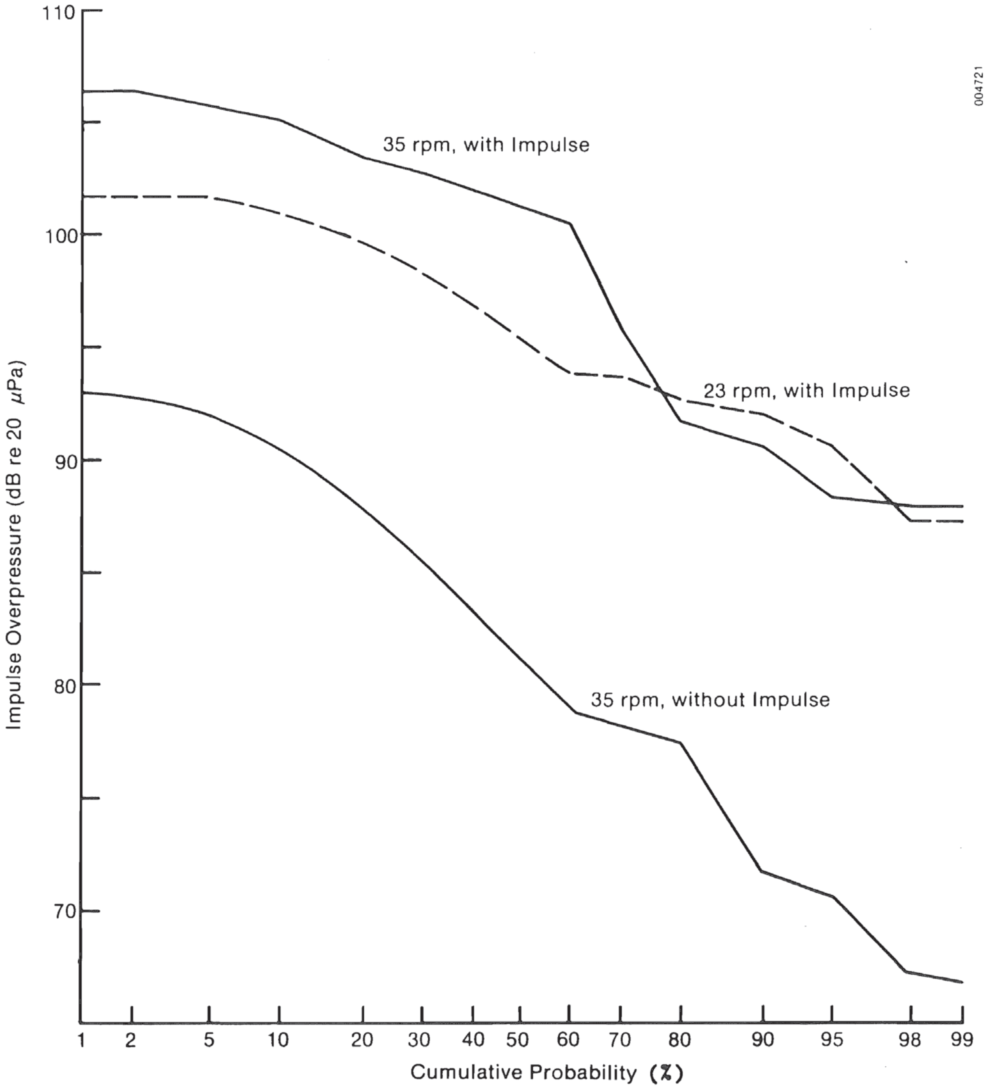

Figure 4-16. Cumulative Probability Plot of Impulse Overpressure as a Function of Rotor rpm. (The probability of acoustic pressure levels without an impulse present is shown for comparison.)

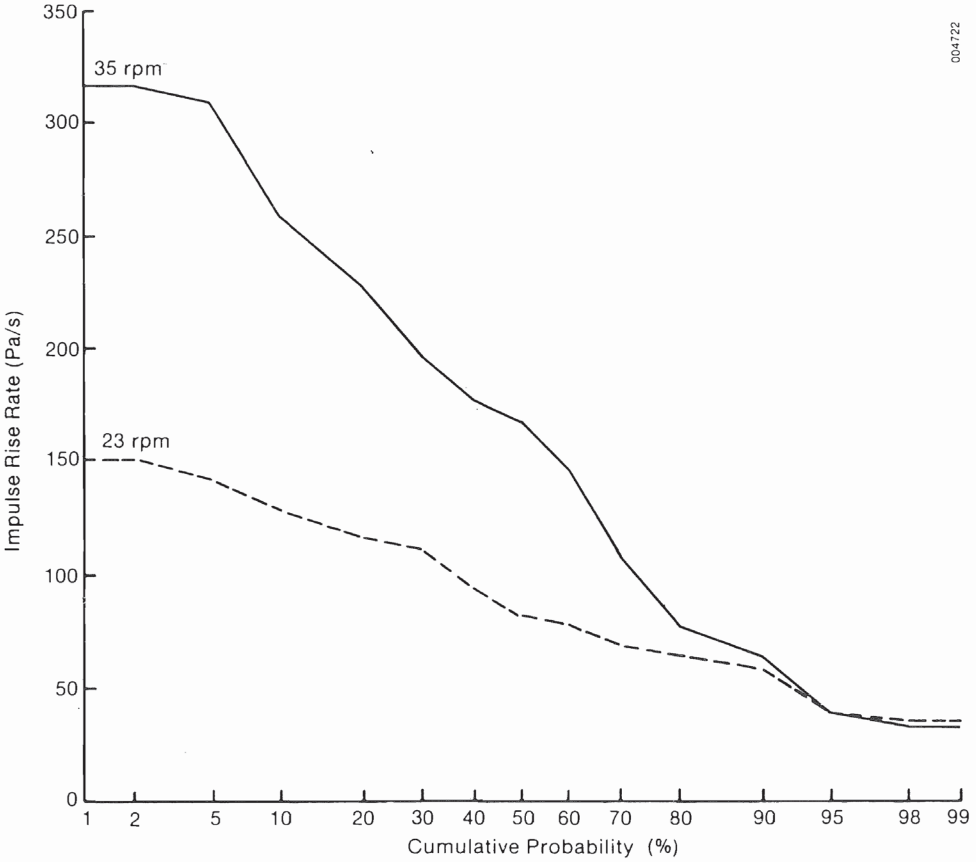

Figure 4-17. Cumulative Probability Plot of Impulse Rise Rate as a Function of Rotor rpm

severity of the 35-rpm impulse which exhibits a rise rate over twice that of the 23-rpm case at the 95th-percentile (5%) level. Table 4-1 indicates that at 35 rpm there are significant levels of positive correlation with the impulse characteristics with hub-height wind speed and blade pitch angle and negative correlation with the distance to the nearest tower leg and generator load. The 23-rpm data indicate a significant negative correlation with the nacelle azimuth and blade attack angles, and the distance from the tower leg, as well as a lesser positive correlation with the blade pitch angle. In contrast to the 35-rpm operation, little correlation existed with wind speed.

Some of the correlations (or lack thereof) are somewhat surprising at first glance. A partial explanation lies in the bias of the two data set divisions, i.e., 35 and 23 rpm operations. Generally, with one or two exceptions, the 35-rpm operation of the turbine occurred at higher wind speeds, the choice of the supervising field director. This is reflected in the sensitivity of the impulse parameters to wind speed. Further, the June 1980 data, which encompass a large percentage of the available information, also reflect the severe off-design operation of the turbine when connected to the resistive loadbank (the loadbank had an actual capacity of about 750 kW in contrast to the grid-connected capacity of 2 MW). This off-design influence is seen in the correlation of the mean attack angle; i.e., a negative correlation in the impulse parameters in the 23-rpm case when one would expect a positive relationship (higher attack angle equating to an increased airload on the rotor blades). The limited capacity of the loadbank necessitated a reduction in the attack angle for the generator output to stay within limits at high wind speeds or commanded load level. The same argument (negative correlation instead of the expected positive one) also applies to the correlation with the generated load.

Table 4-2 summarizes the key statistics for the March 1980 study of the mean impulse characteristics and operational parameters for the 39 and 26 sample periods for 35-rpm and 23-rpm operations, respectively. An examination of these figures generally supports previous comparisons, that the 35-rpm-generated impulse generally can be expected to be more severe, but not always as indicated by the extremes listed in Table 4-2 and the probability plots of Figures 4-15, 4-16, and 4-17. The stochastic nature of the impulse radiation and its relationship to the turbine operating parameters are evident in these figures and table. However, some positive statements can be made such as attributing the lesser severity of the 23-rpm-generated impulse to the increased residence time of the rotor blade in the leg wake, which is reflected principally in the smaller rise rate statistics in Table 4-2.

Effect of Blade Passage Distance from Tower Leg. The distance the rotor blades pass downwind from the tower legs was believed to be an important operational influence on the characteristics and severity of the generated impulses. Available data were divided into two major classifications: i.e., the impulses generated downwind of both the east legs and the south legs of the support tower (see Figure 3-7). The data were further classified into March and June 1980 survey periods to compare these two series of experiments and to evaluate the effects of the wire mesh that had been placed on the south and north tower legs for the June experiments.

Tables 4-3 and 4-4 summarize statistics from the sample periods of the March and June 1980 surveys in terms of the impulses generated in the lee of the east and the south tower legs. We can see that the impulse severity associated with both tower leg wakes was far more intense for June than for March. In both cases, the rotor blades were passing closer to the east tower leg in the mean, but the impulse characteristic statistics indicate that more severe impulses were being generated by the wake associated with the south leg. The south leg wake was being intersected by the blade at about twice the downwind distance of that of the east leg. This indicates that the mean wake velocity deficit was not a major contributor, since it decreases as downstream distance increases.

Table 4-2. **Summary Statistics of Mean Impulse Characteristics and Operational Parameters for March 1980 Data**

	Mean	Coef. of Var. (%)[a]	Maximum	Minimum	Median
35 rpm (39 sets of observations)					
Parameter					
Impulse energy intensity (mJ/m^2)	112.2	80.5	329.5	4.43	115.1
Impulse overpressure (dB)	99.1	5.7	106.6	88.0	101.2
Impulse rise rate (Pa/sec)	163.8	48.4	331.7	32.9	169.2
Nacelle azimuth angle (deg)	307.8	30.5	350.0	007.0	342.0
Hub-height wind speed (m/s)	12.5	29.1	18.7	7.2	13.8
Blade pitch angle (deg)	12.1	19.0	15.9	7.9	13.0
Blade distance from nearest leg (diam.)	6.1	14.2	7.2	5.1	5.4
Generator output power (kW)	455.4	103.4	1250.0	0.0	248.0
23 rpm (26 sets of observations)					
Impulse energy intensity (mJ/m^2)	67.8	90.1	235.1	10.3	41.6
Impulse overpressure (dB)	95.9	4.0	102.0	87.3	95.4
Impulse rise rate (Pa/sec)	89.9	35.4	168.9	34.7	82.1
Nacelle azimuth angle (deg)	326.7	13.7	360.0	225.0	343.0
Hub-height wind speed (m/s)	11.0	21.4	15.0	6.7	11.0
Blade pitch angle (deg)	9.7	39.8	18.6	3.5	9.3
Blade attack angle (deg)	8.0	50.1	12.1	1.7	8.6
Blade distance from nearest leg (diam.)	5.4	19.0	7.5	4.0	5.4
Generator output power (kW)	387.3	75.4	799.0	0.0	338.0

[a] Coefficient of variation = (standard deviation/mean) x 100.

Tables 4-5 and 4-6 present the correlation matrices for the two leg impulses and study periods. The blade pitch and attack angles are missing from the March survey; they were not available because of an insufficient number of available SERI recording channels. All the data taken in March and used in this table were recorded with the turbine operating at 35 rpm. These matrices indicate that impulse severity was correlated more with wind speed for the south leg during both observational periods than the east leg. The correlation with leg-to-tower distance shifts from high positive during March to low negative during June for the south leg for all impulse characteristic parameters. A mixed picture emerges from the east leg correlations. Table 4-6 indicates the high degree of sensitivity of impulse severity to blade rotational speed, which was discussed previously. The correlations with the mean blade pitch and attack angles are almost a mirror image, particularly for the south leg. This is to be expected, since the attack angle was derived from the pitch and the wind speed and is an artifact of the off-design operating condition.

Table 4-3. **Summary Statistics of Mean Impulse Characteristics and Operational Parameters for March 1980 Data**

	Mean	Coef. of Var. (%)[a]	Maximum	Minimum	Median
East Leg Impulse (10 observations)					
Impulse energy intensity (mJ/m^2)	25.0	65.7	58.7	4.43	26.9
Impulse overpressure (dB)	91.8	3.4	97.0	88.0	91.6
Impulse rise rate (Pa/sec)	17.9	42.5	169.2	38.1	76.4
Nacelle azimuth angle (deg)	286.4	38.0	356.0	007.0	181.5
Hub-height wind speed (m/s)	11.1	27.1	14.6	7.2	10.9
Blade pitch angle (deg)	--	--	--	--	--
Blade attack angle (deg)	--	--	--	--	--
Blade distance from leg (leg diam.)	7.8	28.3	11.7	6.7	6.9
Rotor rotational speed (rpm)	32.6	15.5	35.0	23.0	25.7
Impulses processed	200				
South Leg Impulse (9 observations)					
Impulse energy intensity (mJ/m^2)	37.7	93.7	101.8	9.5	24.5
Impulse overpressure (dB)	95.2	4.2	102.0	91.2	94.8
Impulse rise rate (Pa/sec)	93.4	41.3	146.9	32.9	94.4
Nacelle azimuth angle (deg)	244.7	57.2	356.0	007.0	254.0
Hub-height wind speed (m/s)	10.6	28.2	14.6	7.2	10.8
Blade pitch angle (deg)	--	--	--	--	--
Blade angle of attack (deg)	--	--	--	--	--
Blade distance from leg (leg diam.)	13.9	70.0	27.2	5.2	8.1
Rotor rotational blade speed (rpm)	35.0	0.0	35.0	35.0	35.0
Impulses processed	180				

[a] Coefficient of variation = (standard deviation/mean) x 100.

Comparison of Treated and Untreated Tower Legs. During the June 1980 field studies, the large vertical members of two bays on the north and south tower legs were wrapped with several layers of wire mesh. This was done to see if the dynamics of the flow around these cylindrical elements could be altered to decrease the severity of the impulses. The purpose of treating the legs on a diagonal was to provide an "A-B" comparison; i.e., to compare treated versus untreated legs under the same operating conditions. The wind direction during this phase of the experimentation positioned the rotor blade downwind of the southeast face or flat of the tower and allowed us to compare the treated south and untreated east legs.

Table 4-7 summarizes the observed mean impulse characteristics and associated operational parameters for both tower legs in the March and June 1980 field studies. The coefficient of variation for each parameter is shown in parenthesis. The greater severity of the impulses observed in June are again evident in the table. Examining the March statistics shows that while the blades, in the mean, were passing farther away from the south tower leg

Table 4-4. Summary Statistics of Mean Impulse Characteristics and Operational Parameters for June 1980 Data

	Mean	Coef. of Var. (%)[a]	Maximum	Minimum	Median
East Leg Impulse (10 observations)					
Energy intensity (mJ/m^2)	121.9	61.8	238.4	20.4	122.1
Overpressure (dB)	99.4	4.3	105.5	90.6	100.9
Rise rate (Pa/sec)	173.2	52.1	331.7	34.7	168.9
Nacelle azimuth angle (deg)	335	12.7	360	225	343
Hub-height wind speed (m/s)	12.4	56.8	18.7	6.7	11.7
Blade pitch angle (deg)	10.9	32.3	18.6	3.5	11.0
Blade attack angle (deg)	6.2	57.2	12.1	1.7	4.8
Blade distance from leg (diam.)	6.7	45.8	16.0	5.0	5.4
Rotor rotational speed (rpm)	28.7	21.3	35.0	23.0	23.0
Impulses processed	460				
South Leg Impulse (treated with wire mesh)					
Energy intensity (mJ/m^2)	103.5	89.1	329.5	10.3	78.5
Overpressure (dB)	98.9	5.0	106.6	90.7	100.1
Rise rate (Pa/sec)	126.5	47.1	232.0	49.8	104.2
Nacelle azimuth angle (deg)	335.5	10.6	360.0	225.0	343.0
Hub-height wind speed (m/s)	12.4	27.2	18.7	6.7	11.7
Blade pitch angle (deg)	10.9	33.1	18.6	3.5	11.1
Blade attack angle (deg)	6.0	58.8	12.1	1.7	4.6
Blade distance from leg (diam.)	11.4	46.8	28.0	7.5	5.4
Rotor rotational speed (rpm)	28.7	21.3	35.0	23.0	23.0
Impulses processed	440				

[a] Coefficient of variation = (standard deviation/mean) x 100.

(16.1 leg diameters versus 7.8 for the east), the impulse characteristics were not much different, indicating that the wake from the south leg was inherently more energetic than that from the east leg or that its unsteady characteristics persisted farther downstream. The coefficients of variation for the impulse characteristics for the south leg tend to indicate a more consistent generation process.

The statistics for the June 1980 data set show the rotor position closer to both tower legs than in March, but again, the blades are passing about twice the downstream distance from the south leg than the east. This time, however, the mean statistic characteristics show that the impulses tended to produce similar dynamic peak (overpressures), but those from the treated south leg contained less total energy and exhibited a less severe rise rate. Also, in this case, the south leg impulses tended to be less consistent, as indicated by the larger variation coefficients, compared with the east leg impulses.

Table 4-5. Correlation Matrix of Mean Impulse Characteristics and Operational Parameters for June 1980 Data

	Energy Intensity	Impulse Overpressure	Rise Rate
East Leg Impulse			
Nacelle azimuth angle	-0.318	-0.211	0.035
Hub-height wind speed	0.300	0.331	0.416
Blade pitch angle	0.453	0.457	0.407
Blade attack angle	-0.671	-0.636	-0.568
Blade distance from leg	0.253	0.055	-0.149
Rotor rotational speed	0.704	0.764	0.876
South Leg Impulse			
Nacelle azimuth angle	0.183	0.073	0.278
Hub-height wind speed	0.732	0.623	0.682
Blade pitch angle	0.473	0.495	0.399
Blade attack angle	-0.385	-.496	-0.394
Blade distance from leg	-0.193	-0.076	-0.282
Rotor rotational speed	0.748	0.845	0.912

Table 4-6. Correlation Matrix of Mean Impulse Characteristics and Operational Parameters for March 1980 Data

	Energy Intensity	Impulse Overpressure	Rise Rate
East Leg Impulse			
Nacelle azimuth angle	0.434	0.083	-0.335
Hub height wind speed	0.362	0.253	-0.107
Blade pitch angle			
Blade attack angle			
Blade distance from leg	-0.138	0.070	0.588
Rotor rotational speed			
South Leg Impulse			
Nacelle azimuth angle	0.321	0.292	0.199
Hub height wind speed	0.884	0.934	0.949
Blade pitch angle			
Blade attack angle			
Blade distance from leg	0.870	0.919	0.841
Rotor rotational speed			

Table 4-7. Summary Statistics for a Comparison of Leg Wake Mean Impulse Characteristics

Parameter	Untreated East Leg (Mar. 1980)	Untreated South Leg (Mar. 1980)	Untreated East Leg (June 1980)	Treated South Leg (June 1980)
Impulse energy intensity (mJ/m^2)	21.3 (57.1)[a]	20.5 (53.4)	121.7 (61.8)	107.1 (86.5)
Impulse overpressure (dB)	91.3 (3.2)	93.4 (2.1)	99.4 (4.3)	99.1 (5.0)
Impulse rise rate (Pa/sec)	84.8 (44.0)	78.1 (35.3)	173.1 (52.1)	128.6 (60.1)
Nacelle azimuth angle (deg)	255.5 (19.6)	248.8 (22.4)	273.5 (13.0)	273.1 (13.3)
Hub-height wind speed (m/s)	11.1 (28.6)	10.5 (32.7)	12.4 (27.2)	12.3 (27.9)
Blade attack angle (deg)	n.a.	n.a.	6.2 (57.2)	6.0 (58.8)
Blade downwind distance (diam.)	7.8 (30.1)	16.1 (61.3)	6.7 (45.8)	11.5 (47.7)
Rotor rotational speed (rpm)	35.0 (0.0)	35.0 (0.0)	28.7 (21.3)	29.0 (21.2)
Number of impulses processed	180	140	460	440

[a] Coefficient of variation (%) in parentheses.

While the mean values and variation coefficients of Table 4-7 are revealing, the stochastic nature of the impulse generation process is demonstrated in the cumulative distributions of Figures 4-18, 4-19, and 4-20 of the sample mean impulse energy intensity, overpressure, and rise rate parameters, respectively. As before, greater impulse severity is evident in the June data compared with the impulses generated in March. What these distributions also show, with one exception, is the tendency for the 90th percentile (or 10% cumulative probability level) of the observed south leg impulses to be more energetic and exhibit higher peak dynamic pressures than those associated with the east leg in both surveys. The exception occurs in the rise-rate characteristic for the south (treated) leg impulses in the June data. Here, the rise rate is about 30% less than that observed for the east leg impulse, though energy and overpressure are greater for the south leg than the east 10% or less of the time. One interpretation is that the wake is becoming wider and blade residence time is increasing, resulting in a less abrupt rate of change in lift but extending over a greater period of time which increases the energy content as defined by Eq. 3-1. A similar conclusion can be drawn from the June mean and probability data, but obviously a more energetic process is at work than we observed in March, with the stronger impulses coming off the south tower leg. There is evidence, however, that the wire mesh did influence the wake characteristics from the south tower leg. We believe the mesh may have caused a more rapid spreading or diffusing of the wake turbulence as evidenced by the reduced rise rate and greater variation in the observed impulses.

Multiple Linear Regression Models. As discussed previously, we noted the interactions of operational variables and their combined effect on the severity of the observed impulses. The somewhat confusing picture painted by the bivariate correlations in Tables 4-5 and 4-6 bear this out. In order to overcome this difficulty, we computed a multiple linear regression model of each of the subclassified data sets discussed above. Table 4-8 lists the regression coefficients associated with each of the data set classifications; i.e., survey period and tower leg wake location. Of major interest are the correlation coefficients. These reflect the degree to which the regression model has explained the observed variance, 0 for totally random and 1 for a complete explanation. With the exception of the east leg mean impulse energy intensity and overpressure during March, the model correlations are very good, explaining more than 90% of the observed variance in most cases. The regression coefficients of the subclassifications of Table 4-8 now can be used to compare the sensitivities of the impulse characteristics for the different cases. For example, the greater sensitivity of the mean energy intensity with the tower leg-to-blade distance for the south leg impulse, compared with the east leg, is evident both for March and June, and the latter is far more sensitive.

Having established the multiple linear regression models summarized in Table 4-8, we can now use these tools to assess the interdependence of the major operational variables on the observed acoustic impulse characteristics of energy intensity, overpressure, and rise rate and try to relate them to what may be happening physically through the equations developed in Sections 4.1.1.2 and 4.1.1.3. From an examination of Tables 4-5, 4-6, and 4-8, we see that the most influential operational parameters are the blade rotational speed (rpm), the hub height wind speed, and the blade-to-tower-leg distance.

Table 4-8. Multiple Linear Regression Coefficients

	Nacelle Azimuth	Hub Wind Speed	Attack Angle	Leg Distance	RPM	Correlation Coefficient	Impulses Processed
Energy Intensity (mJ/m^2)							
Untreated east leg impulse (Mar. 1980)	-0.096	1.398		-0.327	*	0.588	180
Untreated south leg impulse (Mar. 1980)	0.384	0.976		-2.478	*	0.934	140
Untreated east leg impulse (June 1980)	-1.704	2.597	-0.607	-4.049	9.273	0.919	460
Treated south leg impulse (June 1980)	-26.566	6.765	5.034	-170.452	9.878	0.935	440
Overpressure (dB)							
Untreated east leg impulse (Mar. 1980)	-0.053	0.403		-0.067	*	0.594	180
Untreated south leg impulse (Mar. 1980)	-0.241	0.277		-1.316	*	0.986	140
Untreated east leg impulse (June 1980)	-0.135	0.148	-0.050	-0.897	0.538	0.951	480
Treated south leg impulse (June 1980)	-0.156	0.310	0.177	-0.644	0.637	0.938	460
Rise Rate (Pa/s)							
Untreated east leg impulse (Mar. 1980)	-0.382	4.905		13.299	*	0.811	180
Untreated south leg impulse (Mar. 1980)	-4.635	3.883		-22.696	*	0.836	140
Untreated east leg impulse (June 1980)	-1.976	2.053	-0.492	-16.017	12.721	0.945	480
Treated south leg impulse (June 1980)	-6.246	2.915	3.617	-38.777	8.814	0.970	460

*All runs at 35 rpm.

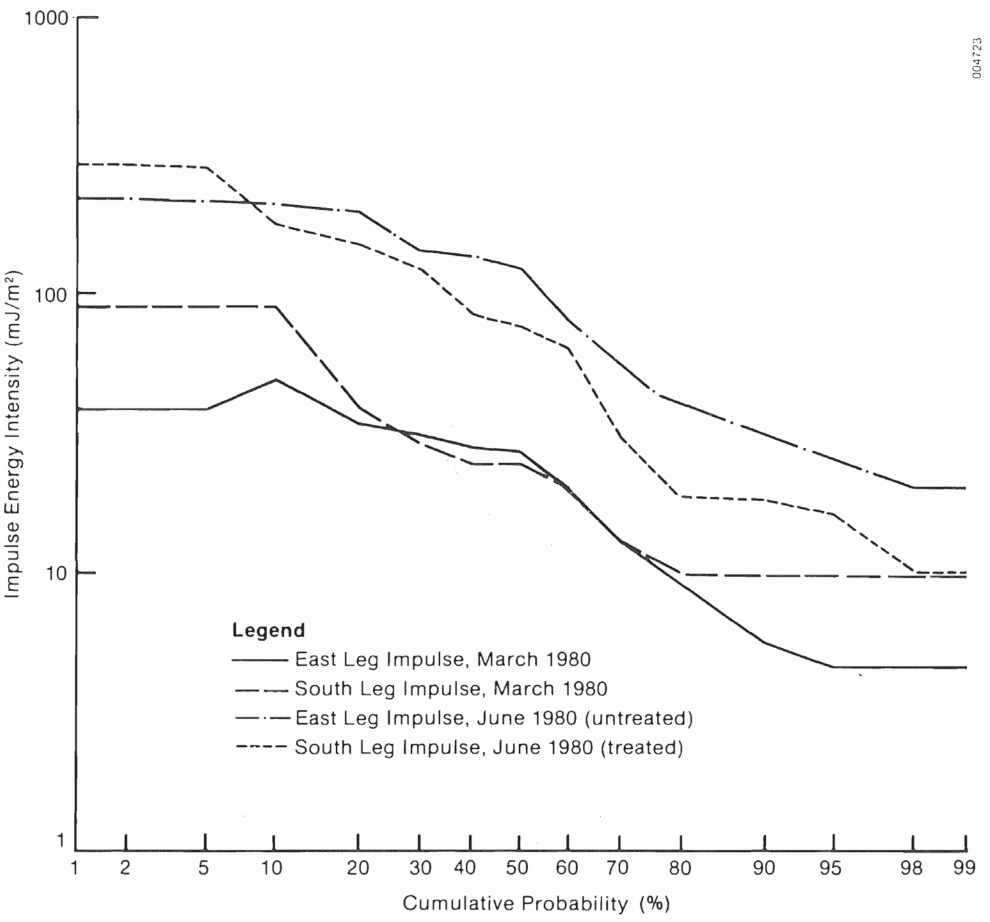

Figure 4-18. **Cumulative Probability Plot of Impulse Energy Intensity as a Function of Survey Period and Specific Tower Leg Wake** (East or south)

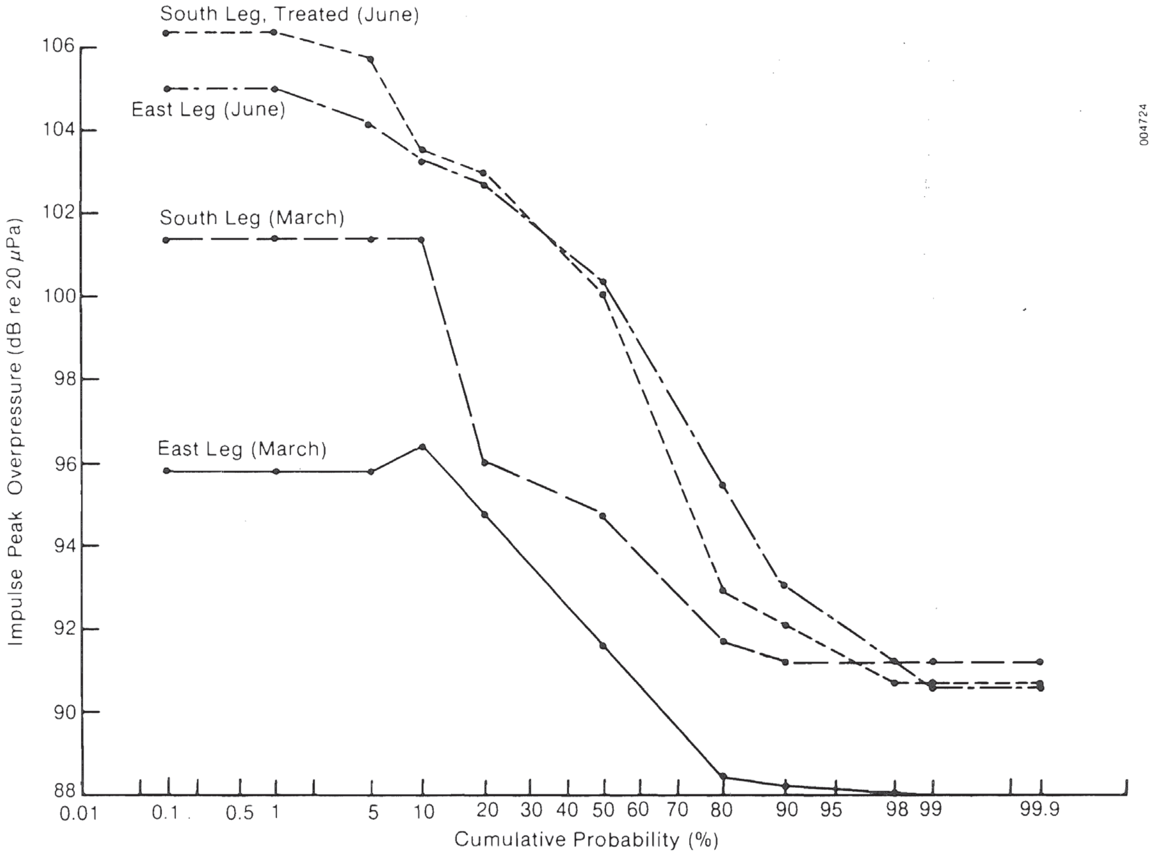

Figure 4-19. Cumulative Probability Plot of Impulse Peak Overpressure as a Function of Survey Period and Specific Tower Leg Wake (East or south)

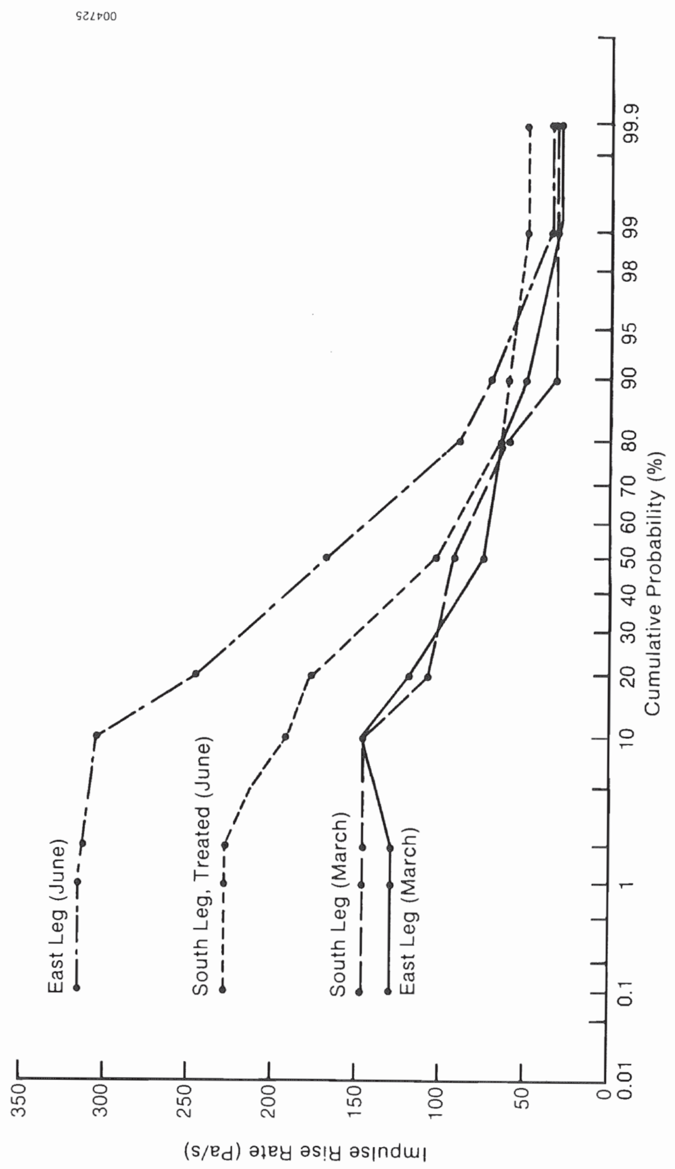

Figure 4-20. Cumulative Probality Plot of Impulse Rise Rate as a Function of Survey Period and Specific Tower Leg Wake (East or south)

When adding variables to the models, we generally found the addition of the pitch and/or attack angles made little difference in reducing the unexplained variance as did just including only the nacelle azimuth but no leg-to-blade distances. Therefore it was decided to fix the pitch, attack, and nacelle azimuth angles at their median values and allow the rotor speed, wind speed, and leg-to-blade distance to vary as inputs to the models to examine the influence on the mean impulse characteristics.

Figures 4-21, 4-22, and 4-23 display the resulting variation of the three impulse characteristics as a function of leg-to-blade distance and hub height wind speed for the impulses associated with the east and south tower legs at a constant rotational speed of 35 rpm for the June 1980 study. The curves are plotted only over the ranges of leg-to-blade distances actually encountered. Figure 4-21 shows that the average impulse energy falls with increasing leg-to-blade distance for the east leg (solid lines) but does increase with hub-height wind speed. In contrast, the impulse energy associated with the south, mesh-treated leg peaks when the blade passes about 8 leg diameters from the tower and, for the same wind speed, radiates a much more energetic impulse compared with the east leg at that distance. It is interesting to note as the leg-to-blade distance increases, the curves representing radiations from both legs appear to approach parallelism, but the south leg impulses remain stronger at the same wind speed.

The plots of impulse overpressure and rise rate in Figures 4-22 and 4-23 show somewhat similar distributions, but the most severe impulse characteristics are found closest to the east tower leg. The south leg impulse overpressures also appear to reach a peak similar to the energy intensities in Figure 4-21, but somewhere between 11 and 13 diameters downstream instead of 8. The rise rate distribution in Figure 4-23 also peaks at approximately the same downstream distance as the energy intensity curves. This plot graphically displays the differences between the east and south leg-generated impulses. There also appears to be a possible discontinuity in the spacing of the 11.1 and 13.4 m/s (25 and 30 mph) wind speed isopleths, indicating what could be a non-linear increase in rise rate in this speed regime. Nothing similar is indicated in the east leg family of curves.

The same impulse characteristic distributions are displayed in Figures 4-24, 4-25, and 4-26 for the March 1980 field survey. The energy intensity (Figure 4-24) and overpressure (Figure 4-25) follow the same shapes as the June data with peaks at about 8.5 and 11-12 diameters downstream of the south leg and the closest passage for the east leg. One difference is that greater overpressures are found near the peak at all wind speeds for the south leg impulses, compared with those from the east. There is a considerable shift in the rise rate distribution for the east leg impulses in the March data, compared with those observed in June, as evidenced by Figures 4-23 and 4-26. The March data tend to indicate peak rise rates beyond 10 leg diameters downstream of a similar magnitude for both leg impulses. But the June results show the east leg peak is closest and is much more severe than those associated with the south leg at that distance.

A comparison of the effects of changing the blade rotational speed is demonstrated in Figures 4-27, 4-28, and 4-29 for the June data at a hub wind speed of 12.3 m s^{-1} (27.5 mph) and an attack angle of 6 degrees. The chief result

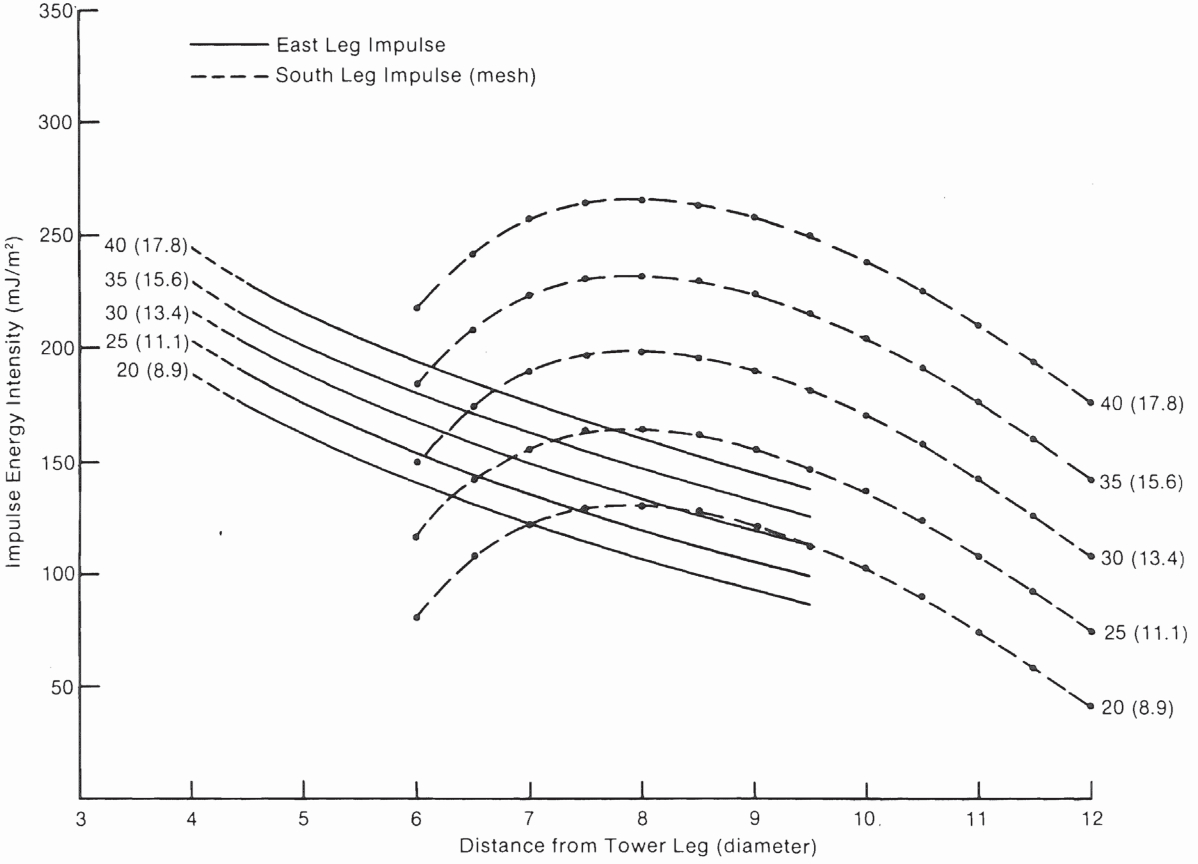

Figure 4-21. Impulse Energy Intensity as a Function of Tower Leg-to-Blade Distance (in leg diameters) and Hub-Height Wind Speed for June 1980 Survey Period (Shown in mph with ms^{-1} in parentheses)

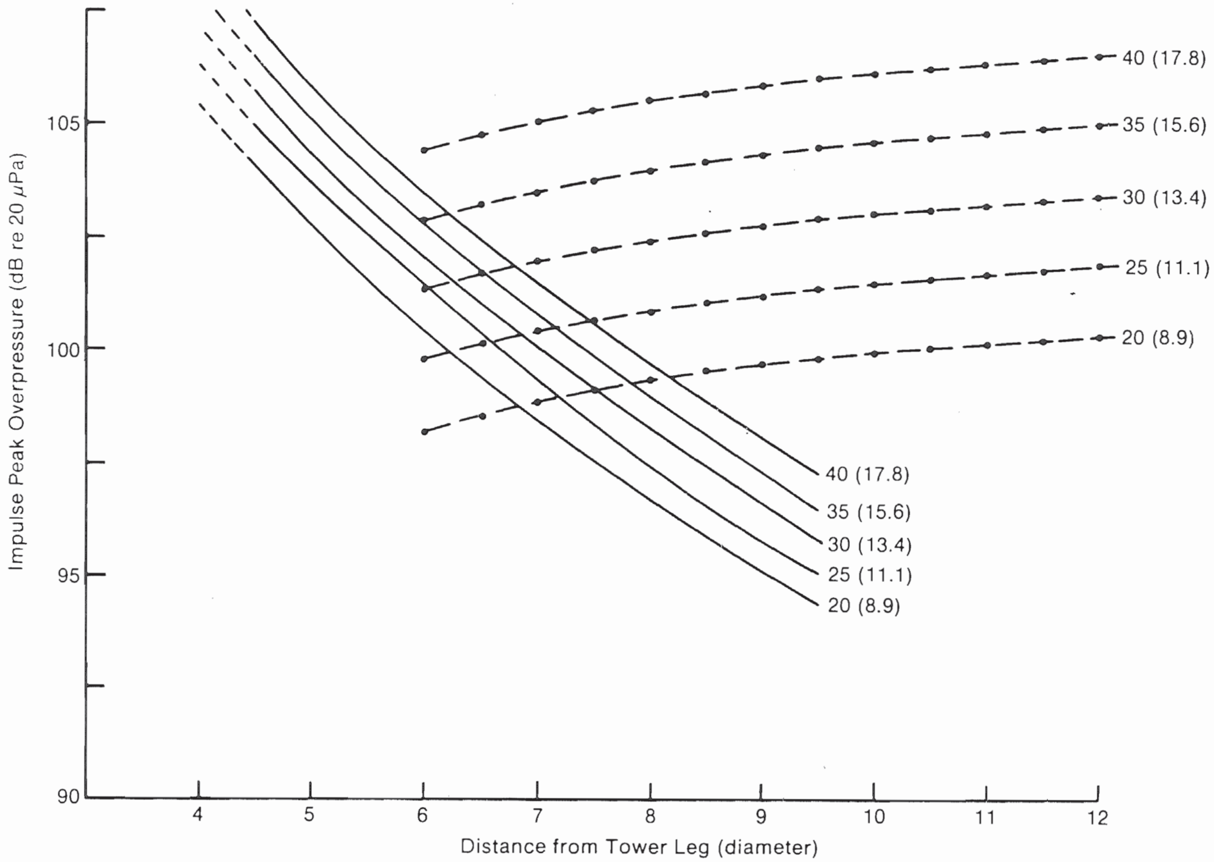

Figure 4-22. Impulse Peak Overpressure as a Function of Tower Leg-to-Blade Distance and Hub-Height Wind Speed for June 1980 Survey Period (East, solid curves; south, dashed curves)

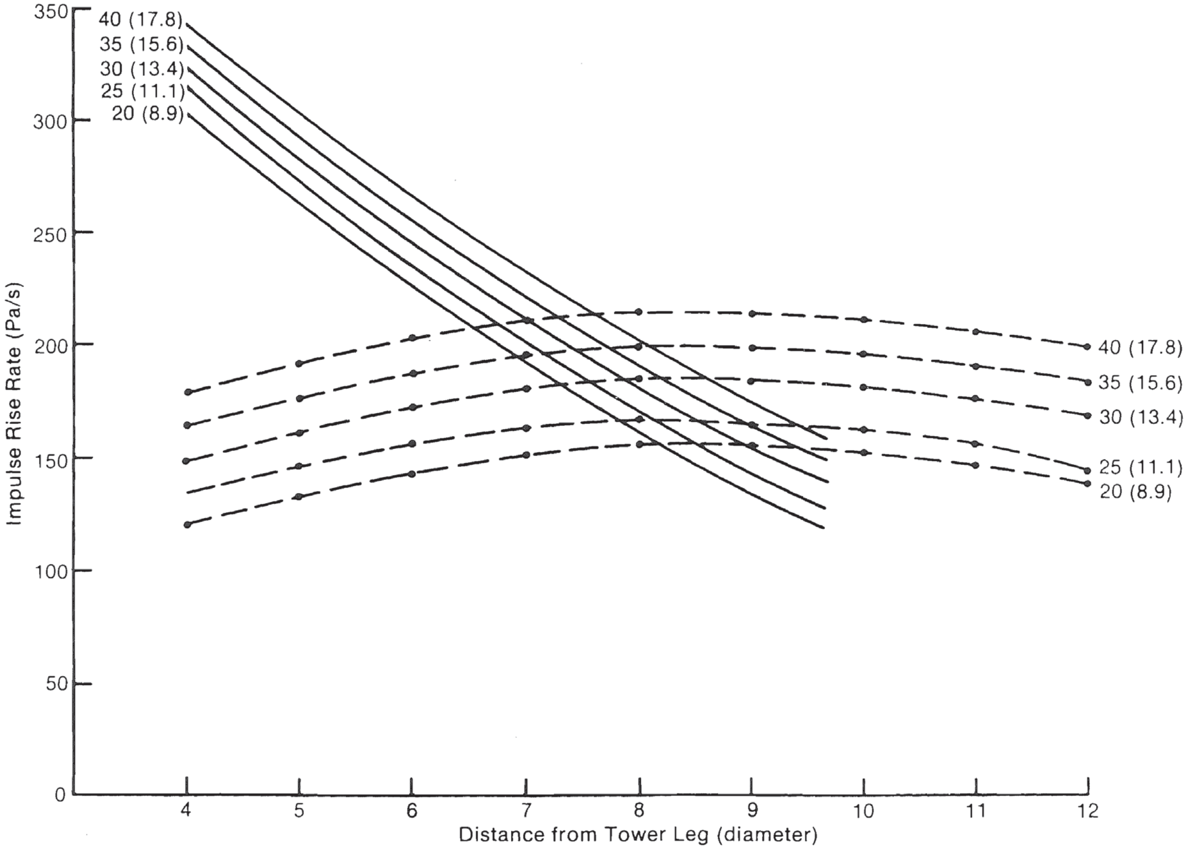

Figure 4-23. **Impulse Rise Rate as a Function of Tower Leg-to-Blade Distance and Hub-Height Wind Speed for June 1980 Survey Period** (East, solid curves; south, dashed curves)

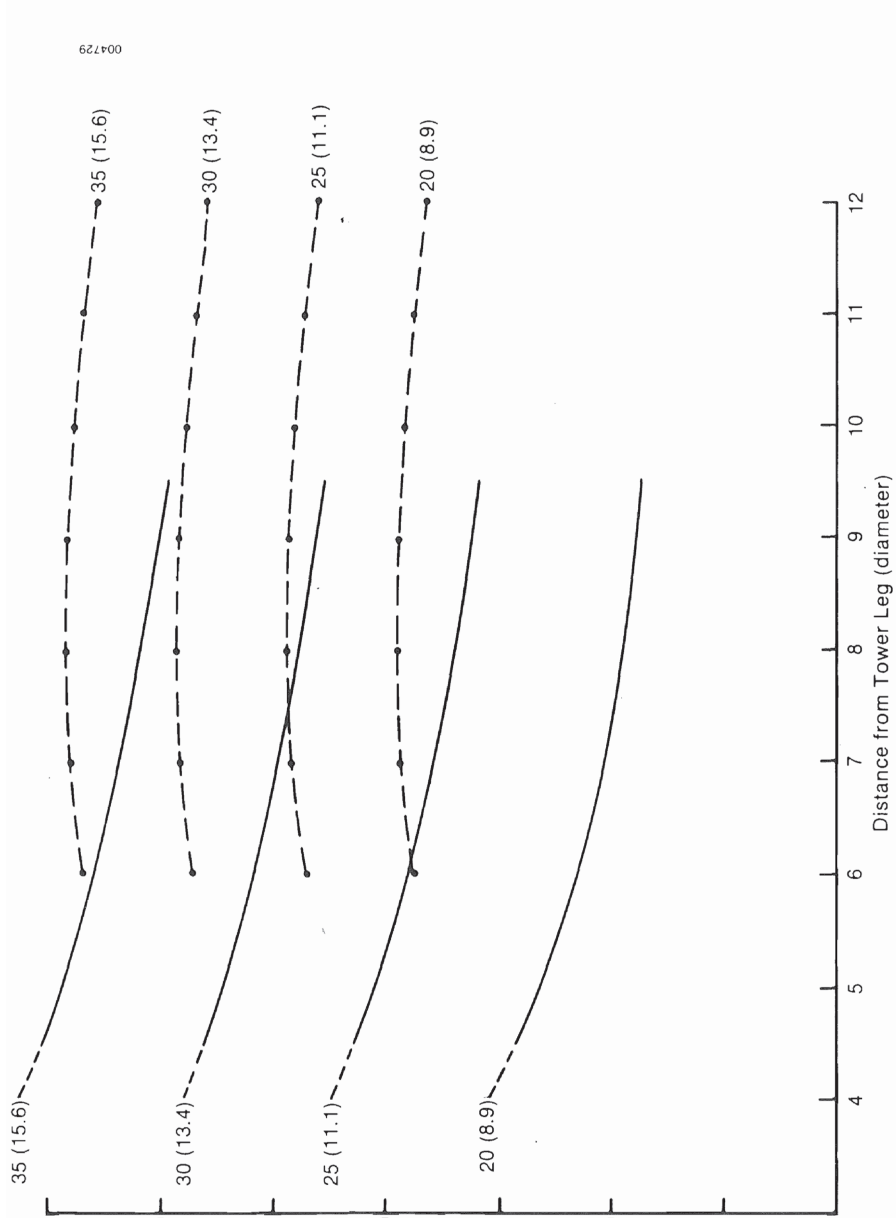

Figure 4-24. Impulse Energy Intensity as a Function of Rotor Distance from Tower Leg and Hub-Height Wind Speed for March 1980 Survey Period (East, solid curves; south, dashed curves)

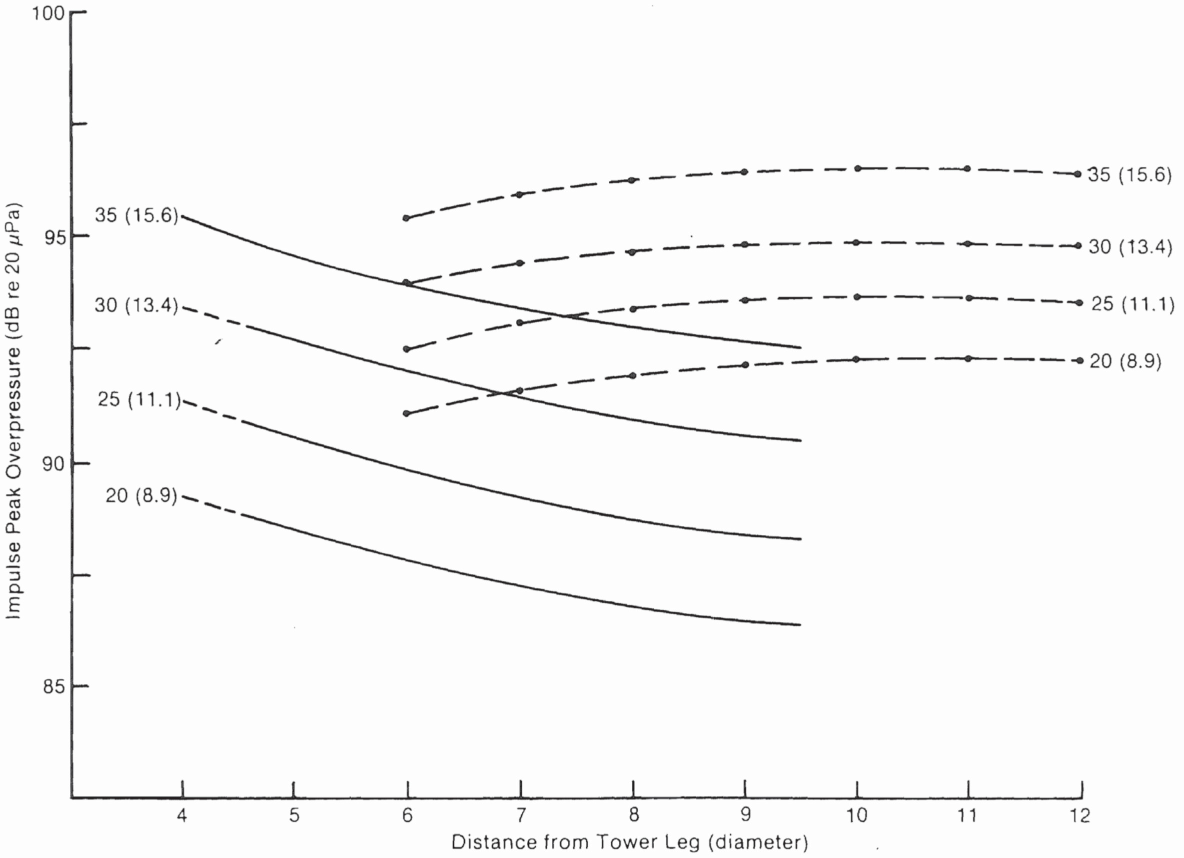

Figure 4-25. Impulse Peak Overpressure as a Function of Rotor Distance from Tower Leg and Hub-Height Wind Speed for March 1980 Survey Period (East, solid curves; south, dashed curves)

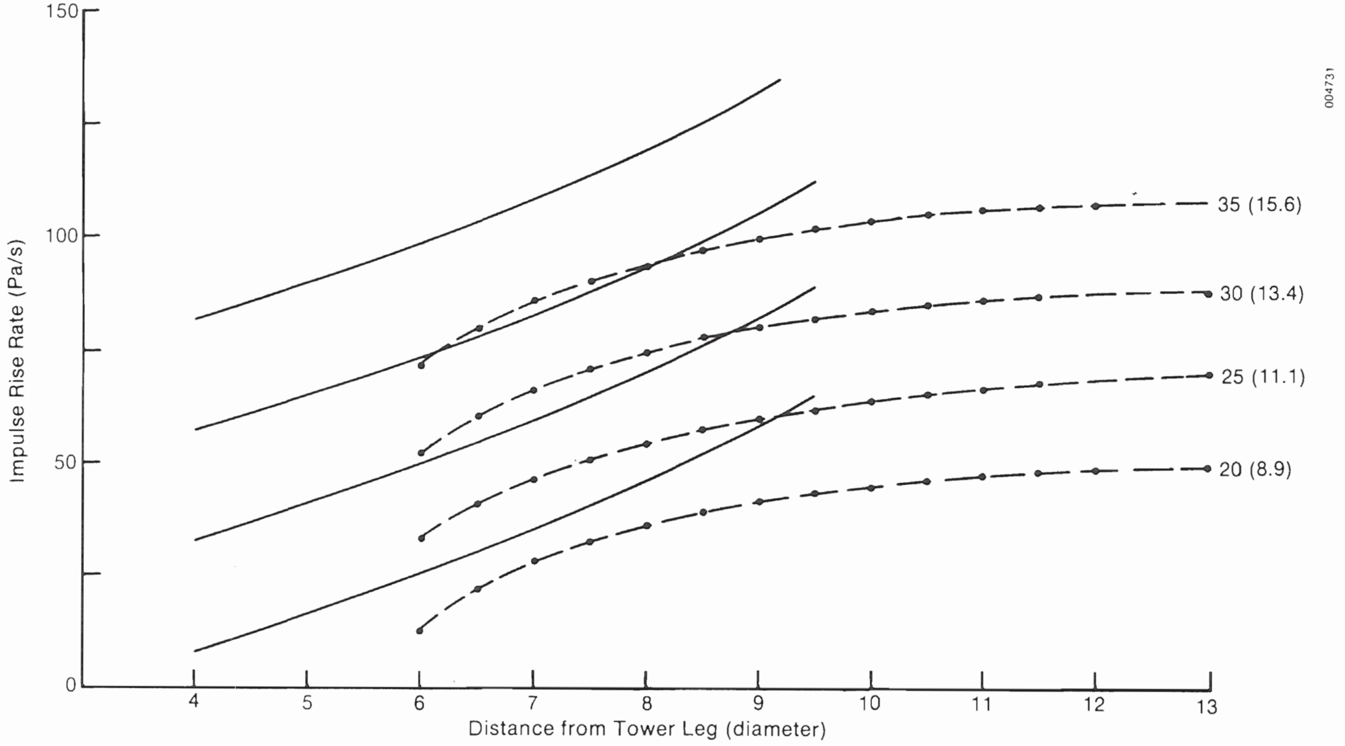

Figure 4-26. Impulse Rise Rate as a Function of Rotor Distance from Tower Leg and Hub-Height Wind Speed for March 1980 Survey Period (East, solid curves; south, dashed curves)

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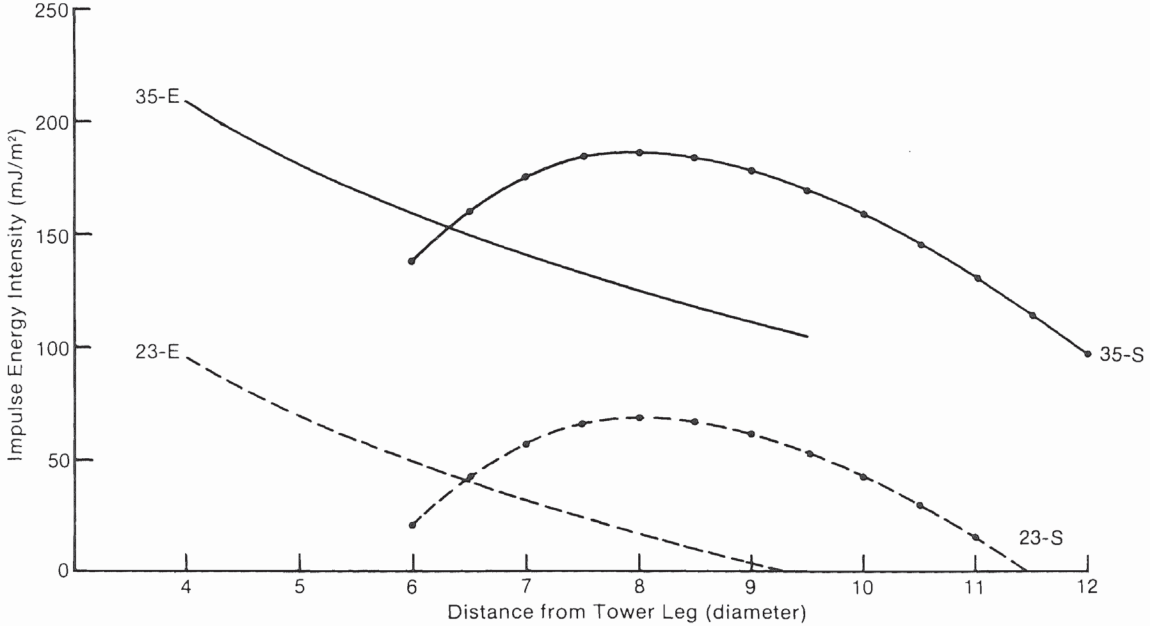

Figure 4-27. Comparison of Energy Intensity of Impulses Associated with the East Tower Leg as Function of the Rotor rpm and Tower Leg-to-Blade Distance (June 1980)

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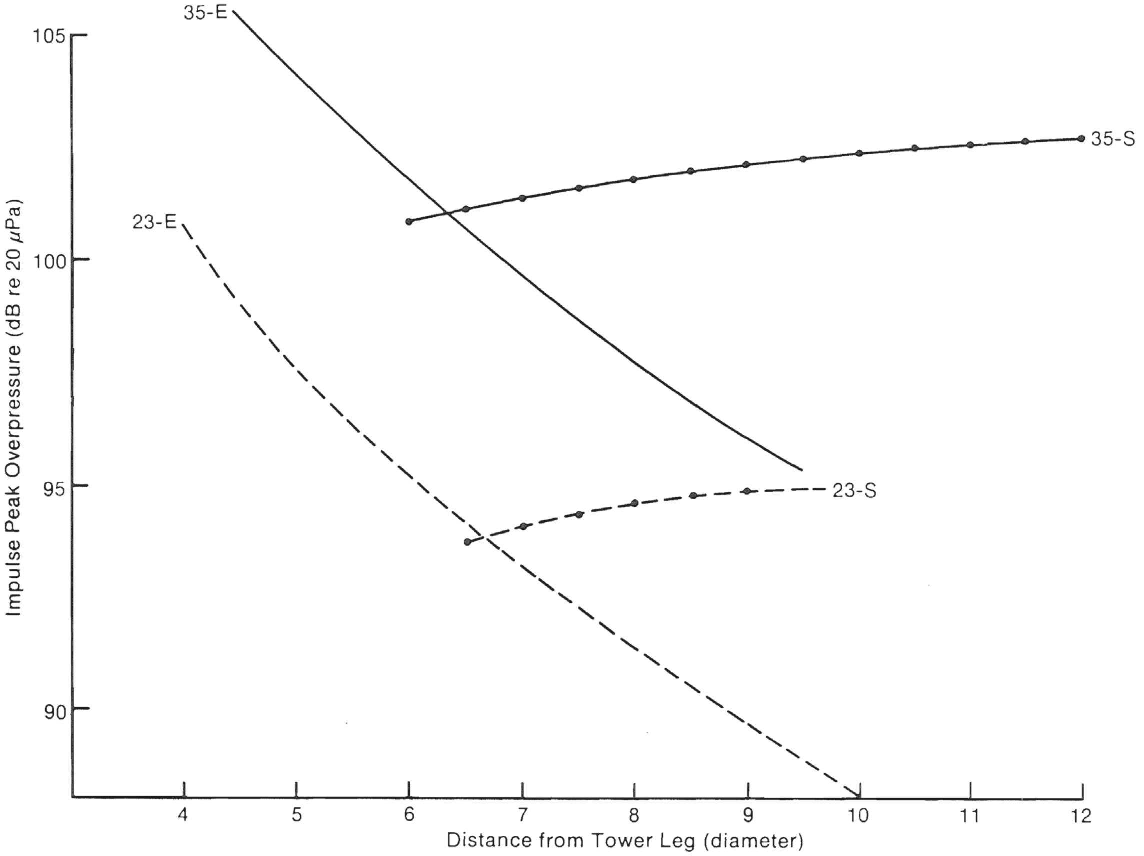

Figure 4-28. Comparison of Peak Overpressures of Impulses Associated with the East Tower Leg as Functions of the Rotor rpm and Tower Leg-to-Blade Distance (June 1980)

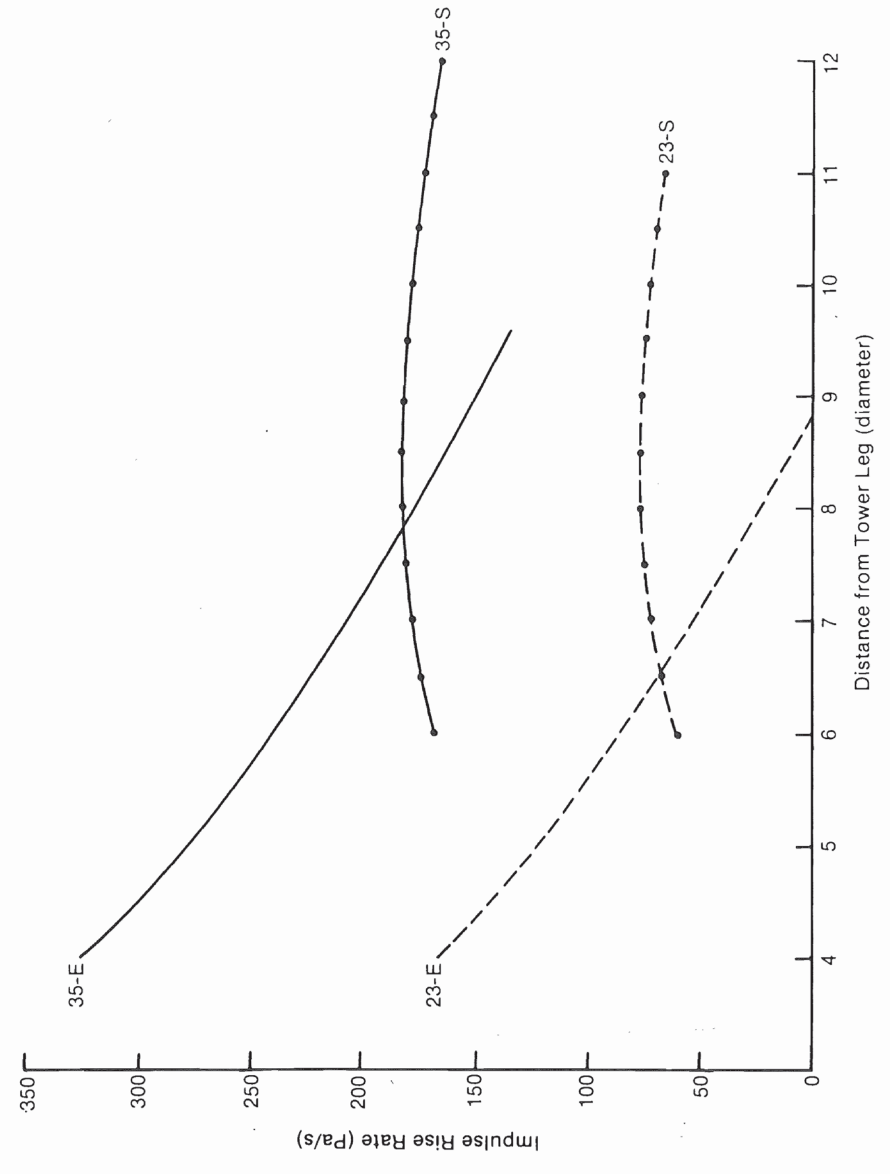

Figure 4-29. Comparison of the Rise Rate of Impulses Associated with the East Tower Leg as a Function of Rotor rpm and Tower Leg-to-Blade Distance (June 1980)

of lowering the rotational speed is to reduce the relative blade speed, often referenced to the speed at the blade tip. As shown, the average decrease in energy intensity for the south and east induced impulses are 63% and 57%, respectively. The average decreases in the impulse overpressures for the south leg impulses is 57% versus 52% for the east. The rise rate decrease is 61% and 64% for the same legs, respectively. Thus, reducing the rotational speed from 35 to 23 rpm, or 34%, results in about a 60% decrease in the average impulse characteristic levels, apparently through the increased residence time of the rotor blades in the tower leg wakes.

4.2.3.3 Impulse Analysis Interpretation and Conclusions

The results of the acoustic impulse analysis presented in the previous section have shown that the sensitivity of the impulse generation process is related to a complex interaction of several operational parameters, including the rotor rotational speed, wind speed, and blade passage distance from the tower support legs. In particular, the following results have been found:

1. The average characteristics of impulses generated in the wake of the east and south tower legs demonstrate strong differences which are similar for both the March and June surveys in form if not in severity.
2. The hypothesis that the impulse generation is strictly a function of wake velocity deficits (or a function of wind speed and separation distance) is not borne out by the marked differences in the severity of levels of impulses generated in the east and south leg wakes plus the unexplained overall increase in severity of the impulses observed during the June experiments over much the same wind-speed range experienced in March.
3. Reducing the rotor rotational speed from 35 to 23 rpm results in an approximately 60% decrease in the average levels of the three impulse characteristic parameters; i.e., the energy intensity, peak dynamic or overpressure, and rise rate.
4. The variation in impulse characteristic parameters with the two leg wakes, particularly the rise rate, indicates that the dynamics of the two wakes must be substantially different in some important aspects.
5. The effect of the wire mesh on the south tower leg appears to have had minimal influence on the generated impulses, the principal effect being a decrease in observed rise rates (Figures 4-16, 4-23, and 4-26) and an average attendant shift in the impulse energy to somewhat lower frequency bands.

The results listed here have strengthened our belief that the acoustic impulse generation process is the result of a complex, unsteady aerodynamic interaction between downstream wakes emanating from various tower structural members, from the large, 0.5-m vertical legs in particular, and the dynamics of the aerodynamic lift being developed by the turbine rotor blades, as described by Eq. (4-5). We also believe that the shape and characteristic parameters of the observed impulses are indicative of the wake dynamics present at the time of blade passage and therefore describe a stochastic process or processes.

The evidence accumulated so far points to the need for understanding the development of, and downstream dynamics of, the wakes of the tower legs in three dimensions since the rotor blades parallel the legs as they pass the tower, as shown in Figure 4-30. The role of the upstream tower members must be also considered. The peaks in many of the characteristics of impulses generated in the lee of the south leg occurred when the rotor was close to paralleling the SE flat of the tower, a time when the west and north legs were immediately upstream and may have influenced the wake development of the downstream members.

In addition to developing an understanding of leg wake dynamics, it is also necessary to assemble a body of knowledge regarding the effects of the transient, unsteady lift fluctuations forced on the rotor blades as they pass through the tower leg wakes. Understanding both of these processes is essential to the development of abatement procedures that could keep impulses from reaching annoyance levels. These matters are discussed in the following sections.

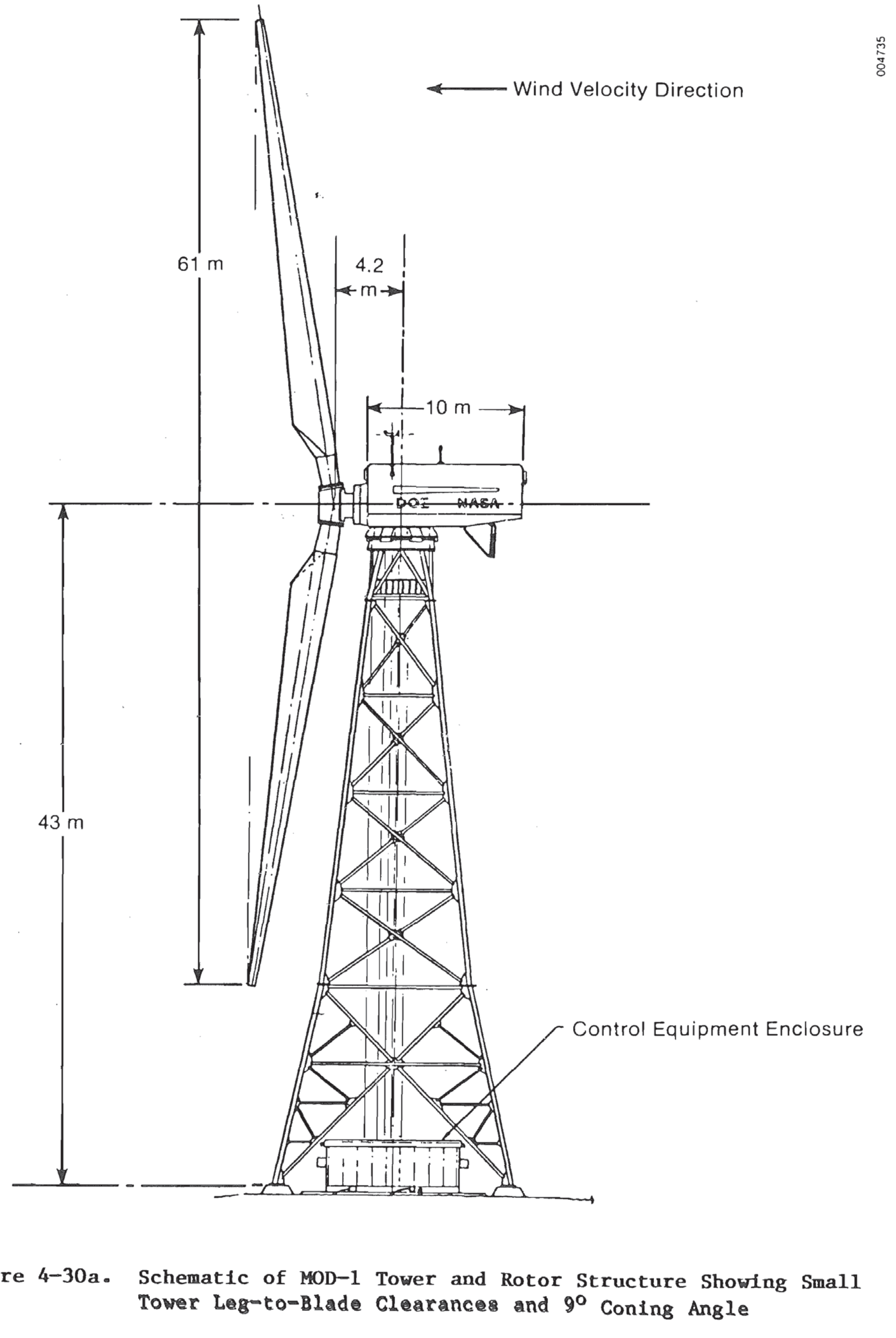

Figure 4-30a. Schematic of MOD-1 Tower and Rotor Structure Showing Small Tower Leg-to-Blade Clearances and 9° Coning Angle

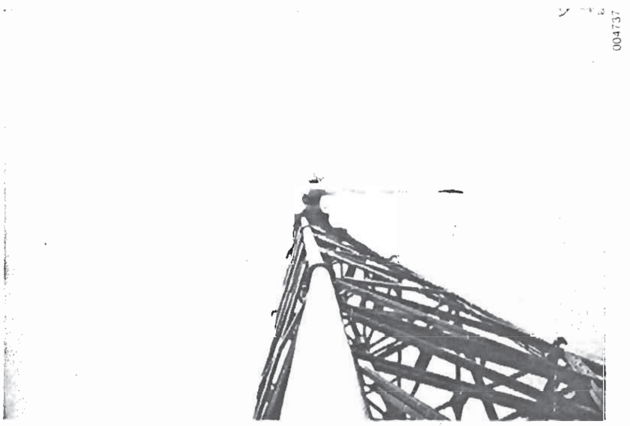

Figure 4-30b. Tower Leg-to-Blade Clearance with Rotor Nominally Parallel to Southeast Flat

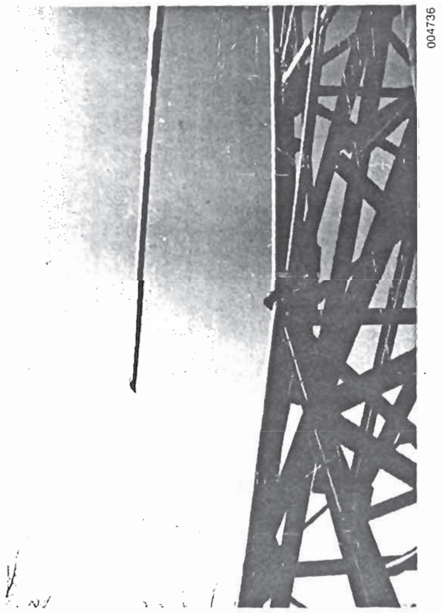

Figure 4-30c. Vertically Oriented View, Similar to Figure 4-30b

SECTION 5.0

AERODYNAMIC NOISE-GENERATING MECHANISMS

It is evident that the ultimate source of the annoying acoustic impulses being generated in the lee of the MOD-1 tower legs is aerodynamic in origin. In this section, we discuss the physical processes that are responsible for the observed transient, unsteady rotor blade loads which are radiated as acoustic impulses containing considerable pressure energy. Figure 5-1 summarizes the physical processes leading up to the radiated acoustic emissions from a rotating, lifting blade. While both broadband incoherent and discrete emissions are indicated in the figure, we are presently interested only in the latter. From Figure 5-1, we see that the following factors need to be considered in developing an understanding of the MOD-1 noise problem, in particular, and Wind Energy Conversion Systems (WECS) acoustic noise emissions, in general:

- The role of the upwind fetch and the vertical hydrodynamic stability of the atmospheric surface layer in shaping the freestream turbulent structure entering the rotor disk of an upwind turbine design or influencing the wake shedding characteristics of a tower structure ahead of the rotor blades in the case of a downwind design such as the MOD-1
- Aerodynamic processes that control the generation and unsteady structure of downstream wakes from upwind tower elements such as the large cylindrical legs of the MOD-1
- The unsteady aerodynamic response of the airfoil of a turbine rotor blade to the turbulent structures encountered as the blade moves around the rotor disk, resulting in an unsteady airload pressure spectrum on the blade surfaces
- The partitioning of spectral energy derived from the unsteady aerodynamic loading, e.g., that fraction aeroelastically extracted by the blade mechanical structure in the form of dynamic stresses and the small amount $[O(10^{-5}\ J)]$* radiated as acoustic emissions with various temporal and frequency domain characteristics; i.e., the degree of coherency.

In this section we examine each of these processes with respect to its influence on the MOD-1 noise situation. Note that some of the material was derived from SERI experimentation which has not been completely analyzed, but appears in more complete form in several other reports. The areas to be considered here, not necessarily in this order, include physical factors influencing the generation of wakes and the unsteady aerodynamic response of airfoil sections similar to those used in WECS applications.

5.1 WAKES FROM CYLINDRICAL BLUFF BODIES

Although wakes from cylindrical bodies have been studied from the time of Archimedes to the present, there are still gaps in our knowledge about this

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*$O(10^{-5}) \equiv$ order of 10^{-5} J.

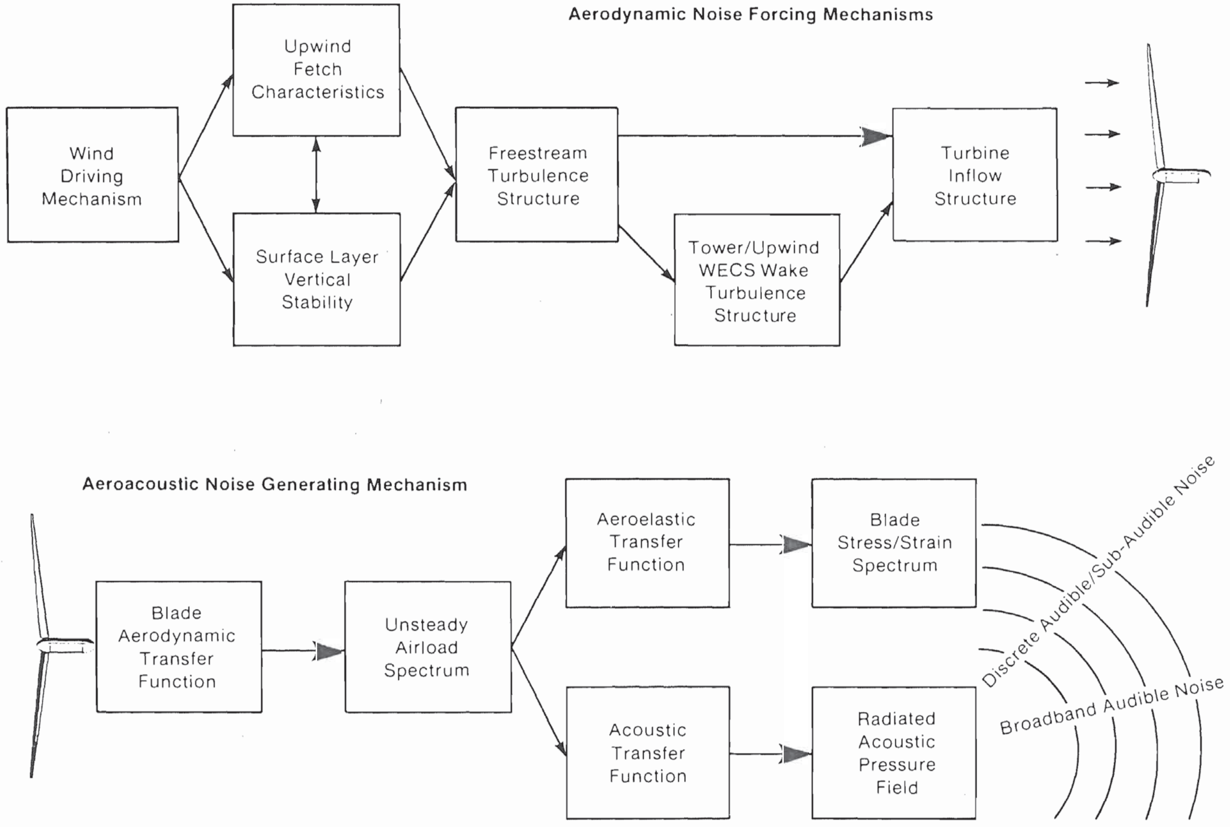


Figure 5-1. Physical Mechanisms Responsible for Noise Generation by Wind Energy Conversion Systems (WECS)

physical phenomenon. The general characteristics of cylinder wakes, which are usually studied as a two-dimensional (2-D) problem, include such parameters as mean velocity deficits (shadowing effects), wake lateral spreading with distance, and the existence of a mean return flow circulation in the near wake region close to the cylindrical body. Dynamic parameters of interest include the shape, frequency, and persistence of vortex sheets, and free shear layer-induced and overall turbulence characteristics. Figure 5-2 highlights some of the major features of cylinder wake flows. Greene [45] made an initial study of the concepts discussed in this section.

The dynamic characteristics of cylinder wake flows are of primary interest to the MOD-1, and all downwind WECS, since the events described in Section 4.0 occur with each blade passage forcing the resulting impulse characteristics to form random variables. Physical factors that influence cylinder wake characteristics include

- the freestream velocity
- freestream turbulence levels and spatial structure
- surface roughness
- the physical diameter of the body itself.

The boundary layer dynamics, which are viscous in nature and therefore a function of the Reynolds number based on the diameter, or

$$Re = \frac{\rho U_\infty D}{\mu} = \frac{U_\infty D}{\nu} , \qquad (5\text{-}1)$$

where

U_∞ = freestream velocity

ρ = air density

D = cylinder diameter

μ = absolute viscosity

ν = kinematic viscosity = μ/ρ

determine the wake structural characteristics; i.e., a periodic vortex street or a random shedding of vortices, for example. The frequency at which vortex shedding occurs is related to the cylinder boundary layer stability and expressed in terms of the Strouhal number, St, or

$$f_s = \frac{St\ U_\infty}{D} , \qquad (5\text{-}2)$$

where f_s is the cyclic or Strouhal (vortex) shedding frequency.

Critical to the MOD-1 problem is the relevant cylinder Reynolds number range, because the boundary layer viscous forces influence the wake structure the

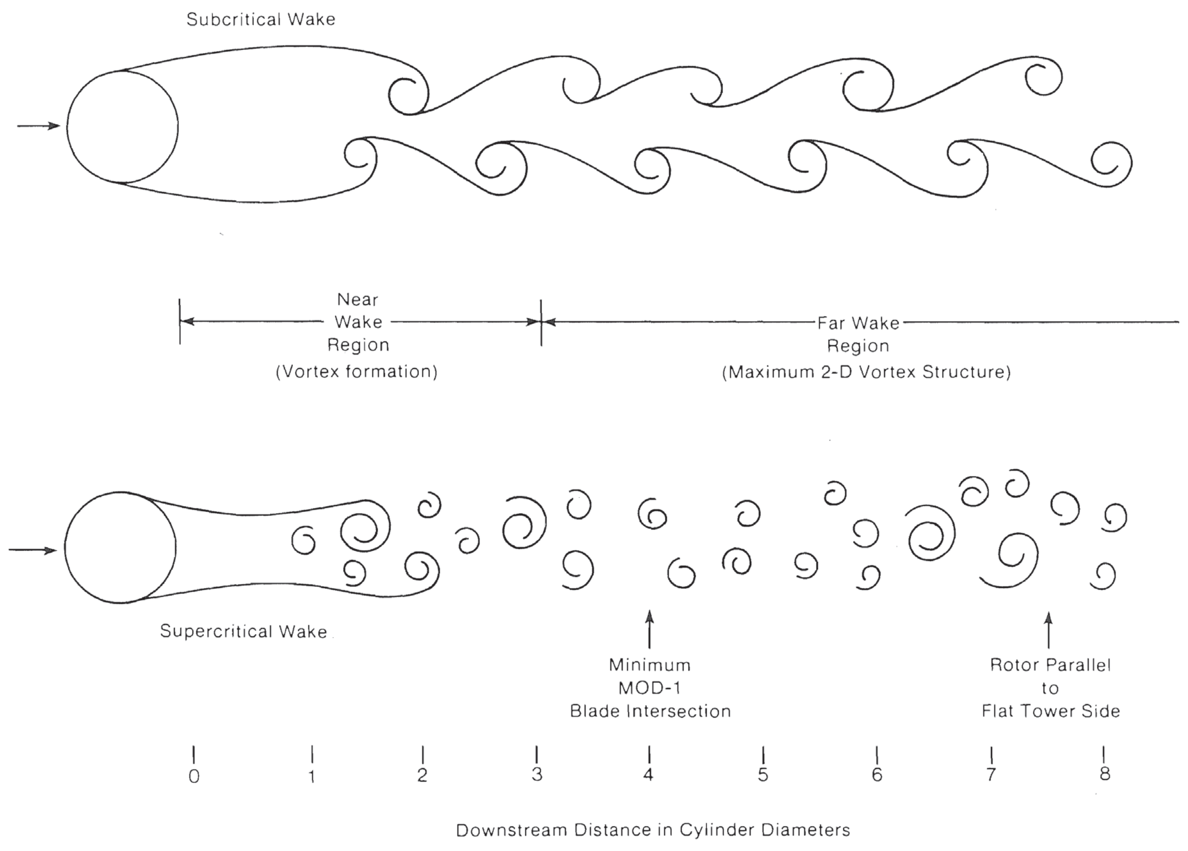


Figure 5-2. Schematics of Cylinder Wake Flows in the Subcritical and Supercritical Regimes

blades are passing through. It is clear that the freestream velocity, particularly as seen by the downstream tower legs (the east and south numbers immediately responsible for the impulse generation as discussed in Section 4.0) do not normally see the hub height values due to the vertical shear existing below the hub and above the forest canopy. The canopy, which reaches the lowest extent of the blade tips, the upwind fetch of complex, mountainous terrain, and drag losses in the tower structure itself all contribute to the generation and maintenance of this shear zone at the rotor disk. Figure 5-3 indicates the level and variability of this shear layer below hub height. This shear is also enhanced by tower blockage effects which are dependent on the approach angle of the wind, as shown by Savino et al. [4]. Garstang et al. [10] have found, from a series of measurements taken during March 1979, that the mean inflow velocity entering the west flat of the tower is typically 15%-25% less than the hub value at the height of the two lower tower structural bays, which are immediately upwind of the rotor blades. Therefore, the downwind tower legs experience a wide range of freestream velocities, often much less than hub value. Translating the turbine operating wind speed range of about 7 to 18 ms^{-1} (15-40 mph) measured at hub height, we would expect the freestream values at the downwind legs to vary from 50% to 90% of those figures or 3.5 to 16 ms^{-1}, depending on conditions. For the 0.5-m diameter legs, the Reynolds number can range from 280,000 to 1,260,000 at the altitude of the turbine and an air temperature of 10^{o}C, with a nominal value of 350,000 at an assumed freestream value of 10 ms^{-1} at this tower height, and with a hub figure estimated to be 25% greater or 13 ms^{-1}. The expected shedding frequency range, defined by Eq. (5-2) for a Strouhal number of 0.21, would be 1.5 to 6.7 per second and 4.2 at the 10 ms^{-1} windspeed expressed above. Therefore, a wide Reynolds number range and vortex shedding frequency can be experienced. A frequent intersection of the blade with a vortex is certain since the shedding frequency range, in all cases, is greater than the blade passage frequency of 1.17 per second at 35 rpm and 0.77 at 23 rpm.

5.1.1 Effect of Reynolds Number on Wake Characteristics

Roshko [11] has shown with cylinder flows at Reynolds numbers less than about 200,000, or in the "subcritical" regime, that the resulting downstream wake forms with a dominant shedding periodicity whose frequency is given by Eq. (5-2) and a nominal Strouhal number of 0.21. Above a "critical" Reynolds number (the exact number depends on the roughness characteristics of the surface of the cylinder and the turbulent structure of the inflow), a noticeable narrowing of the wake occurs as a turbulent reattachment of the boundary layer takes place, causing the dominant periodicity of the subcritical regime to cease but strong vortex shedding to continue. This later flow condition, what Roshko refers to as the "supercritical" regime, has been described as "wideband" and not completely random [12], as well as being very sensitive to freestream turbulence levels, surface roughness and three-dimensional disturbances. The Strouhal shedding frequency f_s has been observed to vary considerably from a nominal value of 0.21 in subcritical flows, but ranging as high as 0.42 in the supercritical regime. Thus, the freestream flows surrounding the downwind legs of the MOD-1 tower were probably transcending the critical Reynolds number at various times which, as a consequence, influenced the characteristics of the leg wakes to introduce yet another stochastic degree of freedom into the noise generation process.

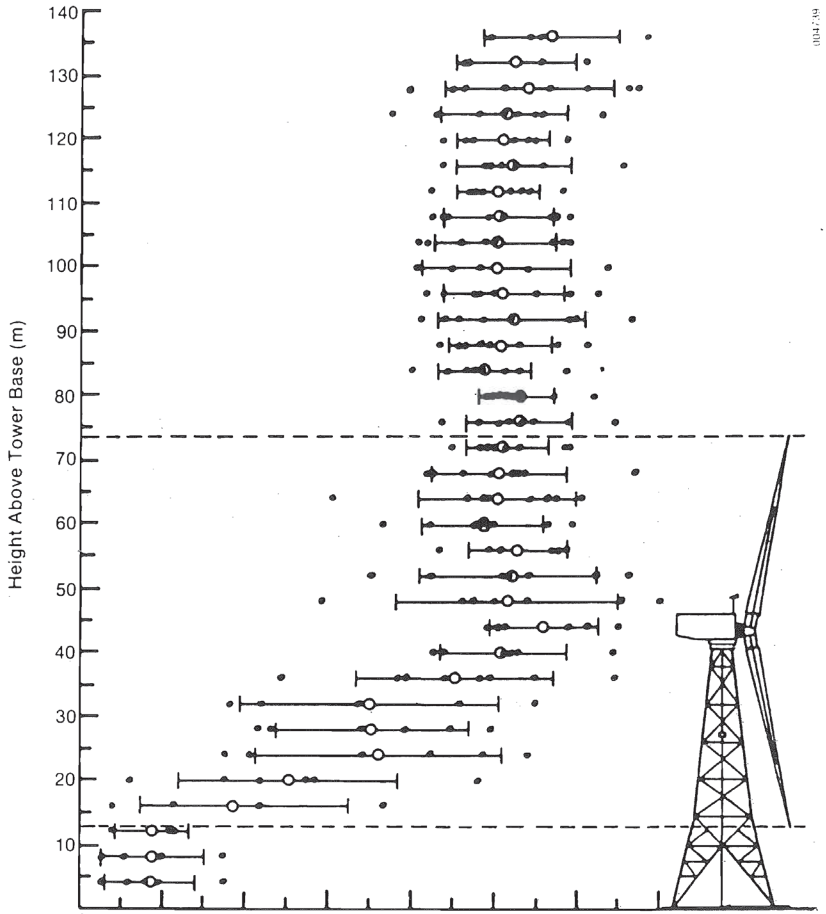


Figure 5-3. Example of the Vertical Windshear Variability Immediately Upwind of the MOD-1 Turbine

Source: Ref. [10].

5.1.2 Three-Dimensional Aspects of Cylinder Vortex Shedding

An examination of Figure 4-29a, b, and c shows, because of the coning angle, how parallel the rotor blade is to the vertical, cylindrical tower members. We noted in Sections 4.1.1.2 and 4.1.1.3, the dependence of coherent, impulsive acoustic radiation on the spanwise lift correlation function, defined as

$$\delta_c = \int_o^{span} f(x)\, dx \quad , \tag{5-3}$$

which is related to the radiated dynamic pressure field by

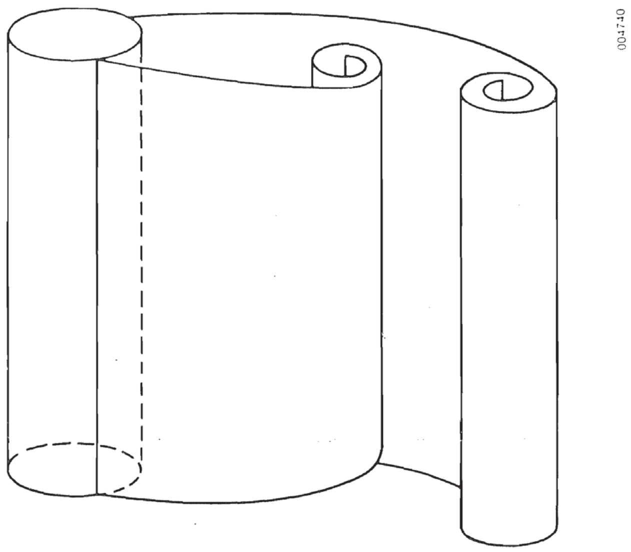
$$\hat{p}(t) = \frac{X_N}{4\pi c_o r^2} \; \frac{dL(t)}{dt} \; \delta_c \; . \tag{5-4}$$

It is clear that, due to the positioning of the rotor blade with respect to the cylindrical tower leg shown in Figure 4-29, a 2-D cross section of the wake containing vortex elements may also extend into the third dimension or vertically along the leg. The intersection of a turbine blade with such a vertically coherent wake structural element would most certainly produce a lift fluctuation over a sizable portion of the span, as defined by Eq. (5-3).

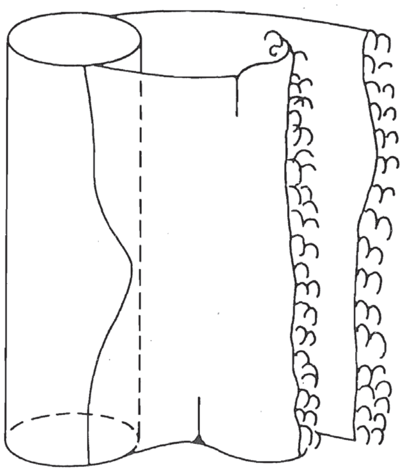
The three-dimensional (3-D) aspects of cylinder vortex shedding have been studied by Naumann and Quadflieg [13]. From a series of experiments, they concluded that what amounts to a periodic "vortex tube" develops in the wake of a cylinder, as shown in Figure 5-4, initially along a separation line which is parallel to the cylinder major axis. Should the separation line become distorted along the cylinder surface, circulation differences develop and, at a short distance downstream, the 2-D vortex structure breaks down into generally chaotic, 3-D turbulence. Therefore, a physical mechanism potentially exists which is capable of producing a vertically coherent turbulent wake structure and which, if intersected by a turbine blade, could produce large values of ℓ_c as defined by Eq. (5-3) and large, radiated acoustic pressure fluctuations as expressed by Eq. (5-4).

5.1.3 Cylinder Far Wake Characteristics

The major elements of a 2-D cylinder wake flow are shown in Figure 5-2. Many investigators have found that this 2-D structure is generally most fully developed downstream of the formation region (about 3-4 cylinder diameters) and extending 10-12 diameters or more before viscous vortex decay and the entrainment of freestream turbulence converts the 2-D structure to 3-D chaotic. Stability factors are also known to control this rate of decay. Under stable, low freestream turbulence conditions, discrete cylinder wakes have been detected out to 50 diameters. Recently, Snyder and Wentz [14] conducted a study of the wake characteristics of cylindrical bluff bodies, including both true circular and 12-sided, polygonal-shaped cylinders. They found that the mean wake profile expands laterally an included angle of about 1.5^o from the wake centerline for subcritical flow and only about 1^o for the supercritical regime.



Vortex Shedding from a Linear and Parallel Separation Line



Shedding from a Distorted Separation Line

Figure 5-4. Sketch of Cylinder Vortex Shedding from a Vertical Separation Line Parallel to Major Axis and when this Line is Distorted

Source: Ref. [13].

5.1.4 Field Verification of Vertical Coherency of Cylinder Wake Structures in Natural Flows

To verify the existence or nonexistence of vertically coherent structures in the downstream wake of a cylindrical tower element, an experiment (which was part of a larger effort) was performed at the Rocky Flats Wind Energy Research Center during the summer of 1981. A cylindrical section 2.4 m long and 0.5 m in diameter (same as a MOD-1 leg) was mounted approximatly 10 m above the ground on a small wind turbine support tower. Two constant-temperature, hot-film anemometers with measuring elements 50 µm in diameter were mounted on a boom support mount attached to the arm of a lift truck, as shown in Figure 5-5. The two anemometers were mounted approximately one meter apart vertically and placed in the wake of the cylindrical element on the tower at various downstream distances.

Figures 5-6 and 5-7 plot the resulting averaged cross spectrum and standard coherence function for the two wake velocity signals. The two probes saw a correlated shedding signal at a frequency of 1.244 Hz. The mean freestream velocity was 3.6 ms^{-1} with a peak coherent wake velocity of 1.10 ms^{-1} or 31% of the freestream value at that frequency. The calculated Strouhal shedding frequency (St = 0.21) for this mean freestream velocity is 1.51 Hz, compared with the 1.244 Hz measured. The peak coherence was 0.591, indicating that the two velocities can be considered partially vertically coherent in the mean.

These and other similar measurements have confirmed the existence of wake structures that are partially coherent along a dimension parallel to the major axis being shed from vertically mounted cylindrical bluff bodies in a natural wind. Figure 5-8 further confirms the periodic shedding attribute through a comparison of the local wake dynamic pressure amplitude spectrum, as measured at the base of the cylinder and 2 cm from its surface (upper trace), with a corresponding wake velocity spectrum 1-1/2 cylinder diameters downstream.

5.2 IMPULSIVE NOISE GENERATION MECHANISM(S)

Because of the extreme difficulty of making detailed aerodynamic measurements near the MOD-1 turbine, as well as the highly nonstationary conditions surrounding the impulse generation process itself, we performed a series of supporting experiments to aid us in developing a more clear understanding of what physical processes were operating but under conditions in which some control could be exerted. These ancillary experiments included field measurements using both the full-scale DOE/NASA MOD-0 experimental turbine at Plumbrook, Ohio and a small downwind turbine installed at the Rocky Flats Wind Energy Research Center near Golden, Colorado. Two wind tunnel experiments were also performed using the MIT Anechoic Wind Tunnel and the University of Colorado-Boulder subsonic wind tunnel facilities. Due to the incompleteness of much of the analyses of these supporting studies, only excerpts from the results obtained so far can be presented in this document; the remainder is to be included in future SERI reports.

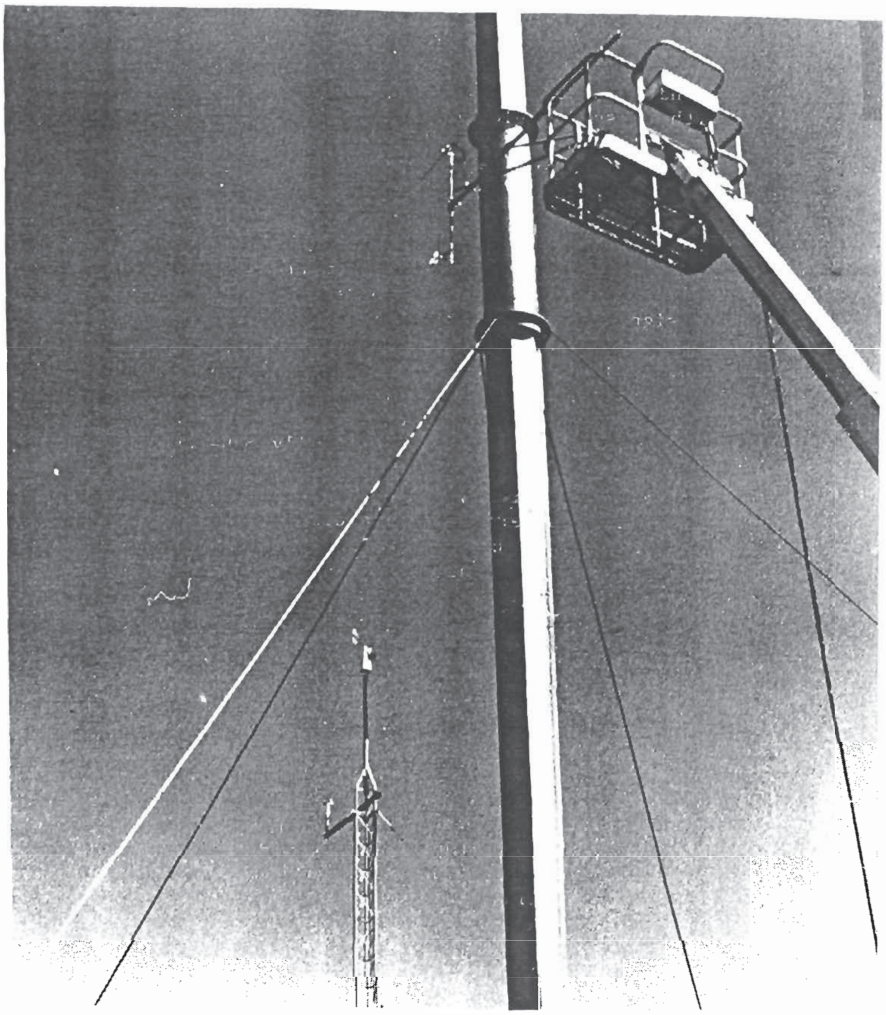


Figure 5–5. **Vertically–Separated, Dual Hot–Film Anemometer Configuration for Measuring Cylinder Wake Characteristics in Natural Turbulent Flow**

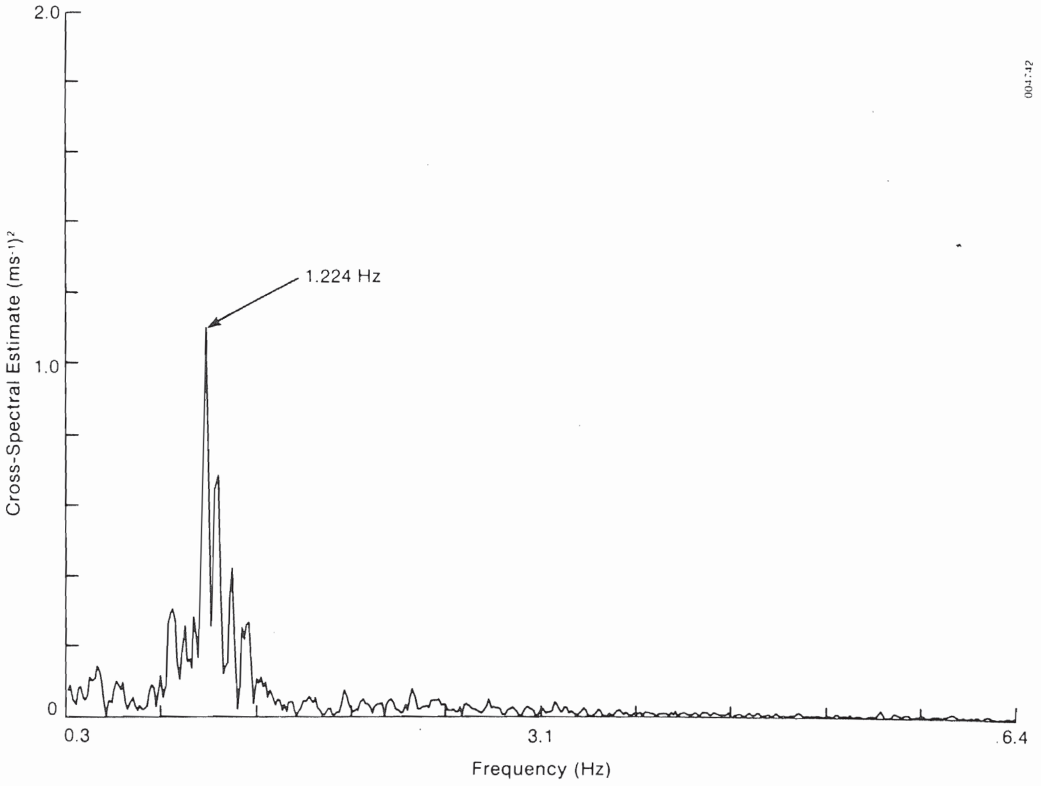


Figure 5-6. Cross-Spectral Estimate of the Upper and Lower Bare Cylinder Wake Velocities as Measured by the Technique Shown in Figure 5-5

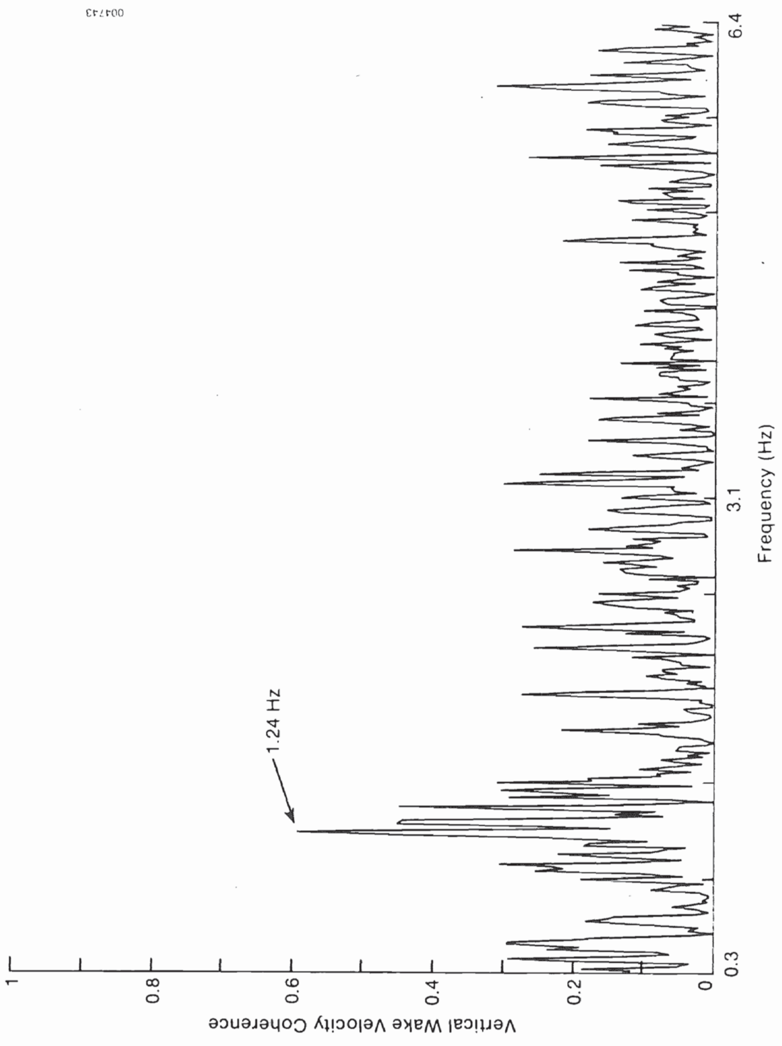


Figure 5-7. Vertical Coherence of Bare Cylinder Wake as Determined by Measurements of Figure 5-5

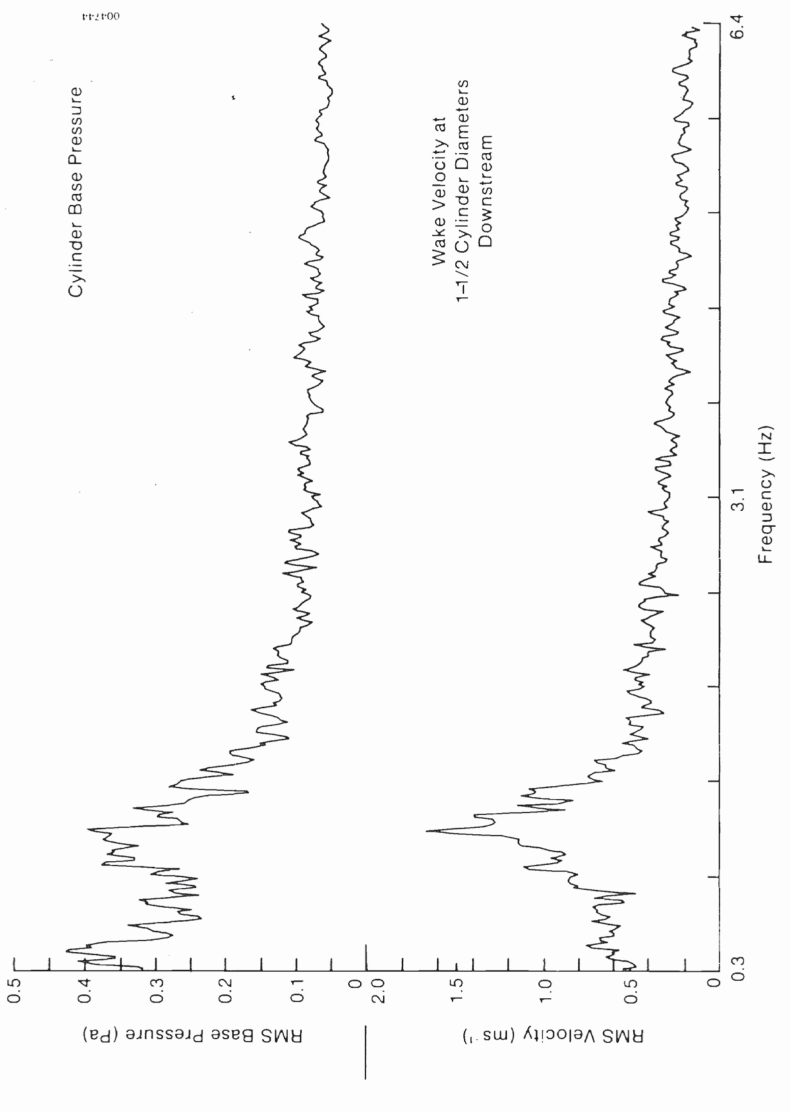


Figure 5-8. Comparisons of Cylinder Base Pressure and Wake Velocity RMS Spectra for Bare Cylinder Tower Element

5.2.1 Wind Tunnel Verification of Tower Leg Wakes as the Principal Cause of Impulse Generation

The purpose of using the MIT anechoic wind tunnel was to confirm, at least on a semiquantitative basis, the role of tower leg downstream wakes in the generation of acoustic impulses and as the source of homeowner complaints. Figure 5-9 is a sketch of the experimental setup. Details of the actual experiments are discussed in Refs. [15] and [16]. Essentially, the experiments consisted of placing a series of cylinders of varying diameters in the inflow of an unloaded, two-bladed rotor operating at a tip speed ratio of between 9 and 10. Cylinder diameters were chosen based on diameter/blade-chord ratios of 0.31, 0.63, 1.0, and 2.5 to simulate upstream tower structural element diameters ranging from the MOD-1 (0.31) to the Hamilton-Standard Model WTS-4 turbine (2.5) and including two intermediate values, 0.63 and 1.0. The leg-to-blade distance was also varied by moving the blocking cylinder to upstream positions normalized by the cylinder diameter (D), i.e., 3, 5, 10, and 15D. When there was sufficient clearance, a second cylinder identical to the first was placed upstream at a distance of 17D to evaluate the effects of augmenting the inflow of the cylinder immediately ahead of the rotor disk. The purpose of this was to simulate a quasi-periodic turbulent structure containing disturbances related to the cylinder Strouhal frequency similar to that found on a pipe truss tower when the downstream legs are emersed in the wake from those immediately upstream. In the case of the MOD-1, this arrangement corresponded to the most common rotor azimuth position, a result of the prevalence of a WNW wind direction. A constant-temperature, hot-wire anemometer was placed in the cylinder wake at a distance slightly ahead of the rotor plane to measure the turbulent structure actually entering the blades. Two SERI VLF microphone systems were used to measure the acoustic emissions of the blade-wake interaction, one on-axis and one in the rotor plane in the acoustic far field. Unfortunately, dynamic similarity with the MOD-1 could not be achieved with this arrangement. The 5.5-cm constant-chord rotor achieved a blade speed of 50 ms^{-1} at 80% span for a chord Reynolds number of 160,000, compared with the MOD-1 80%-span-speed of 88 ms^{-1} at 35 rpm and a chord Reynolds number of 10^7. Similarly, the maximum cylinder Reynolds numbers ranged from 14,000 for the smallest diameter to 115,000 for the largest, compared with a value of about 350,000 for the MOD-1 at a freestream velocity of 10 ms^{-1}.

5.2.1.1 Acoustic Results

Some of the acoustic results of these tests are summarized in Figure 5-10 in terms of the peak SPL measured by the on-axis microphone at a freestream velocity of 13.4 ms^{-1}. The smallest cylinder (which is the same cylinder-diameter/chord ratio as the MOD-1 at 80% span) radiates the most severe impulse levels compared with the larger cylinder wakes, a full 11 dB above background. The effect of placing an identical cylinder 17D upstream of the first was to intensify the impulses being emitted by the blade-wake interaction. Figure 5-11 shows two pressure-time plots of a single blade passage through the wake of the smallest cylinder 3.5D upstream and with and without a second cylinder 17D upstream of the first. The impulse generated by the augmented wake has a peak dynamic pressure almost four times or 12 dB greater than the single-cylinder-induced impulse. The acoustic pressure-time

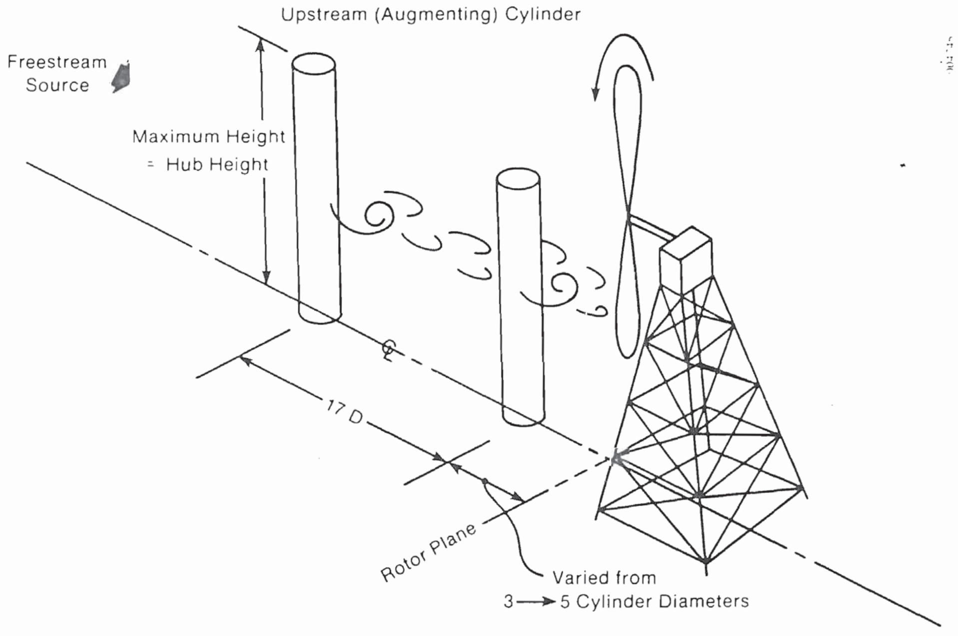


Figure 5–9. Experimental Configuration Used in the MIT Anechoic Wind Tunnel Testing

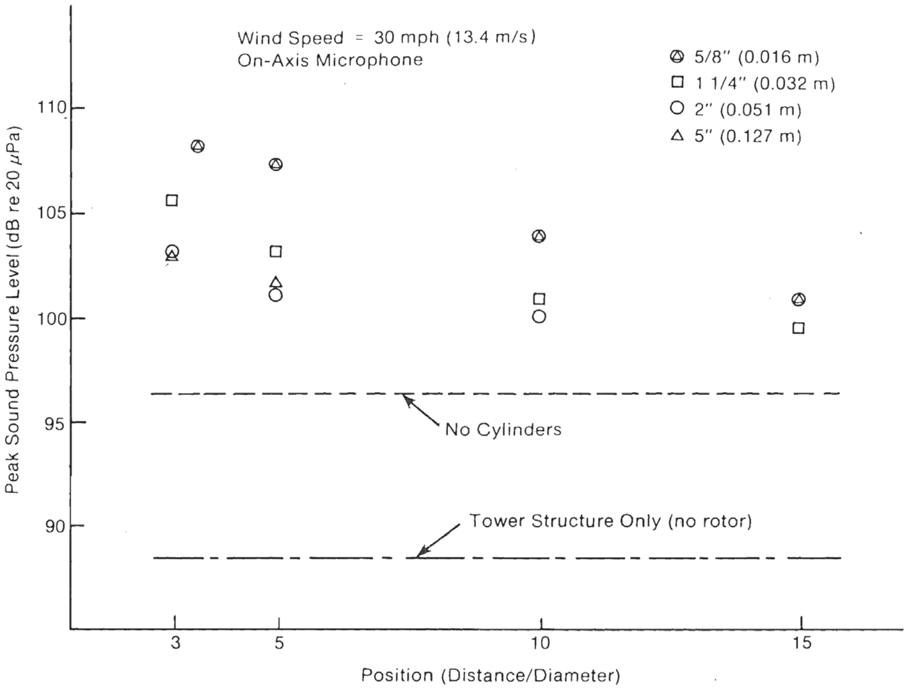


Figure 5-10. On-Axis Peak Impulse Pressure as a Function of Cylinder-to-Rotor Distance and Upstream Cylinder Diameter

Source: Ref. [15].

histories of three blade passages for the dual and individual cylinder wakes are plotted in Figure 5-12, which again show the variability of the impulse signatures and the increased severity of the impulse associated with the augmented wake, even under controlled wind tunnel conditions.

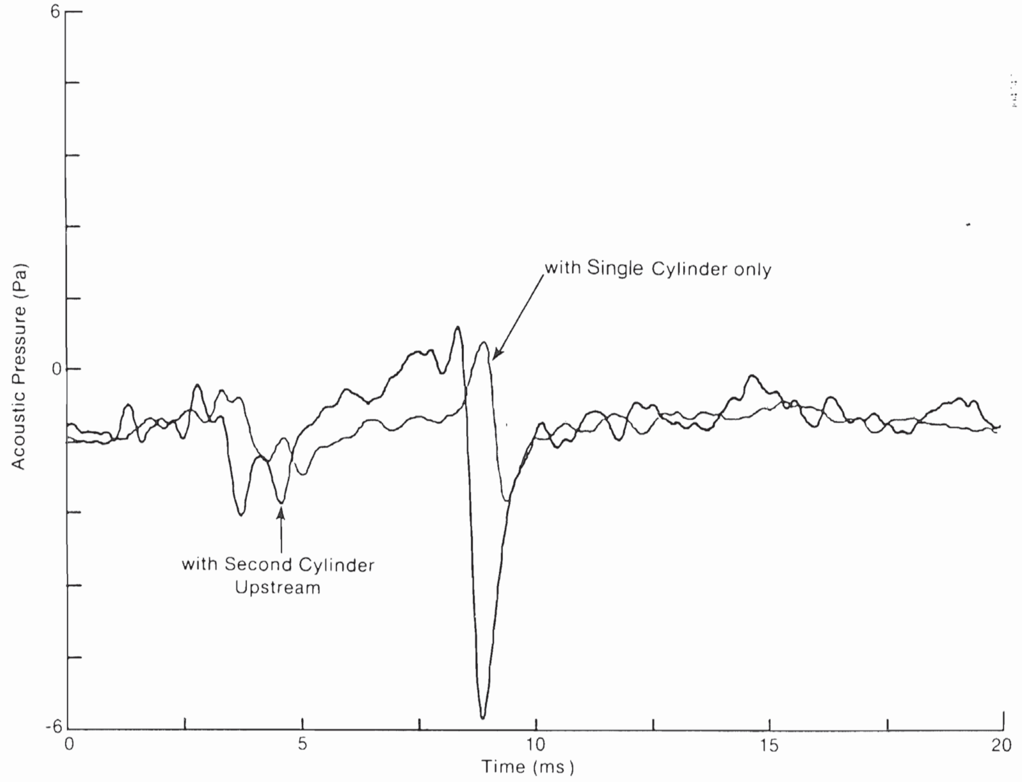


Figure 5-11. Acoustic Pressure-Time Plot of Impulses Emitted from Cylinder Wake-Blade Interaction with a Single Upstream Cylinder and with a Second Augmenting Cylinder Present

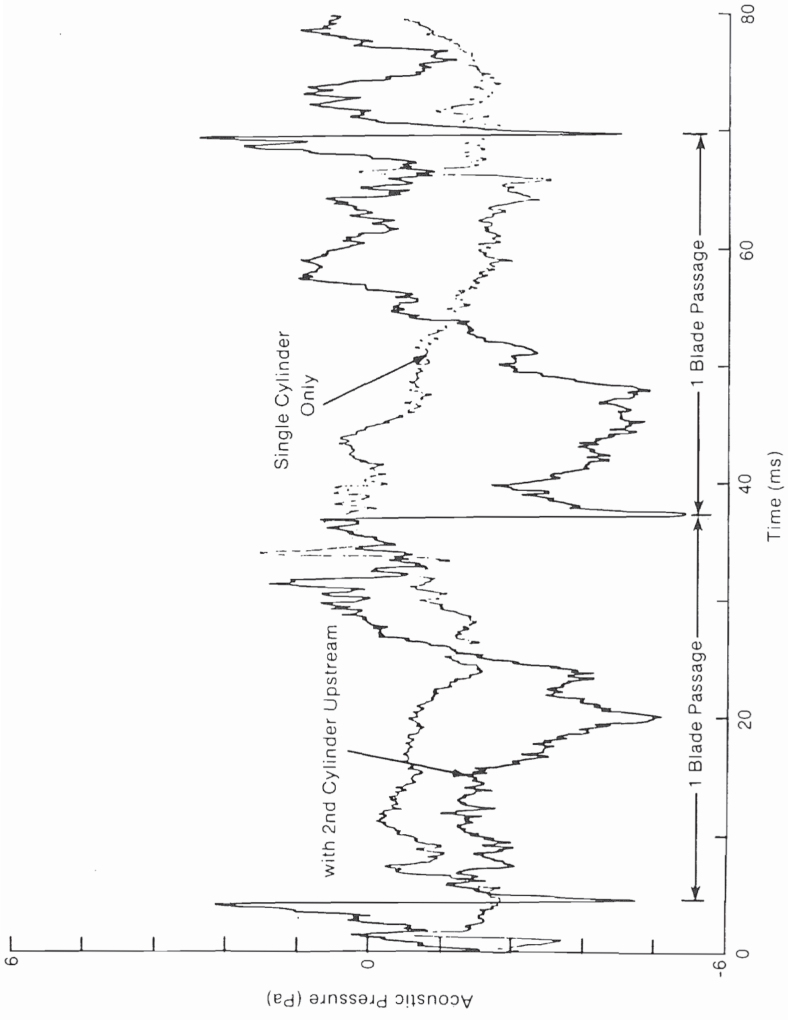


Figure 5-12. On-Axis Acoustic Pressure-Time Plot of Impulses Generated by Three Passages through Wakes Produced by Single and Dual Upstream Cylinders

5.2.1.2 Aerodynamic Results

The advantage of this experiment, when compared with actual field measurements of the MOD-1, is that we gain at least a partial knowledge of the turbulent structural characteristics of the cylinder wakes entering the rotor disk while being able to compare the induced acoustic effects on the same time base. Under these conditions, we are also able to examine the features of the single- and upstream-cylinder-augmented wakes to gain insight into why the latter were intensified. Figure 5-13 plots the averaged velocity power spectral density spectrum of the smallest cylinder wake with and without upstream augmentation (which corresponds to the acoustic impulses shown in Figures 5-11 and 5-12). The spectrum of the augmented wake is seen to be less energetic and more discrete than that of the single-cylinder wake. The probability density curves of Figure 5-14 for these two time series (which have been passed through a bandpass filter whose 3 dB breakpoints reside ±20 Hz of the shedding frequency of 87 Hz) show that the single-cylinder wake is not only more broadband but also exhibits a more-or-less uniform density distribution in the wake vortex shedding frequency range. The augmented wake, in contrast, not only is more discrete but tends to be more Gaussian. From this we find that the more intense acoustic impulses are being generated in a wake containing a greater number of discrete vortices and exhibiting narrowband properties, compared with the single-cylinder wake which inherently exhibits a wideband characteristic. Thus, the disturbances present in the wake of the upstream bluff body will tend to intensify the unsteady aerodynamic process related to the wake generation of a downstream cylinder, the latter being directly responsible for the rapid lift fluctuations and impulse radiation from a passing turbine blade.

These characteristics are difficult to see in an actual sample time series of the wake velocity. However, because of the nature of this experiment, i.e., what may be called stationary in the wide sense due to the external conditions imposed, underlying wake structures both containing and not containing a predominance of these qualities may be viewed in Figure 5-15a and 5-15b. Here, two wake velocity signals representing the augmented and unaugmented cases have been ensemble-averaged over a period of 100 seconds using a once-per-revolution synchronizing pulse. A close study of these two statistical ensembles reveals many of the structural characteristics described by the frequency and probabilistic presentations of Figures 5-13 and 5-14. In particular, the wideband nature of the unaugmented wake is clearly evident (the excess of signal peaks over the augmented signature), and the greater range over which this wake velocity can be found in comparison with the two-cylinder case bears out the uniform density distribution of Figure 5-14.

One additional interpretation of the statistical ensembles of Figure 5-15a and 5-15b can be made in terms of the mean distribution of the eddies or vortices present in the wake flow. In the unaugmented wake (Figure 5-15a) many more such elements exist than in the augmented case, supporting the position that the latter situation contains fewer but more discrete vortices than the former. One parameter unfortunately missing in this experiment is the vertical coherence, δ_c, defined by Eq. 4-7. Hence, we can only speculate on the effects on δ_c by the augmented and unaugmented wake flows present.

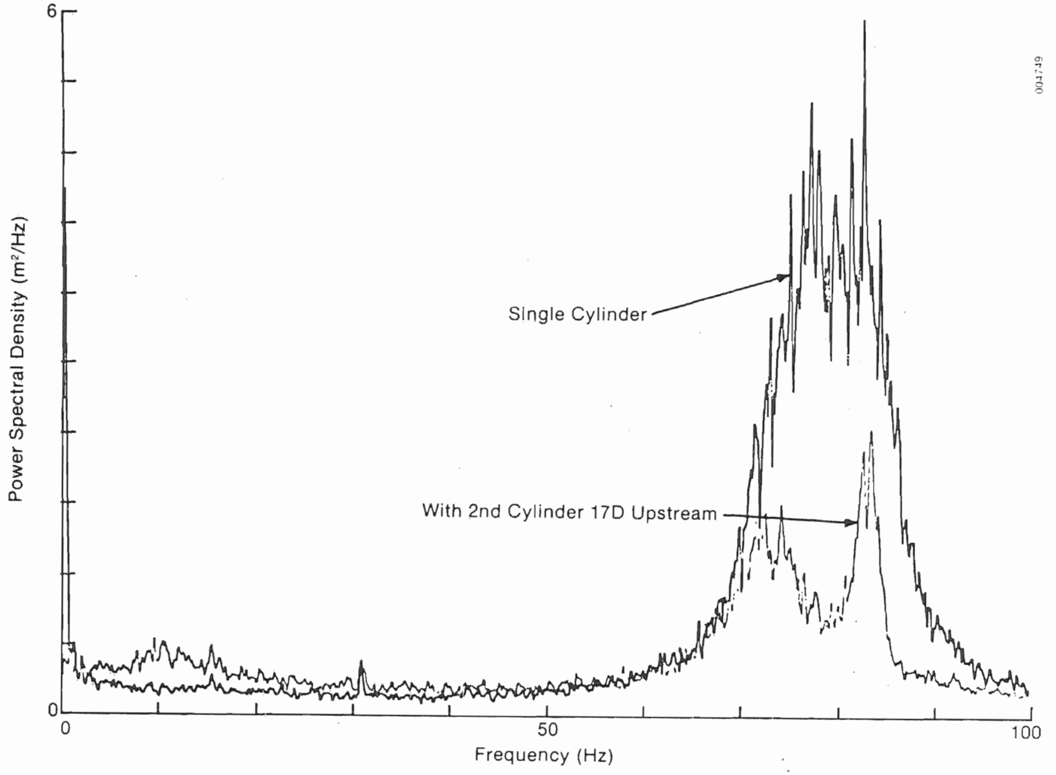


Figure 5-13. Power Spectral Density of Wake Velocities Associated with Single and Dual Upstream Cylinders

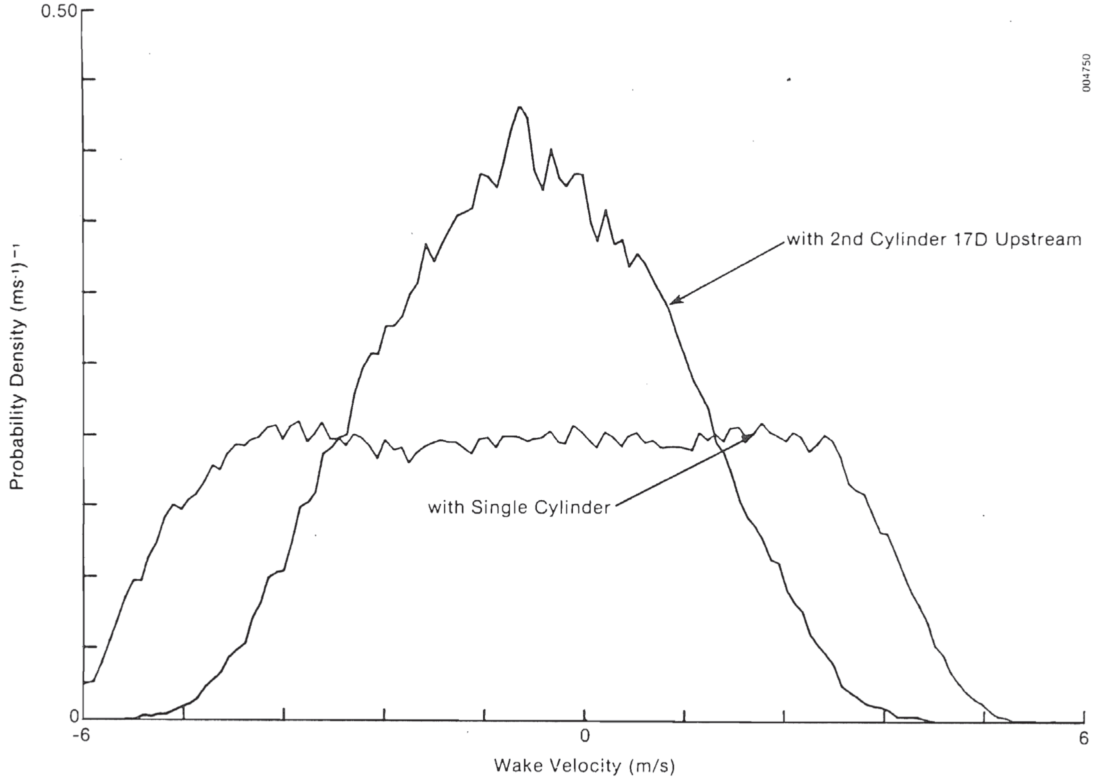


Figure 5-14. Wake Velocity Probability Densities for Both Single and Dual Upstream Cylinders (dc component removed)

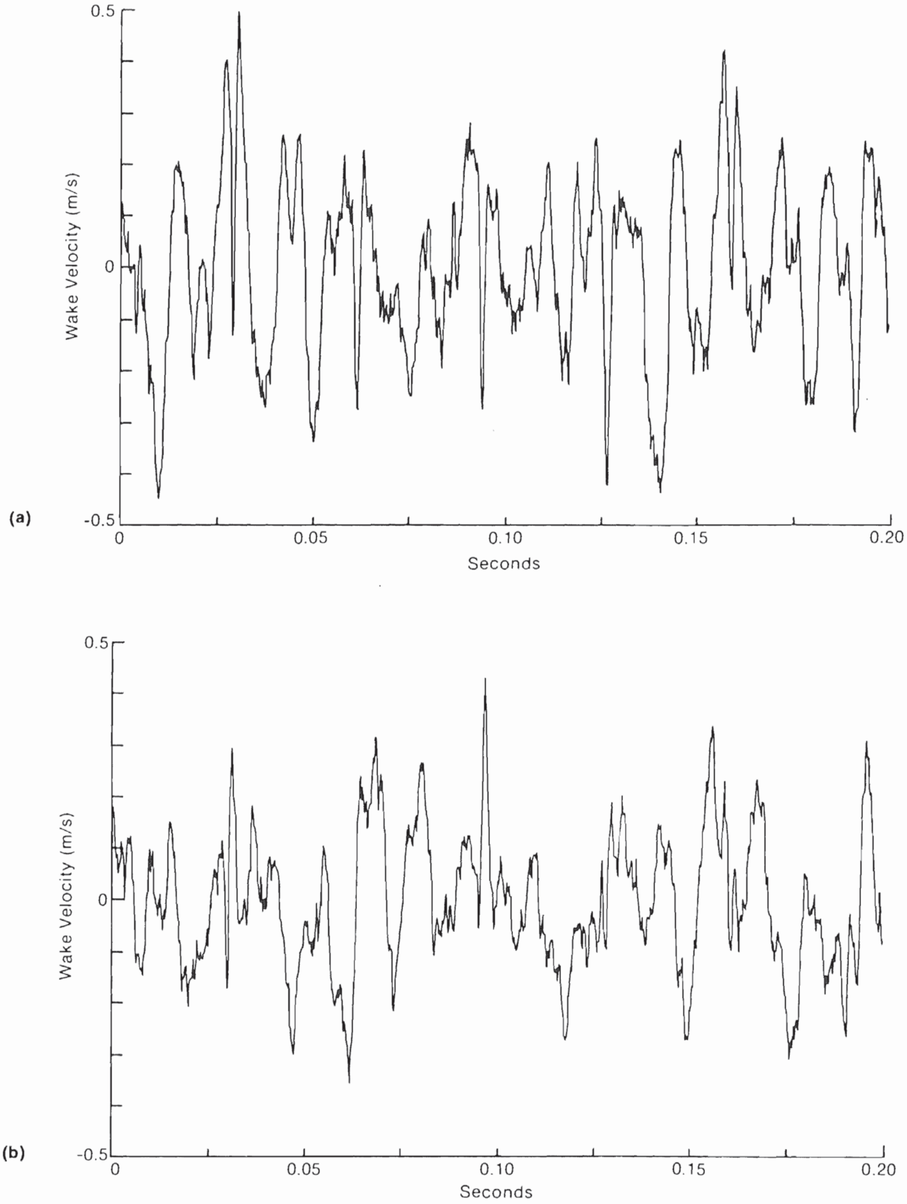


Figure 5-15. Statistical Ensemble Averages of a Single-Cylinder Wake (a) and a Wake Augmented by a Second Cylinder Installed 17D Upstream (b)

5.2.1.3 Conclusions from the Anechoic Wind Tunnel Experiment

The results of this experiment, including conclusions reached by Park and Harris [15] and from a follow-on experiment based on the same experimental procedure by Marcus and Harris [16], have indicated the following:

1. Aerodynamically generated acoustic impulses associated with downwind wind turbine designs can, at least qualitatively, be reproduced in an anechoic wind tunnel environment.
2. The strong on-axis or dipole directionality of the impulse radiation predicted by numerical models [2] has been confirmed.
3. The severity of the observed impulse becomes less as the cylinder-to-blade distance increases, indicating a change in the character of the cylinder wake and emulating a similar decrease found in the impulses derived from the MOD-1 east leg wake discussed in Section 4.2.3.
4. The most intense impulses associated with the interaction of a wake from a solid upstream cylindrical body were produced with the smallest cylinder-diameter/chord ratio (0.31), indicating the importance of vortex elements whose dimensions are the order of the chord in this process.
5. Adding a second cylinder of the same physical dimensions 17D upstream of the one immediately ahead of the blade plane increases the severity of the observed impulses.
6. Augmentation by a second upstream cylinder significantly alters the turbulent wake structure of the downstream cylinder by changing the vortex shedding from essentially a wideband to a narrowband stochastic process with an attendent increase in acoustic impulse severity as the turbine blades pass through the altered wake.
7. The statistical nature of the rotor/wake impulse generation process has again been demonstrated, this time under controlled laboratory conditions, underscoring the need for employing stochastic as well as deterministic analysis tools in order to achieve a reasonably complete understanding of the physical processes involved and to lay the groundwork for the development of effective amelioration procedures and techniques.

5.2.2 The Role of Freestream Turbulence in Influencing Severity of Impulse Generation

The results of the previous section have shown that the wake of an upstream cylinder when it intersects a similar downstream cylinder can alter the turbulent wake structure of the latter. Such a mechanism could be important in determining the severity of acoustic impulse generation from downwind turbines employing pipe-truss towers since, for certain wind directions, the downwind legs closest to the rotor plane are being similarly influenced, as is true of the MOD-0, MOD-0A, and MOD-1 turbine designs. This may also be true for single-column towers (WTS-4) if the natural inflow contains a sizable proportion of turbulent eddies whose spatial dimensions translate close to the Strouhal shedding frequency when intersecting a cylindrical tower structure.

5.2.2.1 Field Experimentation

To investigate the possibility of tower-turbulence interaction, we designed our experiment at the Rocky Flats Wind Energy Research Center to measure the influence of natural inflow turbulent energy in a spectral frequency band defined by a Strouhal shedding frequency range for the 0.5-m (20-inch) bare cylinder and the compass of wind speeds encountered. Figure 5-16 sketches the physical arrangement. A rugged, constant-temperature, hot-film anemometer with a maximum frequency response of 10 Hz was installed upwind of the small wind turbine tower to measure the horizontal turbulence component. It was located about 15 m upstream and at a height equivalent to the center of the cylindrical test section, about 12 m. Two VLF microphone systems were used, one installed at the base of the cylinder on the tower to measure the pressure field near the cylinder surface and the other on the boom of the lift truck which was positioned as close to the rotor axis as practical to capture the radiated impulses. The vertically coherent shedding characteristics of the bare cylinder were discussed in Section 5.1.4.

Figure 5-17 shows an averaged sound pressure level spectrum as measured by the microphone mounted at the foot of the test section for an impulsive episode with the bare cylinder in place. The level of the discrete bands (tones) are a measure of the severity of the impulses being generated. Because the frequencies associated with these averaged tonal peaks are principally a function of the constant rotational rate of the turbine and therefore subject to little or no frequency variation, we chose the average narrowband (0.125 Hz) pressure levels of six of these discrete tonal frequencies (including 23.5, 27.35, 31.25, 35.25, 39.125, and 43.0 Hz) as quantitative measures. While clearly discernible tones could occasionally be found at frequencies as high as 100 Hz and perhaps more (a function of the impulse shape and intensity), these six tone levels could almost always be identified above background, particularly at the higher wind speeds. The tone levels were determined by averaging 2-minute acoustic records simultaneously with sample records of the freestream velocity and the mean-square turbulence inflow in the 2.5-8.0 Hz frequency band, the Strouhal shedding or excitation range. Thus, the wind speed and 2.5-8.0 Hz band mean-square turbulence values were used as forcing functions, and the acoustic tonal peaks as the output of the process under investigation. A total of 35 2-minute records were assembled from the available data covering a wind speed range of 4.7 to 10.9 ms^{-1}. Table 5-1 summarizes the observed statistics of these 2-minute samples.

5.2.2.2 Results

Figure 5-18 plots the relationship between the freestream velocity and the turbulent energy in the 2.5-8.0 Hz Strouhal excitation band. The correlation coefficient for the indicated linear regression is 0.787 with a standard error of estimate of $\pm 0.385\ (\mathrm{ms}^{-1})^2$. Figure 5-19, as an example, plots the observed bivariate relationship between the freestream velocity and the mean 35.25 Hz tone level (dB). The correlation coefficient for the indicated linear regression is 0.671 with a standard error of estimate of ±4.15 dB. A similar plot of the 23.5 to 43.0 Hz tone, root-sum-square equivalent bandwidth tone level (BPL) is presented in Figure 5-20, with the regression explaining 65% of the

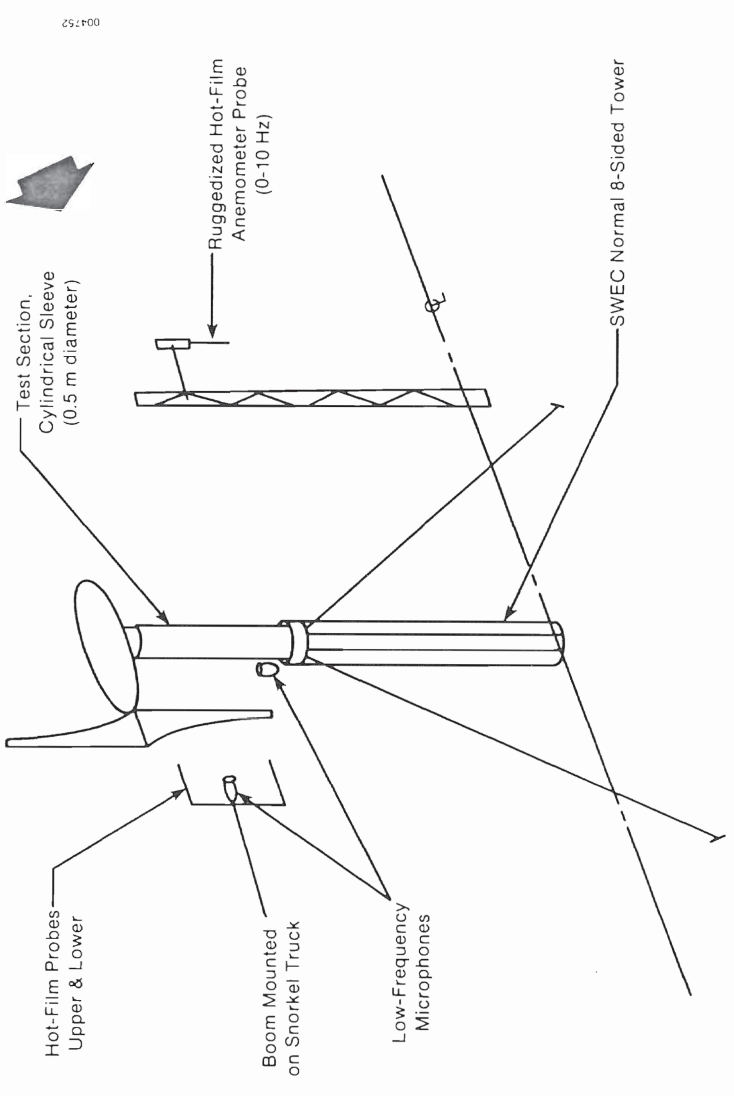


Figure 5-16. **Sketch of Experimental Setup Used for Acoustic/Aerodynamic Studies of Small Wind Turbine and Various Test Section Configurations**

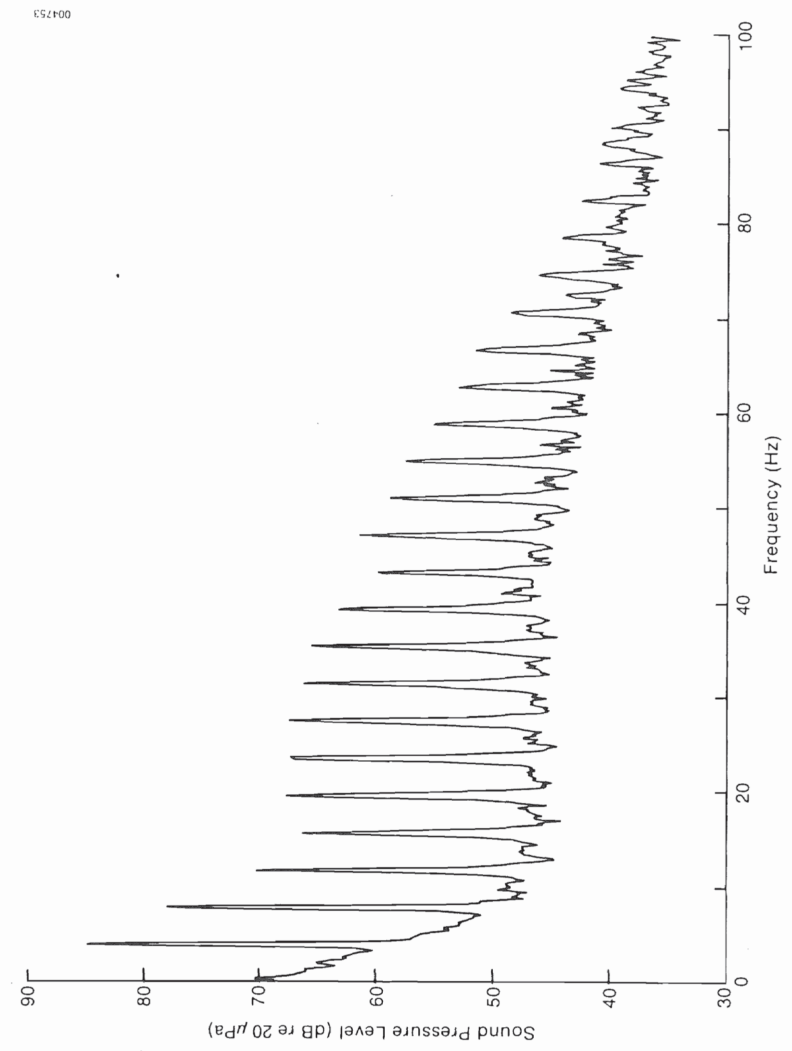


Figure 5-17. Averaged Acoustic Spectrum as Measured by a VLF Microphone Mounted at the Base of the Cylindrical Test Section (See Figure 5-16)

Table 5-1. Summary Statistics of Natural Strouhal Excitation of Acoustic Impulses for 0.5-m Cylinder (35 samples)

Parameter	Mean	Maximum	Minimum	Coefficient of Variation (%)
Freestream velocity (m/s)	7.31	10.9	4.7	20.0
2.5-8 Hz band[a] Mean-sq. velocity $(m/s)^2$	1.15	3.33	.077	53.6
23.5 Hz BPL[b] (dB)	63.3	71.6	50.9	7.5
27.35 Hz BPL (dB)	61.3	69.4	49.4	8.2
31.25 Hz BPL (dB)	60.2	68.5	48.0	8.4
35.25 Hz BPL (dB)	58.1	67.2	45.3	9.5
39.125 Hz BPL (dB)	55.8	64.7	41.9	10.0
43.0 Hz BPL (dB)	54.5	63.2	41.2	10.5
Total[c] BPL (dB)	67.5	80.0	55.5	7.5

[a] Strouhal excitation band.

[b] 0.125 Hz bandwidth tone level.

[c] Root-sum-square of individual 0.125 Hz tone levels.

observed variance and a standard error of estimate of ±3.89 dB. Table 5-2 summarizes the results of both a bivariate regression analysis using the freestream velocity and the 2.5-8.0 Hz (Strouhal excitation) band mean-square turbulence level, and a trivariate model incorporating both parameters. Figures 5-21a,b plots the trivariate regression model for the root-sum-square band pressure total as a function of the freestream velocity and Strouhal excitation turbulence band energy. As indicated in Figures 5-21a,b and Table 5-2, the latter model explains 75% of the observed variance with a standard error of estimate of ±3.3 dB.

5.2.2.3 Interpretation and Conclusions

The influence of natural turbulent energy in the Strouhal excitation band (2.5-8.0 Hz, corresponding to a shedding frequency defined by Eq. (5-2) and a Strouhal number of 0.21 for a range of 4 to 12 ms^{-1}) has been demonstrated. The physical significance of Strouhal number is related to a cylinder boundary layer instability that controls the vortex shedding characteristics of the wake. At subcritical Reynolds numbers encountered by operating wind turbines, the cylinder Strouhal number is within 5% of 0.21 but may vary as much as 100% higher in the low supercritical flow regime, depending on local environmental conditions [12]. The relationship between the freestream velocity and the

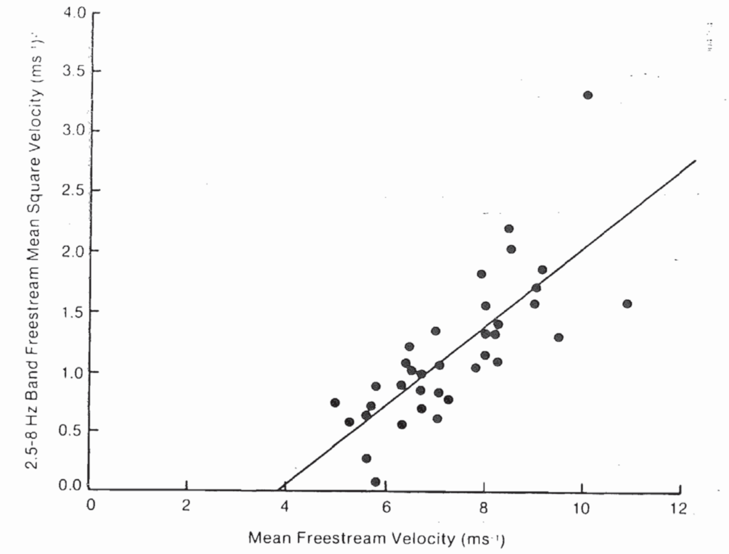


Figure 5-18. Scatter Plot and Indicated Linear Regression for the Mean-Square Velocity in the 2.5-8.0 Hz (Strouhal Excitation) Band vs. the Mean Freestream Velocity

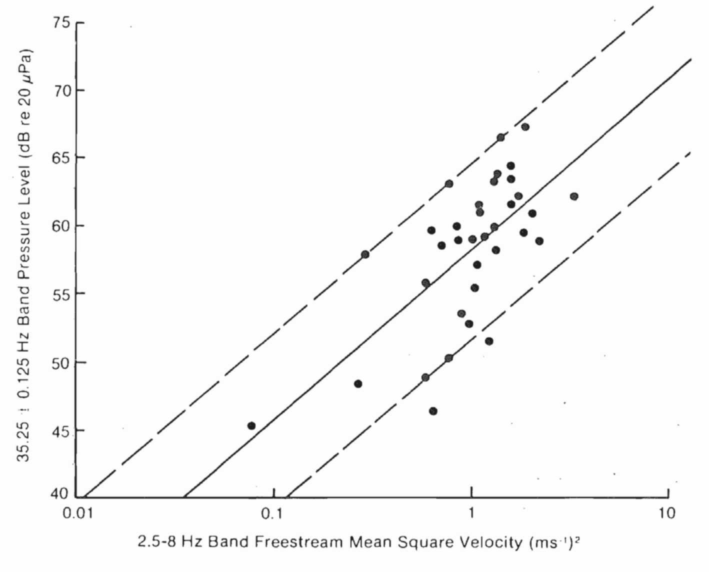


Figure 5-19. Scatter Plot of the 35.25 ±0.125 Hz Tone Band Pressure vs. the Strouhal Excitation Band (2.5-8.0 Hz) Mean-Square Inflow Velocity. (Solid curve is the linear regression and the dashed curves represent ± one standard error.)

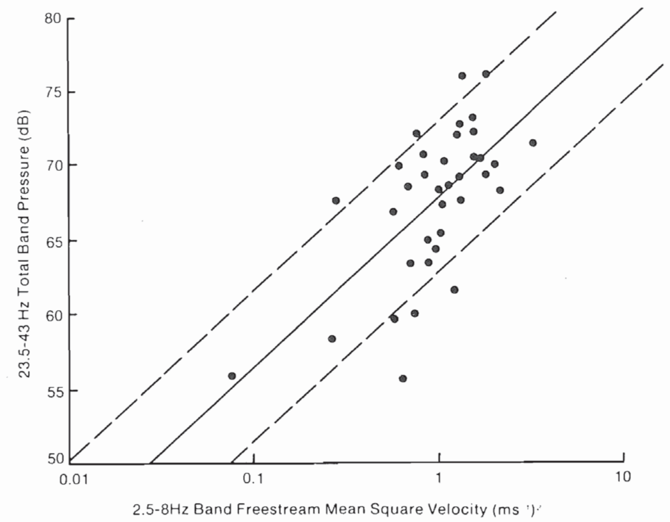


Figure 5-20. **Same as Figure 5-19, but for the 23.5-43.0 Hz Root-Sum-Square Tone Pressure Sum vs. the Inflow Strouhal Excitation Band Mean-Square Velocity**

turbulent energy present in this particular frequency band (disturbance space scale) for this experiment (shown in Figure 5-18) indicates a more or less monotonic increase with windspeed. Although almost 80% of the variance is explained by the linear regression, the relationship will probably not hold, in general because (a) it reflects the available data set, which is biased by the acoustic impulses observed; and (b) the dynamic stability of the local atmospheric surface layer undoubtedly also plays a role. The stability, which may account for some of the unexplained variance, was unavailable as an observable parameter.

The data set analyzed here was collected on two separate days, each in the late afternoon between 1530 and 1716 hours local standard time. The data sets used in this analysis contained 22 and 15 sets of two-minute observations, respectively, but the impulse statistics were quite different for each. Table 5-3 lists the pertinent statistics of each of these series of observations. On the surface there appears to be not much difference in the aerodynamic forcing parameters, the wind speed and the 2.5-8.0 Hz band turbulence; in fact, one would expect the second (August 24) to show a tendency toward more severe impulse generation. This is not the case, however, as the August 20th impulse levels average 4-5 dB higher. The answer may lie in the correlation statistics of the Strouhal excitation band turbulence and the freestream velocity. In the August 20th case, the correlation coefficient

Table 5-2. Impulse Generation Relationship with Natural Tower Strouhal Excitation: Correlation Analysis Results

Tone (Hz)	Bivariate Correlation Coefficient			Trivariate Regression Analysis			Correlation Coefficient	Standard Error (dB)
	Wind Speed	2.5-8 Hz	Log Mean Square Velocity	Wind Speed Coefficient	Log Mean Square Coefficient	Constant		
23.5	0.708 (3.41)[a]	0.638	(3.71)	1.68	4.34	51.1	0.731	3.33
27.35	0.740 (3.44)	0.638	(3.93)	2.01	3.74	46.6	0.756	3.40
31.25	0.722 (3.56)	0.633	(3.99)	1.92	4.07	46.0	0.740	3.52
35.25	0.765 (3.60)	0.671	(4.15)	2.23	4.50	41.7	0.765	3.54
39.125	0.768 (3.62)	0.727	(3.89)	1.93	6.66	41.7	0.806	3.41
43.0	0.793 (3.53)	0.725	(3.99)	2.20	5.90	38.4	0.820	3.37
Total Band[b]	0.749 (3.39)	0.651	(3.89)	2.01	4.01	52.9	0.766	3.34

[a] Standard error of estimate (dB).

[b] Root-sum-square equivalent of the six individual tone (0.125 Hz band) pressure levels.

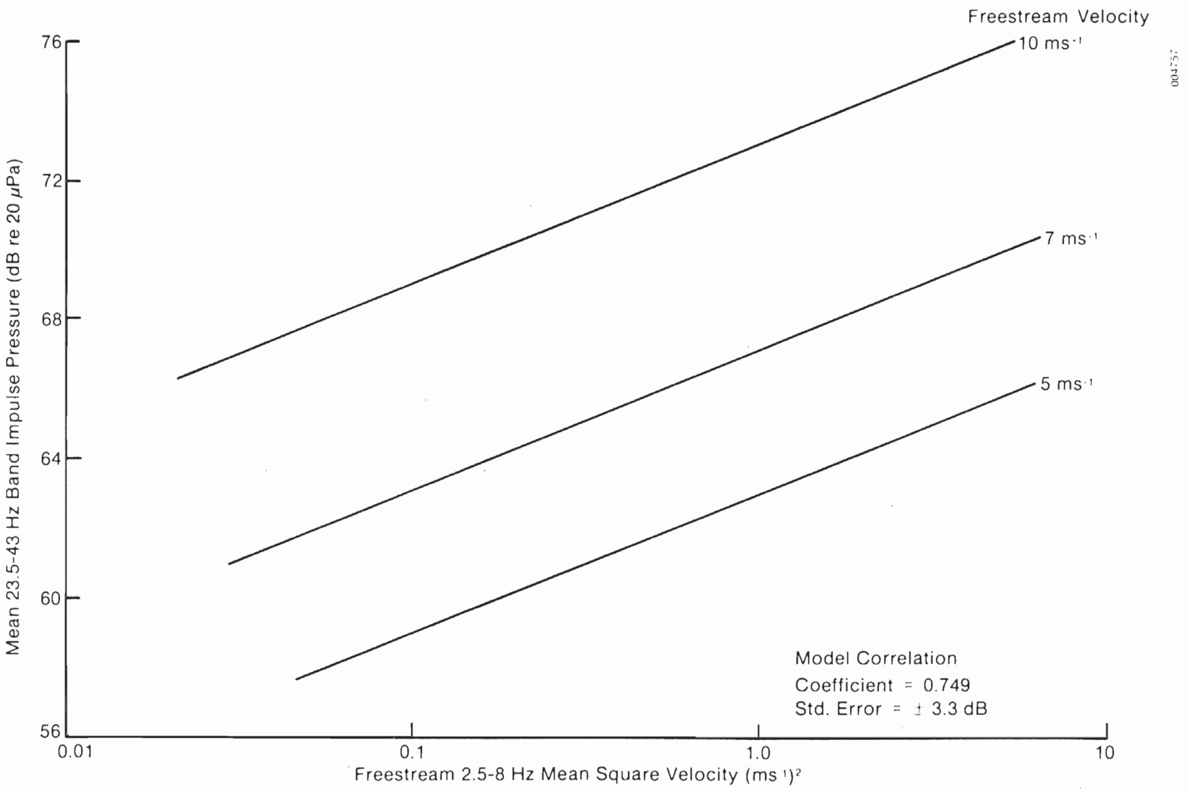


Figure 5-21. Results of Trivariate Linear Regression Model Relating the Mean 23.5-43.0 Hz Total RSS Acoustic Band Pressure to the Inflow Strouhal Excitation Band Turbulence Level and Velocity

Table 5-3. Statistical Summary of Aerodynamic and Acoustic Impulse Parameters for Observations made on August 20 and 24, 1981

Period/Parameter	Mean	Maximum	Mininum	Coefficient of Variation (%)
August 20, 1981 (1614 - 1716 MST)				
Freestream velocity (m/s)	7.00	9.2	5.6	14.8
2.5-8 Hz band mean-sq. velocity $(m/s)^2$	0.969	1.87	0.284	43.1
23.5 Hz BPL[a] (dB)	65.8	71.6	61.5	5.7
27.35 Hz BPL (dB)	64.1	69.4	59.6	4.6
31.25 Hz BPL (dB)	63.0	68.5	57.1	5.1
35.25 Hz BPL (dB)	61.2	67.2	55.8	5.6
39.125 Hz BPL (dB)	58.3	64.7	53.1	6.7
43.0 Hz BPL (dB)	56.8	63.2	51.3	7.4
Total BPL[b] (dB)	69.9	76.0	63.4	5.2
August 24, 1982 (1531 - 1625 MST)				
Freestream velocity (m/s)	7.54	10.9	4.7	22.4
2.5-8 Hz band mean-sq. velocity $(m/s)^2$	1.27	3.34	0.078	55.2
23.5 Hz BPL (dB)	61.5	67.4	50.9	8.0
27.35 Hz BPL (dB)	59.6	65.8	49.4	9.0
31.25 Hz BPL (dB)	58.4	64.4	48.0	9.1
35.25 Hz BPL (dB)	56.3	63.4	45.3	10.2
39.125 Hz BPL (dB)	54.2	61.0	41.9	11.1
43.0 Hz BPL (dB)	53.0	60.5	41.2	11.6
Total BPL (dB)	65.9	72.2	55.5	8.0

[a] 0.125 Hz tone level.

[b] Root-mean-square of tone levels.

between these two parameters was 0.836 compared with a value of 0.764 for the August 24th case. From this we conclude that the vortex shedding of the second period was somehow less coupled to the freestream energy in the Strouhal excitation band, possibly due to a less stable surface layer environment, since the observational period took place almost an hour earlier than the data collected on August 20th. There is some support for this interpretation in the increased scatter of the 2.5-8.0 Hz band mean-square velocity with increasing freestream velocity as shown in Figure 5-22b. In comparison, the August 24th observations plotted in Figure 5-22a show the opposite effect. From our experience in the field, we have noted consistently that increased and more severe impulsive action occurs during the cool outflows of thunderstorms in the vicinity, a fact we depended on while performing the experiments during the light winds of the summer months at the Rocky Flats site.

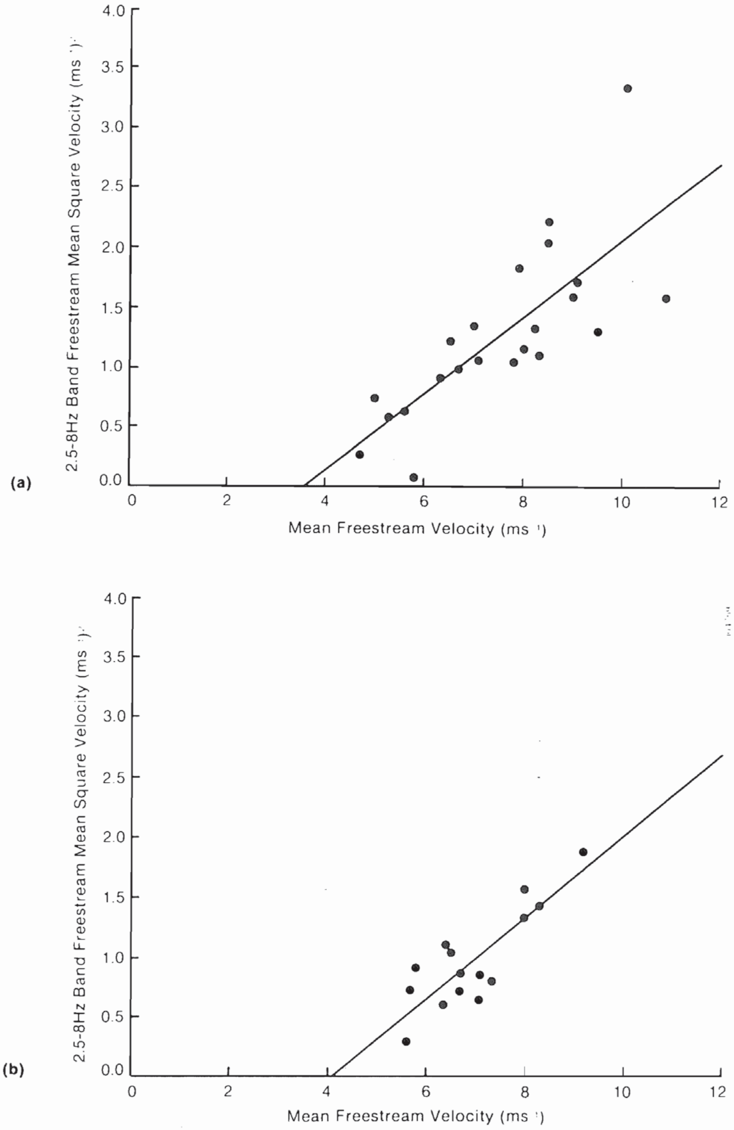


Figure 5-22. Scatter Diagrams for Inflow Strouhal Excitation Band Turbulence Levels vs. Freestream Velocity for (a) August 24, 1981, and (b) August 20, 1981

The influence of the freestream Strouhal excitation band in the tower-wake impulse generation process is summarized in Figure 5-21 using the trivariate regression model listed in Table 5-2. The sensitivity to both the freestream velocity, which determines the aerodynamic load on this fixed-pitch machine, and the Strouhal excitation band level, is evident. We have therefore concluded that turbulent energy in the Strouhal band influences the dynamic characteristics of the downstream wake by exciting a boundary layer instability in the cylindrical, bluff body. We also suspect the hydrodynamic stability of the atmospheric surface layer, in which the turbine and its support tower reside, also exerts a definite, but so far undefined influence, on this process as well. We also believe the combination of the level or energy content of the Strouhal band turbulence and the vertical stability are the missing factors that may well account for much of the unexplained variance in the multivariate regression model of the MOD-1, discussed in Section 4.2.3.2. The identification of this process continues to underscore the stochastic nature of the physical processes providing the excitation for the MOD-1 impulsive noise generation.

5.2.3 Role of Blade Unsteady Aerodynamic Response in Impulsive Noise Generation

In the previous sections, we discussed the role of the cylindrical tower legs in modifying the turbulence inflow to the turbine rotor and, to some extent, the freestream parameters exerting influence on the leg (cylinder) wakes entering the rotor plane. It is now important to examine the physics of the actual impulse generation process experienced by the rotor blades as they transversely slice through what we have identified as vortex tubes being shed by each tower leg in order to further establish a physical basis for the design of appropriate abatement procedures. Efforts to achieve this understanding have been derived largely from the University of Colorado wind tunnel experiment and the full-scale tests performed at the Rocky Flats Wind Energy Research Center. Since neither of these experiments have been fully analyzed, the results here, while correct and indicative, represent only a small fraction of the total information that should eventually be obtained. Our previous discussion has established that the annoying impulses are being produced as the rotor blades pass through the leg wakes. We have also shown the importance of the wake turbulent structure; e.g., vertical coherence, discreteness, and possibly, existing hydrodynamic stability, among others, in determining the level of impulse severity. We have not, however, examined what dynamic, physical process actually occurs that causes the blade pressure field to radiate such intense and coherent pressure waves, nor have we identified the corresponding dominant physical parameters responsible. These matters are addressed in this section.

5.2.3.1 A Physical Description of the Turbine-Radiated Acoustic Impulse

A number of examples of observed impulse pressure-time plots have been given previously that have been taken from actual wind turbine measurements or the model turbine in the MIT anechoic tunnel. The instantaneous impulse depicted in Figure 5-23 (taken from the MIT tests for the smallest cylinder diameter at a freestream velocity of 13.4 ms^{-1}) is typical. Figure 5-24 plots the

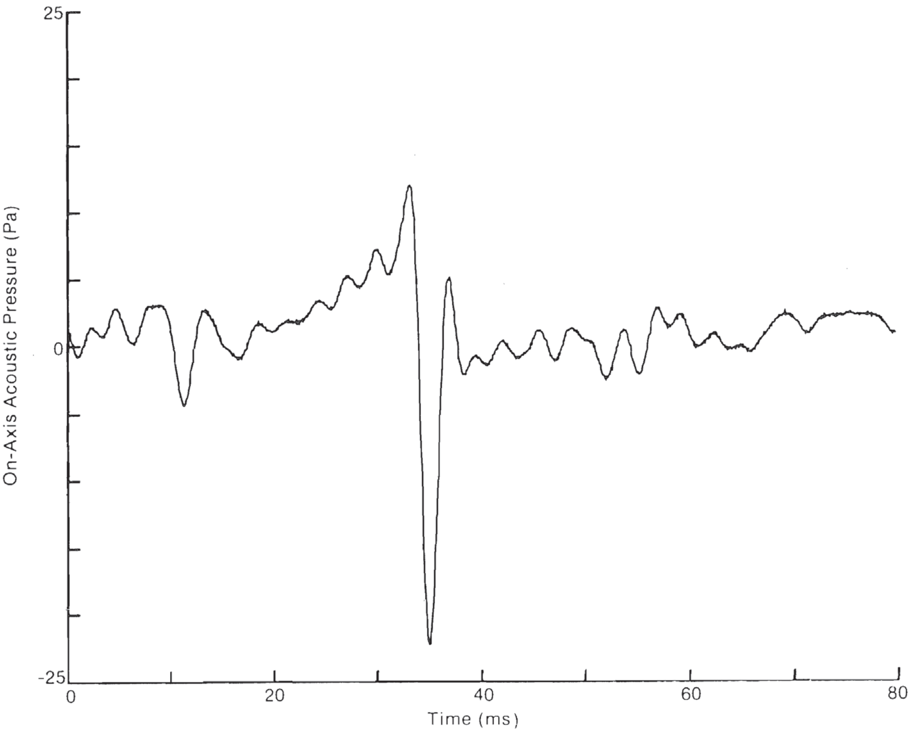


Figure 5-23. On-Axis Acoustic Pressure-Time Plot of Impulse Generated by 1.6-cm Cylinder Wake at a Freestream Velocity of 13.4 ms^{-1} in MIT Anechoic Tunnel

pressure-time signature from two of our VLF microphone systems, one installed at the base of the test cylinder on the tower of the small downwind turbine at the Rocky Flats Wind Energy Research Center and the other on the instrument boom. The figure shows three passages of the rotor blade past the tower. Because the tower base microphone is installed on the upwind or pressure side of the rotor, the pressure rises (dashed curve) as the blade approaches the tower, reaches a peak as it passes, then falls back until the next blade comes within range. The solid curve of Figure 5-24 traces the suction or downwind side acoustic field (boom-mounted microphone), revealing the gradual pressure decrease as the blade approaches the tower, then positive peaking as it passes, and finally increasing again as the blade moves toward the horizontal.

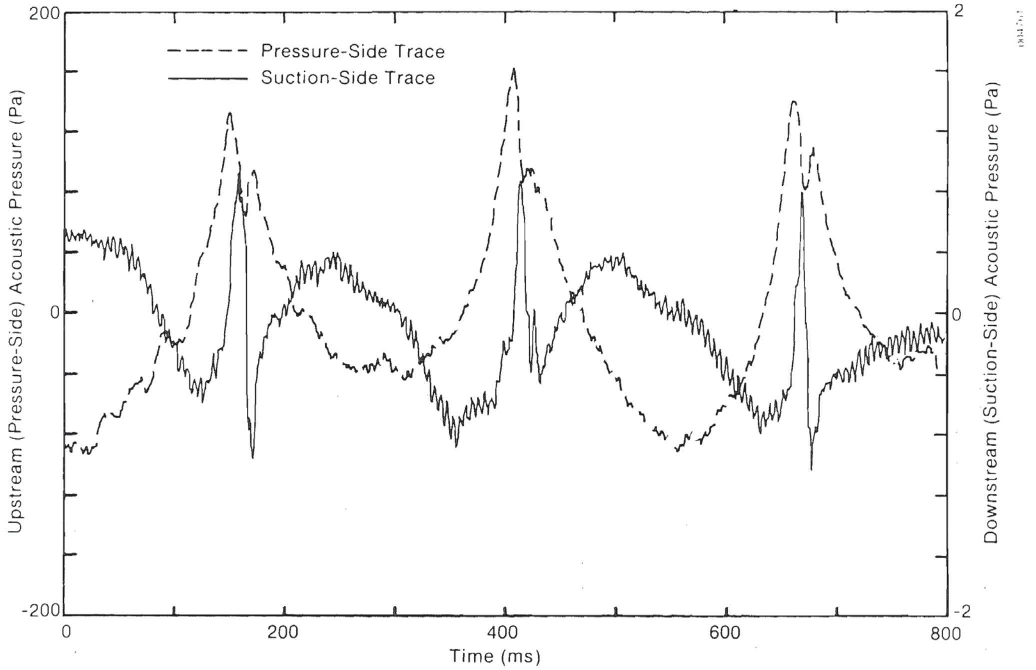


Figure 5-24. **Acoustic Pressure-Time Plots Made on Both the Pressure (Upwind) and Suction (Downwind) Sides of a WECS Rotor Periodic Unsteady Lift in the Wake of a Cylindrical Tower Element**

As can be seen, there are sharp discontinuities or rapid drops in the pressure-side (base microphone dashed) traces as the peak is reached on all three passages while the suction-side (boom-mounted microphone, solid trace) pressure suddenly peaks positive at the same time or rotor position. Figure 5-25 is an exploded view of a single instantaneous impulse measured on both sides of the rotor blade which presents the important temporal relationships in greater detail. The expected out-of-phase cyclic relationship between these two acoustic pressure traces is also in evidence in Figure 5-24; i.e., a pressure rise at the tower mike and a decrease at the downwind, boom-mounted position.

We believe that these rapid fluctuations (durations of 10-15 ms) reveal that the rotor blade is undergoing what amounts to a form of transient stall as it passes through the tower wake. This is clearly indicated by the sudden changes in both the pressure and suction values over that short duration. We also believe we are not just seeing a wake momentum deficit effect, since the severity and overall shape of these transients change from blade passage to blade passage, as shown in the traces of Figure 5-26. Occasionally, there is no evidence of a stall-induced transient at all--even during periods when almost every other passage exhibits some form of an impulse. Figure 5-27 illustrates a single blade passage when no transient was produced even though the freestream velocity was 17-18 ms^{-1}. From this we must conclude that the concept of a wake deficit exists only in the mean, and the rotor blades of a turbine see only whatever is there each time they pass behind the tower! Based on this, we must also argue that the variation in the severity, shape, and duration of the observed lift transients must be a function of the instantaneous, turbulent structure of the wake; i.e., the strength and distribution of shed vortices that vary stochastically.

Based on the discussions of Sections 4.1.1.2 and 4.1.1.3, the essence of the time history of these transient lift fluctuations is reflected in the acoustic pressure traces described by Figures 5-23 through 5-27. For the model-generated impulse in Figure 5-23, the duration of the sharpest portion of the signature was about 2 ms, which corresponds to a linear travel distance of the blade tip of 5.4 cm or about one chord width (5.1 cm). The width of the wake at this position 5D downstream would be about 2 cm, according to Ref. [14], for the subcritical operating regime ($Re \sim 14 \times 10^3$). Therefore, the spatial duration of the impulse is about equal to half the chord width. In the case of the small turbine and the cylindrical test section, the average impulse duration shown in Figures 5-24 through 5-26 is about 12 ms, which corresponds to a space scale of 0.75 m or 3.25 blade chords at the blade tips and 0.57 m or 2.5 chords, respectively, at 80% span. The lateral dimension of the mean wake at the point of intersection with the rotor (1.5D downstream), which is relatively insensitive to the Reynolds number due to the nearness of the cylinder (the near wake region), is estimated to be 0.80 m for supercritical flow and 0.79 m for subcritical. The MOD-1, in contrast, exhibited a typical impulse duration of about 0.008 s at the 35 rpm rotational rate, which translates to a space scale of 1.0-1.2 mean wake widths (subcritical) or about 40% of the blade chord at the 75% span position, intersecting the leg wakes at 7.5D downstream. It is clear from the preceding that whatever the true width of the wake is at the instant of blade passage, the transient lift fluctuation is taking place over a space scale on the order of the mean chord width of the outer 40% of the span. This is the region of the blade span that develops the maximum aerodynamic lift. Also, this transient scale is determined by the wake dimensions and not the blade chord width, at least for the examples here.

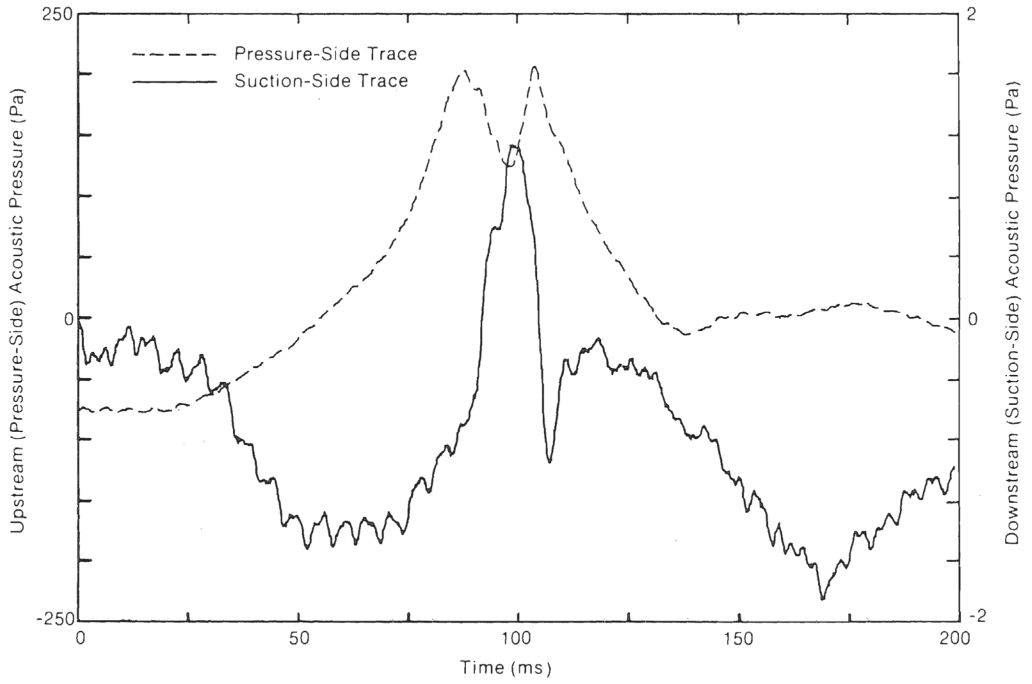


Figure 5-25. **Acoustic Pressure Time Signature of a Single Blade Passage and Impulse Generation** (Similar to Figure 5-24)

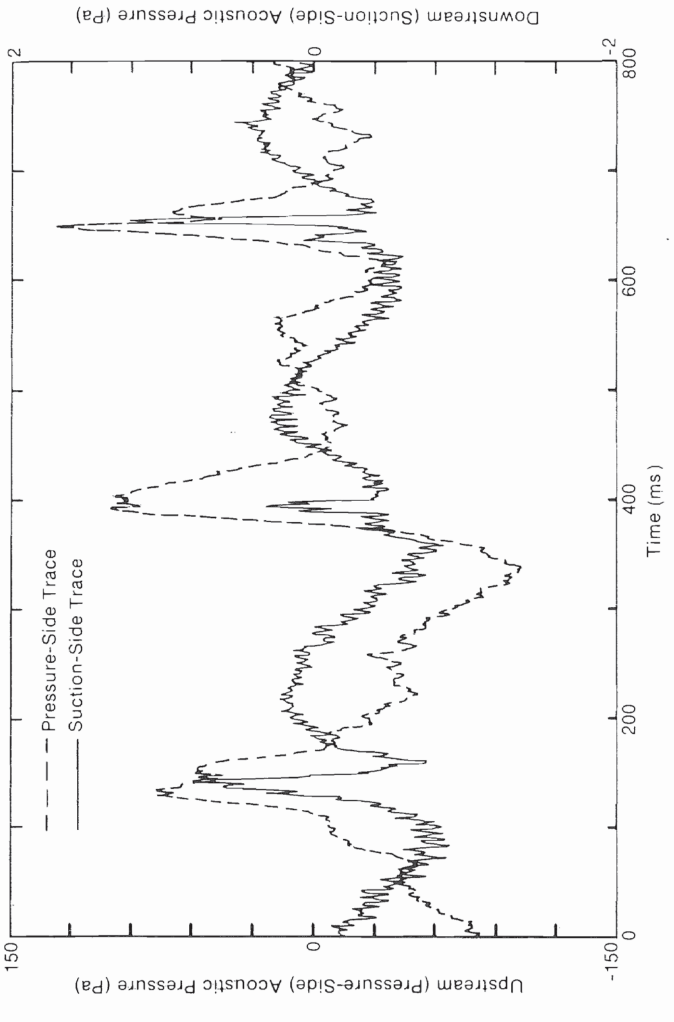


Figure 5-26. **Acoustic Pressure-Time Trace Showing Variability from Blade Passage to Blade Passage through Tower Wake**

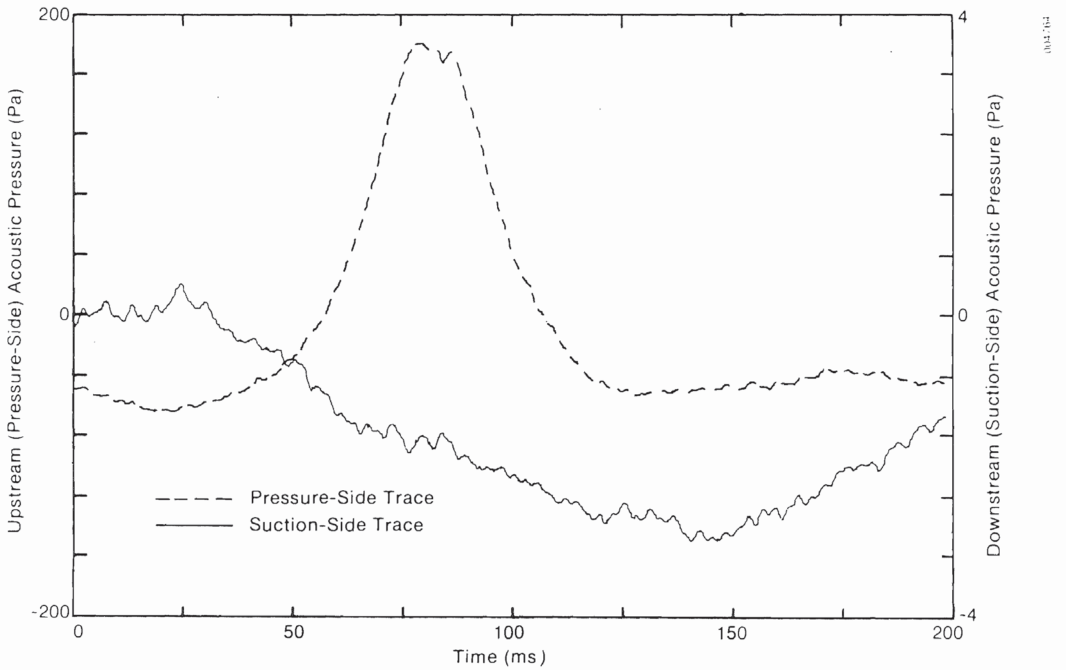


Figure 5-27. **Acoustic Pressure Signature Showing No Evidence of Transient Lift Behavior and Impulse Generation**

5.2.3.2 Proposed Unsteady Aerodynamic Mechanism Responsible for Impulse Generation

From the discussion in the previous sections, it is clear that the dynamic process responsible for creating the severe transient lift fluctuations that radiate as strong acoustic impulses is influenced by the following environmental parameters:

1. The magnitude of the freestream velocity
2. A space scale on the order of the rotor blade mean chord $(\bar{c})$ dimension; i.e., $10 \leqslant \bar{c} \leqslant 0.1$, with a dimension near the chord size apparently being the most acoustically sensitive
3. The degree of spanwise coherence in the turbulent structures encountered by the moving blade
4. The presence of narrowband turbulent flows; i.e., containing a predominance of discrete elements (eddies or vortices).
5. The fluctuating (unsteady) flow characteristics and not mean quantities making the process narrowband stochastic.

These parameters strongly suggest that the process is related to an unstable interaction between the blade viscous boundary layer and the coherent elements in the tower leg turbulent wakes. The condition for spanwise coherency brought about by the transverse intersection of the blade and the vortex tube structure being shed by the tower legs has already been discussed in Section 5.1.4 and accounts for one of the physical parameters necessary for impulse generation. At this point, we need to review the factors influencing airfoil boundary layer instabilities and observable consequences.

5.2.4 Airfoil Unsteady Boundary Layer Dynamics Applicable to the MOD-1 Situation

Much of the theoretical basis for the aerodynamic design of large wind turbine rotors such as the MOD-1 has been steady or quasi-steady lift generating processes. This has been the practical approach, since we can draw upon a relatively large body of available knowledge. The acoustically related process (or processes) we have described above is a direct result of the unsteady aspects of operational wind turbine aerodynamics and therefore may not follow the quasi-steady design models as closely as we would like (if at all, under some circumstances). At issue here are the physical consequences of unsteady flow over the airfoil surfaces of large wind turbine blades, particularly involving short-period, transient lift fluctuations that influence the characteristics of the radiated acoustic pressure field, the dynamic structural loads, and their interrelationship. The discussion here, by necessity, must be kept short. For a more complete review of the subject the reader is referred to the summary papers by McCroskey [17,18].

5.2.4.1 Factors Influencing the Magnitude of Blade Airload Fluctuations

The airfoil section shape used in the MOD-1 blades, as in most wind turbine designs, was at least partially chosen, on the basis of its ability to develop high lift coefficients within the operational wind-speed envelope. In order to reach the design lift coefficients necessary to meet the load generation requirements, it is usually necessary to program the pitch (or blade) angle (referenced at 75% span) so that the blade encounters the incident flow at only one or two degrees below the static stall. This is particularly true below the rated wind speed to achieve maximum efficiency. The NACA 44xx-series airfoil sections, particularly the 15% thick section (4415) are known to be susceptible to a sudden leading edge separation (stall) under "rough" inflow conditions, whereas the quasi-static characteristic under a slowly increasing incidence angle exhibits a stall beginning at the trailing edge. Thus, the turbine blade normally operates at attack angles not far from static stall except at wind speeds near the cut-out value. The significance of this is discussed below.

A review of the literature concerning the causal factors influencing lift fluctuations in unsteady flow over an airfoil has identified the following physical characteristics of the airflow [19] and the flow it is passing through:

- the pressure distribution in the external flow
- the airfoil surface roughness
- the turbulent structure of the free flow the airfoil passes through.

We have already shown that the transient lift fluctuations responsible for acoustic impulse generation are a function of the spanwise coherency of the free-flow turbulent structure. The role of surface roughness in this situation remains unknown, since we have no direct information about it at this time. We believe, however, that it does not exert a major influence in the MOD-1 situation. The influence of the external pressure distribution does warrant a closer examination, however, as discussed in Section 5.2.4.2 below.

From our previous discussions regarding the downstream wake characteristics influencing the severity of impulses generated, we noted the distinct sensitivity of this unsteady process to the level of discreteness found in the wake velocity mean frequency spectrum. We also found this spectral characteristic was indicative of a flow containing a predominance of discrete elements or vortex circulations. A vortex superimposed on a mean flow imparts its own velocity and pressure distribution due to the effects of viscosity. It has already been noted that the space scale over which the lift transients are generated is on the order of the blade chord which, with perhaps one exception, corresponds very closely to the mean cylinder wake dimensions at the point of the blade plane intersection. Thus, if a vortex circulation exists within the wake boundaries, the blade section may experience an abrupt oscillatory inflow as it passes through. Therefore, in our search for the impulse physical generation mechanism, we must examine the effects of oscillatory excitations as a result of both velocity and pressure perturbations on the lift of a turbine blade operating not far from static stall.

McCroskey [18] has summarized the importance of unsteady fluid dynamic parameters influencing the onset of forms of dynamic stall (i.e., an abrupt stalling of an airfoil due to a sudden leading edge separation) that are listed along with observed effects in Table 5-4. As can be seen, the most critical parameters include the mean incidence (attack) angle, the Mach number (the MOD-1 tip Mach number is ~ 0.33 at 35 rpm and 0.25 at 75% span), the airfoil shape, and the reduced frequency. The mean incidence angle is important because of its relationship to the peak excursions, α_{max}, and increased airload hysteresis with an accompanying overshooting of the lift and moment coefficients, as illustrated in Figure 5-28. For these reasons, the dynamic airloads often far exceed the steady values and, if negative aerodynamic damping is present, energy is extracted from the airstream and dissipated in the blade mechanical structure, as indicated diagrammatically in Figure 5-1.

The role of blade speed (Mach number) has been investigated by Liiva et al. [20, referenced in 18] and illustrated in Figure 5-29 for Mach numbers of 0.2 and 0.4. The most noticeable effect of an increase in Mach number is a reduction in the negative aerodynamic damping, resulting in less aeroelastic but not much change in the normal force hysteresis. Thus, increasing the local Mach number along the turbine blade span may result in a stabilizing effect as the tips are approached, at least in terms of freestream aeroelastic excitation.

Table 5-4. Relative Importance of Unsteady Fluid Dynamic Parameters in Leading Edge Stall Phenomena
(Source: Ref. [18])

Parameter	Effect
Airfoil shape	Large, in some cases
Mach number	Small (below $M_\infty \sim 0.2$), Large (above $M_\infty \sim 0.2$)
Reynolds number	Small (?) at low Mach number, Unknown at high Mach number
Reduced frequency	Large
Mean incidence angle	Large
Type of motion	Virtually unknown
3-D effects	Virtually unknown

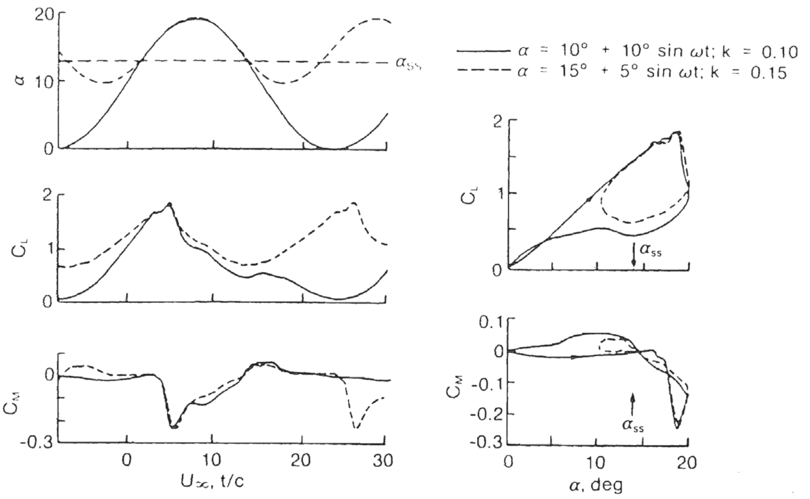


Figure 5-28. Effect of α_{max} on Dynamic Airloads ($\alpha = 10^\circ \pm 10^\circ$ and $\alpha_{ss} = 15^\circ \pm 5^\circ$)

Source: Ref. [18].

The influence of the airfoil shape has been found to be a major parameter in determining leading-edge separation characteristics. Particularly sensitive are sections that exhibit chordwise pressure distributions along the suction or upper surface which concentrate the greatest negative pressures very close to the leading edge and reach an extreme at high incidence angles. Figure 5-30 shows the development of this chordwise pressure distribution for half a cycle of an incidence angle oscillation of 5° above the steady value of 10° (3° below static stall) for a NACA 0012 airfoil section. To the authors' knowledge, all commonly used airfoil sections employed in wind turbine designs (e.g., NACA 0012, 0015, 44xx-series, and the 230xx-series) possess similar chordwise distributions at the high incidence angles of normal operation (low blade or high pitch angles). The 44xx-series airfoil shape employed in the MOD-1 rotor will be discussed more fully below.

The reduced frequency parameter k, which is defined by

$$k = \frac{\pi f c_s}{U} = \pi \left(\frac{c_s}{\lambda}\right) , \qquad (5-5)$$

where

f = the cyclic frequency of the exciting perturbation

c_s = the section chord dimension

U = mean blade speed (or resultant velocity)

λ = wavelength of disturbance,

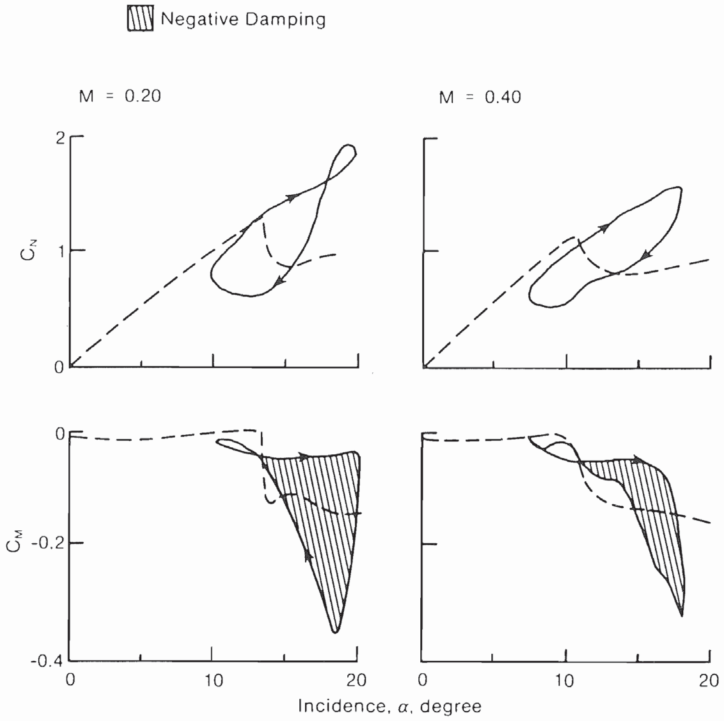


Figure 5-29. Effect of Mach Number on Dynamic Normal Force and Moment Coefficients

Source: Ref. [20].

represents the ratio of the section chord length to the wavelength of the disturbance encountered in the freestream. It relates how the perturbation is sensed by various parts of the section. Figure 5-31 shows the increase in the airload hysteresis and overshoot for an increasing reduced frequency for a NACA 0012 airfoil section oscillating $\pm 5^{\circ}$ from a mean incidence angle of 10° at a Mach number of 0.30. It should be pointed out that the Strouhal number defined earlier may be thought to serve a similar function for perturbations affecting bluff body unsteady aerodynamics.

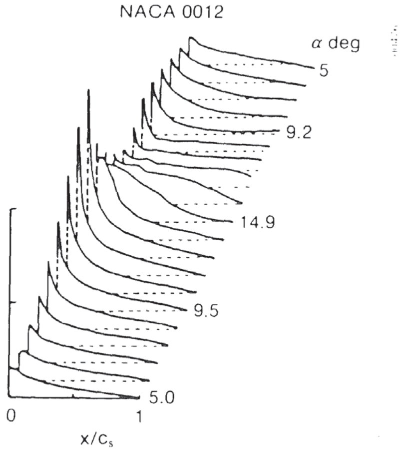


Figure 5-30. Chordwise Pressure Distribution as a Function of the Incidence Angle for a NACA 0012 Airfoil

Source: Ref. [18].

From the preceding it is apparent that the higher-order, nonlinear aspects of unsteady flows over various airfoil shapes is a complex subject with a number of fluid dynamic parameters exerting influence over the process (in comparison with static stall, where the incidence angle and airfoil shape are most important). McCroskey [18] has identified various transitory lift phenomena involving strong, viscous effects on airfoils being subjected to aerodynamic excitation by turbulent perturbations in the freestream, resulting in an oscillatory response in the airfoil boundary layer. If the angle of attack oscillates around a high mean value, the resulting aerodynamic excitation may lead to leading edge separation and transitory stall. The depth of the induced stall has been shown to be largely a function of the maximum incidence angle α_{max}. McCroskey [18] has classified the degree of stall severity into two regimes: light stall and deep stall. The former is characterized by sudden loss of lift and significant increases over inviscid values in the drag and nose-down pitching moments as the incidence angle α exceeds a certain value. Also, this regime is subject to increasing airload hysteresis and the accompanying effects of negative aerodynamic damping. This condition is also highly sensitive to most of the unsteady parameters listed in Table 5-4, including, as McCroskey speculates, 3-D circulations (such as spanwise coherence).

The classification of the deep stall regime is characterized by a large excess in α_{max} accompanied by overshoot values of the lift, drag, and moment coefficients that far exceed their static values. Figure 5-32 compares the stall regimes. Particularly significant is the abrupt drop in the lift after the

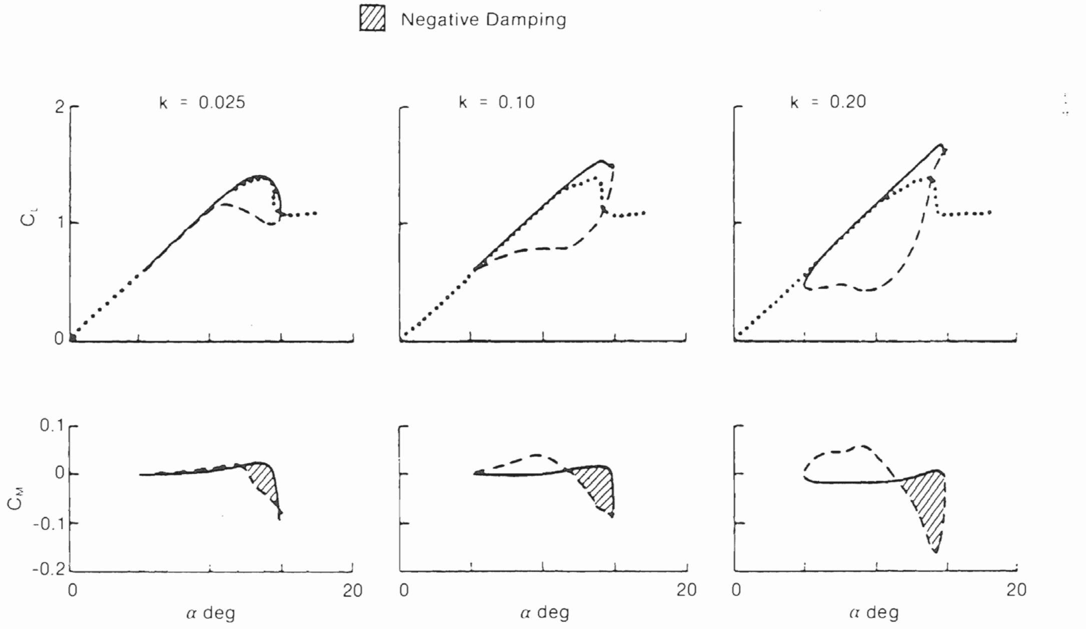


Figure 5-31. Effect of Reduced Frequency on the NACA 0012 Airfoil (M_∞ = 0.30 and α_{ss} = 10 ±5°)

Source: Ref. [18].

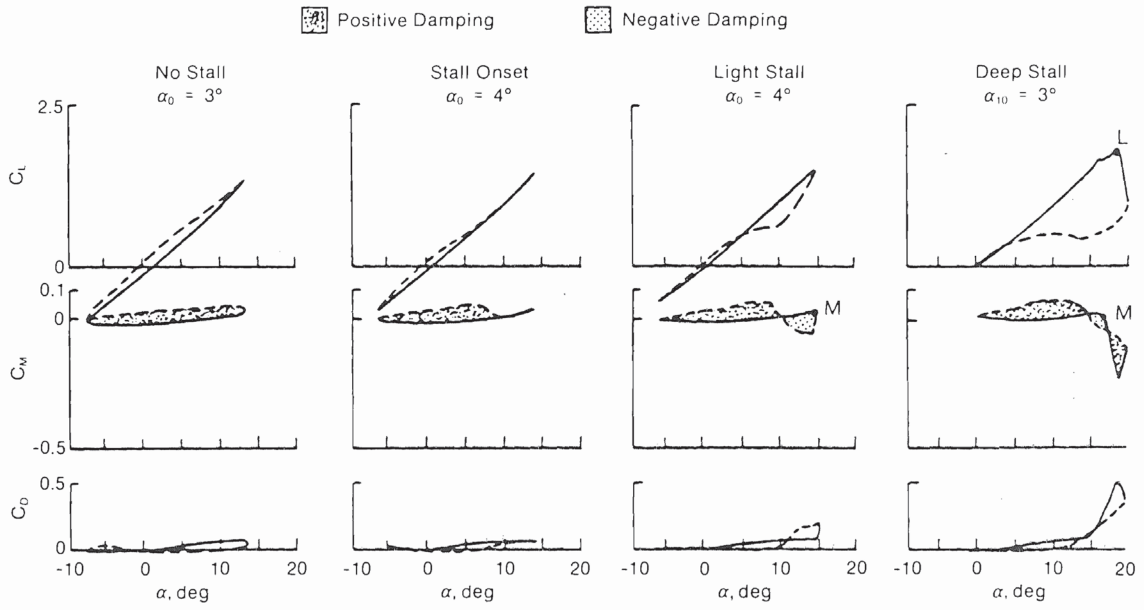


Figure 5-32. A Comparison of Dynamic Stall Regimes (NACA 0012 airfoil, $\alpha = \alpha_{ss} + 10^{o} \sin \omega t$, k = 0.10; solid lines denote increasing α, dashed lines decreasing α)

Source: Ref. [18].

CL_{max} value is reached in deep stall which is not noticeable in the light-stall case. Also, as McCroskey points out, large pitch change rates $\dot{\alpha}$ and values of α_{max} are necessary for deep stall. Ericsson and Reding [21] have qualitatively defined the overshoot $\Delta\alpha_s$ as

$$\Delta\alpha_s = \left[\frac{\partial\alpha_s}{\partial\left(\frac{c\dot{\alpha}}{U_\infty}\right)} \right] \frac{c\dot{\alpha}}{U_\infty} \quad , \qquad (5\text{-}6)$$

where α_s is the static stall incidence angle and the quantity in brackets is the overshoot derivative. An example of the CL_{max} overshoot, defined as $\Delta CL_{max} = CL_\alpha \cdot \Delta\alpha_s$, is shown in Figure 5-33 for a NACA 2301x airfoil section (which is used on the MOD-0, MOD-0A, and MOD-2 turbines); a shape (like the NACA 44xx-series used on the MOD-1) which is susceptible to leading edge stall. McCroskey has also pointed out that the deep stall regime is relatively insensitive to airfoil motion and geometry as well as the flow Reynolds and Mach numbers as long as shock waves do not develop along the leading edge. The primary controlling factor is the incidence angle overshoot $\Delta\alpha_s$, defined by Eq. (5-6).

A reflection on the observed acoustic impulse shapes of Figures 5-23 through 5-26 in which an abrupt loss in lift is evident as the blade passes through the tower wake strongly suggests that the deep stall regime is being reached under these conditions primarily because of the suddenness and large change observed. However, we also know that the space scale over which this process is acting is on the order of the blade chord, a fact which will be treated next.

5.2.4.2 Role of Blade-Vortex Interaction in Impulse Generation

In the previous section, we discussed the influence of various unsteady fluid dynamic parameters in the leading edge separation of airfoils causing abrupt losses of lift. While they are descriptive of the two-dimensional turbulent structure the blade is encountering, they do not address the existence of pressure perturbations existing in the inflow, which has also been listed in Section 5.4.2.1 as a potential factor. Wakes shed by circular cylinders are known to contain strong vortex elements, and the observed discreteness in the frequency domain is attributed to these circulation features. Before examining the potential role of the vortex shedding in the unsteady aerodynamics problem at hand, it is first useful to present a very brief review of vortex dynamics.

Dynamics of Vortex Flows. The rate of vorticity K being generated in a boundary layer separating from a body in 2-D flow has been shown by Birkhoff and Zaratonello [22, referenced in 23] as

$$K = \Gamma f_s = \Lambda U_\infty^2 \quad , \qquad (5\text{-}7)$$

where Γ is the circulation of the vortex, f_s the cyclic shedding frequency, and Λ a dimensionless parameter relating the rate of vorticity generation to the freestream velocity U_∞ and most likely a function of the Reynolds number, body surface roughness, and inflow turbulence. We can rewrite Eq. (5-7) as

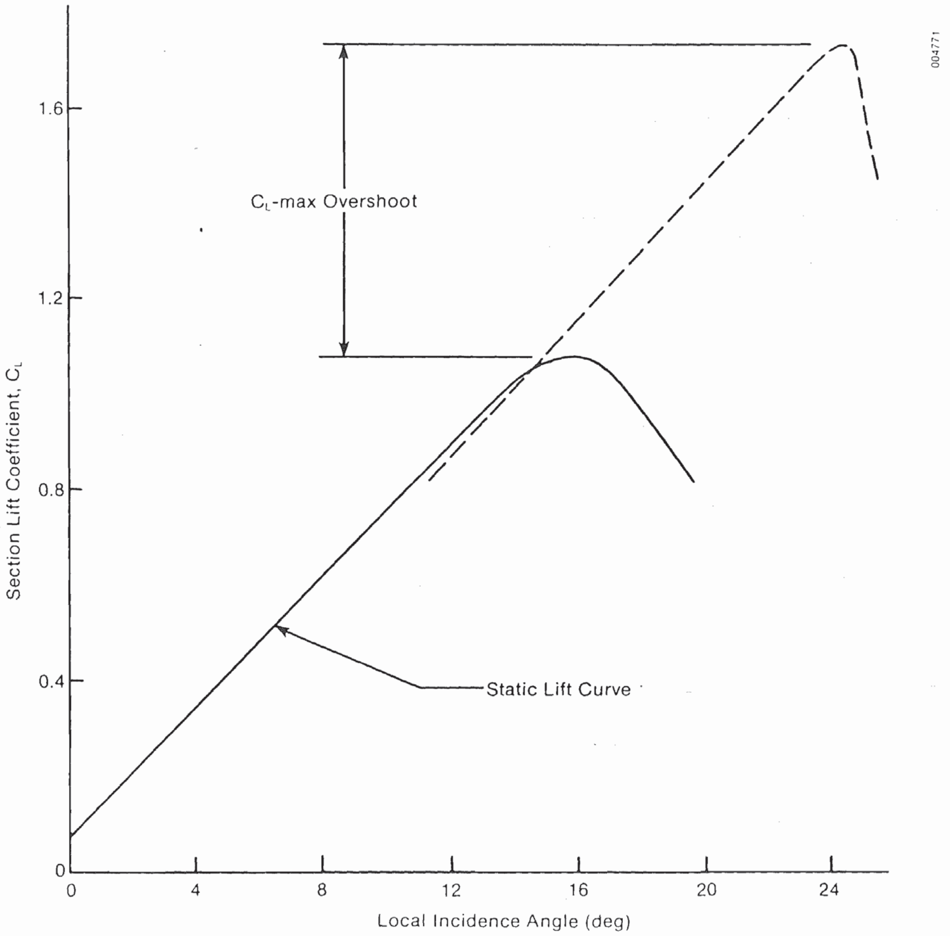


Figure 5-33. Example of CL_{max} Overshoot for NACA 2301x Airfoil

Source: Ref. [21].

$$\Gamma = \frac{\Lambda U_\infty^2}{f_s} \quad , \tag{5-8}$$

which relates the vortex strength to the square of the freestream velocity. Vortices are the result of viscous phenomena and contain both a radially dependent velocity and pressure distribution. Figure 5-34 illustrates typical 2-D vortex velocity and pressure profiles. If the fluid in which the vortex exists is inviscid, irrotationality constraints require the radial velocity to become infinite at the center or core. In a real fluid, this does not occur, because the effects of viscosity prevent it from happening. Following Loth [24], the vortex is often modeled as a core region in constant solid-body rotation surrounded by an inviscid, irrotational region with a constant circulation $\Gamma = 2\pi r U_{\theta_r}$, where U_{θ_r} is the tangential velocity at radius r. The maximum tangential velocity occurs at the edge of the solid rotating core (r = a) or $U_{\theta_a} = \Gamma/2\pi a$. The flow inside the core is given by

$$U_{\theta_r} = U_{\theta_a} \cdot r/a = \Gamma/2\pi a \cdot r/a \ . \tag{5-9}$$

In the ideal or model vortex, there is no total pressure deficit beyond the core radius a, where the pressure is $p_a = p - \frac{1}{2} U_{\theta_a}$.

At any radius within the core (r < a), the total pressure, p_{t_r} , is given by

$$p_{t_r} = p_t - \rho U_{\theta_a}^2 \, [1-(r/a)^2] \ . \tag{5-10}$$

From Eq. (5-10) it can be seen that the ideal vortex core has a pressure deficit that translates to a total pressure flux deficit of $(\rho U_\infty \Gamma^2)/8\pi$ for the ideal vortex [24]. The total flux deficit for a real vortex has been found by Loth [24] to be 0.78 $(\rho U_\infty \Gamma^2/8\pi)$. The decay of a vortex element, considered to behave like a single filament carried by the flow, is described by

$$U_{\theta_a}(t) = \frac{\Gamma}{2\pi a}\left(1-e^{-a^2/4\nu t}\right) \ , \tag{5-11}$$

where ν is the kinematic viscosity [25]. Roshko [26] has found remnants of vortex circulations as far downstream as 40-50 cylinder diameters. Obviously, Eq. (5-11) is only an approximation, since it is also known that the entrainment of freestream vorticity is also a consideration.

Vortices in MOD-1 Leg Wakes and Impulse Generation. We are interested in assessing the potential of the perturbative velocity and pressures of the vertically coherent, vortex tube structures contained in the MOD-1 tower leg wakes as a contributory influence in the unsteady aerodynamic process responsible for the acoustic impulse generation. Much of our discussion in Section 5.4.2.1 was centered on the α_{max} parameter derived from a time-varying upwash as a major factor controlling the depth of the transient stall observed. Another important physical parameter to be considered is the existence of a transient adverse pressure gradient encountered by the blade particularly at high incidence angles. We have already identified what we believe to be transient leading edge separation taking place within the leg wake boundaries, which we have found to contain vortex tubes extending more or less parallel to the blade span upon intersection. Because these vortex structures contain strong imposed pressure deficits as well as radial velocity fields, we believe both may be important in initiating the stalling process.

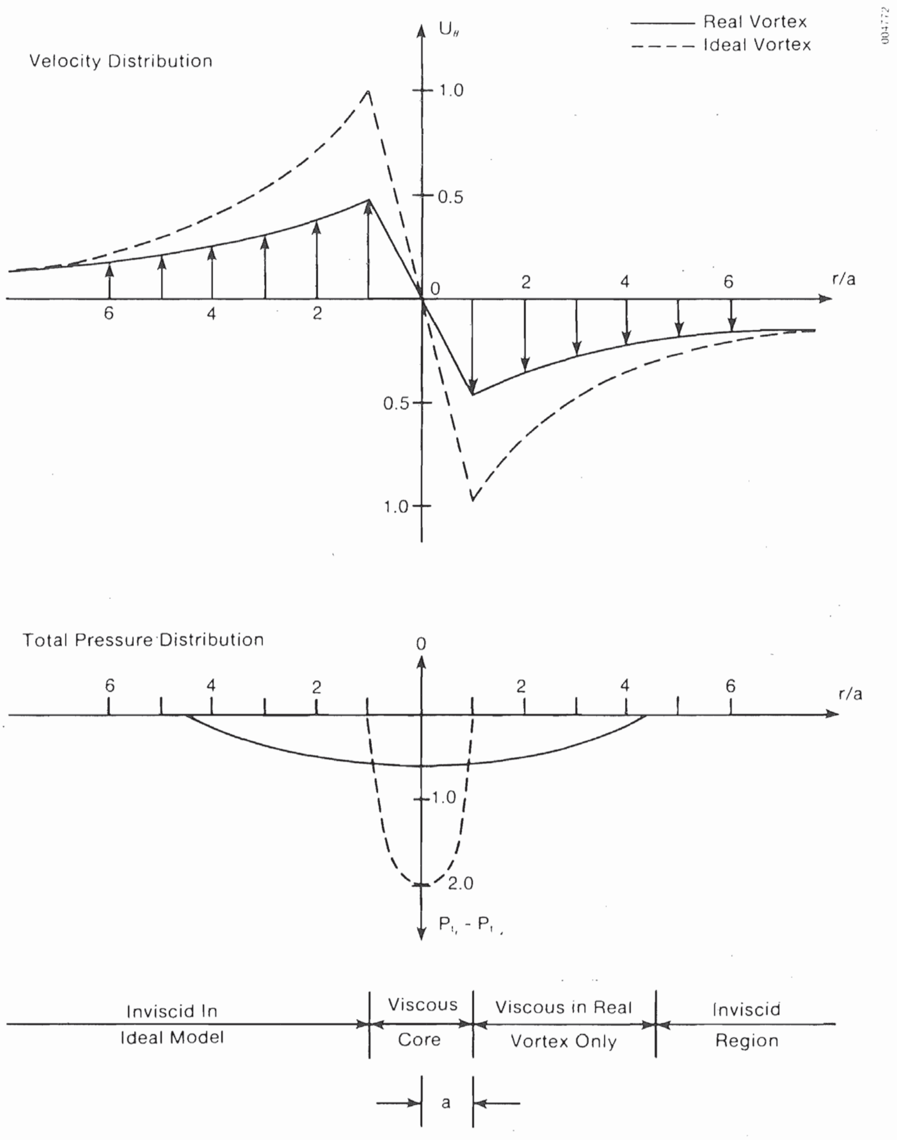


Figure 5-34. Typical Vortex Radial Velocity and Pressure Distributions
Source: Ref. [24].

It is well known that a positive or normal pressure gradient is a stabilizing influence on the boundary layer of an airfoil surface while, under the right conditions, an adverse gradient (decelerating flow) will promote separation. Figure 5-35 demonstrates the process. A normal gradient will allow a small region of laminar flow or "bubble" to exist near the leading edge of the suction side of an airfoil at a positive incidence angle. As the angle is increased, the laminar region contracts and the turbulent transition point moves forward toward the stagnation point. It should be noted that a turbulent inflow acts to favor transition and therefore delay separation. The $c\dot{\alpha}/U_\infty$ term of Eq. (5-6) decreases the adversity of the pressure gradient, causing a lag to develop between the static and unsteady regimes and a delay in separation [21]. However, as previously discussed, there is a critical value of α_{max} at which an abrupt separation will occur.

Because of the leading edge separation sensitivity to adverse pressure gradients, and after considerable study of the characteristics of cylinder wake flows, we tentatively conclude that viscous interaction effects (primarily manifested as the pressure-deficit flux gradients in the viscous cores of shed vortices) may also be important. This point is illustrated by the two frequency spectra plotted in Figure 5-36. The mean frequency spectrum of the wake velocity measured at 1-1/2 diameters downstream of the bare cylinder on the small wind turbine tower is shown in the lower trace with the corresponding wake dynamic pressure spectrum, as measured by a boom-mounted VLF microphone, above. The coherence of these two spectra is quite noticeable. The sharp peaks of the pressure spectrum at one particular frequency, compared with a more broadband spectrum velocity with several discrete peaks, hints of pressure deficits in the cores of the vortices being convected past the measurement point. This strong, narrowband coherence between the wake dynamic velocity and pressure fields is further illustrated in Figure 5-37 by the sharp cross-spectral peak at 3.04 Hz derived from an intense and highly discrete wake flow from the same tower with a perforated shroud installed over the cylindrical surface.

The discrete, coherent relationship exemplified by Figures 5-36 and 5-37 suggests that the pressure deficit in the viscous cores of the shed vortices may be of sufficient intensity and spatial dimension to overcome the quasi-steady normal gradient (strengthened by the more broadband turbulence component of the wake) as the blade passes through. Because we know the impulse generating process is taking place within a space scale on the order of the blade chord, the relationship of the vortex viscous core dimensions in terms of its pressure deficit region and the dimensions of the positive pressure gradient on the leading edge of the blade airfoil may be quite important, particularly since (a) this positive gradient region decreases with increasing incidence angle; (b) the intensity of the peak core pressure deficit increases with enhanced vortex strength, which is proportional to the freestream velocity as indicated by Eq. (5-8); and (c) the positioning of the peak negative pressure is very near the leading edge of airfoil sections at high incidence angles.

In order to evaluate a plausible role for the vortex pressure distribution as a contributor in the causal relationship for leading edge separation, we must develop both the spatial and pressure deficit intensity aspects and their relationship to the dimensions of the cylinder wakes and blade chords. Roshko [26] has proposed a relationship for the vortex strength of a cylinder as

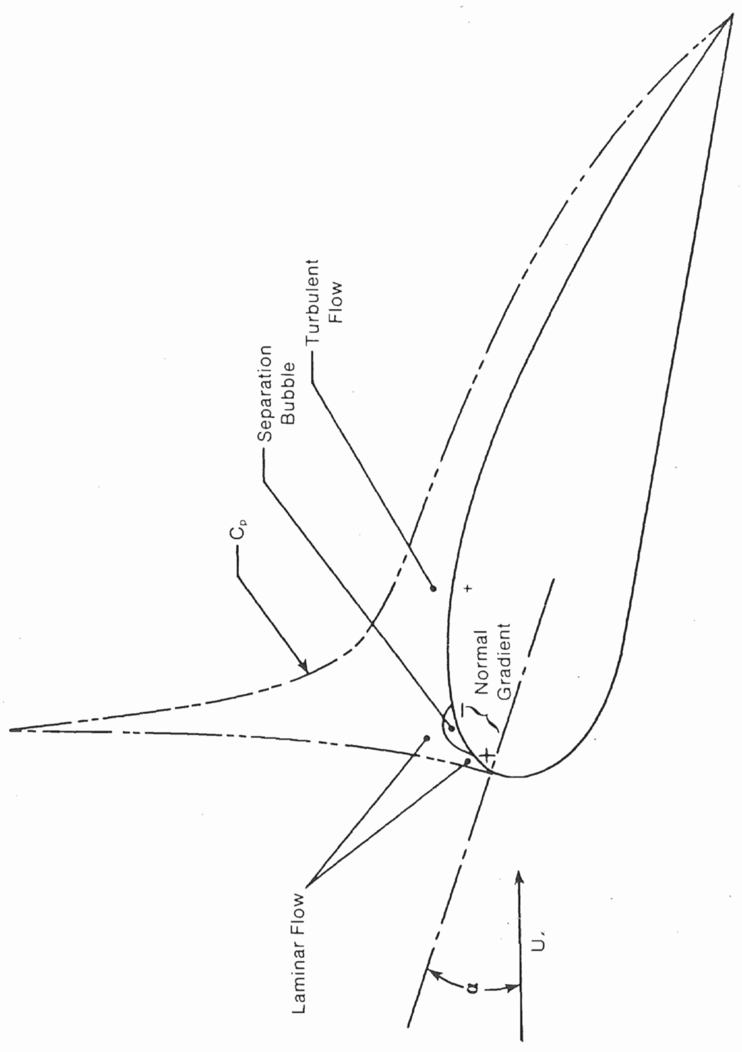


Figure 5-35. Schematic of Airfoil Boundary Layer and Chordwise Pressure Distribution Properties

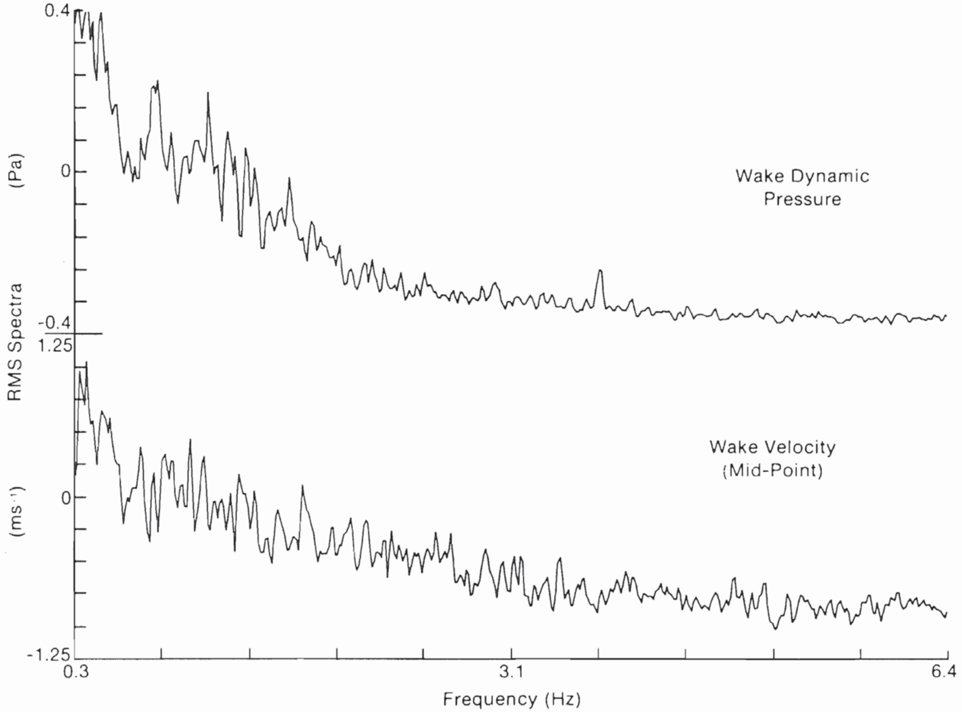


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Figure 5-36. Comparison of Wake Velocity and Dynamic Pressure Spectra 1.5D Downstream of a Cylindrical Tower Element

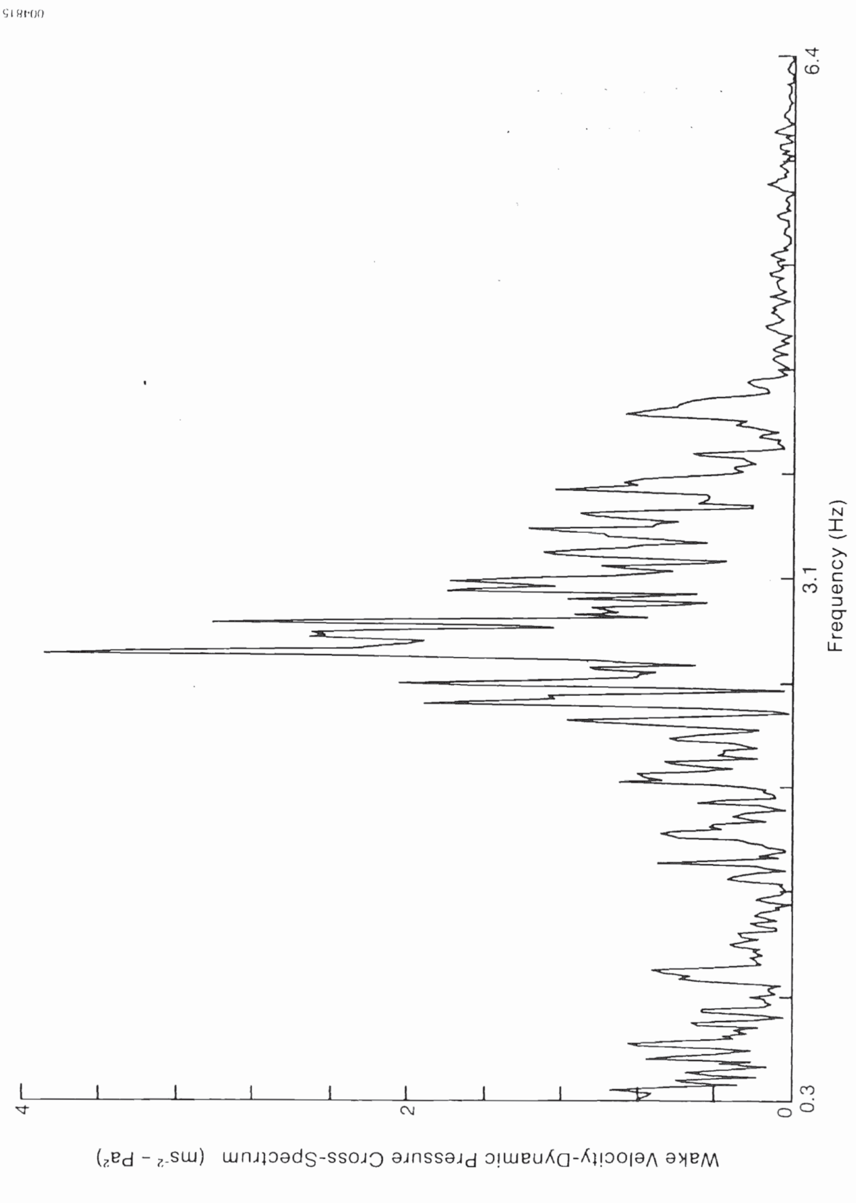

Figure 5-37. Comparison of Wake Velocity and Dynamic Pressure Spectra Taken 1.5D Downstream of a Perforated Shroud-Covered Cylinder

$$\Gamma = \frac{U_\infty D}{St} , \qquad (5\text{-}12)$$

where he has defined the proportionality constant Λ in terms of the Strouhal shedding frequency or $f_s = (St \bullet D)/U_\infty$, where D is the cylinder diameter and St the Strouhal number. For a freestream velocity of 10 ms^{-1}, St = 0.21, and a cylinder 0.5 m in. diameter, the vortex strength, using Eq. (5-12), would be 12.1 s^{-1}. We assume that Eq. (5-12) defines the vortex generation process (i.e., the value of Γ) and the laws of momentum conservation determine the distribution of the fluid dynamic parameters in the downstream wake. If we further assume that the diameter of the vortex viscous core is equal to or a fraction κ of the mean cylinder wake diameter d_w, or $2a = \kappa d_w$, which is consistent with the findings of Roshko [26] and Fage and Johnson [27], we can write an expression using Eq. (5-10) for the core pressure deficit, or

$$\Delta p_v = \rho \frac{\Gamma}{2\pi\kappa d_w}{}^2 = \rho U_\infty{}^2 \left[\frac{1}{2\pi\kappa \; St} \; \frac{D}{d_w}\right]^2 . \qquad (5\text{-}13)$$

Equations (5-9), (5-12), and (5-13) now give us some insight into the physical parameters influencing the intensity of both the induced velocity and pressure fields in the vortices of cylinder wake flows. The core pressure deficit increases as the square of the freestream velocity and the maximum vortex-induced tangential velocity U_a (occuring at κd_w) is directly proportional to this velocity and inversely proportional to the core width κd_w. Many of these relationships have already been identified in Section 3.0; i.e., the strong correlation with wind speed and the downstream leg-to-wake distance related to d_w.

The potential importance of the pressure deficit encountered by the rotor blade can now be demonstrated. The measured chordwise steady pressure distribution along the upper (suction) surface as a function of incidence angle for a NACA 4412 airfoil section, as an example, (approximately that at the 95% span position on a MOD-1 blade) is plotted in Figure 5-38 and summarized in Table 5-5. The forward movement of the peak negative pressure and steepening positive pressure gradient with increasing incidence angle is evident, as is the very small percentage of the chord involved; i.e., less than 2% for $\alpha > 8^o$. Employing Eq. (5-13) for a freestream velocity $U_\infty = 10 \; ms^{-1}$, estimated wake widths of 0.8 and 0.46 m at a 7.5D downstream distance for subcritical and supercritical wakes, respectively, based on the data of Eq. [14], and a Strouhal number of 0.21, we computed estimates of the pressure gradient existing across a viscous vortex for core diameters or κ = 0.10, 0.25, and 0.5 of the wake width d_w. The results have been plotted as two curves representing sub- and supercritical wake widths as functions of both the estimated vortex core diameters and as a percentage of the MOD-1 blade chord at the 95% span. From the data in Table 5-5, the steady leading edge positive pressure gradients have been indicated in Figure 5-39 for four incidence angles. These curves indicate that the steady, leading edge gradients will become adverse with a superimposed vortex pressure deficit when the core diameter is less than 50% of the wake width (at the 7.5D distance), involving about the leading 35% or less of the blade chord upon encountering a subcritical cylinder wake. In the case of a narrower, more energetic supercritical wake, the figure indicates that adversity is possible with vortex cores covering 75% or less of the wake but again, the first 35% or less of the blade chord would be

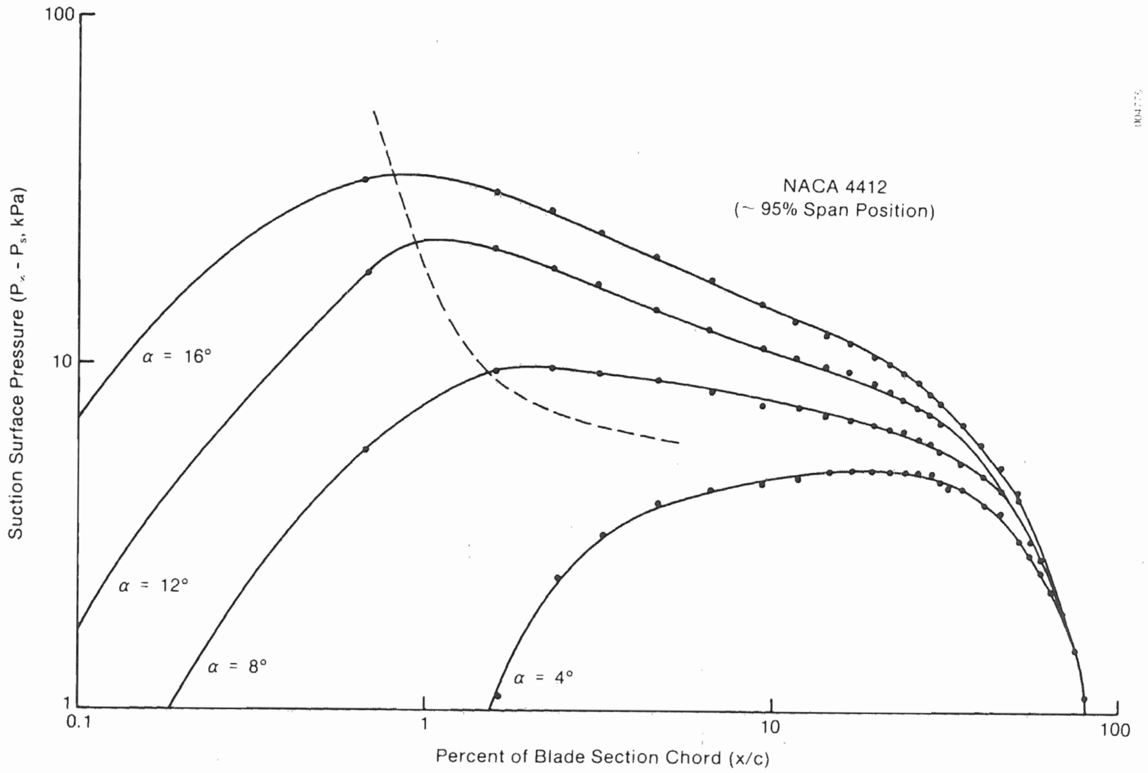

Figure 5-38. Mean Chordwise Pressure Distribution for a NACA 4412 Airfoil Section as a Function of Incidence Angle

Source: Ref. [28].

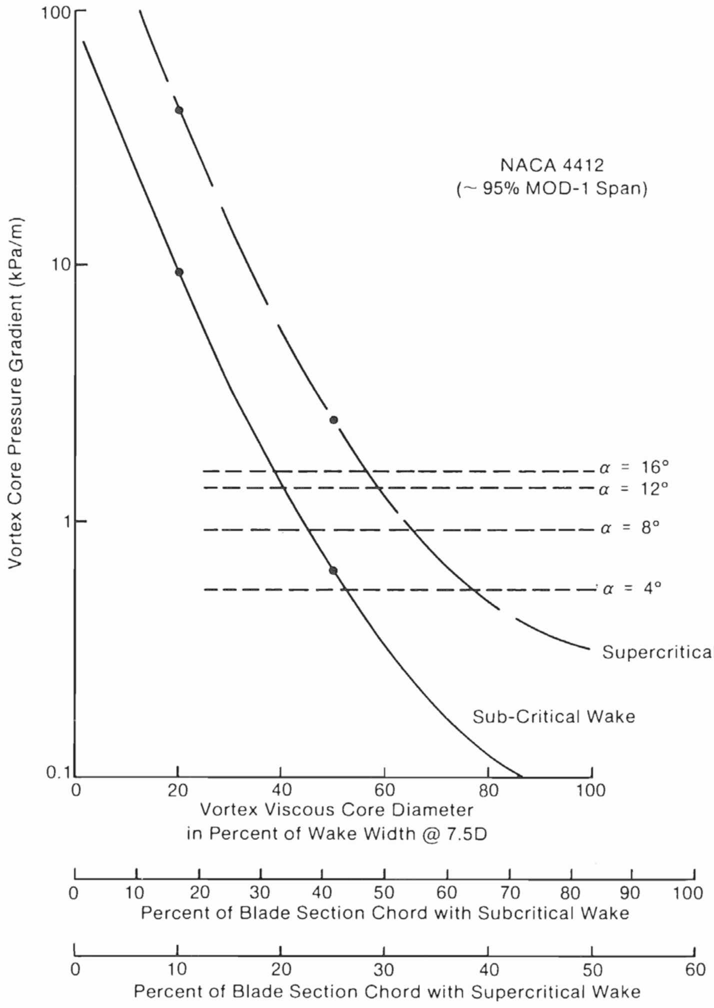

Figure 5-39. Vortex Core Pressure Gradient vs. Core Diameter in Percent of Leg Wake Width at 7.5D Downstream for Both Subcritical and Supercritical Regimes (D = tower leg diameter)

Table 5-5. **Steady Leading Edge Chordwise Pressure (Suction) Gradients for a NACA 4412 Airfoil Section (95% MOD-1 Span) at Equivalent 35 rpm Rotational Speed**

Incidence Angle (deg)	Normal Mean[a] Gradient			Peak[a] Normal Gradient	
	x/c (%)	Surface Distance (cm)	Gradient (kPa/m)	Gradient (kPa/m)	Location from Leading Edge (cm)
4	16.0	10.6	0.081	0.54	0.68
8	1.3	1.85	0.457	0.93	0.68
12	0.7	1.41	0.928	1.36	0.94
16	0.7	1.41	1.008	1.58	0.94

[a] Mean gradients are calculated by normalizing by total surface distance covered by normal gradient, peak value is determined by maximum gradient found between two pressure measurement stations.

involved, as shown by the lower abscissa scale. The data shown in Figure 5-39 demonstrate that the blade-vortex interaction of a 4412 airfoil section and tower leg wakes is a leading edge phenomenon. It is certainly probable that the pressure deficits within the vortex circulations exert a viscous influence, leading to boundary layer separation and an accompanying sudden loss of lift through the imposition of a transient adverse pressure gradient as well as an upwash-induced incidence angle α_{max}.

5.2.4.3 Wind Tunnel Verification

The possibility that the pressure deficits contained within the wake vortices is a contributing factor in the suspected leading edge separation has, at least in terms of the existence of adverse pressure gradients, been confirmed by a wind tunnel experiment conducted in the University of Colorado subsonic wind tunnel. Figure 5-40 illustrates the basic tunnel testing configuration. A series of constant chord airfoil sections was constructed with a chord length of 17.8 cm and an aspect ratio of 5 and included the symmetrical NACA 0015, 0018, and 63_2-015 and cambered 4415, and 23015 shapes. Unfortunately only the three symmetrical sections have been tested and only preliminary analysis results are available at this writing.

The tests were designed to expose a rigidly mounted airfoil section to a reasonably narrowband turbulent flow generated by a series of upstream cylinders (5D cylinder upstream spacing) whose streamwise dimensions (diameter) were an integral or integral fraction of the subject blade chord (i.e., 1/4, 1/2, 1, and 2 chords, similar to the model rotor tests conducted in the MIT anechoic tunnel) and to simultaneously measure the leading surface pressures and radiated acoustic pressure field. This approach allowed us to examine the

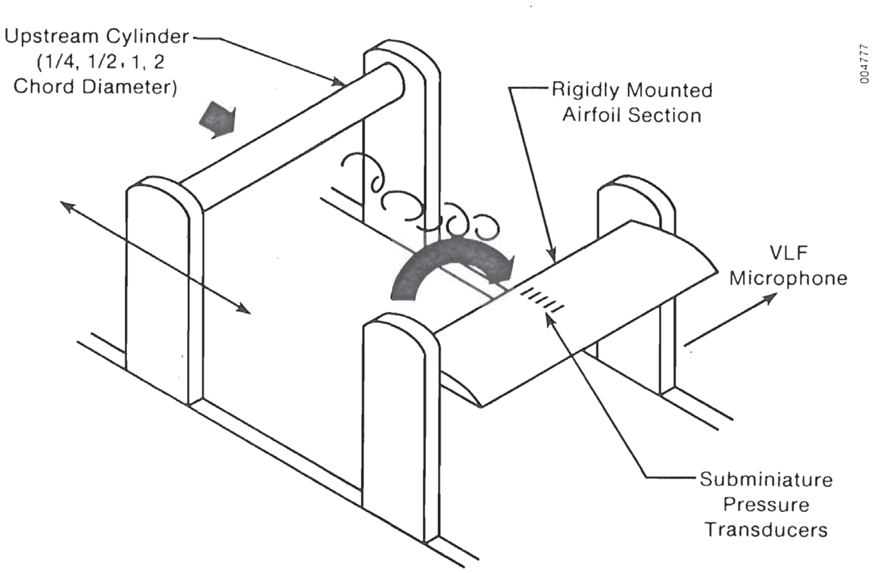

Figure 5-40. Sketch of Experimental Configuration for Unsteady Flow Testing of Rigid Airfoil Sections

unsteady aerodynamic processes responsible for the radiated acoustic pressure characteristics in terms of many of the fluid dynamics parameters discussed previously while holding others constant. The surface pressures were measured by a series of subminiature pressure transducers with a sensing region 2.4 mm in diameter (or slightly more than 1% of the section chord dimension) placed at the leading edge and the 15%, 25%, and 40% chord positions on the upper (suction) surface and at the 40% chord location on the lower or pressure side. The design frequency response of the experiment was dc-1250 Hz, the upper limit imposed by the tape speed of the FM magnetic recording. The acoustic pressure field was measured by a single VLF microphone equipped with a nose cone and mounted above and slightly downstream of the test airfoil. Measurements of the wake turbulence inflow were taken with two 50-μm, constant-temperature, hot-film anemometers mounted parallel to and 2 cm ahead of the airfoil leading edge. A single tunnel speed was used (37.5 ms^{-1}) which, when coupled with the cylinder wake deficits, translated into a chord Reynolds number of 265,000 at a Mach number of 0.085 compared with about 2,200,000 and 0.26, respectively, for the 80% span position of a MOD-1 blade at 35 rpm.

The objective of these tests was to determine if the properties of wake flows leaving an upstream cylinder could invoke dynamic negative pressure gradients over the leading edge region of the test airfoil sections as a function of incidence angle. The NACA 0015 and 0018 sections, while not used on the MOD-1 or most horizontal axis turbines, are commonly employed on vertical axis machines. All three of these sections, however, exhibit suction-side, chordwise pressure distributions similar to the NACA 44xx section used on the MOD-1; i.e., the maximum negative pressure very close to the leading edge at incidence angles in excess of about 8 degrees, as indicated in Figure 5-38. While the conditions for dynamic similarity have again not been met, the relative insensitivity to the Reynolds and Mach number parameters found by other investigators, for at least the deep stall phenomenon, should allow us to at least qualitatively examine the roles of the disturbance-imposed reduced frequency, adverse pressure gradients, and turbulence space scales at three incidence angles in the process leading to the development of transient lift fluctuations and the generation of acoustic impulses.

The NACA 63(2)-015 section was found to be increasingly sensitive to the cylinder wake disturbances with increasing incidence angle, as would be expected. Figures 5-41 and 5-42 present the upper surface leading edge-to-15% and -25% chord pressure gradient probability density functions (PDF) downstream of the two-chord-diameter cylinder at 4-, 8-, and 12-degree incidence angles. A normal gradient exists to the right of the center line (i.e., a pressure decrease between the transitory leading edge and either the 15% or 25% chord position) and an adverse one to the left. As can be seen from both figures, the gradient stays normal for an attack angle of 4° all but a minute fraction of the time. However, as the angle is increased, adverse gradients occur a greater and greater percentage of the time, particularly between the leading edge and the 15% chord position. It is interesting to note the high degree of adversity for an incidence angle at least two degrees below the static stall value. This indicates the effectiveness that turbulence structures containing the right properties have in controlling the boundary layer dynamics of airfoil sections with chordwise pressure distributions peaked near the leading edge. These figures also confirm an increased tendency to transitory leading edge separation with increasing incidence angle.

The role of the turbulent structure being encountered by the airfoil section in Figures 5-41 and 5-42 for a 12-degree angle of attack is shown by the relative transfer function magnitude relating the dynamic response of the radiated acoustic pressure field as excited by the inflow turbulence spectrum in Figure 5-43. The abscissa scales are plotted for both the reduced frequency k (one for 1/4-chord excitation and one for two-chord excitation, due to the differences in the wake deficits), and a wavelength or space scale normalized by the blade chord dimension. The broad and narrow peaks corresponding to the excitation by the relatively broadband two-chord cylinder wake and narrowband, discrete wake of the 1/4-chord cylinder are quite obvious. The maximum response to the broadband excitation occurs between the k-values of 0.5 and 2, with a peak at k = 1 and a corresponding disturbance space scale range of 1.5 to 6 chord lengths, peaking at 3.1. The peak response to the narrowband, discrete wake occurs at k = 3.5 (1/4-chord scale) with a perturbation wavelength of 1 chord. The responses to the 1/2- and 1-chord wake excitations, while exhibiting a narrowband peaked response similar to that of the 1/4-chord, occurred at k-values of 2.0 and 1.4 and wavelengths of 1.6 and 2.1 chords, respectively, but falling coincident with the curve defined by the two-chord wake excitation. In addition, a severe, high-frequency aeroelastic response was visually noted, though not directly instrumented for, during the two-chord broadband forcing including violent pitching (torsional) and translation movements, with the latter exceeding an estimated ±1 cm vertical excursion of the rigidly mounted airfoil. In contrast, the 1/4-chord-wake-excitated peak exhibited essentially a visually inperceptable elastic response but, as shown, it was reflected only in the radiated acoustic field. The behavior of these two peaks does vary with the smaller incidence angles, the acoustic peak at k = 3.5 becoming predominant at the 4-degree incidence angle.

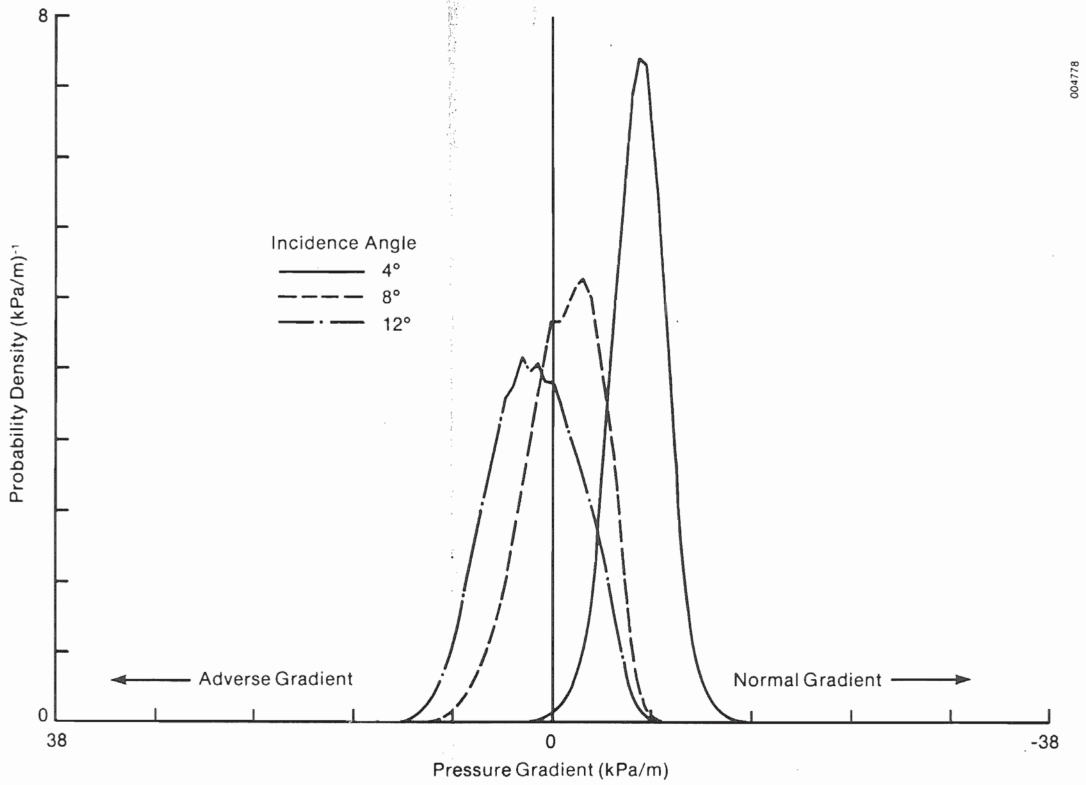

Figure 5-41. Probability Density of Leading Edge-to-0.15 Chord Pressure Gradient for the 63(2)-015 Airfoil with Two-Chord-Diameter Upstream Cylinder Excitation

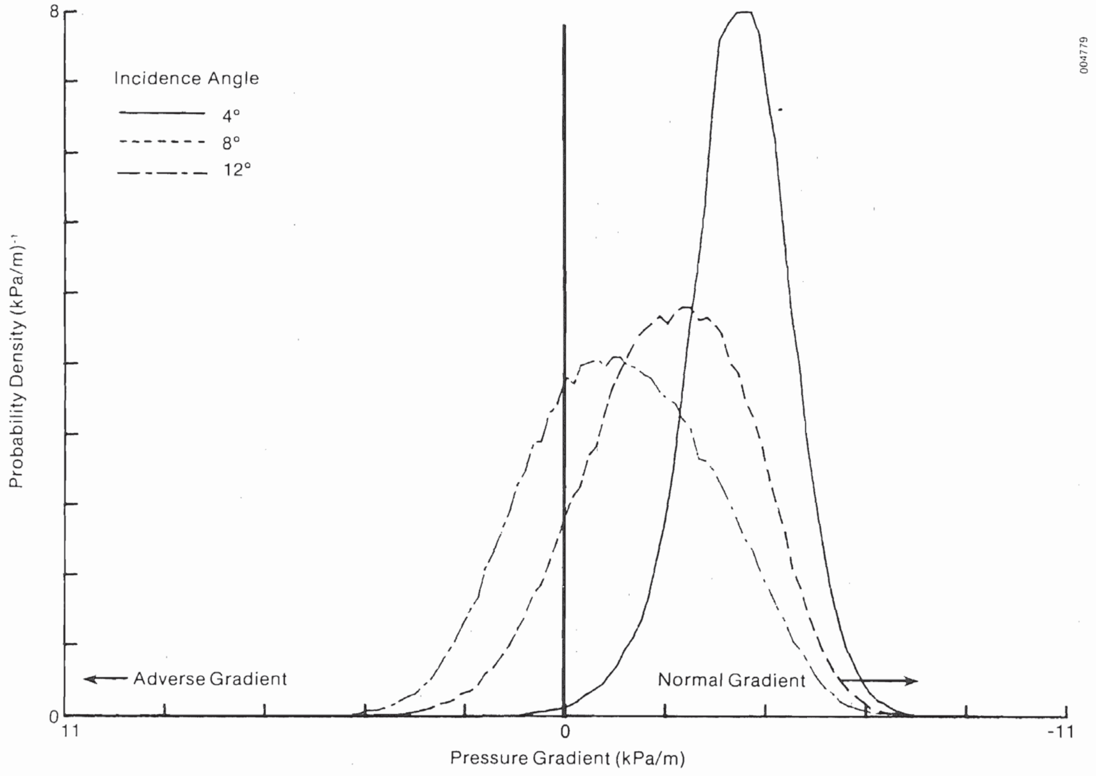

Figure 5-42. **Probability Density of Leading Edge-to-0.25 Chord Pressure Gradient for 63(2)-015 Airfoil with Two-Chord-Diameter Upstream Cylinder Excitation**

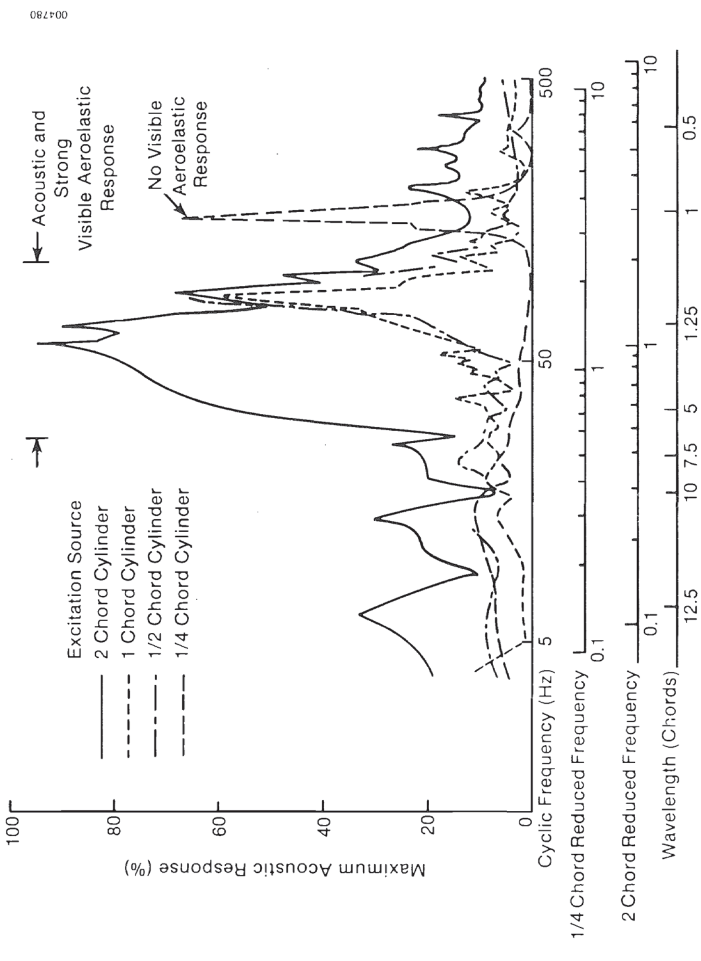

Figure 5-43. Relative Aeroacoustic Transfer Function for the 63(2)-015 Airfoil Section as a Function of Cylinder Wake Perturbations

We conclude from this that perturbations present in a turbulent wake flow can have a significant effect on the unsteady behavior of an airfoil section highly loaded at the leading edge. The relationship between the perturbation-induced unsteady airload (see Figure 5-1) and the resulting acoustic and aeroelastic responses of the NACA 63(2)-015 test section are summarized in Figure 5-44. Figure 5-44a plots the observed acoustic transfer function modulus for three incidence angles: 4-, 8-, and 12-degrees. The measured static structural modes are included in this figure and also summarized in Table 5-6. The transfer function modulus for the 15%-chord position normal force (C_n) is presented in Figure 5-44b. Figures 5-44c, d, and e compare the transfer function moduli for the 15%-chord normal force and acoustic radiation at the three incidence angles, respectively. The conclusions one may draw from these graphs (at least as far as the fluctuating surface pressures near the leading edge are concerned) include (a) the acoustic response peak of Figure 5-43 at about k = 1 is essentially independent of incidence angle (and therefore the mean airload) and any structural modes at that particular frequency; and (b) above about k = 1.5, the acoustic and structural responses are not necessarily tightly coupled, an exception being the mode at 140 Hz or k = 3.2, where a strong acoustic/aeroelastic coupling exists.

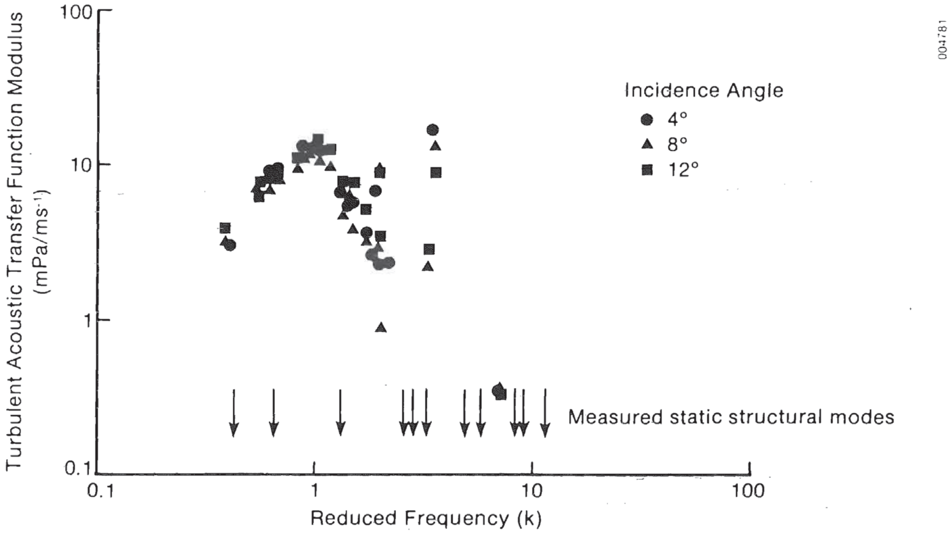

Figure 5-44a. Measured Turbulent Acoustic Transfer Function Modulus for 63(2)-015 Test Section at Incidence Angles of 4, 8, and 12 Degrees

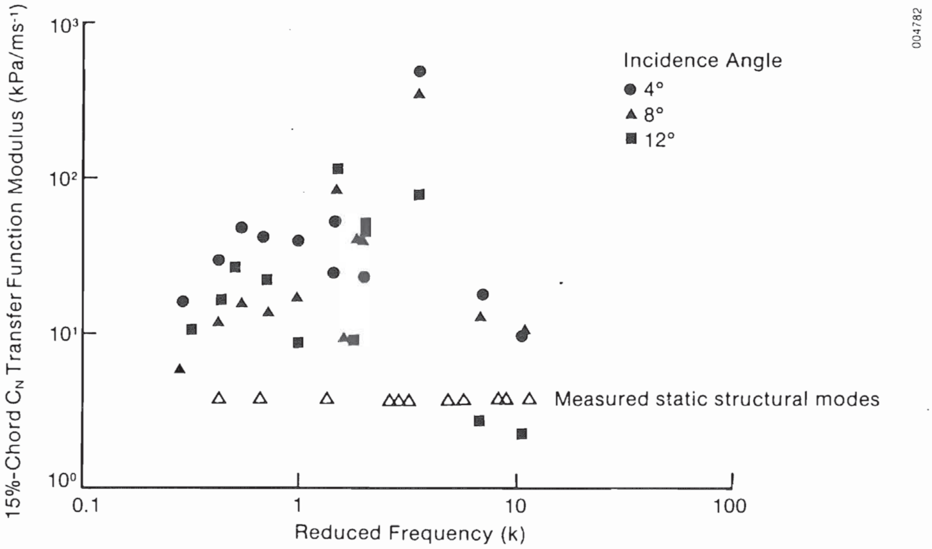

Figure 5-44b. Measured Turbulence Normal Force (C_n) Transfer Function Modulus at 15%-Chord for 63(2)-015 Test Section at Incidence Angles of 4, 8, and 12 Degrees

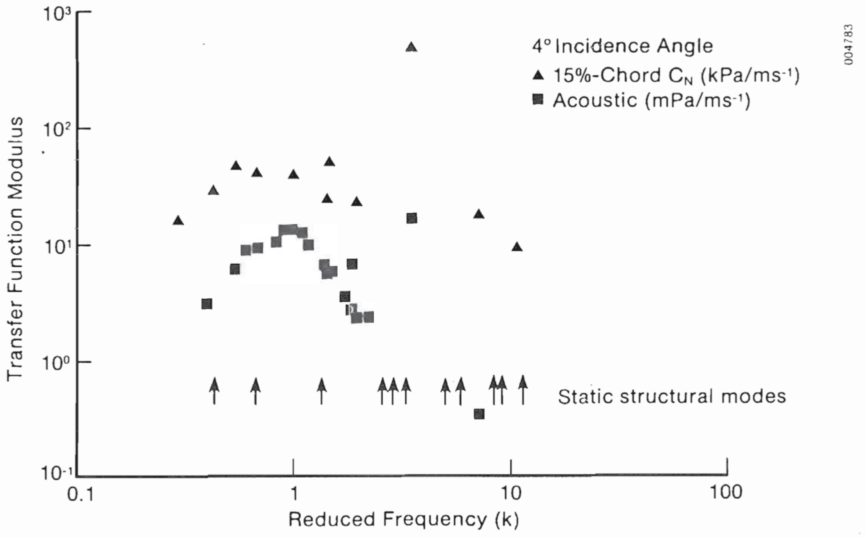

Figure 5-44c. Comparison of Acoustic Emissions and Normal Force (C_n) at 15%-Chord Transfer Function Moduli for 63(2)-015 Airfoil Section at an Incidence Angle of 4 Degrees

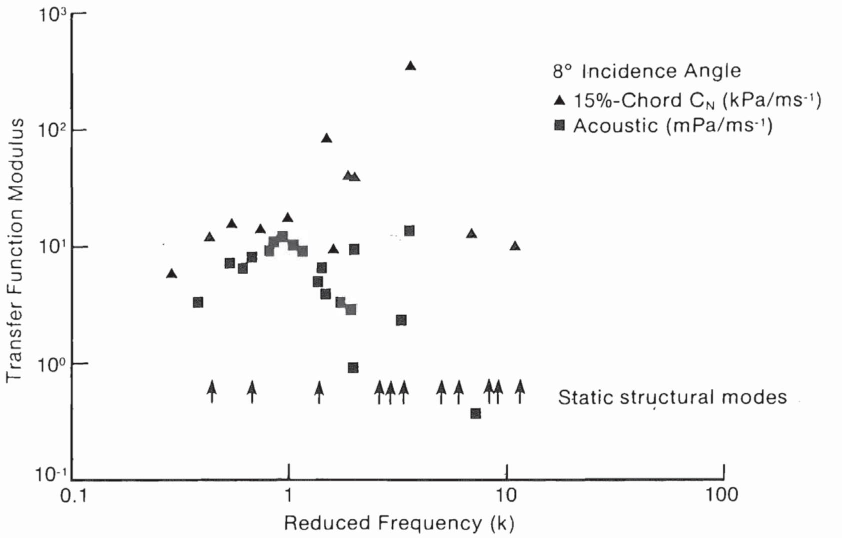

Figure 5-44d. Comparison of Acoustic Emissions and Normal Force (C_n) at 15%-Chord Transfer Function Moduli for 63(2)-015 Airfoil Section at an Incidence Angle of 8 Degrees

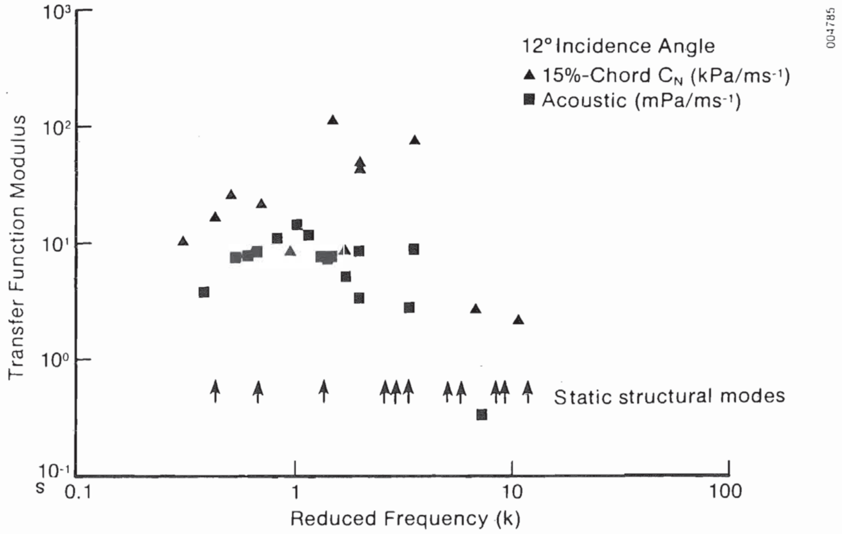

Figure 5-44e. Comparison of Acoustic Emissions and Normal Force (C_n) at 15%-Chord Transfer Function Moduli for 63(2)-015 Airfoil Section at an Incidence Angle of 12 Degrees

Table 5-6. Measured Structural Resonant Modes of 63(2)-015 Airfoil Test Section

Excitation Frequency Cyclic (Hz)	Excitation Frequency Reduced[a] (k)	Torsional Mode Damping Characteristic[b]	Bending Mode Damping Characteristic[b]	Modal Cross-Coupling Characteristic[c]
19.2	0.44	Low	High	Weak
29.6	0.67	Moderate	Moderate	Strong, inphase
58.4	1.33	Low	Moderate	Moderate
112	2.56	Low	Low	Strong
124	2.83	Low	Moderate	Weak
140	3.20	Moderate	High	Weak
228	5.21	Moderate	Moderate	Moderate
255	5.82	Moderate	Moderate	Moderate
364	8.31	Moderate	Moderate	Moderate
385	8.80	High	High	Moderate
480	11.00	High	High	Strong
500	11.42	High	Very High	Weak

[a] Based on 2-chord cylinder excitation tunnel velocity of 32.1 ms^{-1}.

[b] Mode damping degree estimate: low = $\zeta < 0.05$; moderate = $0.05 \leq \zeta_c$; high = $\zeta > \zeta_c$.

[c] Cross-coupling mode estimate: weak = $A_B(f) < 0.1\ A_T(f)$; moderate = $0.1\ A_T(f) \leq A_B(f) \leq 0.9\ A_T(f)$; and strong = $A_B(f) \simeq A_T(f)$, where $A_T(f)$ = torsional response and $A_B(f)$ = bending response.

5.3 SUMMARY AND CONFIRMATION OF CAUSAL FACTORS RESPONSIBLE FOR AERODYNAMIC GENERATION OF MOD-1 ACOUSTIC IMPULSES

In this section, we summarize the physical parameters that contribute to the large transient lift fluctuations and resulting impulsive noise generation by the MOD-1 wind turbine. We also relate, where possible, which of those parameters and their interactions are responsible for the results discussed in Section 4.0.

5.3.1 Summary of Physical Parameters Responsible for MOD-1 Acoustic Impulse Generation

The breadth and depth of the dynamic physical mechanism responsible for the lift transients and impulse noise are substantial and the interactions are complex. The best overall view is found in Figure 5-1, in which the component processes are systematically presented. In order to provide a comprehensive summary of the process, it is both necessary and convenient to subdivide the overall situation into three major components which exert influence over the impulse generation characteristics: operational, cylinder wake, and rotor blade aerodynamic properties. We will identify the major causal factors in each of these categories.

5.3.1.1 Operational Parameters

The pertinent physical parameters in this classification can be further subdivided into those that are design related and those that are environmental. The design parameters include the physical shape of the turbine rotor and its support tower consistent with a rated power generation capacity. These constraints have been translated into the rotor diameter and rotational speed and the size of the elements of the pipe-truss tower required to safely support the power train under both operating and survival conditions. The rotor disk size and required rotational speed determine the operating Reynolds and Mach number regimes, which vary as a function of the span distance because of the $R\ \Omega$ dependence (where R is the rotor (span) radius and Ω the rotation rate). These two parameters, in conjunction with the airfoil shape, heavily influence blade boundary layer stability and leading edge separation characteristics, thus "locking in" the type of transient, unsteady, lift response that occurs should the outer portions of the rotor encounter the "right" inflow structures. The basic tower design has dictated the cylinder wakes and the blade-to-leg distances that control the downstream blade intersection distances and therefore the wake vortex circulation scales encountered, a major factor in the unsteady processes involved.

Environmental parameters, dominated by the magnitude and turbulence characteristics of the freestream inflow, exert considerable influence over the impulse generation process. Specifically, they are

1. Freestream velocity--controls leg vortex intensity, blade section local Reynolds and Mach numbers, and the quasi-steady value of the blade incidence angle.
2. Vertical wind shear below hub height--controls shedding characteristics of tower legs which in turn determines the range of the reduced frequency parameter k as well as the level of discreteness found in the wakes. May also exert considerable influence over whether or not the tower leg boundary flows become supercritical, subsequently enhancing the intensity of the vortex elements and setting the wake width.
3. Vertical (hydrodynamic) stability--believed to affect the discreteness of the tower leg wake flows (and therefore the k-range) through influencing the freestream shear or the leg wakes themselves, or both.
4. Upwind fetch--coupled with the vertical stability, it controls the vertical shear and the turbulence space scales which have a strong influence on the shedding characteristics of the cylindrical tower legs.
5. Wind direction--coupled with the geographic orientation of the tower, it controls the blade-to-leg position in the wakes and the upstream fetch.

As can be seen from the above, the machine designer does have control over many of the factors listed, but an understanding of the complex interaction of these and those following is necessary to minimize impulsive noise generation by design and siting.

5.3.1.2 Cylinder Wake Parameters

As the flow diagram in Figure 5-1 indicates, freestream turbulence impinging on a downwind WECS support tower is somehow modified by the incorporated structural elements. We have previously identified the vertical, 0.5-m-diameter, cylindrical legs as the primary source of the MOD-1 impulse noise through the strong wake circulations created in their lee. A number of environmental parameters that exert influence over the dynamic characteristics of these leg wakes were summarized in Section 5.3.1.1.

In Section 5.2, we identified the vortex-dominated wake circulation with its strong, transverse (to the blade plane) velocity fields and viscous core pressure deficits confined to a space scale equivalent to the mean blade chord dimension as the direct cause of the transient lift fluctuations. More comprehensively, the list should include the following:

1. Wake vertical coherency--related to separation along a straight line, these vortices become vortex tubes, which are intersected by the rotor blade simultaneously along a good portion of the span supporting the greatest airload, causing maximum impulsive radiation if involved in a transient leading edge separation and loss of lift.
2. Wake width--bounds the scale of the vortex circulations, thereby effectively bounding the reduced frequency parameter for the transverse direction; has been shown to be the source region for the impulse generation, the peak of which occurs at a disturbance/space scale of the blade chord dimension ($k \sim \pi$).
3. Viscous effects--the strong transverse velocity gradients containing pressure deficit disturbances have been found to be instrumental in causing a transient separation of the blade's leading edge boundary layer.
4. Level of discreteness--broadband wake turbulence has been shown to impart a stabilizing influence on leading edge boundary layer separation, whereas a narrowband, discrete wake exerts a destabilizing effect.
5. Time-varying properties--are far more important in developing an understanding of the unsteady, blade-wake interaction process.

5.3.1.3 Blade/Airfoil Properties

The shape of the airfoil section employed in the rotor design, when combined with the local quasi-steady incidence angle, determines the chordwise pressure distribution and separation characteristics; i.e., leading versus trailing edge. The abruptness of leading edge separation, in addition to the blade shape, is influenced by the disturbance reduced frequency k, inflow pressure deficit Δp_v, and the quasi-steady incidence angle, $\overline{\alpha}$.

5.3.2 Comparison of Supportive Research Effort Results with Analysis of Physical Parameters Related to MOD-1 Noise Situation

From the results of the full-scale field experiment and the two wind tunnel experiments discussed in this section, we now believe we can offer at least a partial explanation of some of the results of the MOD-1 impulse analysis presented in Section 4.0. First, we must review the significance of the impulse rise-rate and overpressure parameters; the meaning of the energy intensity is not altered. The rise-rate parameter reflects the rate of change in the radiated acoustic pressure field which, through Eq. (4-5) in Section 4.1.1.3, is given by the time rate of change of the lift fluctuations. Thus, the rise-rate parameter can be viewed as a sensitive measure of the lift characteristic related to transiently separating and reattaching boundary layers. The acoustic peak dynamic or overpressure parameter is a measure of (1) the extent of the transient stall observed (i.e., is the lift completely cancelled or does reattachment occur after a delay?); and (2) the magnitude of the instantaneous airload, which is a function of the quasi-steady incidence angle and any hysteresis overshoot present. The statistical distributions of these two parameters, particularly the former, can therefore provide some insight into the unsteady aerodynamic process operating as the MOD-1 rotor blades pass through the tower leg wakes.

5.3.3 Interpretation of the MOD-1 Impulsive Noise in Terms of the Unsteady, Fluid Dynamic Parameters

In Section 5.2 we identified several aerodynamic parameters that are responsible in some way for the unsteady, nonlinear phenomena observed. Confirming these with our identification of the spanwise coherency ℓ_c from Section 4.1.1.2 (which describes a 3-D effect), we can summarize the known or at least suspected unsteady, fluid dynamics parameters that have an influence over the transient, unsteady lift-generated acoustic impulses as the MOD-1 blades pass through the tower leg wakes, including

- the blade airfoil shape
- the reduced frequency k
- the quasi-steady incidence angle $\bar{\alpha}$
- the section chord Reynolds number Re_c
- the section Mach number M_∞
- the spanwise lift coherency ℓ_c
- the imbedded vortex core pressure deficits Δp_v.

The principal environmental parameters affecting the unsteady, structural characteristics of the tower leg wakes include

- the freestream velocity U_∞
- the surface-to-hub height vertical shear $\partial U_\infty/\partial z$
- the vertical stability of this layer expressed by the gradient Richardson number, or

$$Ri = g(\partial\overline{\theta}/\partial z)/\overline{\theta}(\partial\overline{U}_\infty/\partial z)^2 \quad , \qquad (5\text{-}14)$$

where

θ = $T(p/P_o)^{0.287}$ = potential temperature

p = local barometric pressure, kPa

P_o = 100 kPa = reference barometric pressure

g = gravity acceleration

T = absolute air temperature (K)

z = height (m) ,

plus

- the Strouhal excitation band mean-square velocity $\overline{U}^2_{St,\Delta f}$
- the wake downstream distance d_s (in leg diameters)
- the diameter of cylindrical legs D
- the cylinder Reynolds number, Re_D
- the wind direction.

The overall situation (at least from a generation perspective) with at least 14 known variables, not all of which are independent, provides some perspective into the complexity of the process. If we look only at the turbine itself for a moment and concentrate only on 35 rpm operation, the list of blade variables may be reduced to k, $\overline{\alpha}$, ℓ_c, and Δp_v, all of which are functions of time. These may be thought of as "receptor" parameters, since they are instrumental in transforming the characteristics of the turbulent wake inflow into an unsteady aerodynamic lift response. At least seven environmental variables influence the structure of the leg wakes, but treating the leg diameter as a constant allows the six remaining to be thought of as "excitor" variables, all of which are tied to local atmospheric conditions. The stochastic nature of these six parameters makes the impulsive acoustic output itself probabilistic.

5.3.3.1 Confirmation of Influence of Reduced Frequency Parameter on MOD-1 Impulse Noise Generation

Our wind tunnel experimentation, using a symmetrical airfoil section that exhibits a chordwise pressure distribution similar to the 44xx-series used on the MOD-1, has revealed the reduced frequency sensitivity of the inflow turbulence structure on the radiated acoustic pressure field. Figure 5-43 indicates the most sensitive range of k from approximately 0.5 to 3.5. The peak sensitivities occurs at $k \simeq 1$ and π signifies a maximum coupling between the wake perturbation excitation and an airfoil. In order to compare the model test results, which admittedly do not achieve the proper dynamic similarity with the operational MOD-1 situation, we have repeated Figure 3-10 as Figure 5-45 of the acoustic frequency spectrum of a single MOD-1 impulse reaching out of houses 1 km away. In this later figure, we have included the reduced frequency scale. The peaks, as indicated, occur at 13.5, 28, and in the band from 41.8 to 59.1 Hz, which translate to k-values of 0.71, 1.47, and 2.19-3.11 for a blade span position of 80%. It is also reasonably clear from this plot and others that the bulk of the impulse radiation occurred over a k-range of 0.5 to 3.2 during moderate-to-severe generation episodes. The entire range is broader when all cases are considered, varying from 0.33 to 5.1 (6.25-97.3 Hz) at 35 rpm and 0.15 to 2.26 (4.4-6.5 Hz) at 23 rpm. Thus, the moderate-to-severe acoustic impulse radiation occurred over the same reduced frequency range observed in the wind tunnel tests, and this indicates that a similar unsteady physical process is taking place on the MOD-1 blade in the leg wakes.

5.3.3.2 Comparison of MOD-1 Results with Other "Receptor" Variables

The remaining "receptor" variables include the quasi-steady incidence angle $\bar{\alpha}$, the coherent spanwise lift ℓ_c, and the imbedded vortex pressure deficits Δp_v. In only $\bar{\alpha}$ do we have any direct information from the MOD-1, because of the extreme difficulty of obtaining direct measurements of the other quantities. The statistical analysis of the impulses and corresponding operating parameters reported in Section 4.0 found that the impulse severity associated with the south tower leg was positively correlated with the attack angle (as would be expected), but the impulses related to the east leg were weakly negatively correlated (Table 4-8). As mentioned, we attribute some of what was found to the off-design operating conditions under which the data were taken; i.e., the load bank used in the June 1980 testing. We do, however, believe that the marked differences in the attack angle correlation for the two wakes are indicative of substantial turbulent structural variations in the two wakes; this is borne out by other measures, some of which were discussed in Section 4.0.

5.3.3.3 Comparison of MOD-1 Results with Available "Excitor" Information

Of the seven "excitor" variables identified in Section 5.3.3, we have quantitative information on only two: the hub-height freestream velocity and the leg-to-blade distance D. We can, however, make some comments regarding the vertical stability and wind shear parameters.

Attack Angle Correlation. The results of the statistical analysis reported in Section 4.0 have confirmed that the severity of the generated impulses depends strongly on the magnitude of the wind speed. We indicated earlier, in our discussion of vortex dynamics, that the freestream velocity was a key parameter in determining the embedded vortex radial velocity and core pressure deficit distributions in the tower leg wakes which, when cut transversely by the blade, control the $C_{L\max}$ overshoot and leading edge separation.

Leg-to-Blade Distance Correlation. This variation, previously discussed, is associated with substantial differences between the radiated impulses as a function of downwind distance from the south and east tower legs. We have attributed this variation to marked differences in the turbulent structural properties of each of these wakes.

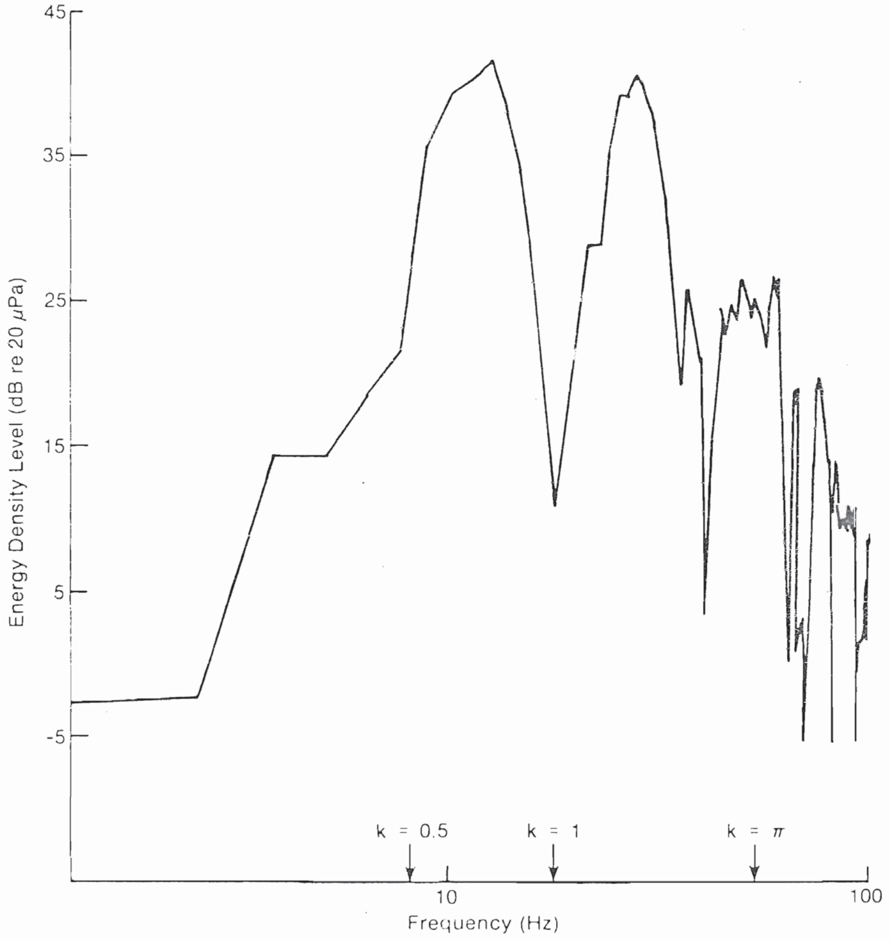

Figure 5-45. Single MOD-1 Impulse Energy Density Level Spectrum Reaching House #8 with Equivalent Critical Reduced Frequency Values Indicated

Effect of Wind Shear, Stability, and Strouhal Excitation on Observed Impulse Severity. While we have no direct information about the vertical shear and stability conditions present during the March and June 1980 testing periods, the results of the Rocky Flats experiments have given us some insight into the importance of these variables. One characteristic of strong shear layers is the tendency for discrete, spatially coherent turbulent flows to develop, particularly if inflectional instabilities also develop. We found, for example, that there is a strong diurnal cycle in the appearance of discrete energy in the tower cylinder Strouhal excitation band. This is tied to the development of the nocturnal boundary layer and is most pronounced an hour or so before to an hour or so after local sunset, with a similar situation at sunrise. The increasing stability of the surface layer in the evening and the opposite in the morning is seen as one of the causes. We observed the worst impulsive situations at the MOD-1 during these periods, particularly during the evening hours, as borne out by the frequency of homeowner complaints.

In Section 4.0 we mentioned the presence of very strong vertical shears upstream of the MOD-1. We believe this has its roots in two sources related to the upstream fetch: the complex terrain upstream of the site and the top of the forest canopy, which reached the height of the lowest elevation of the rotor disk. When compounded by an increased lower layer stability, such turbulence-generating mechanisms could easily produce a flow with considerable discrete energy in the Strouhal excitation band and modify the leg wake turbulent structures in a manner similar to what happend when an augmenting cylinder was placed upwind in the wind tunnel tests. We believe that the more severe impulsive conditions observed during the June 1980 experiments, compared with March (see Figure 4-11), are a direct result of the trees surrounding the turbine being in full leaf. The leaves served to intensify the shear layer existing immediately above the forest canopy and, thus, the Strouhal excitation of the tower legs.

The marked difference in the impulse characteristics between the east and south legs appears to relate to two factors: (1) an upwind fetch influence that affects the Strouhal excitation and therefore the shedding characteristics of the east and south legs, and (2) whether or not the wind direction places these legs in the wakes of their upstream counterparts. All of the June 1980 plots of the impulse characteristics shown in Figures 4-20 through 4-22, particularly the impulse energy intensity plot of Figure 4-20, reflect this upstream influence on the south leg impulses by the peak in the curves when the blade was passing between 7.5 and 8.5 downstream leg diameters. Under this condition, the north and west legs are immediately upstream. That this does not occur for the east leg suggests that different fetch characteristics exist for the flow upstream and parallel to the northeast side of the tower. The open parking area on that side of the tower may have been responsible. The March data, Figures 4-23 through 4-25, show a similar but less intense picture, except for the rise-rate plot of Figure 4-25. This graph indicates a somewhat similar pattern for both legs. Again, the lack of leaves on the upstream forest may have had an influence.

SECTION 6.0

THE ROLE OF ATMOSPHERIC PROPAGATION IN THE MOD-1 NOISE SITUATION

The multidisciplinary group from Penn State was responsible for examining the role of atmospheric and ground propagation of the impulsive noise radiated by the MOD-1 turbine. As mentioned, a more detailed discussion of their initial conclusions appears as SERI Report No. TR-635-1292. In this section, we have included some of the highlights of their investigation.

6.1 ATMOSPHERIC AND TERRAIN STRUCTURAL FEATURES CONTROLLING MOD-1 NOISE PROPAGATION TO AFFECTED HOMES

During our first on-site visit to the MOD-1 late in October 1979, we realized immediately upon viewing the turbine, located atop Howard's Knob (see Figure 6-1) and surrounded by deep valleys in almost every direction, that it presented a complex propagation situation because of terrain features alone. The low-frequency acoustic energy contained in the impulses generated by the MOD-1 is not significantly attenuated by the atmosphere; the only effective extinction mechanism is spherical divergence as the distance from the source increases, or what is usually referred to as "geometric spreading." Furthermore, the acoustical impedance of the surrounding ground and forest in this frequency band (0-100 Hz) is essentially infinite, making reflections from the complex terrain a major factor in the propagation paths.

The large elevation differences between the height of the turbine and the houses in the valleys below provide a substantial atmospheric layer in which the vertical distribution of wind velocity and temperature can serve to bend or refract the sound waves away from a radially diverging pattern that would occur in a windless, isothermal atmosphere. Vertical gradients of wind velocity (shear) are about twice as effective in the refraction of sound waves as temperature (density) gradients are. In the deep terrain surrounding the turbine site, it was not initially clear which of these were more important, because strong temperature inversions (stable atmospheric layers in which the temperature increases with height) commonly form in such valleys at night, the time when many of the complaints were received.

Two acoustic sounders or "sodars" were deployed remotely to measure the vertical distributions of thermal disturbances and stratification with height on a continuous basis. One unit was placed in the deep valley immediately to the east of the turbine and the other in a generally upwind location near a home that experienced frequent annoyances (see Figure 6-1). During the major field measurement effort of March-April 1980, two tethered sounding balloon systems supplemented the sodars to obtain direct measurements of vertical profiles of wind velocity and temperature in the valleys to the east and southeast. Figure 6-2 presents three consecutive tethered balloon wind velocity profiles taken from the site at the Appalachian State University (ASU) water treatment plant northeast of the turbine. The marked positive shear (increase in velocity with height) is quite evident up to the height of the turbine. Also significant is the substantial variation in the wind shear at turbine height evidenced by the three profiles, particularly between numbers 133 and

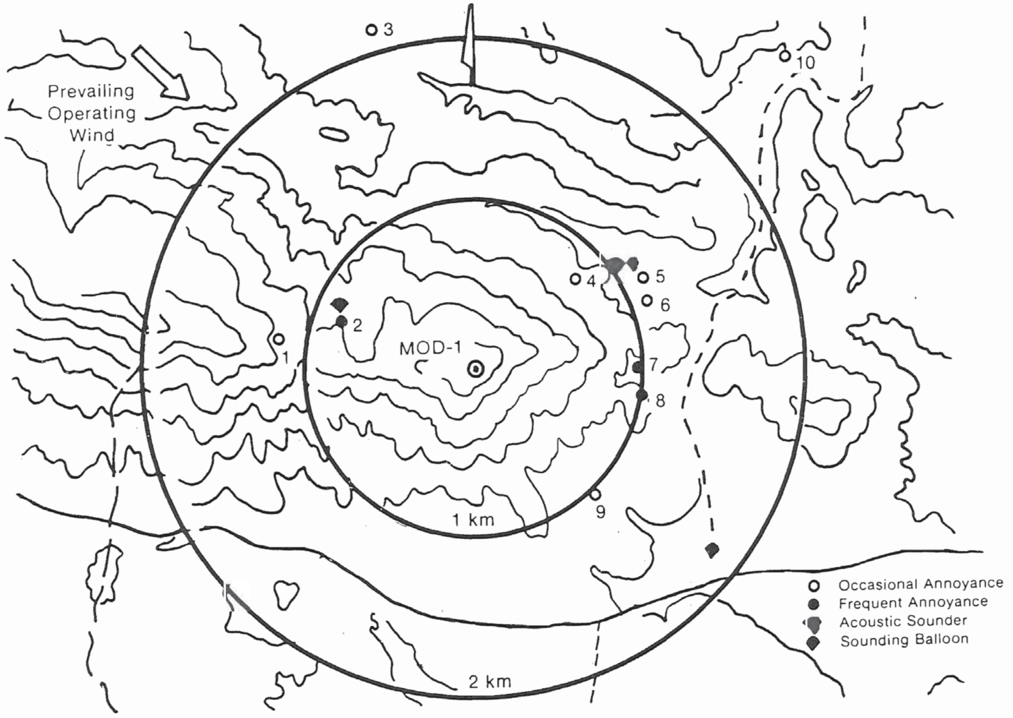

Figure 6-1. **Area Surrounding MOD-1 Site Showing Terrain and Locations of Complainants' Homes**
(Also appears as Figure 1-2)

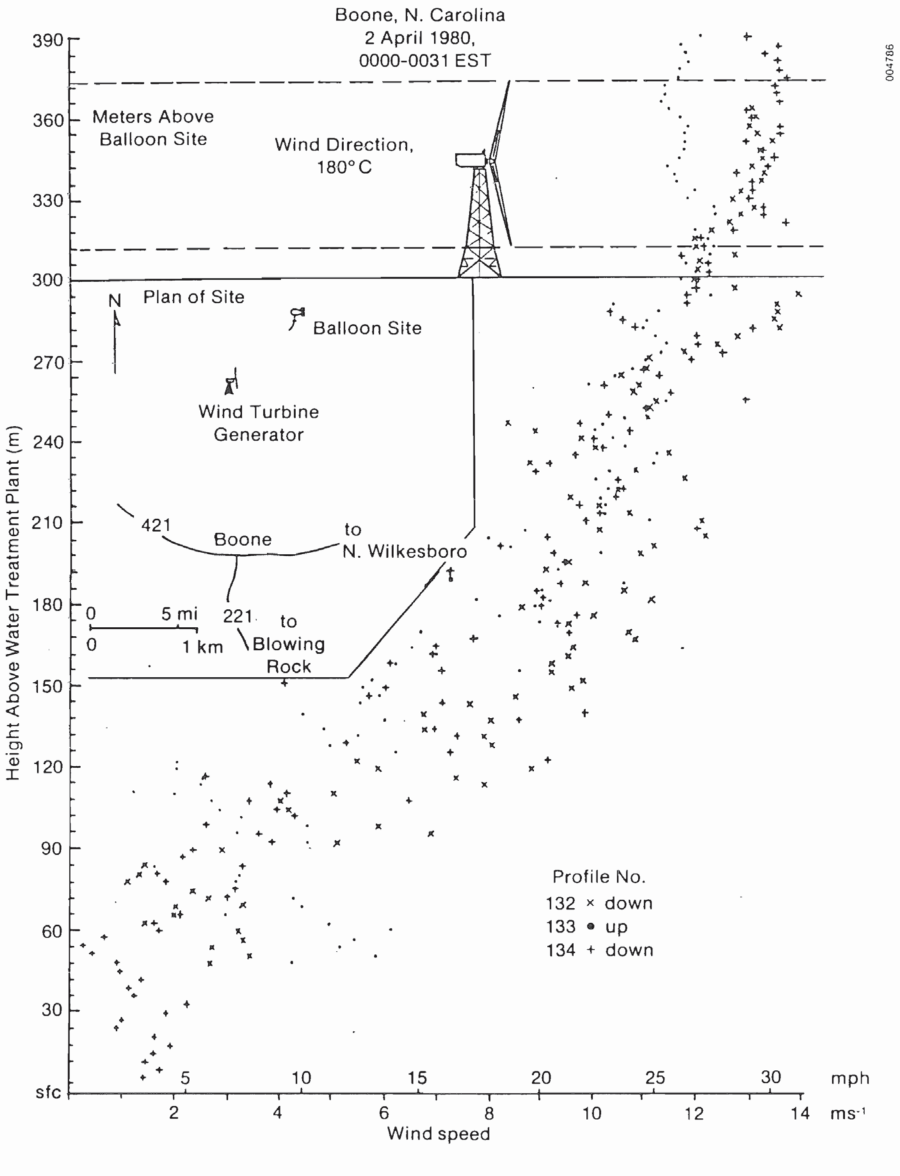

Figure 6-2. Three Consecutive Tethered Balloon Profiles of Wind Speed above the ASU Water Treatment Plant

134, which were taken 10 minutes apart. Figure 6-3 presents representative vertical profiles of wind velocity and temperature, in which a mean has been fitted to the observed points through the use of digital cubic spline filters. Figure 6-4 presents an actual sodar record taken at the ASU water plant on the night of 7 February 1980, when the SERI staff were taking sound measurements at the turbine. The formation of an inversion is evident just below the elevation of Howard's Knob (300 m) and just before 2100 hours local. From 2115-2150 hours the inversion rose from its mean height of 260 m to 420 m, a period when the resident of house #4 complained of being disturbed by the turbine. Again, note the strong shear zone between 175 and 200 m.

6.2 RESULTS OF THE PROPAGATION INVESTIGATION

One the objectives of the Penn State study was to determine whether the turbine-generated disturbance was being propagated through the air, the ground, or both. As we discussed in Section 3.1.2.3, they found that the airborne acoustic impulse was the propagation mechanism responsible for the residents' complaints.

Armed with both the direct and indirect vertical profile measurements acquired from the tethered balloons and sodars, plus information on local terrain contours, Penn State developed a computer program for calculating acoustic ray tracing of the MOD-1 noise propagation along chosen radials. These directions were chosen to pass near or through several of the complainants' homes, to obtain a better appreciation of the acoustic propagation. In particular, the interactions of the terrain, vertical wind and temperature profiles, and occurrences of complaint episodes at these specific locations were of interest.

Figures 6-5 and 6-6 illustrate ray traces made along a 048° bearing (with respect to true north) from the turbine, that intersects house #4 (see Figure 6-1) and for which the radial position is shown. These traces represent the modeled acoustic propagation for two vertical profiles taken one hour apart (1930 and 2032 hours, 18 March 1980). Both figures show an enhancement (referred to as a caustic) of the propagated turbine-induced acoustic pressure field over that which would be observed from geometric spreading alone at the base of the ridge at a horizontal radial distance of 1200 m. The trace of Figure 6-6, however, shows this caustic to be more severe, indicating that a higher level of turbine noise would be experienced at this location, while at the same time, turbine sounds are being carried long distances by the acoustic duct present at the elevation of the turbine. Figure 6-6 indicates that the turbine noise levels may be slightly higher at the location of House #4, more than Figure 6-5 does, because of the greater number of rays intersecting the general area.

Figure 6-7 displays an acoustic ray trace analysis for the 105° radial from the turbine which passes approximately midway between houses #7 and #8, both of which experienced frequent periods of severe annoyance. This trace shows the existence of an area of enhanced sound levels (caustic) at these homes' position with respect to the turbine. Also, the role of the terrain on the east slope of Howard's Knob in reflecting acoustic energy toward these residential structures is obvious. Figures 6-8 and 6-9 present representative

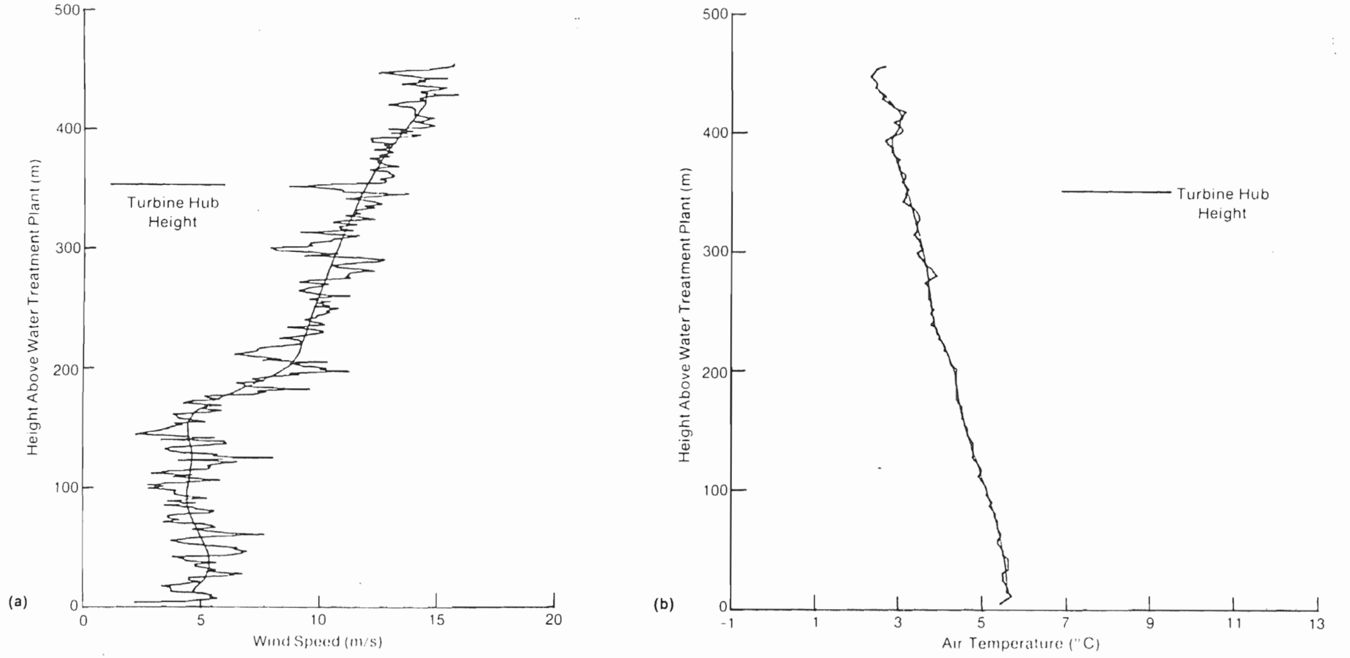

Figure 6-3. Representative Vertical Profiles of (a) Wind Speed and (b) Air Temperature Taken above ASU Water Treatment Plant

Source: Ref. [3].

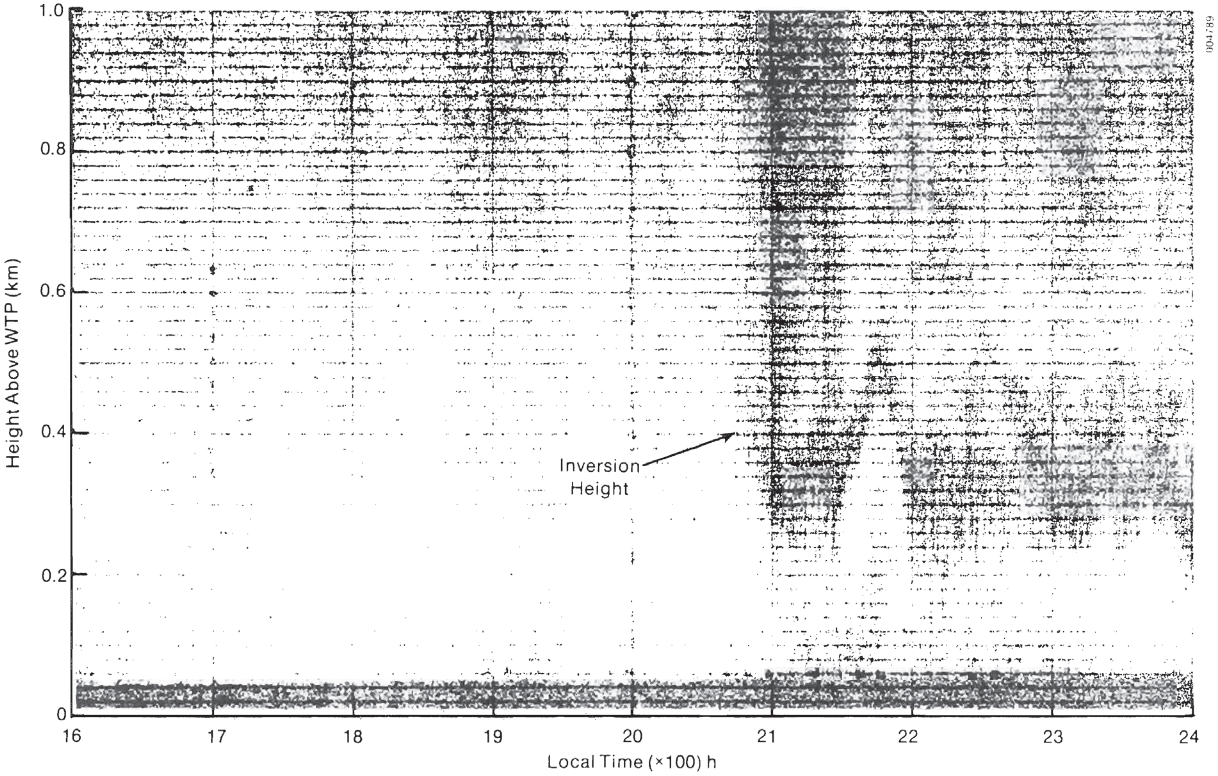

Figure 6-4. SODAR Record of 7 February 1980 above ASU Water Treatment Plant

Source: Ref. [3].

004790

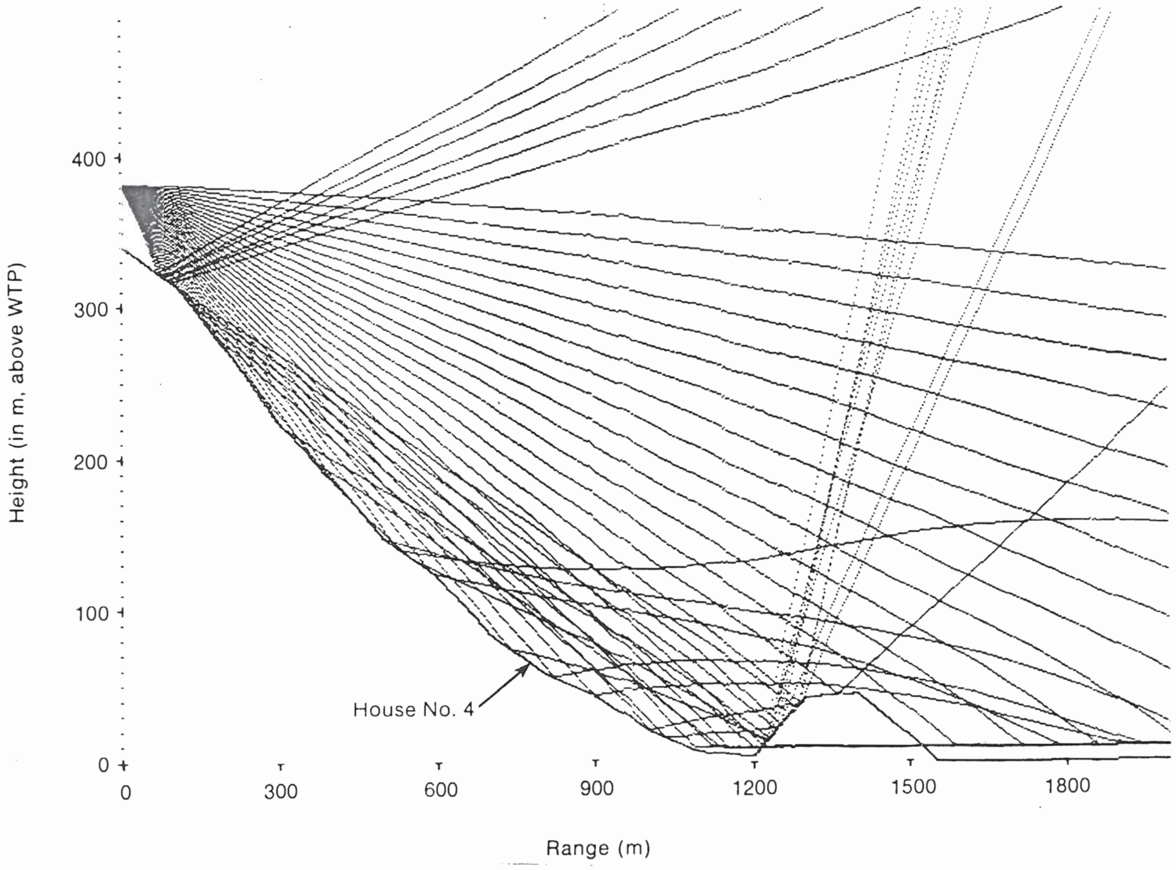

Figure 6-5. Acoustic Ray Tracing for 1930 Hours, 18 March 1980, along 048° Radial from MOD-1 Site (Heights shown above water treatment plant [WTP])

Source: Ref. [3].

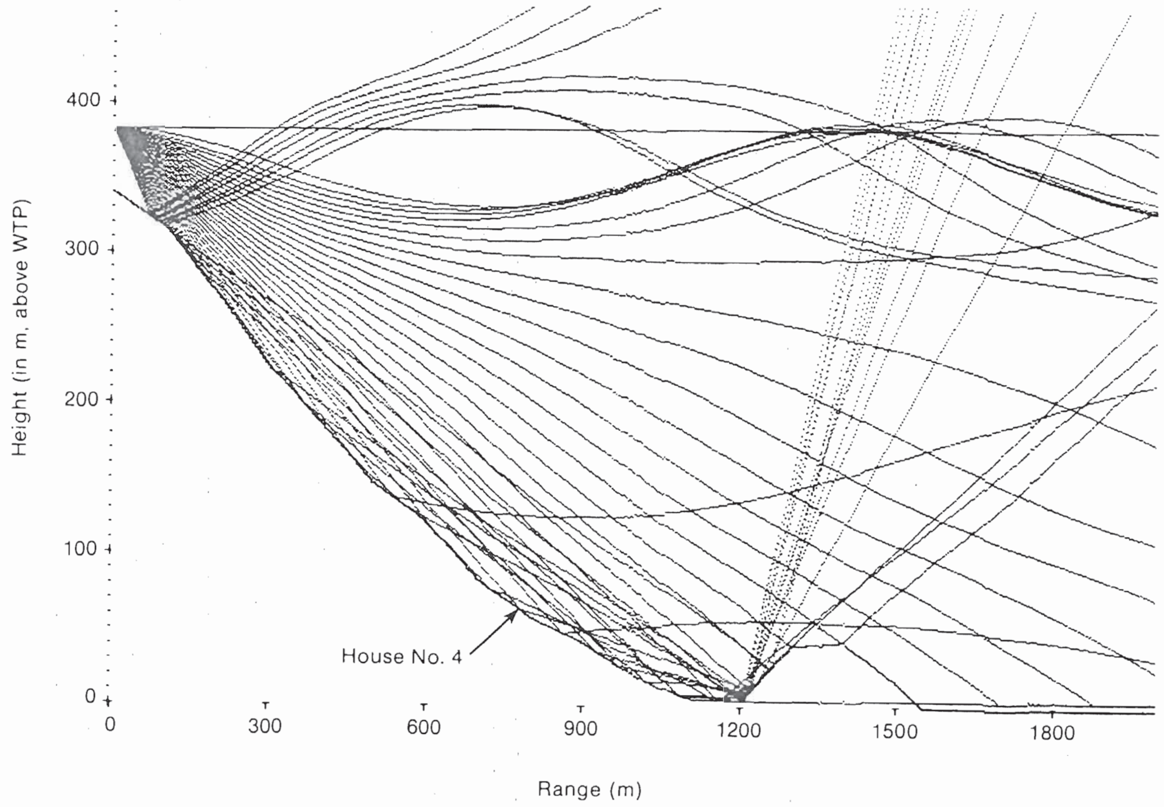

Figure 6-6. Acoustic Ray Tracing along 048° Radial for 2032 Hours, 18 March 1980

Source: Ref. [3].

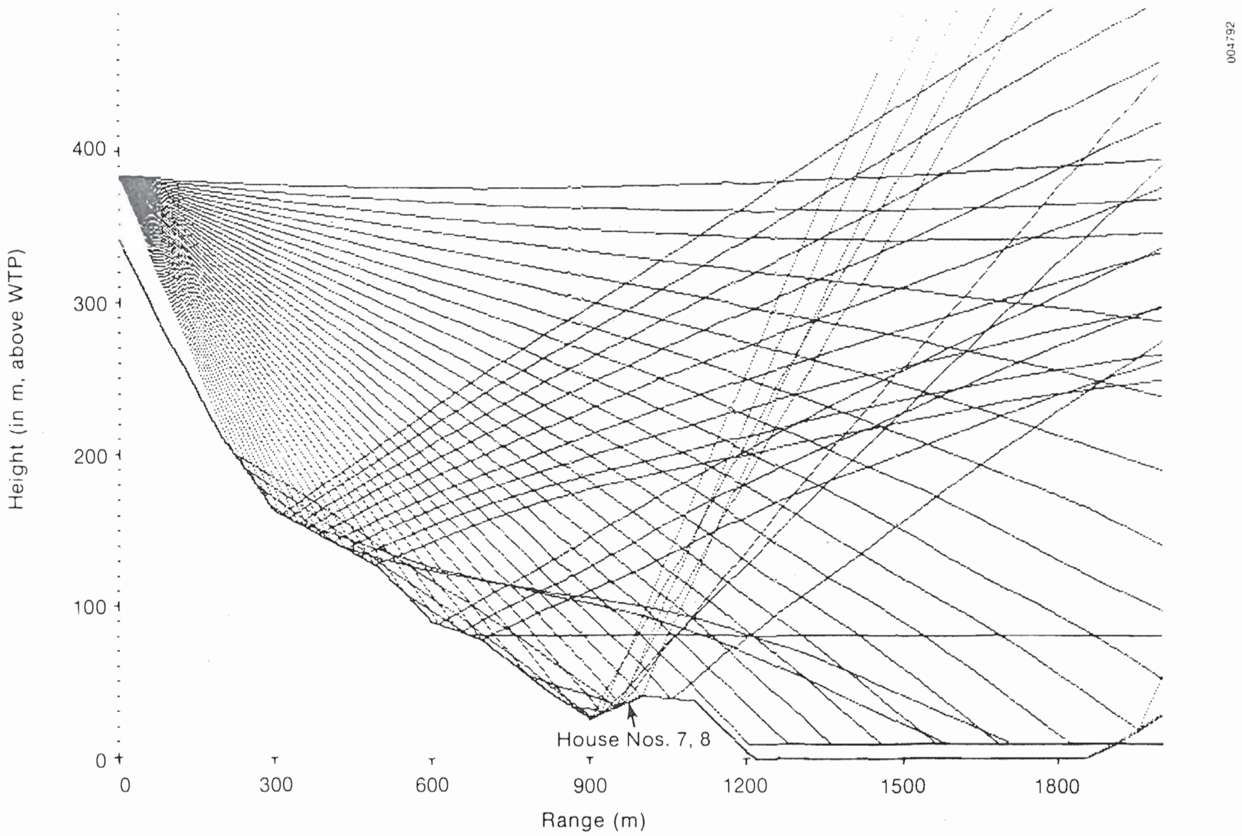

Figure 6-7. Representative Acoustic Ray Tracing along 105° Radial from MOD-1 Site Passing near Houses #7 and #8

Source: Ref. [3].

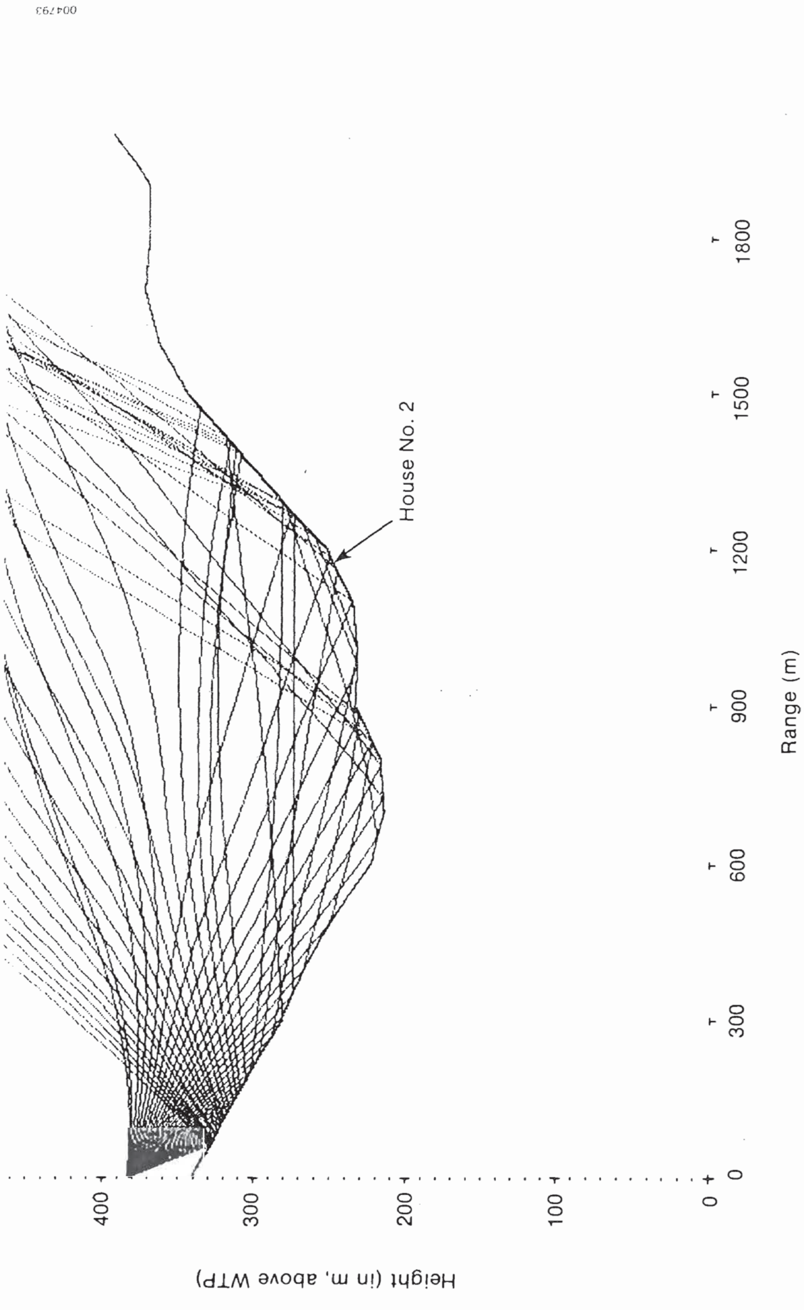

Figure 6-8. Representative Acoustic Ray Tracing along 277° Radial from MOD-1 Site Passing near House #2

Source: Ref. [3].

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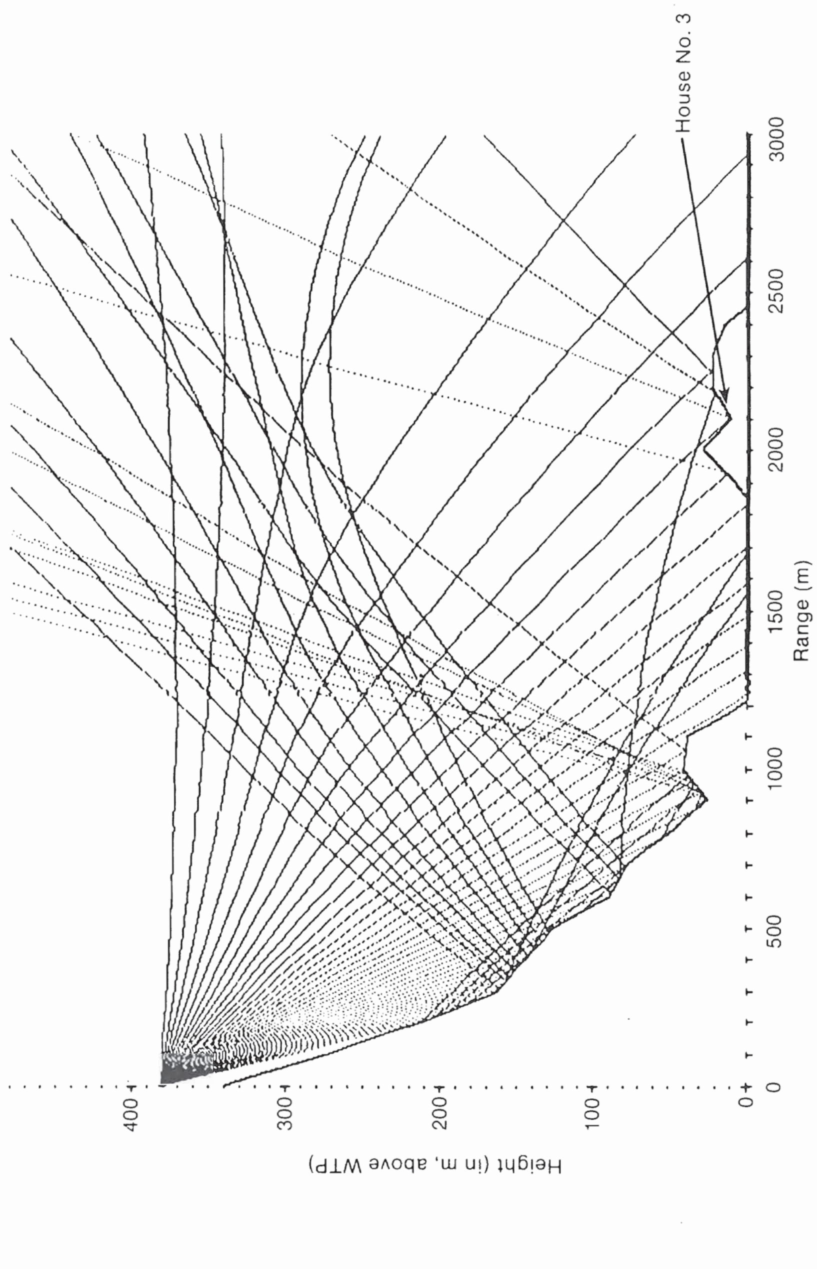

Figure 6-9. Representative Acoustic Ray Tracing for 355^{o} Radial from MOD-1 Site Passing near House #3

Source: Ref. [3].

traces for bearings of 277° and 355°, which correspond to radials passing through houses #2 and #3, which experienced annoyance infrequently. The radial positions of the homes with respect to the ray paths indicates, at least in these examples, slightly elevated acoustic levels above a spherically propagated field. Thus, the modeled traces of this series of figures show a strong interaction between the terrain and the sound propagation to produce turbine acoustic radiation patterns that can significantly deviate from the simple spherical divergence model.

6.3 INFLUENCE OF SITE WIND DIRECTION ON PROPAGATION FREQUENCY OF ANNOYANCE

One lobe of the acoustic dipole radiation pattern as a function of azimuth angle for MOD-1 peak emission levels has been calculated in Ref. [2] and resembles the pattern shown in Figure 6-10. The peak occurs approximately 6° off the rotor axis (the half-power ±3dB points are +22 and -12 deg with respect to the same reference). To relate this pattern to the MOD-1 operating true azimuth orientation, Figure 6-11 plots the October 1978 through September 1979 probability distribution or "power wind rose" of hub-height wind speed as a function of azimuth for speeds greater than 6.5 ms^{-1}, the approximate cut-in velocity. A comparison of Figures 6-10, 6-11, and 6-1 reveals at least one reason why houses #2, #7, and #8 reported such high frequencies of annoyance. Those homes lay in the most prevalent radiation pattern lobes, dictated by the most prevalent rotor azimuth. House #4, however, tended to be affected only when the wind direction came from the secondary peak in the distribution; i.e., the south-southwest. Thus, in addition to terrain and atmospheric refraction, the wind direction at hub height also influenced the distribution of annoyance by controlling the directivity of the emitted radiation pattern. A compilation of the total wind record taken at the MOD-1 site [29] indicates the overall mean wind direction was 290.0° at hub height but became 286.3° during the critical 1600-2400 hours, the dusk-to-evening period, when the bulk of the complaints were received. The long-term meteorological record indicates a further reason why residents of houses #2, #7, and #8 complained the most frequently.

6.4 CONCLUSIONS REGARDING THE EFFECTS OF PROPAGATION ON THE MOD-1 NOISE SITUATION

Thomson [3,30] has reached the following conclusions, based on the initial Penn State analysis of the MOD-1 situations:

1. The intensity, duration, and location of enhanced, far-field noise levels depend upon the details of the wind- (and bearing) and temperature-dependent sound speed profiles (as well as the orientation of the turbine rotor plane) to such an extent that monitoring is unlikely to yield a satisfactory on-off criteria for a noisy turbine. Controlling the source was the only viable, long-term solution.
2. Conditions appropriate for the most efficient operation of the MOD-1 would most likely produce adverse noise propagation, and such conditions were likely to occur about 30% of the time (based on the limited data sample available).

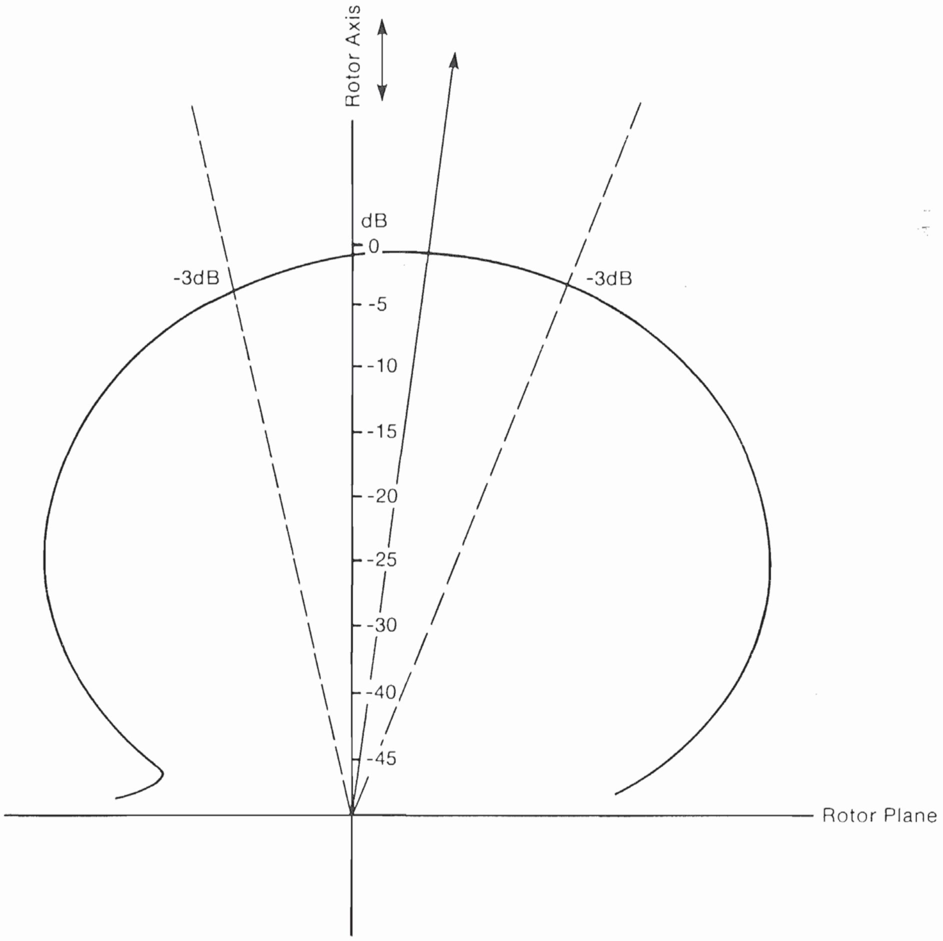

Figure 6-10. One Lobe of MOD-1 Impulsive Noise Dipole Directivity Pattern
Source: Ref. [2].

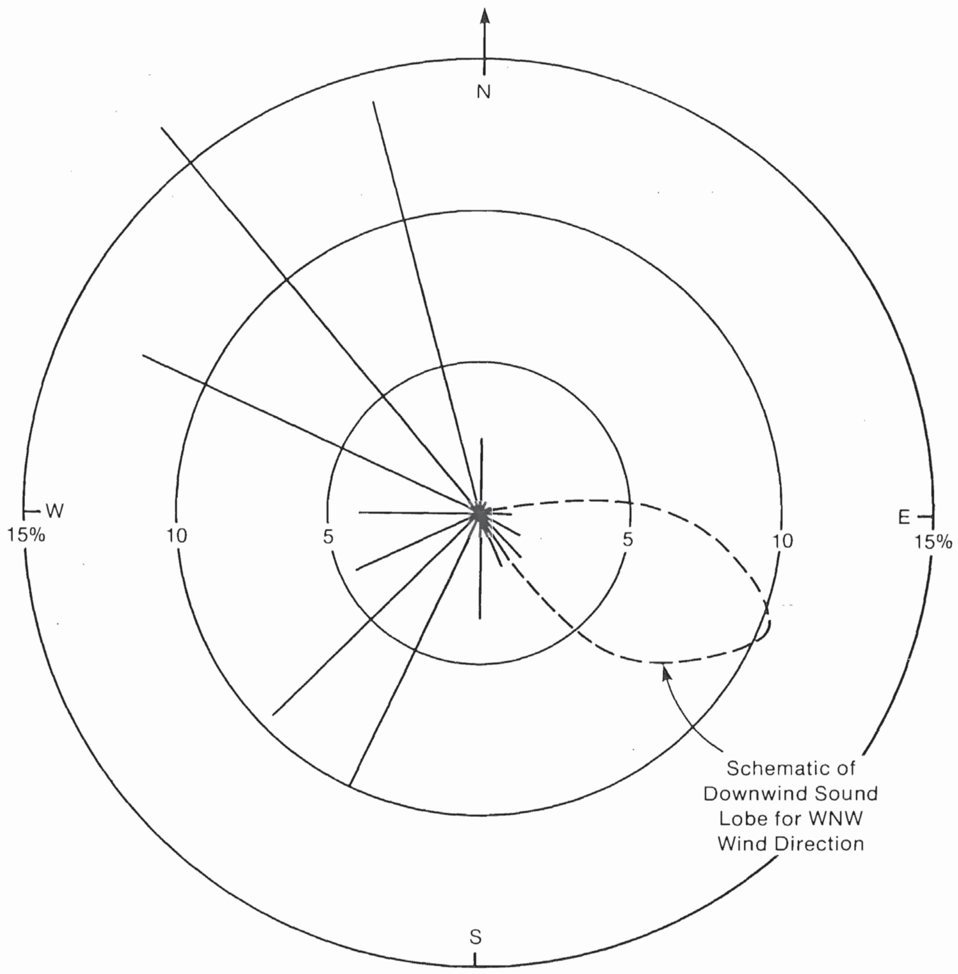

Figure 6-11. MOD-1 Site "Power Wind Rose" with ±3db Impulse Noise Directivity Pattern Added for Mean Wind Direction of 290°

3. For the low-frequency emitted noise from the MOD-1, adverse noise propagation could occur upwind as well as downwind of the turbine site if "thin" atmospheric layers were present. Amplification at resulting caustics probably did not exceed 6 dB.

4. Surface and ground propagation were negligible in comparison with refractive airborne propagation.

5. The strong terrain-atmospheric refraction has resulted in predictions of far-field enhancements in excess of 25 dB as a result of refractive and terrain focusing. Independent measurements taken near the MOD-1 have experimentally confirmed this [31].

SECTION 7.0

A PROPOSED PHYSICAL MECHANISM DEEMED RESPONSIBLE FOR ANNOYANCE FROM MOD-1 IMPULSIVE NOISE

In this section, we discuss our interpretation of the results of the acoustic and seismic monitoring of the two homes discussed in Section 3.1.2 that were undergoing impulsive excitation by the MOD-1. From these measurements and other similar sources, we have derived what we believe to be the physical mechanism primarily responsible for the complaints of the residents of the affected homes. The MOD-1 results are then compared with histories of other cases of low-frequency human annoyance and typical sound levels associated with common events that affect the acoustic environment in residential structures. Finally, we discuss our development of an assessment method to subjectively evaluate the annoyannce potential of low-frequency acoustic emissions from a specific wind turbine.

7.1 CHARACTERISTICS OF LARGE WIND TURBINE NOISE

Figure 7-1 schematically summarizes an averaged, large wind turbine acoustic frequency spectrum and indicates the dominant noise sources as a function of the radiated frequency. Not all of the features shown will be present at any one period of time, as we discussed in Section 3.0. The ultimate cause of most of the aerodynamically generated noise is the unsteady loading of the blades, which, when substantial, is responsible for the temporal distribution of the radiated acoustic energy across the frequency range defined by Figure 7-1.

Conventional classifications of rotor noise include rotational, broadband or vortex, and impulse noise. Rotational noise is characterized by the large number of discrete frequency bands or tones, harmonically related to the frequency of blade passage, in a spectrum in which a large number of rotor revolutions have been averaged. The amplitude of these tones is determined by the sum of the steady and unsteady air loads, the latter arising from many of the mechanisms discussed in Section 5.0. Broadband or vortex noise is the result of an interaction of the unsteady lift and the blade boundary layer and is related to such mechanisms as trailing edge separation and vortex shedding. Broadband noise, which can be described as the "swishing" sounds associated with a wind turbine operation, are distinguished as being largely incoherent, and they cover a wide frequency range with a "spectral hump" sometimes found at relatively high frequencies, as indicated in Figure 7-1. Impulsive noise, such that observed with the MOD-1, is identified with short, transient pulses that can contain considerable acoustic energy. Tonal acoustic energy, in the areas of Figure 7-1 indicated by the vertical dashed lines, which transcends the rotational and broadband regions, is an indication that a rotor is undergoing periodic, transient lift fluctuations. Impulsive noise generally tends to be the most annoying because it dominates all other sources because of its high degree of phase coherency and radiation efficiency. From Figure 7-1, we see that the peak levels of acoustic energy reside in the low audible and what is normally thought of as subaudible (<20 Hz) frequency ranges. The presence of short-period, transient blade loads will increase the levels of discrete or tonal radiation in the higher rotational harmonics, usually peaking in the 10-30 Hz range.

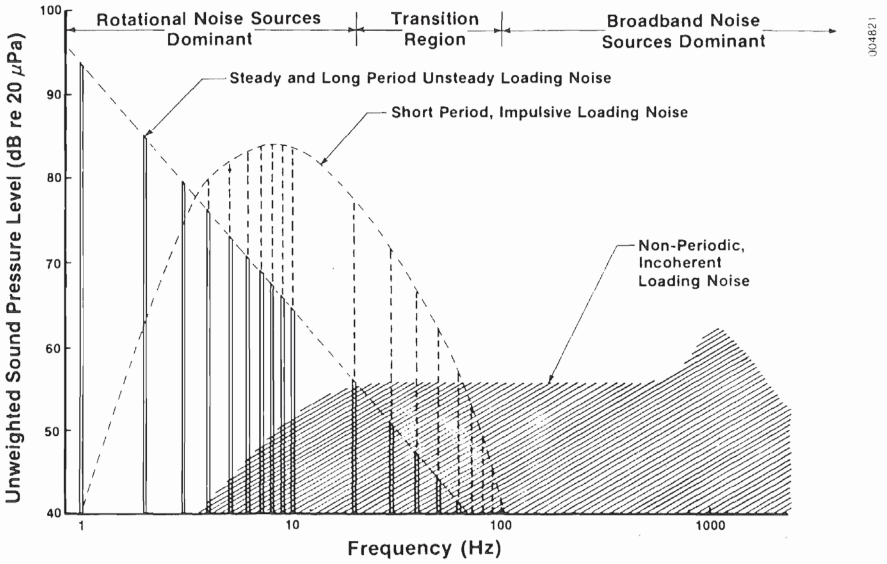

Figure 7-1. **Schematic Representation of an Averaged Radiation Sound Pressure Spectrum from a Large Wind Turbine**

The low-frequency-dominated spectrum of Figure 7-1 is a result of the low rotational speed of a large wind turbine (such as the MOD-1), compared with other forms of turbo machinery. At present, no adequate standard exists for evaluating the potential for human annoyance from impulsive noise, particularly when the acoustic energy tends to be concentrated below 100 Hz, as in this case. This deficiency is a result of our meager knowledge of human psychophysical response and of the important physical factors involved in the perception of transient sounds as annoyance. The psychoacoustics group at the NASA Langley Research Center has made progress in determining a typical human perception threshold to low-frequency impulse sounds which have their roots at frequencies similar to the MOD-1 (~1 Hz) [32]. This work, however, is only applicable in a non-reverberant environment, such as outdoors, because an "anechoic" room was purposely used to collect the subjective response data.

7.2 A PROPOSED PHYSICAL MECHANISM RESPONSIBLE FOR MOD-1 ANNOYANCE

7.2.1 Factors Controlling the Internal Dynamic Pressure Fields of Subject Rooms

A close examination of the acoustic and structural vibration information collected in the two Boone, North Carolina, homes affected by excitation from the MOD-1 impulses has revealed a repeated tendency for both the indoor dynamic pressure field and the vibration frequency spectra to show discrete peaks at the same frequencies, as well as higher dynamic peak overpressures inside the homes than outside. This strong harmonic behavior of the indoor pressure field when excited by the periodic transient loadings of the MOD-1 impulses, points to a complex resonant coupling between a room's air volumes and the vibration deformation of the walls and floors surrounding the room. NASA studied the dynamics of residential structures under acoustic loading [33] as part of their sonic boom noise investigation. Using sinusoidal mechanical excitation, aircraft flyovers, and actual sonic booms, they determined that the characteristic dynamic response of typical frame houses was largely independent of their geographical location and age and more dependent on standardization of building codes, that specify such design details as stud and beam spacing. This study also found, due to the construction similarities called for by the codes, that resonant frequencies associated with the structural elements of most residential construction fall within the same range but also depend on the individual construction details of each house.

The dynamic (acoustic) pressure field within a residential room is controlled by (1) changes in the shape of the room caused by a diaphragm action from internal and external pressure changes (loadings); (2) higher mode resonances in the walls and floors; (3) cavity oscillations (Helmholtz-type resonances) from an air volume moving in and out of the room through an opening such as a door or window; and (4) the resonant modes of the air volume itself. The ranges of these various resonances are plotted in Figure 7-1, and the factors controlling structural mode damping are added in Figure 7-2. Table 7-1 lists the various modes measured and calculated from the dimensions of the two rooms in the Boone homes surveyed.

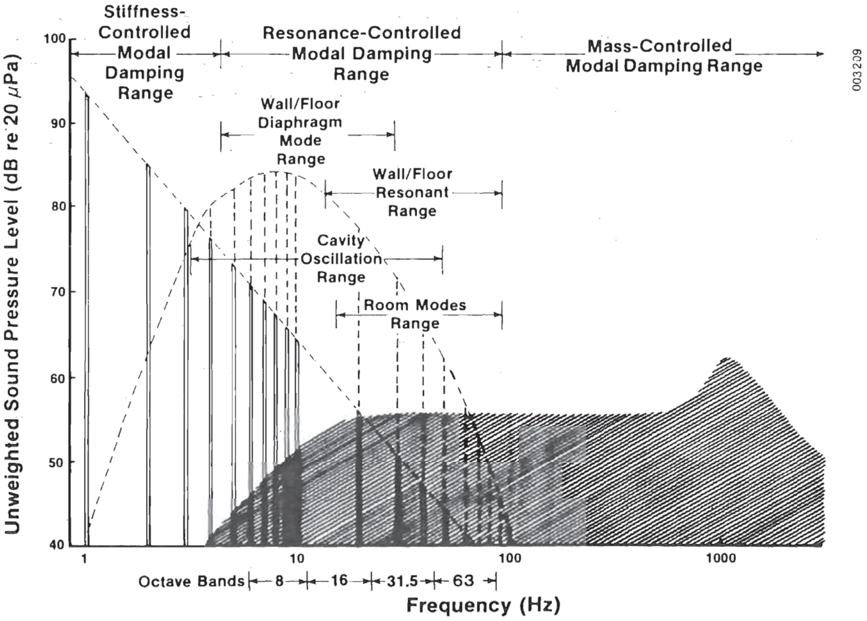

Figure 7-2. Schematic Sound Spectrum of Figure 7-1 with Structural Modes and Applicative Damping Mechanisms Added

Table 7-1. Resonant Modes of Rooms in Houses #7 and #8

	House #7	House #8
Dimensions (m)	3 x 3 x 2.1	3.6 x 3.5 x 2.4
Wall/floor resonances (measured) (Hz)	9,14,20,30,59,79	9,14,21,26,50,60,65
Cavity oscillation (calculated) Frequency (door open) (Hz)	≃ 44	≃ 35
Room mode frequencies (Hz) (calculated)	56[100,010][a]	47[100,010]
	79[110]	68[110]
	80[001]	70[001]
	98[101,011]	85[101,011]
		98[111]

[a] The x,y,z normal modes are in brackets.

Many of the frequencies listed in Table 7-1 can be found in Figures 3-19, 3-20, and 3-21 (observed structural response) as well as in the acoustic spectra of Section 3.1.2, particularly at the 9 and 14 Hz diaphragm modes. Figure 7-3 presents an illustration from Ref. [33] showing the relationship of these modes to the structural features. From the available data, we concluded that the internal pressure field in these rooms is being driven dynamically through the diaphragm action of the outside walls facing the turbine's periodic impulsive loads. This conclusion is supported by the degree of dynamic coupling existing between the horizontal floor vibration deformation and the internal pressure field, as indicated by Figure 3-21. The overshoot of the internal pressure levels, evident in Figure 3-15 and repeated as Figure 7-4, indicates that a dynamic amplification is taking place under the impulsive excitation, intensifying the low-frequency pressure fluctuations in the rooms. Therefore, the impulsive acoustic loads associated with the MOD-1 operation are transiently exciting the lightly damped structural modes of the two houses, resulting in a complex resonance condition occurring between the walls and air volumes of these rooms. Table 7-2 lists the measured major normal and cross-coupled modes for these rooms with estimates of their modal damping characteristics. If we compare the preferred spectral peaks in typical MOD-1 impulses, as summarized in Table 7-3, the close match is obvious. The relationship of the critical reduced frequency k, in a range of $0.5 \leqslant k \leqslant \pi$, can also be noted in this figure. Thus, the houses are being elastically driven by a coupling of the spectral energy in the impulsive acoustic loads through lightly damped structural modes of the walls and windows which subsequently excite higher modes in the walls, floors, air volume, and room cavity resonances, and which set up strong harmonic oscillations between the room deformation and pressure field that last 150-200 times longer than a MOD-1 impulse.

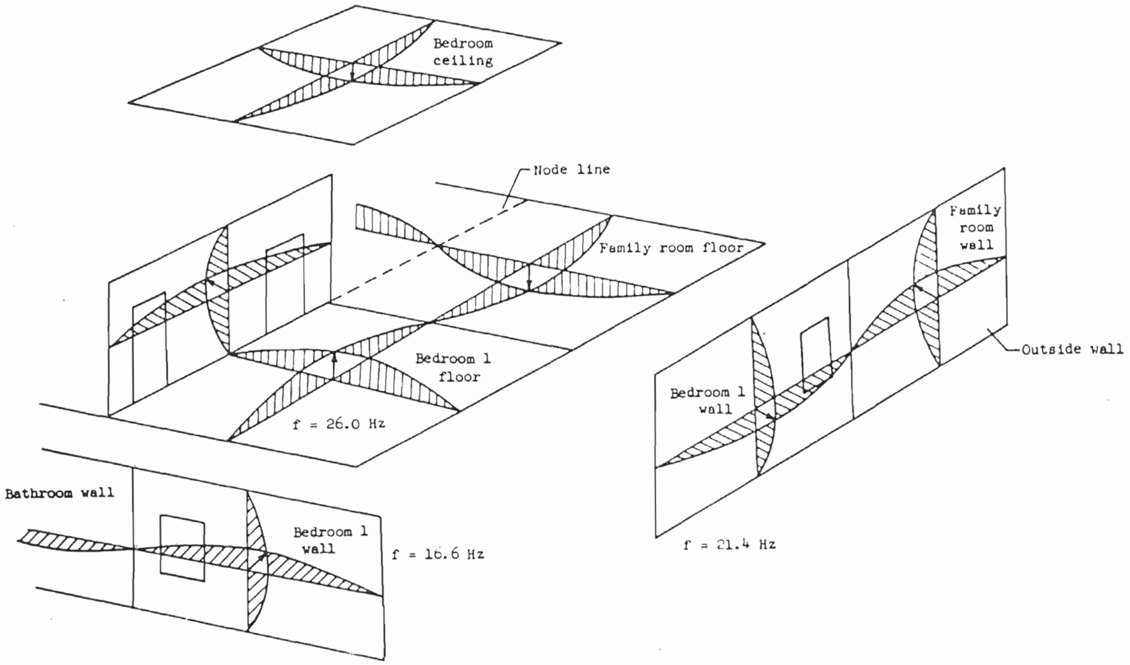

Figure 7-3. Diagram Showing Relationship of Fundamental Structural Resonances to Construction Details of Typical Homes

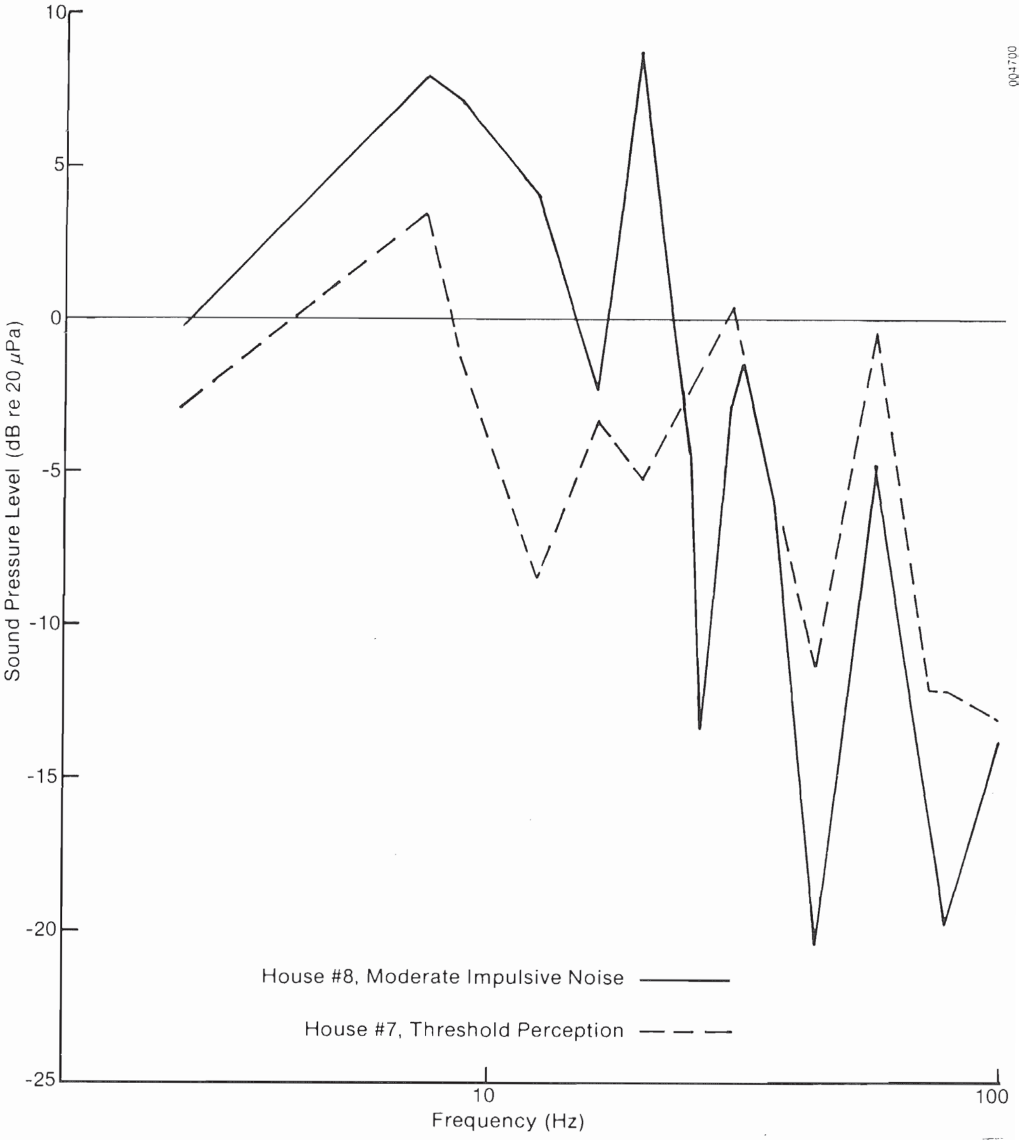

Figure 7-4. **Peak Internal-External Sound Pressure Level Differences for Moderate Annoyance and Threshold Perception in Houses #7 and #8** (B_e = 1.25 Hz)

Table 7-2. Major Normal and Coupled Structural Modes of Houses #7 and #8

Frequency (Hz)	Floor Mode Damping Characteristics			Window Mode Damping Characteristics	
	Vertical[a]	Horizontal[a]	Cross[b]	(Perpendicular Mode)	Cross w/Floor Modes[c]
House #7					
8.6[d]	L	M	M	M	M
20	M	L	S	L	S+
30	M	VL	S+	L	S+
59	L	M	M	L	M
79	L	M	M	L	M
89	VL	M	S	L	S
96	VL	M	M	M	M
House #8					
8.9[d]	L	L	S	VL	S+
14	L	L	S		
21	M	L	S		
26	L	L	S		
32				L	W
50	VL	VL	S+	L	M
60	VL	VL	S+	L	S+
65	L	VL	S+		

[a] Modal damping degree estimate: VL = light ($\zeta < 0.05$); L = light ($0.05 \leq \zeta \leq 0.1$); M = moderate ($\zeta > 0.1$) .

[b] Estimated degree of cross-coupling between vertical and horizizontal modes: M = moderate; S = strong; S+ = very strong.

[c] Estimated degree of cross-coupling between floor and window modes: W = weak; M = moderate; S = strong.

[d] Estimated to be the house's fundamental resonant frequency.

7.2.2 Human Perception of Internal Pressure Field

Not surprisingly, the perceptions of the residents of the rooms in which these strong harmonic pressure fields existed under MOD-1 excitation included both audible and other sensations, including vibration and sensed pressure changes. Figure 3-16, repeated as Figure 7-5, compares both the observed internal peak dynamic pressure spectra for moderate ("thumping") annoyance and minimal perception, as well as that observed outdoors, all referenced above existing background levels. This figure also shows the NASA impulse noise audibility criteria [32] devised for an anechoic environment. A study of the figures of Sections 3.1.2.1 and 3.1.2.2 plus Figures 7-4 and 7-5 indicates that major differences existed in the internal pressure distributions between what was reported as moderate annoyance (thumping sounds and vibration) and threshold stimuli (a barely discernible thumping sound but no sensation of vibration), the peak level of subaudible acoustic energy being most noticeable.

Table 7-3. Preferred Acoustic Pressure Spectral Peaks for Typical MOD-1 Impulses

Rotor rpm	Frequency (Hz)	k_{80}[a]	Relative Level (dB)
35	6.25	0.33	0
	16.25	0.86	-9
	26.25	1.39	-23
	45.0	2.38	-39
	62.5	3.31	-47
	81.3	4.3	-51
	97.3	5.1	-56
23	4.4	0.15	0
	10.6	0.37	-9
	17.5	0.61	-15
	25.6	0.89	-29
	30.6	1.07	-38
	38.8	1.35	-44
	51.9	1.80	-47
	65.0	2.26	-55

[a] Reduced frequency as referenced to the chord dimension at the 80% span position.

7.3 COMPARISON OF ANNOYANCE RELATED TO MOD-1 WITH SIMILAR SITUATIONS

In this section, we discuss the results of our research and that of NASA Langley [32] in locating cases of human annoyance where low or subaudible frequency noise was involved. We also review the structural resonance situation, particularly in the frequency region where the peak wind turbine noise output is known to occur; i.e., the 8-30 Hz band. We examine a situation involving non-impulsive excitation of several residential structures by a 100 MW gas turbine peaking station and compared that with the MOD-1 results. Finally, we compare the severity of the MOD-1 annoyance with other known low-frequency noise sources such as airplanes, road traffic, trains, and normal household noises as well as nearby industrial sources.

7.3.1 Low-Frequency Resonant Properties of Residential Structures

The importance of the resonant properties of typical residential structures in the propagation and interior amplification of the MOD-1 noise has been demonstrated particularly by Figure 7-2, which relates wind turbine impulsive emissions to these dynamic characteristics. In order to assess how serious a problem coherent, low-frequency acoustic radiation would be from large wind turbines such as the MOD-1 in various parts of the country, we searched for sources of data in addition to the NASA report to confirm the potential universality of these sensitivities. A study by Medearis [36] to identify

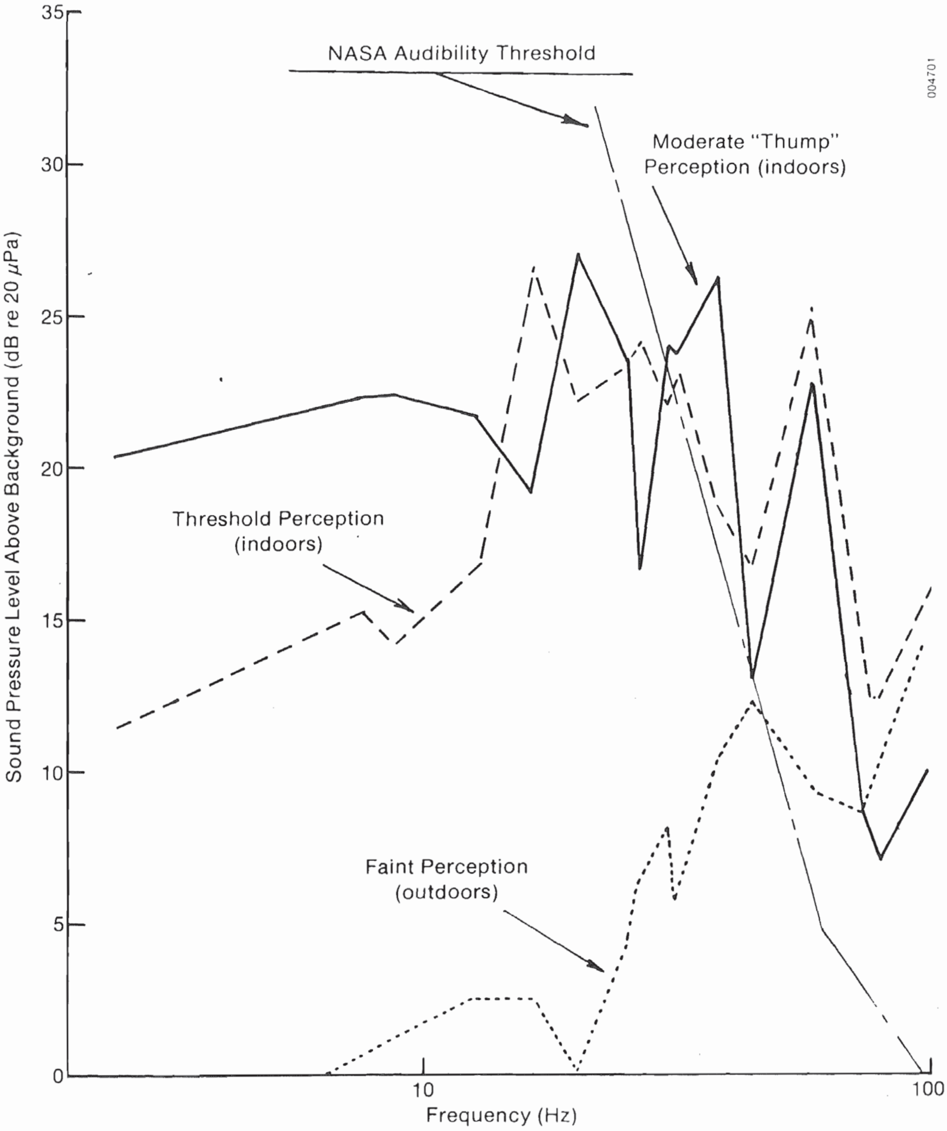

Figure 7-5. Peak Sound Pressure Levels Existing above Background for Moderate Impulsive Excitation (Outdoors and Indoors, House #8) and Threshold Perception (Indoors, House #7) (B_e = 1.25 Hz)

structural damage criteria for low-rise buildings from blasting vibrations gives us some additional house sensitivity data as a function of geographic location. Table 7-4 lists statistics regarding the fundamental natural frequency and damping characteristics of 61 residences in four states as a function of the number of stories. The data in the table clearly indicate that (1) these fundamental resonances lie in the same frequency range as the maximum short period blade load noise from large wind turbines (Figures 7-1 and 7-2); (2) the fundamental tends to decrease with the vertical height of the structure; and (3) very little damping is present at the fundamental mode, averaging 5%-6% of critical, which means it can be easily excited.

Table 7-4. Average Residence Properties By Geographic Location

Structure Stories	Number	Age (Years)	Fundamental Natural Frequency (Hz)	Percent of Critical Damping (%)
Colorado				
1	16	18	12.0	5.0
1-1/2	6	4	10.3	7.4
2	16	50	7.2	6.1
All	38	29	9.7	5.9
New Mexico				
1	4	15	12.0	5.2
1-1/2	1	20	11.7	5.1
2	0	--	--	--
All	5	16	12.0	5.2
Illinois				
1	3	45	10.4	7.9
1-1/2	1	17	10.4	6.0
2	7	68	5.7	4.0
All	11	57	7.4	5.2
California				
1	4	10	12.3	5.7
1-1/2	0	--	--	--
2	3	11	7.5	5.2
All	7	16	10.2	5.5
Total				
1	27	21	11.9	5.5
1-1/2	8	8	10.5	6.9
2	26	50	6.9	5.4
All	61	32	9.6	5.6

Source: Ref. [36].

Medearis found the taller structures "tended to respond exclusively in the fundamental mode and displayed very consistent frequency and damping characteristics." Ford, in his studies of noise and vibration propagation in residential structures [37], found that the fundamental mode is likely to be excited at low frequencies because the acoustic wavelength exceeds the structural bending wavelength, with the higher modes progressively excited, though less efficiently, through cancellation effects. Our measurements of the Boone homes support the NASA, Medearis, and Ford conclusions, particularly in reference to excitation near the fundamental. However, what is unique in the MOD-1 acoustic loading is that energy is not only coupling to the structure at or near the fundamental but simultaneously in several of the higher resonant modes, because of the coherent radiation characteristic of the impulses, as indicated in Tables 7-2 and 7-3. Apparently, this situation increases the audibility of the transient loads inside a house, making the perception of annoyance more severe.

We conclude that the low-frequency coherent aspects of the turbine acoustic radiation must be controlled at the source, because even if such emissions are effectively held to below-normal audibility (<20 Hz), they may be of sufficient magnitude and persistence, when coupled with an unfavorable propagation situation, to excite a nearby residence at the fundamental. Under such excitation, the higher modes may also be excited and become detectable, perhaps reaching annoyance levels. From the NASA studies and the Medearis data in Table 7-4, we see that such structural sensitivities are essentially independent of geography and, in planning for large wind turbine installations, we must consider the possibilities discussed here.

7.3.2 Low-Frequency Excitation by a Nonimpulsive Source

Because the strong impulses associated with the MOD-1 may be unique and the evidence from our measurements seems to indicate that partially coherent radiation is far more likely, we needed to find a well-documented source of low-frequency sound and structural response with which to compare our results in Boone. We were fortunate to obtain data related to the noise emitted from a 100-MW gas turbine peaking station in southwest Oregon [38]. The complaints of the homeowners living near the station were the same as those of the Boone residents in almost all ways except for a lack of distinct interior audibility; i.e., they that reported nonauditory sensations were dominant. Figure 7-6 compares the features of typical averaged outdoor sound pressure spectra for the two types of turbines taken near affected homes. The characteristic sound of the gas turbine, a result of resonances caused by the gases passing through the exhaust stacks (which has since been corrected), was not impulsive, but a slow modulation was reported. While the peak frequencies of the two spectra in Figure 7-6 are different, the levels are almost equivalent in the region near 12 Hz, or the structural fundamental mode range. Figure 7-7 replots the data of Figure 7-4 to which the interior data from one of the homes near the peaking station has been added. These particular occupants reported sensations similar to those of the Boone residents, but very little audible sound; i.e., the feeling of pressure, uneasiness, vibrations, etc.

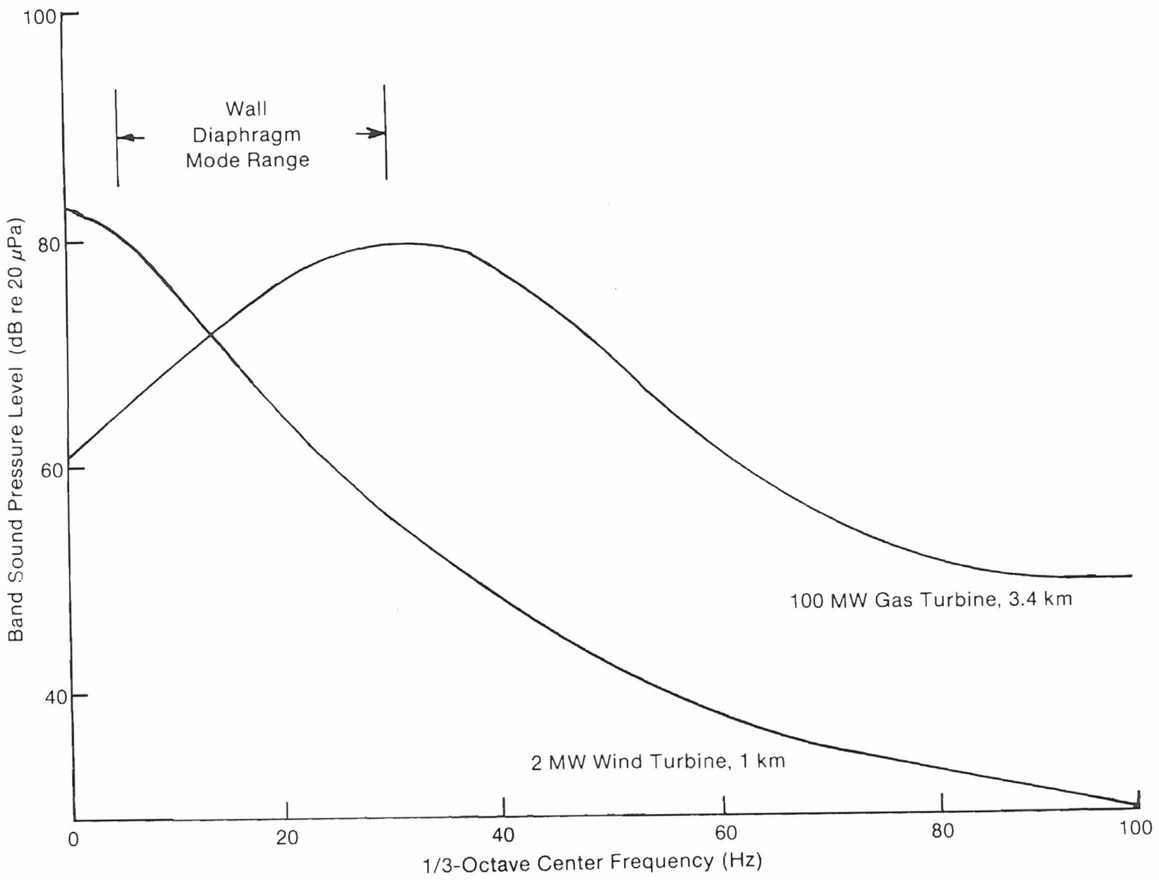

Figure 7-6. Comparison of the External Averaged, Radiated Acoustic Spectral Characteristics of a 100-MW Gas Turbine Peaking Station and the 2-MW MOD-1 Wind Turbine

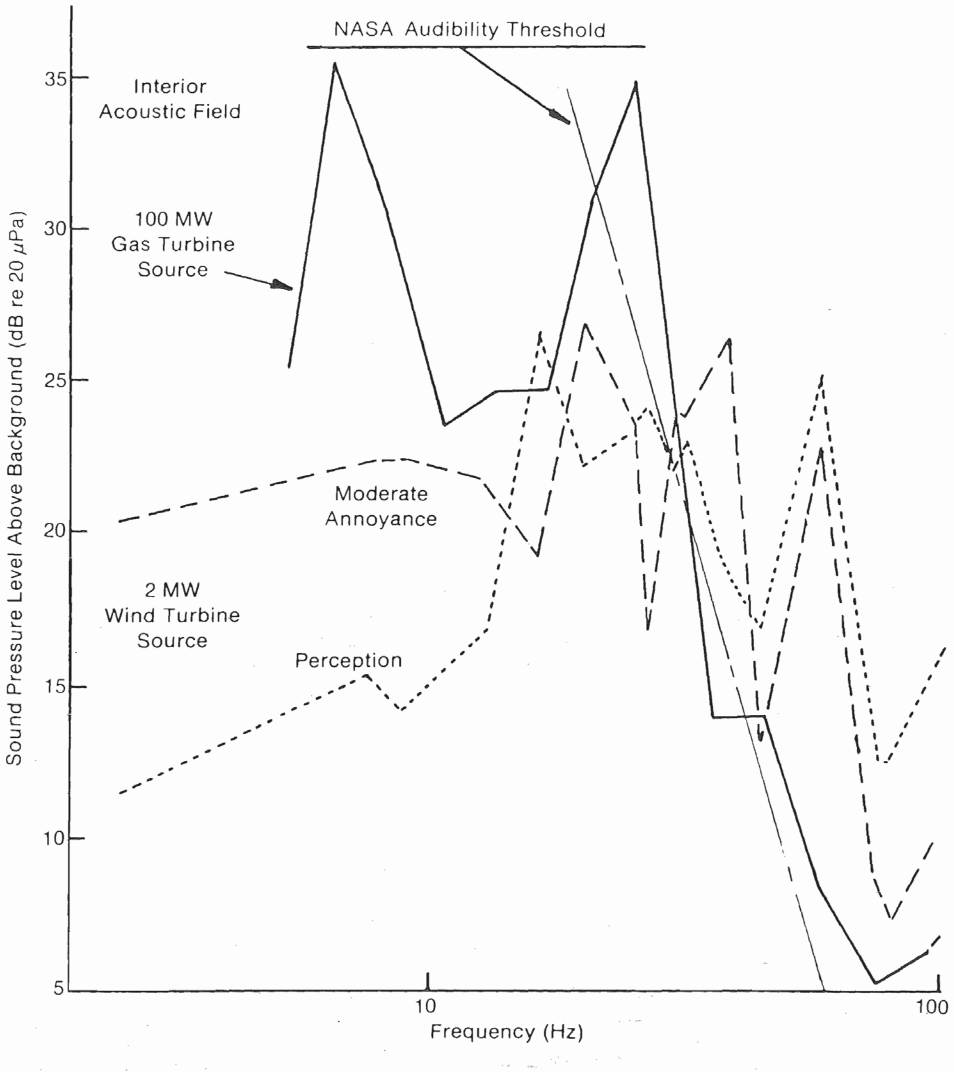

Figure 7-7. Same as Figure 7-5, but Adding the Response of Oregon Home to 100-MW Gas Turbine

Figure 7-8 plots the details of the outdoor, indoor, and indoor-background 1/3-octave band pressure levels for 100-MW operation of the turbine. It is important to note that while the peak of the external excitation is in the 31.5 Hz band, the indoor peak occurs between the 12.5 and 20 Hz bands and is about 30 dB, on the average, and is higher when the turbine is operating than when it is shut down. The quasi-steady dynamic overpressure for this home is compared with those measured in the two Boone homes in Figure 7-9. Here, the gas turbine and moderate MOD-1 impulse excitation are roughly equivalent up to about 20 Hz, but the former spectrum exhibits a very sharp resonant peak, more than 15 dB greater than the wind turbine, at 25 Hz, followed by a very rapid fall-off--which agrees well with Figure 7-8.

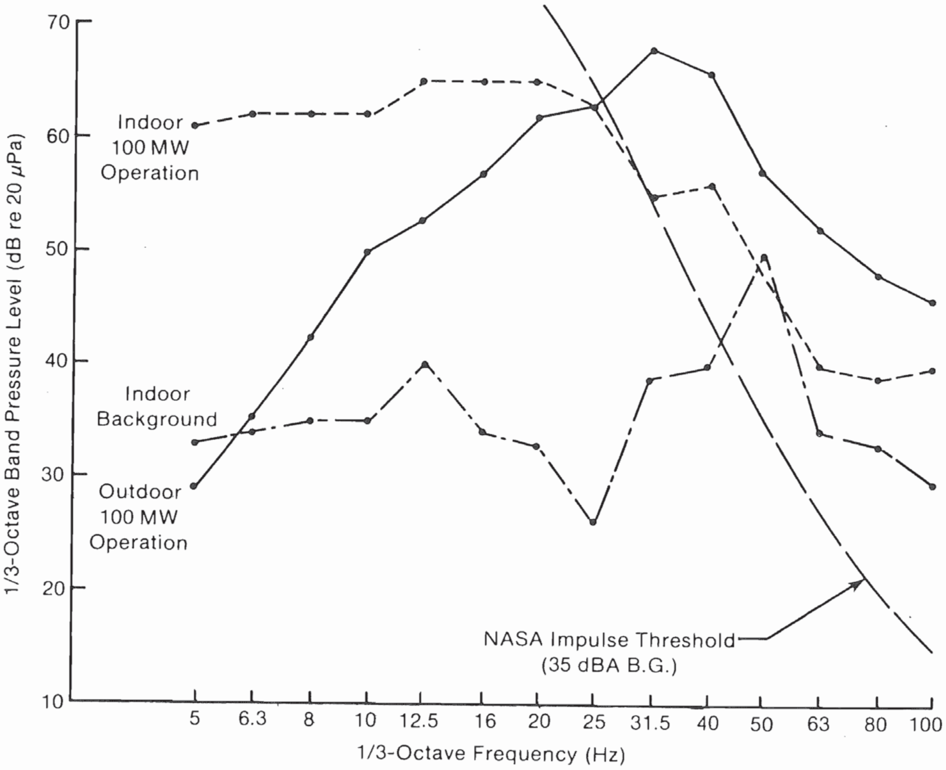

Figure 7-8. **Comparison of Averaged External and Internal Acoustic Pressure Fields Associated with Low-Frequency Annoyance from 100-MW Gas Turbine at a Distance of 1 km** (B.G. = background)

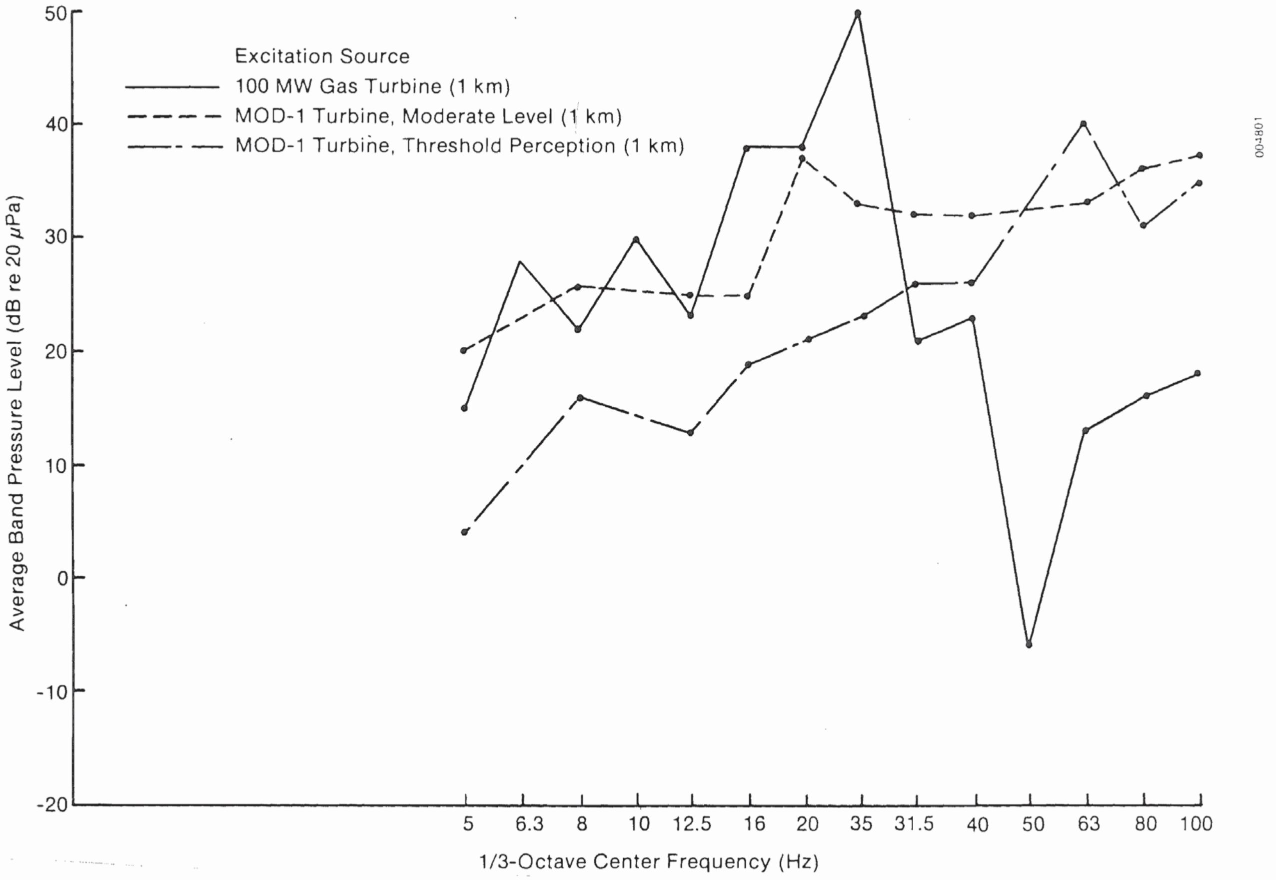

Figure 7-9. Comparison of Averaged, Interior 1/3-Octave Band Pressure Levels for Excitations by 100-MW Gas Turbine and Moderate Annoyance and Threshold Perception from MOD-1 Wind Turbine

We concluded, then, that the annoyance in the Oregon house was being driven primarily through the diaphragm action of the walls facing the turbine, the location of the room in which the acoustic measurements were taken. The strong harmonic peak at 31.5 Hz in Figure 7-7 is to be expected, due to the accompanying external excitation peak at that frequency; but the peak at 6.3 Hz was not expected, and therefore must be a consequence of excitation of the structure fundamental mode. It is also not difficult to see why little audible sound was reported in the Oregon home, in light of the rapid fall-off above 30 Hz in all of the figures. The Boone homes, in comparison, indicate significant harmonic content above the NASA impulsive threshold curve. Also, the instantaneous impulses striking the two Boone houses contained considerable energy in these higher frequency modes which is not evident in the averaged spectra of Figure 7-6. We believe that the energy in these higher modes drives the corresponding structural and air volume resonances and adds to the audibility perception.

We also conclude that while the MOD-1 impulsive excitation contained more energy at higher frequencies, the energy near the structure fundamental mode alone, particularly facing the source, could raise the harmonic pressure levels within the homes to sufficiently high levels to be responsible for an annoyance perception in some people. Thus, comparing these two situations shows that it is not necessary to have a strong, low-frequency impulsive component exciting a residence to produce annoyance. Only similar levels of subaudible acoustic energy near the home fundamental mode and above existing background may be all that is necessary. This process also explains the reported annoyance within homes when no perceptible sounds could be detected outdoors, a situation that occurred in Boone on several occasions. Again, given this evidence, we must stress the need for control of the noise at the source, since little can apparently be done in terms of damping affected structures once the condition exists.

7.3.3 Comparison of the Severity of the MOD-1 Situation with Other Low-Frequency Noise Situations

The MOD-1 noise situation, while it had several unique characteristics such as periodicity and sharp impulsiveness, does fall into a larger category of noise complaints in which low-frequency sound has been documented as playing a role. As part of their sonic boom studies in the early 1970s, NASA collected sound and vibration data of structures being acoustically loaded by a wide range of sources rich in low-frequency components, such as aircraft climbout, heavy truck traffic, slow freight trains, and the noise levels found inside homes themselves from such sources as high-fidelity sound systems, tools, appliances, etc. [39]. Figure 7-10 compares the overall sound pressure levels (OASPL) for these sources with the level measured in house #8 under moderate impulsive excitation and with the Oregon home described earlier near the gas turbine operating at its 100-MW capacity. The OASPL criteria of Figure 7-10, while giving a qualitative comparison, does not fully reflect the differences in the spectral content of both the source and the room interiors, which we have shown may be important.

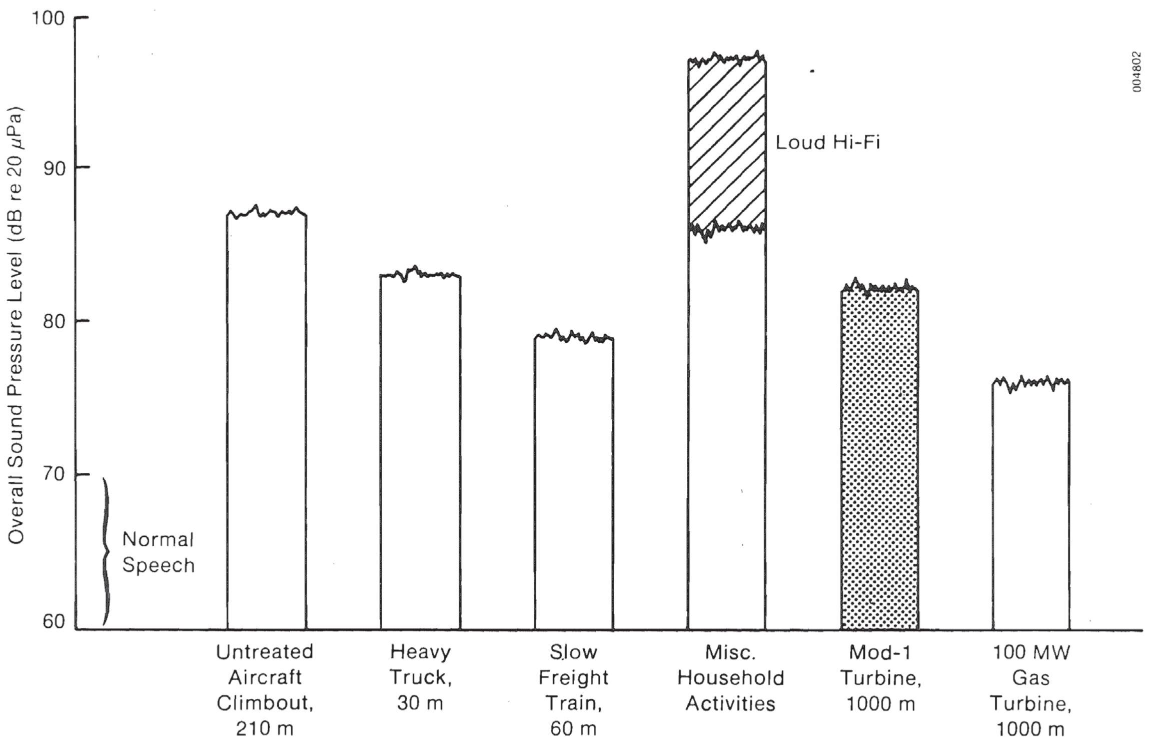

Figure 7-10. Comparison of Interior Overall Sound Pressure Levels (OASPL) for Common Low-Frequency Sources and Moderate Annoyance from the MOD-1 Wind and 100 MW Gas Turbines

Source: Ref. [39].

Hubbard [32] has summarized the available data on industrial operations that have been the source of complaints in nearby residential areas and for which low-frequency sounds are believed to be responsible. Hubbard's cross-hatched area, which encompasses the frequencies and levels thought to have caused the complaints, is shown in Figure 7-11, in which the region of octave band levels measured in house #8 under moderate impulsive excitation by the MOD-1 have been added. The observed points corresponding to octave band levels in the home in Oregon also have to be plotted, as well as the NASA impulse threshold and tone minimal-audible-field (MAF) [40] for comparison. Figure 7-12 presents a similar plot in which the threshold perception measured in house #7 is plotted. These figures indicate that the Boone complaints fall into the same category as similar ones for equivalent frequencies and octave band pressure levels. The observed perception threshold of Figure 7-12 appears reasonable in comparison with the NASA and MAF curves as well. The measurements of moderate annoyance used to develop Figure 7-11 were derived from our March 1980 field investigation, but our analysis of the June 1980 data has uncovered a far more severe impulsive situation, indicating that the annoyance area shown should be expanded upward. We conclude therefore that the conditions causing the Boone residents to complain have in fact been identified previously in documented low-frequency annoyance situations and in that respect are consistent with findings in the limited available literature.

7.4 AN ANNOYANCE POTENTIAL ASSESSMENT METHOD

In order to be able to assess the effectiveness of various noise amelioration techniques and procedures on the MOD-1, as well as compare other turbine designs to the MOD-1, we have developed an acoustic data processing technique that allows us to statistically determine the degree of low-frequency coherence in the radiated turbine acoustic spectrum. Recall that it is the degree of coherency between discrete frequency bands or impulsiveness in the acoustic output of wind turbines that is a factor in the level of annoyance perceived by humans in both interior and exterior environments.

7.4.1 A Synopsis of the Technique

The coherence between discrete energy bands in the structurally sensitive frequency range of 5-100 Hz is determined by computing the joint probability density distributions of the band spectrum levels in a series of four contiguous ISO octave frequency bands. These bands, which are indicated in Figure 7-2, account for more than 90% of the resonance-controlled frequency range and consist of the standard 8, 16, 31.5, and 63 Hz octaves. The 8 and 16 Hz bands cover most of the fundamental and wall/diaphragm modes, and the 31.5 and 63 Hz bands cover the wall/floor cavity and air volume resonances. In order to take into account the nonstationarity of the MOD-1 noise, the time for one complete blade revolution is used as the nominal sampling period for computing the density distributions.

The actual technique involves the use of an 800-line resolution spectrum analyzer under the control of an external computer. The analyzer acquires a sample acoustic time series corresponding to the closest standard sampling period available to a single blade rotation period, transforms it into a nar-

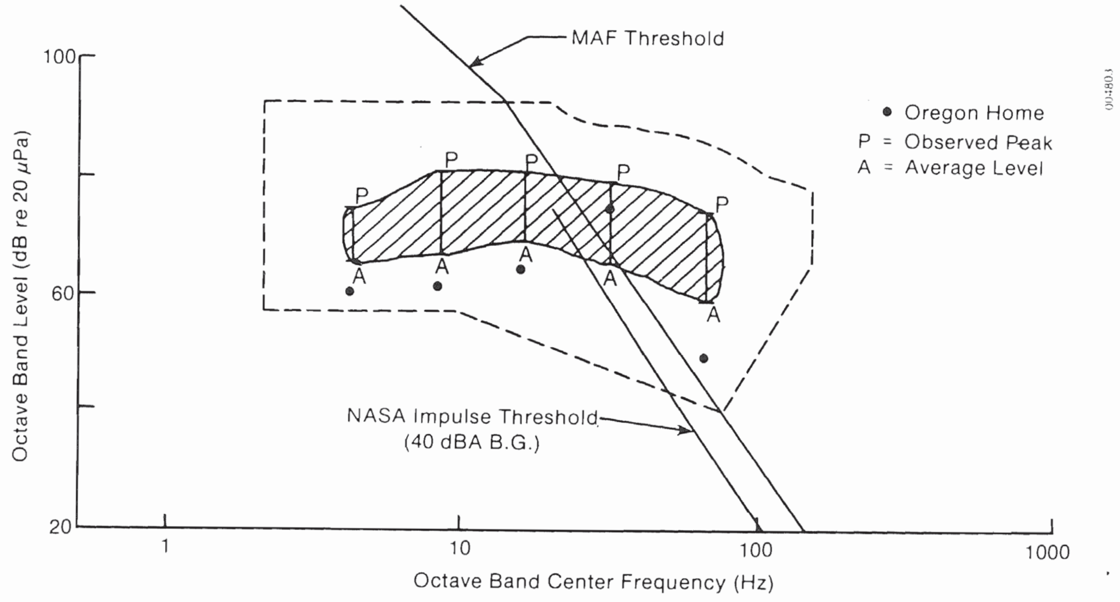

Figure 7-11. Comparison of Summary of Documented Low-Frequency Annoyance Cases with Observed Octave-Band Acoustic Levels Associated with Moderate Annoyance from MOD-1 Turbine in House #8

Source: Ref. [32].

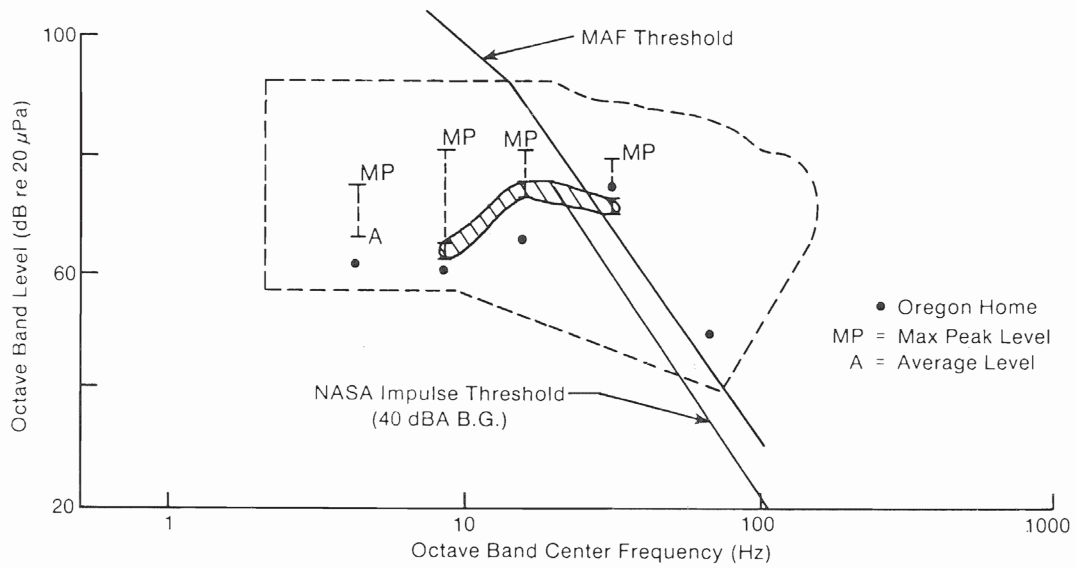

Figure 7-12. Comparison of Documented Low-Frequency Annoyance Cases with Threshold Perception of MOD-1 Impulsive Noise at House #7

Source: Ref. [32.].

rowband frequency spectrum, and finally transfers it to the computer where the four octave band levels are calculated. The computer, using the method of bins, develops the joint probability density functions (PDFs) using a 5 dB pressure level increment for the joint band combinations 8/16, 16/31.5, and 31.5/63 Hz, and a triple combination of 8/16/31.5 Hz. The results are then plotted as a series of surfaces containing isopleths of equal joint probability.

7.4.2 Analysis Results

Figures 7-13, 7-14, and 7-15 display the observed joint PDFs for the 8/16, 16/31.5, and 31.5/63 Hz octave band spectrum levels for the maximum dynamic range of impulse activity we have recorded from the MOD-1. The surfaces at the lower left of each figure represent the local background and the threshold perception case measured outside house #7 in March 1980. The tight surfaces depicted at the upper right reflect the observed distributions for the most severe MOD-1 impulse radiation recorded 1.5 rotor diameters upwind of the turbine late in the evening of 9 June 1980. Figure 7-16 plots the 8/16/31.5 HZ BPL joint probability surfaces for this case in which the conditional probability of an 8 Hz band spectrum level (BSL) of 70 dB/Hz or more was used. The distributions of the night of 9 June also correspond to reports of severe annoyance by the residents of house #8 and their neighbors. Unfortunately, we had no measurements in or outside the affected homes themselves during this period. The surfaces of these figures now allow us to correlate the acoustic radiation characteristics of the MOD-1 over a wide emissions range, particularly in relation to the degree of phase coherency present; i.e., a high joint probability between two or more bands is equivalent to a high degree of phase coherency in the radiated acoustic energy.

The closely packed isopleths to the right and upper right of Figures 7-13, 7-14 and 7-15 indicate coherent radiations of 75, 75, 70, and 58 dB levels as much as 50% of the time (each contour represents a 10% increase in probability) in the 8, 16, 31.5, and 63 Hz bands, respectively. However, according to the threshold values in the lower left, perception (not annoyance) will just occur at 50, 45, 35, and 35 dB in the same respective bands, 20% or more of the time. Figures 7-13 and 7-14 show that interior perception occurs at only 5 dB above background levels in the 8 and 16 Hz bands (which correspond to the fundamental and first harmonic of the wall/floor diaphragm modes), but Figure 7-15 indicates no difference between the turbine radiation and background in the 31.5 and 63 Hz bands, indicating they were probably not contributing to indoor perception.

The results of this joint probability analysis have given us a crude measure of the threshold sensitivity of humans in a structure undergoing low-level, impulsive acoustic loading. In terms of the MOD-1 situation (and for other wind turbines installed near human populations, particularly residential communities), these figures give us a target below which we must limit turbine coherent, low-frequency emissions in the acoustic far-field. Allowing for the effects of terrain and atmospheric refraction on the propagation in which the effects of focusing can reduce the fall-off with distance, as discussed in Section 6.0, we must at least assume that the impulse levels measured at the 1.5 rotor diameter reference point near the turbine should not exceed these

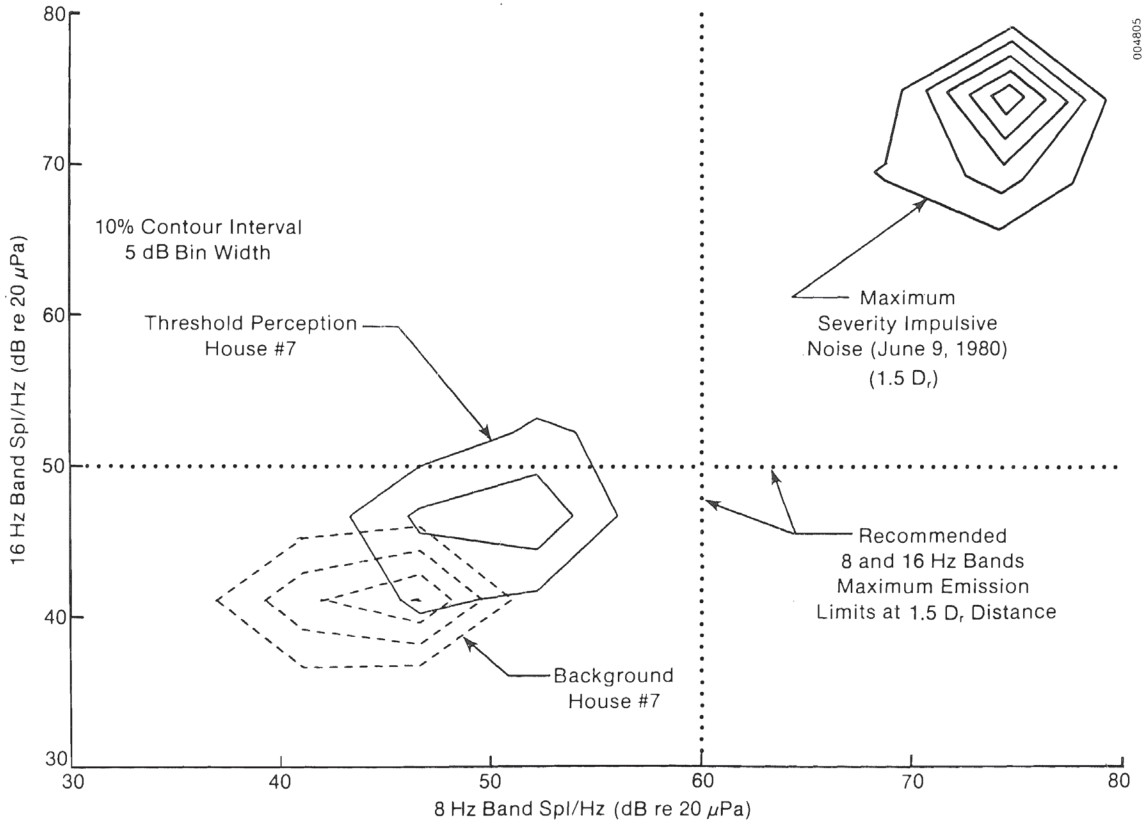

Figure 7-13. **Joint Probability Distributions of 8/16 Hz Octave Band Spectrum Levels for House #7 Background and Threshold Perception and Maximum Impulse Severity at 1.5D from MOD-1 Turbine** (D_r = rotor diameter)

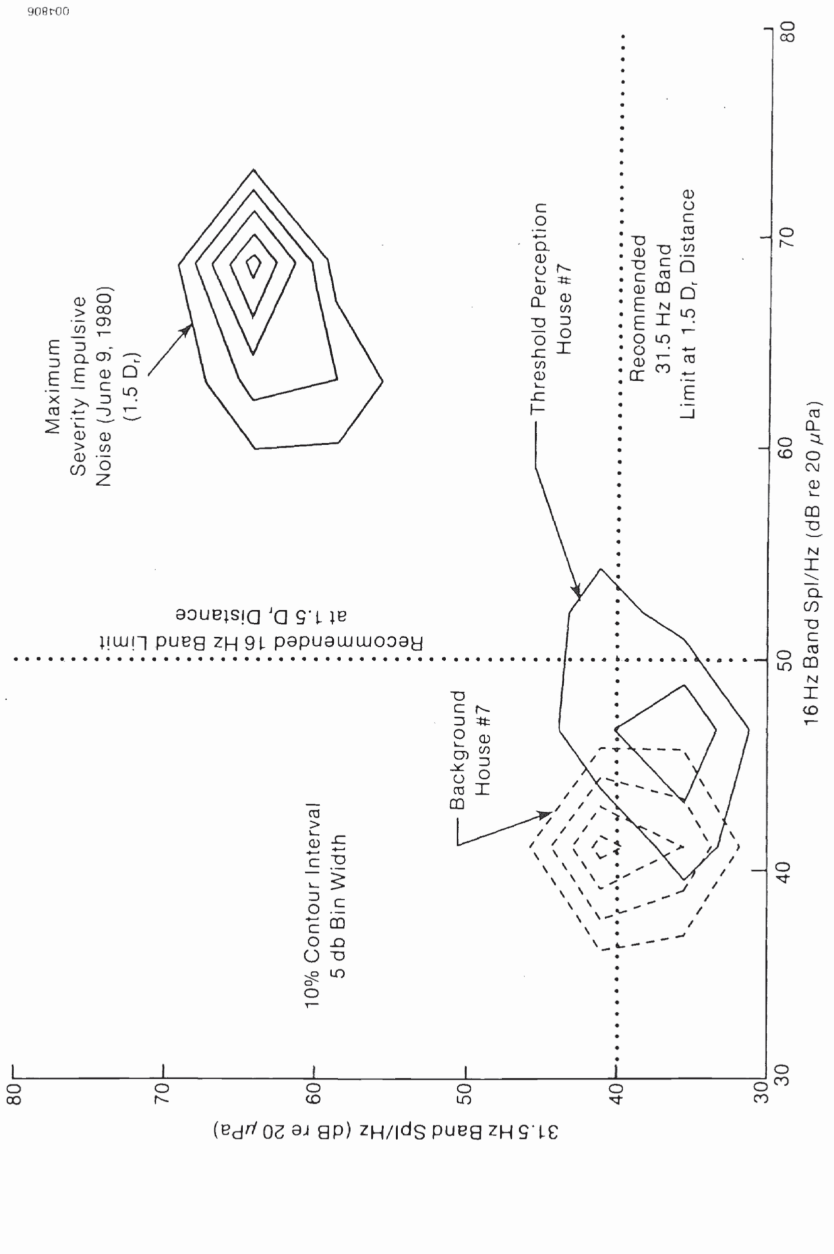

Figure 7-14. Same as Figure 7-13, but for 16/31.5 Hz Octave Band Spectrum Level

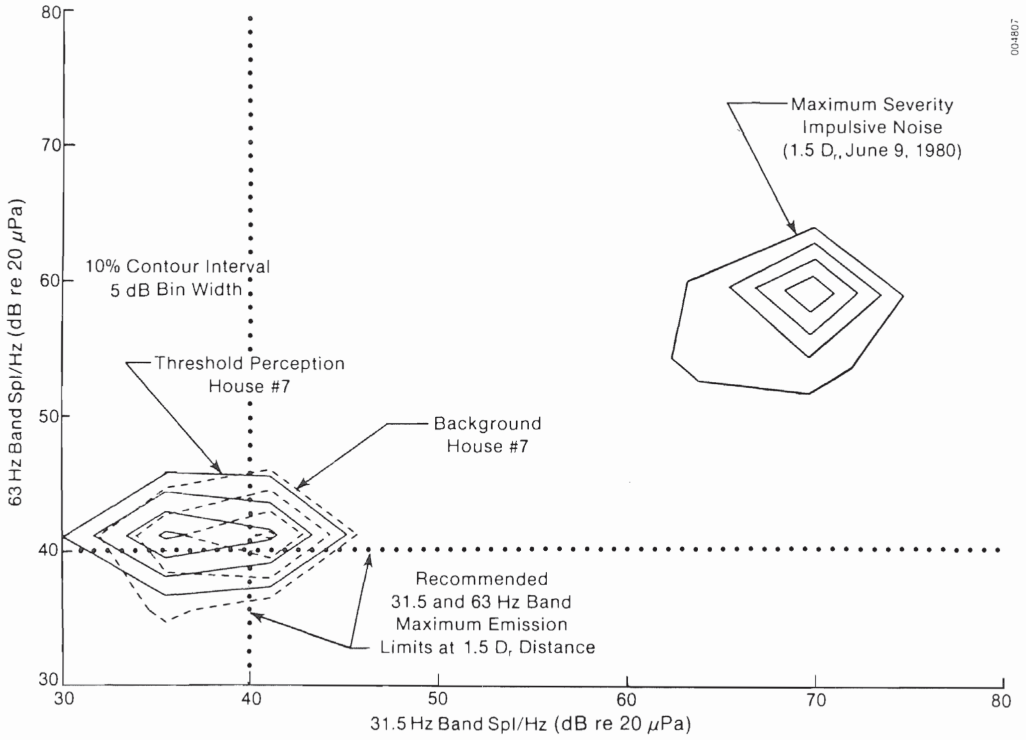

Figure 7-15. Same as Figure 7-14, but for 31.5/63 Hz Octave Band Spectrum Level

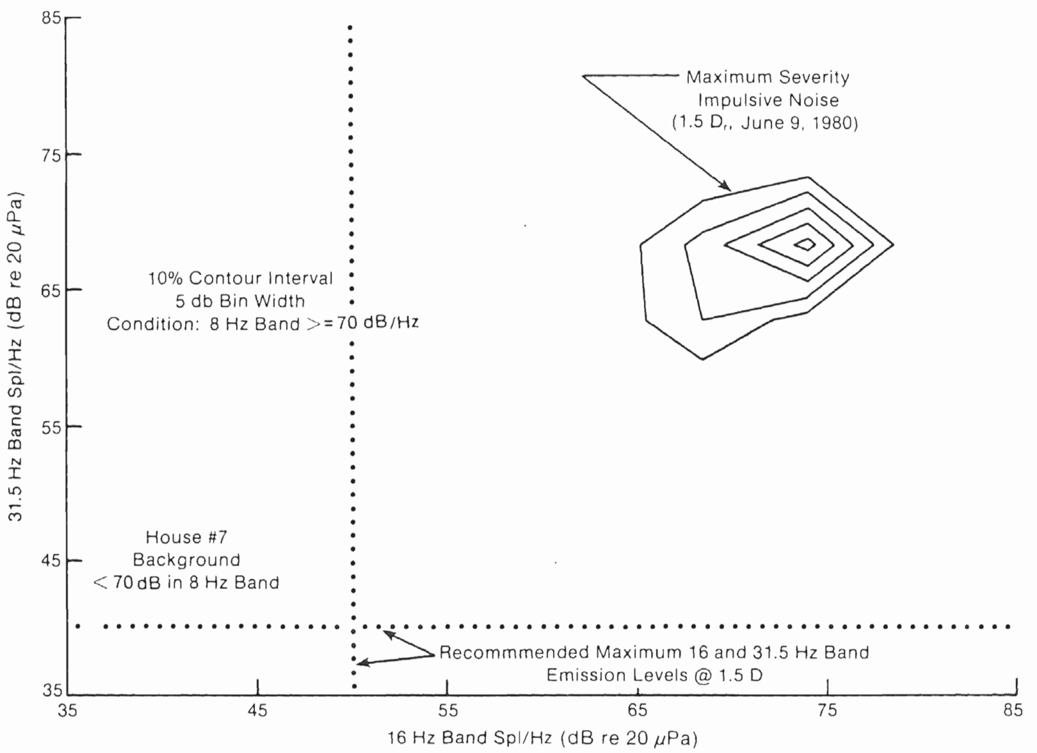

Figure 7-16. **Triple Joint Probability of 8/16/31.5 Hz Octave Band Spectrum Levels with Conditional Probability of an 8 Hz Band Spectrum Level > 70 dB** (House #7 background and threshold levels are < 70 dB BSL and do not appear)

threshold limits as a design guide. In particular, joint radiation in the 8, 16, 31.5, and 63 Hz octave bands should not exceed 60, 50, 40, and 40 dB (re 1 pWm^{-2}) intensity levels more than 20% of the time the turbine is in operation.

7.4.3 Comparison of Proposed Low-Frequency Coherent Emission Guidelines with Available Data

Obviously, these guideline figures are a rough measure because they are based on the reaction of only four people in a single situation. Unfortunately, that is all we have to go on in the Boone situation. We can, however, compare these figures with Hubbard's data summary [32], discussed in Section 7.3.3 and shown in Figures 7-11 and 7-12. Figure 7-17 presents Hubbard's low-frequency annoyance area, but with the threshold octave band levels measured at house #7 shown as rectangles ±5 dB (allowing for systematic errors) about the design guideline levels. As shown, these levels essentially coincide with the lower limit of Hubbard's band pressure level data and agree quite well in frequency, ending within 5 Hz of his upper frequency limit. We believe therefore that our measurements of threshold sensitivities are consistent with the documented low-frequency annoyance literature and can be used as design-goal criteria to reduce noise levels, in the MOD-1, in particular, and in wind turbines, in general.

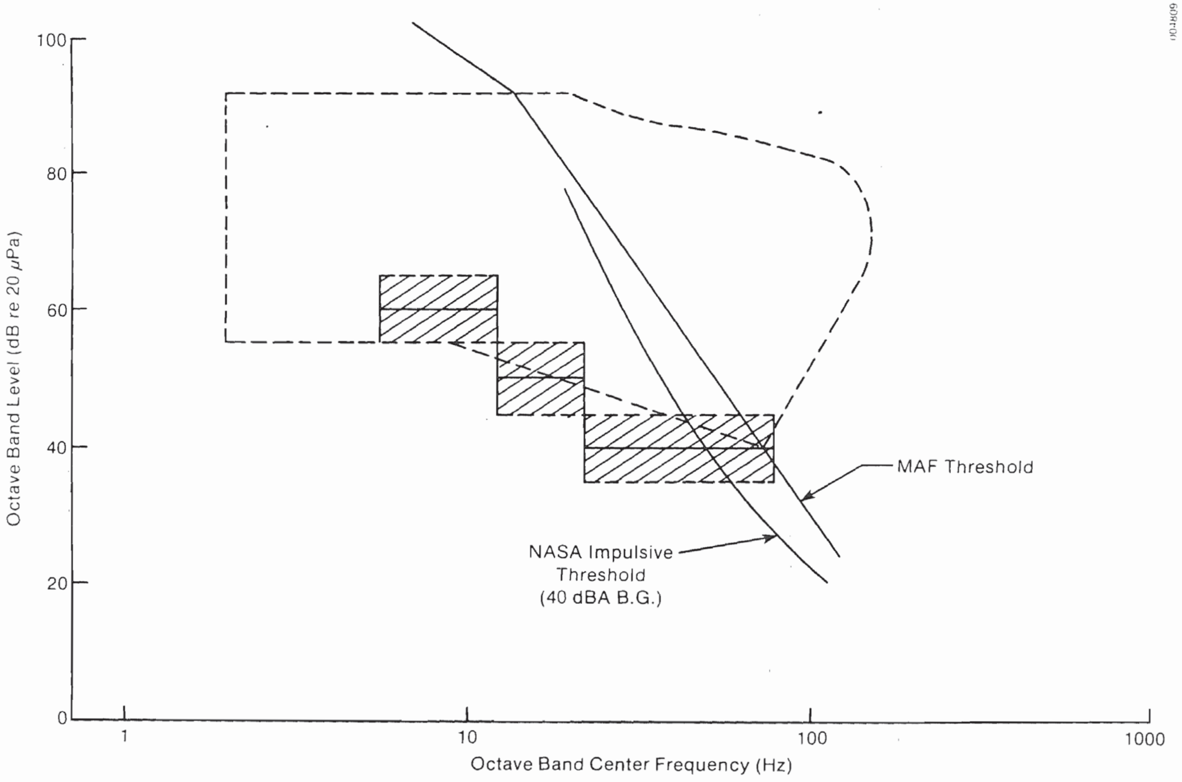

Figure 7-17. Comparison of Suggested Minimum Wind Turbine Radiated Joint Octave Band Pressure Levels at 1.5D with Low-Frequency Annoyance Summary

Source: Ref. [32].

SECTION 8.0

PROCEDURES FOR MITIGATING MOD-1 IMPULSIVE NOISE RADIATION

It is clear from our discussion in the previous sections that the only acceptable method of curtailing complaints from residents in the vicinity of an operating MOD-1 turbine is to eliminate, or at least reduce, the impulsive character of the disturbing acoustic radiation to below perceptible levels. The task was made more difficult by the level of conditioning and resulting sensitivity of a few of the families involved, particularly the residents of houses #2, #7, and #8 (and their immediate neighbors). In this section, we review the options available, some of which have been evaluated in actual practice, and discuss what we believe to be the most effective amelioration approaches, given the constraints of a fixed turbine design (i.e., rotor shape and support tower) but some operational flexibility.

8.1 POSSIBLE WAYS TO AMELIORATE THE MOD-1 IMPULSIVE NOISE

As a result of the intensive investigation by a number of organizations, several possible procedures have been suggested to reduce the intensity of the impulsive acoustic radiation from the MOD-1. The suggestions fall into essentially three categories: (1) convert the turbine to an upwind configuration; (2) reduce the rotor's rotational speed; and/or (3) somehow treat the offending cylindrical tower legs aerodynamically to modify their downstream wakes to reduce the transient lift fluctuations responsible for the impulsive noise. Converting to an upwind configuration, while feasible for limited testing, has been deemed impractical (at least for the current turbine configuration) for several reasons, including tower-rotor clearance and a derated overall efficiency should the blades operate in an inverted position. Thus, reducing the rotor rotational speed and the aerodynamically modifying of the tower legs have been the options considered most. We treat each of these approaches in the following sections.

8.2 DECREASING IMPULSIVE NOISE INTENSITY BY REDUCING ROTOR ROTATIONAL SPEED

Abating impulsive noise by reducing the rotor blade speed was based on the theory that the wake deficits existing in the lee of the large, vertical tower legs are responsible for rapid lift fluctuations and impulsive noise generation. By reducing the blade's relative translational velocity through these deficits, the rapid change in lift experienced at the original design speed will be sharply diminished through the increased residence time of the blade in the wake. This action will then prevent the associated acoustic impulses from reaching annoying levels.

The reasoning behind this approach has been founded on what we believe to be an incorrect assumption that the wake deficit is the primary cause of the impulse generation, as discussed in our analysis presented in Sections 4.0 and 5.0. The resulting reduction in impulse levels is related to the decrease in the magnitude of the steady lift attainable at the lowered relative blade velocity. Strong impulses could still be observed at this slower speed, the result of the transient unsteady lift fluctuations encountered as the blade passes through coherent vortex structures that, as shown in Section 5.0, are independent of the rotor rotational (translational) speed. Thus, while the overall impulsiveness is reduced by this approach, the chief result is the derating of the turbine operating capacity from a 2-MW peak to something less than 1.5 MW under optimum operating conditions.

The reason why all impulses are not reduced below perceptible levels at the slower blade speed under all conditions, as stated above, continues to be the turbulent, discrete characteristics of the tower leg wakes. This can be seen more clearly if we describe these wakes at the point of blade intersection in terms of the time-dependent vortex circulations contained within, in terms of a spectrum of the reduced frequency k. In Section 5.2.4, we described the role of several unsteady aerodynamic parameters in which the reduced frequency k was shown to be of major significance. We confirmed this dependence in the wind tunnel testing described in Section 5.2.4.3 particularly in reference to the result that a reduced frequency range of approximately $0.5 \leqslant k \leqslant \pi$ was responsible for maximum unsteady excitation of the airfoil boundary layer and for the observed strong acoustic radiation and aeroelastic responses. Keeping this in mind, we examine the width of the leg wakes as a function of the tower leg-to-blade distance. Typically, the wake width ranges from about 0.6 m at a downwind distance of four leg diameters to about 0.8 m at 12 diameters [14]. From our vortex analysis in Section 5.2.4.2, we estimated the width of the viscous core vortices to be typically half the wake width. Using the expression $k = \pi c/\lambda$, where λ is the disturbance wavelength (assumed half the wake width), the corresponding critical reduced frequencies for downstream distances of 4, 8, and 12 leg diameters are 3.8, 3.6, and 2.8, respectively, at the 80% span position. All are either within or near the critical k-range ($0.5 \leqslant k \leqslant \pi$) and independent of the rotor speed. Thus, the chief benefit of lowering the rotational speed is derived from a reduction in the upper limit of the static lift, which in turn influences the peak levels of the transient, unsteady component toward lower values. The price of this improvement, of course, is less generating capacity than before, at every wind speed.

8.3 AERODYNAMIC MODIFICATION OF TOWER LEGS TO CONTROL IMPULSIVE NOISE GENERATION

We have identified four important fluid dynamic parameters that control the severity of acoustic impulses generated as the MOD-1 blades pass through the tower leg wakes, including the freestream velocity, vortex core central pressure deficits, vertical or spanwise coherence (vortex tube), and a wake disturbance scale expressed by the reduced frequency parameter k. Wake disturbances, whose spatial scale corresponds to a critical reduced frequency range of approximately $0.5 \leqslant k \leqslant \pi$, are the most important and therefore should be minimized, by aerodynamic modification of the tower legs, as well as the destruction of any vertical coherency. The latter is important because it controls the spanwise lift coherency ℓ_c and therefore the fraction of the blade leading edge radiating impulsively.

The objective of aerodynamically modifying the turbine legs is to prevent the shedding of discrete vortex tubes which, when coupled with the lee disturbance space scale determined by the wake width, produce the optimum conditions for impulse generation; i.e., discrete vortices within the critical reduced frequency range and spanwise coherency. Since little can be done to significantly increase the lateral dimensions of the wake, the primary objective of an aerodynamic device or spoiler attached to the tower leg is to destroy the vertical coherence by converting a flow containing discrete, organized 2-D elements to a much more broadband, 3-D one. In Section 5.1.2 we discussed the role of the separation line which is parallel to the major axis of a cylindrical bluff body and responsible for the roll-up of vortex tubes being shed downstream (see Figure 5-4). We also saw that if this line was distorted from its parallel orientation, circulation differences would develop in the downstream flow causing the 2-D discrete narrowband organization to become 3-D wideband chaotic. A device (or devices) which could be attached to the existing tower legs that would spoil the normal boundary layer to distort the parallel separation has been sought as a potential solution to the situation. Three types of spoiling devices, plus a roughening of two of the actual tower legs with wire mesh, have been investigated in this regard. The purpose of the wire mesh was to force the cylinder boundary layer into the supercritical regime which, it was thought, would produce the 3-D wideband structure. From our acoustic impulse analysis results presented in Section 4.2.3.2 and from measurements taken at the Rocky Flats Research Center using the 0.5 cylinder and small wind turbine, we now know that this approach does not provide the degree of vertical separation line distortion necessary to achieve the desired result. In fact, though the periodic component may disappear in a turbulent supercritical wake, strong vortex circulations are often still present. Below we present preliminary results from our investigation of three potential spoiling devices tested at the Rocky Flats Research Center: the perforated shroud, the vortex generator, and the helical strake.

8.3.1 The Perforated Shroud Spoiler

Practical objectives in evaluating spoiler designs were compatibility and ease of attachment to the legs of the MOD-1, both necessary in view of the difficulties of working on such a large structure. We have reviewed the work of several investigators at the National Physical Laboratory in Great Britain [41] who were responsible for the development of a number of aerodynamic spoiling devices which have been successfully used to prevent catastrophic oscillatory forces from developing in tall cylindrical structures (such as smokestacks) from periodic vortex shedding. In a joint effort with NASA, we initially chose the perforated shroud device developed by Walshe and Wootton [41], a section of which is shown in Figure 8-1. This device had been shown to be effective in reducing oscillatory vortex excitation of cylindrical structures and also was relatively simple to manufacture and attach to the MOD-1 legs. While the devices constructed by NASA have never been actually installed and evaluated on the MOD-1 turbine itself, we were lent a single 1.8-m section to evaluate on the small turbine at Rocky Flats.

As shown in Figure 8-1, the shroud section was attached to the 0.5-m-diameter cylindrical test section mounted on the normal turbine support tower. Acoustic and turbulence measurements of the wake were conducted in a manner similar to those of the bare cylinder reported in Section 5.1.4.

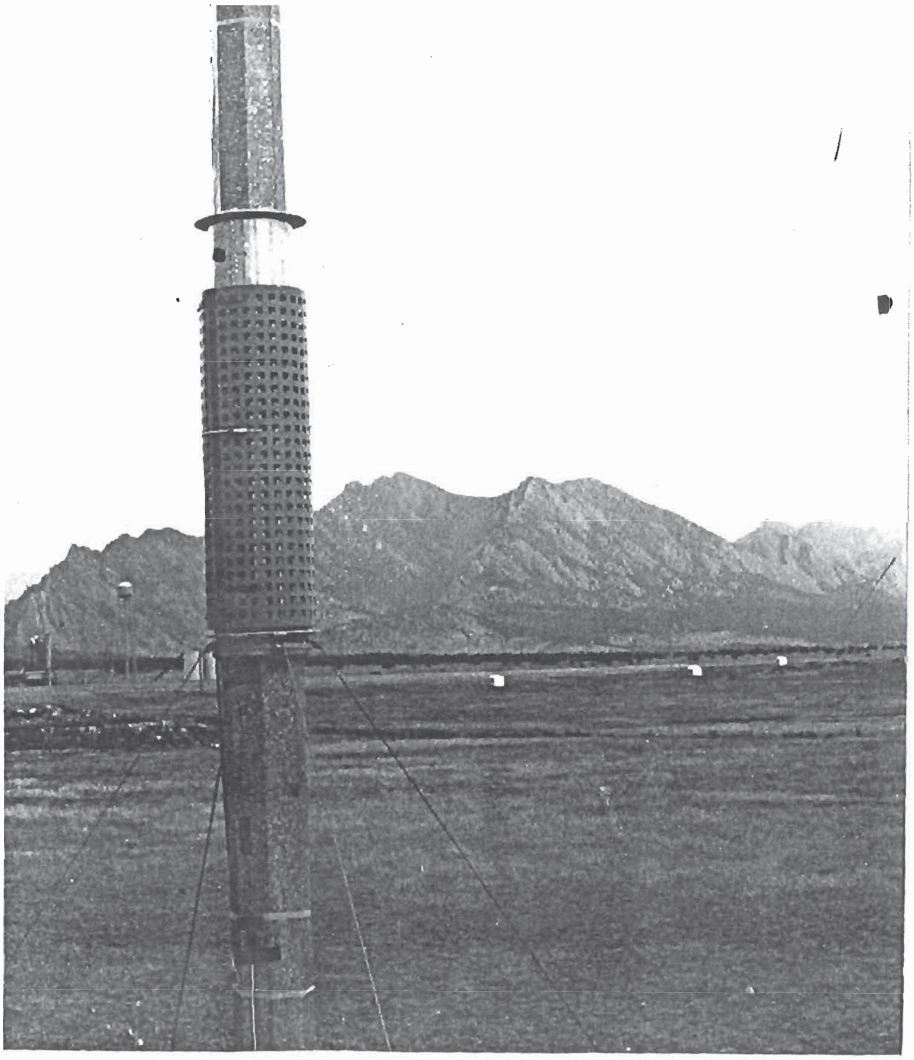

Figure 8-1. View of a Section of the Perforated Shroud Spoiler Installed on the 0.5-m Cylindrical Test Section at the Rocky Flats Wind Energy Research Center

8.3.1.1 Acoustic Results

Surprisingly, we found that the perforated shroud enhanced the impulse intensity, in comparison to the bare cylinder. A deep, transient stall is evident in the acoustic-pressure time signature of Figure 8-2, taken from the tower-mounted microphone on the high-pressure (inflow) side of the rotor as the blade passes through the wake 1.5 tower diameters (D) downstream.

8.3.1.2 Wake Characteristics

The discrete, vertically coherent nature of the wake at 1.5D downstream (the rotor plane) is shown in Figures 8-3 and 8-4 by the velocity and cross-spectra of the upper and lower hot-film anemometer probes (positioned near the center and the shrouded cylinder base, respectively). The strong relationship between the velocity and dynamic pressure fields in the tower wake are illustrated in the spectra and cross-spectrum of the upper hot-film anemometer and boom-mounted microphone of Figures 8-5 and 8-6, respectively.

8.3.1.3 Interpretation

It is obvious that the vigorous impulse activity described in Section 8.3.1.1 is being brought about by strong, vertically coherent vortices present in the shrouded cylinder wake at the 1.5D downstream position. A similar situation occurred during testing at the MIT anechoic wind tunnel, described in Section 5.2.1. In addition to the solid cylinders used in the experiments, NASA furnished a 5.1-cm-diameter cylinder in which elongated perforations had been machined. The resulting on-axis, peak sound pressure level with the cylinder $3D_r$ upstream of the rotor was the highest of all the diameters tested at that position but fell off rapidly as the upstream distance increased, as shown in Figure 8-7.

We have interpreted this behavior to possibly mean that the shroud wake in the downstream region closest to the cylinder (near-wake) maintains a strong discrete nature but is unstable and may eventually become wideband chaotic by the time the far-wake region is reached (3-$5D_r$). After reducing our available aerodynamic data, taken in full-scale and wind-tunnel testing, we may be in a position to support or deny this delayed wake transition theory. In the meantime, we do not recommend the use of this device for this purpose unless a full-scale, operating Reynolds and Mach number wind tunnel test is conducted (similar to those of Snyder and Wentz [14]) and the dynamic characteristics of the wake are documented at downstream spacings out to $16D_r$.

8.3.2 The Vortex Generator Spoiler

Another way we know to destroy or "trip" a smooth boundary layer is by using a series of vanes placed at acute angles to the flow. These are often referred to as "vortex generators" since they produce a broadband, turbulent wake due to their sharp edges. We employed this technique as shown in Figure 8-8 on our 0.5-m cylindrical test section. Each vane was 0.78 cm (2 in.) square or 10% of the cylinder diameter. The purpose of testing this type of spoiling

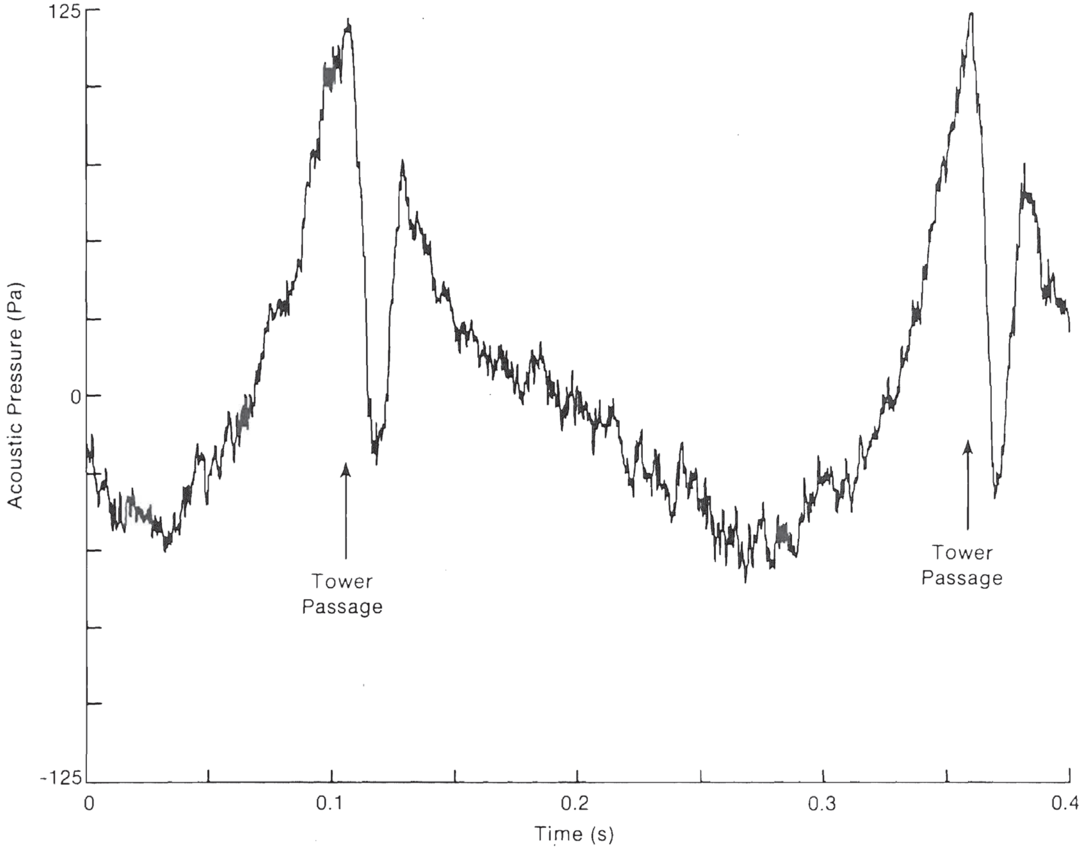

Figure 8-2. Cylinder Base Acoustic Pressure Time Signature for Two Blade Passages by the Tower with the Perforated Shroud Installed

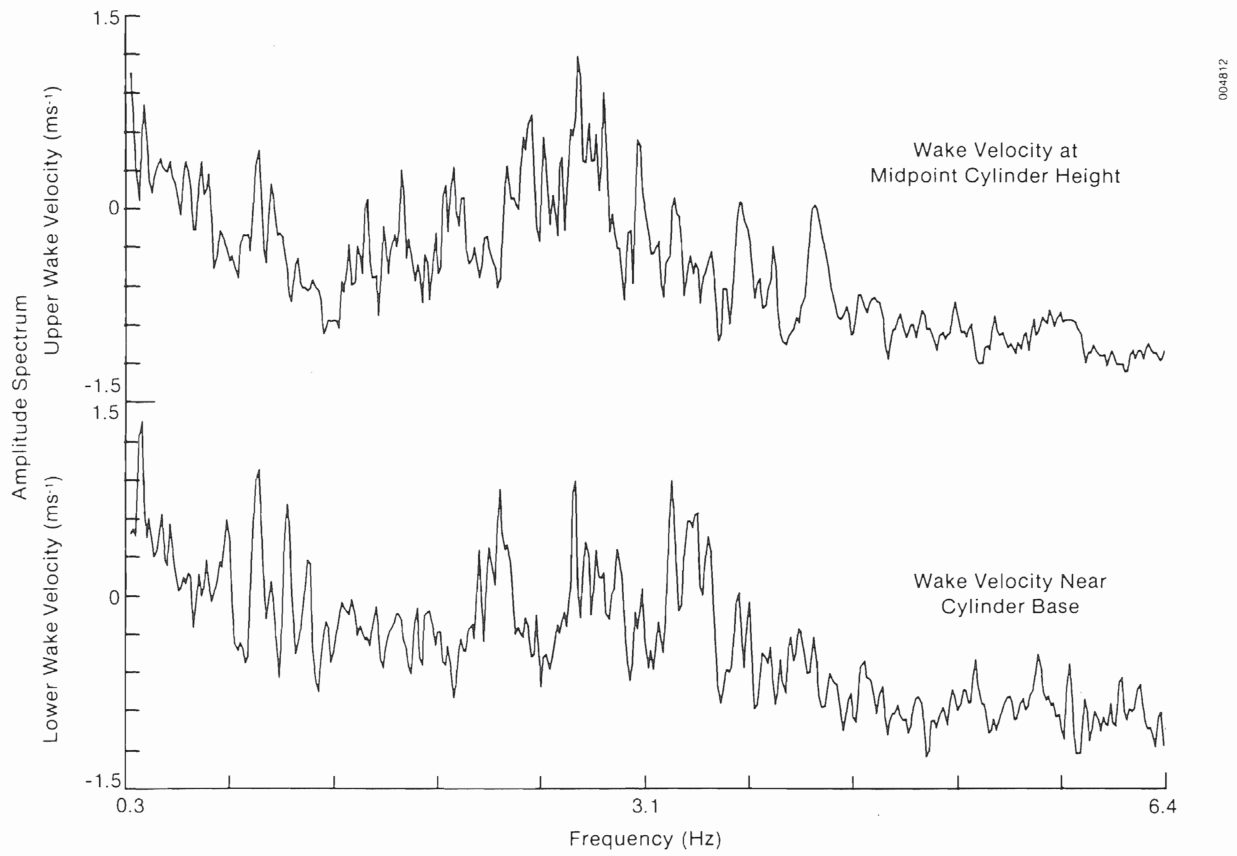

Figure 8-3. **Upper (Cylinder Midpoint Height) and Lower (Cylinder Base) RMS Wake Velocity Spectra Measured 1.5D Downstream of Shrouded Test Section on Tower.** (D = cylinder diameter or 0.5 m)

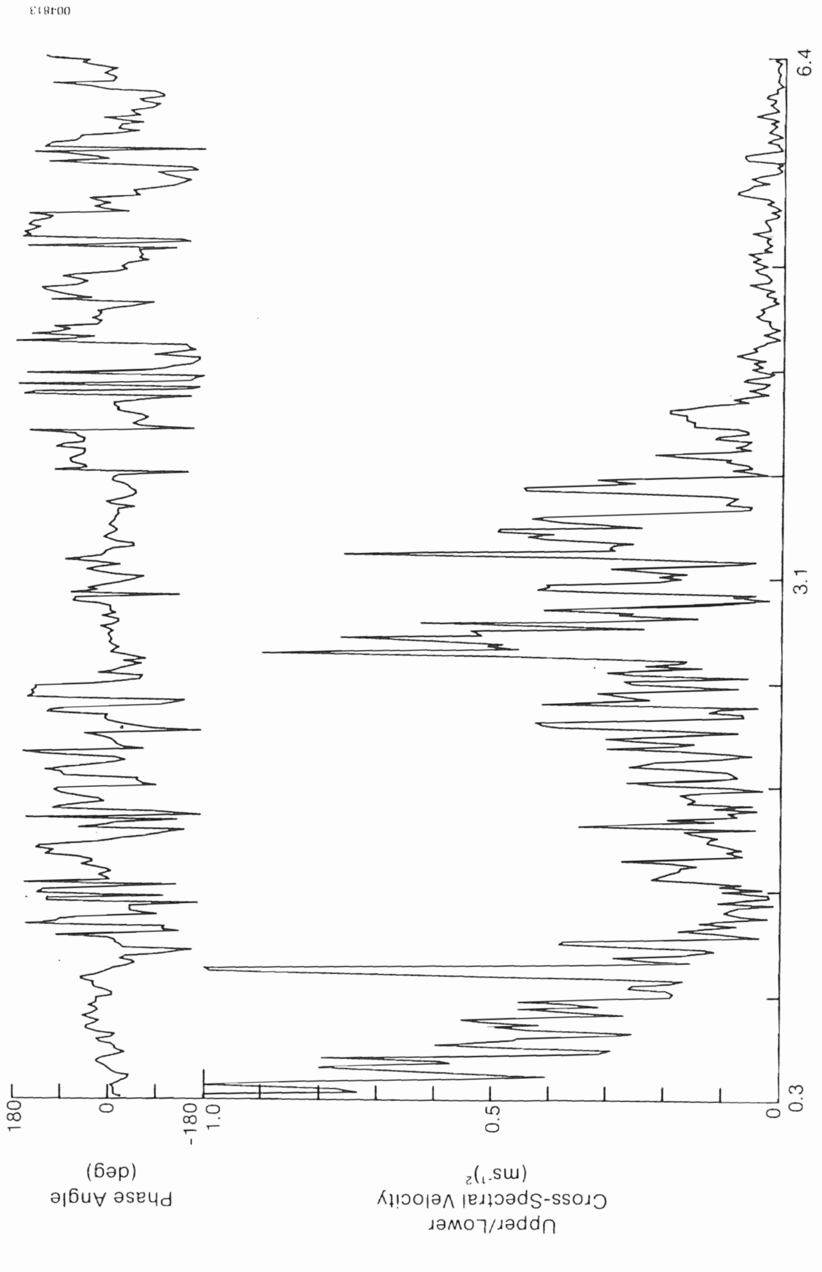

Figure 8-4. Same as Figure 8-3, but Cross-Spectrum and Phase of Upper and Lower Wake Velocities

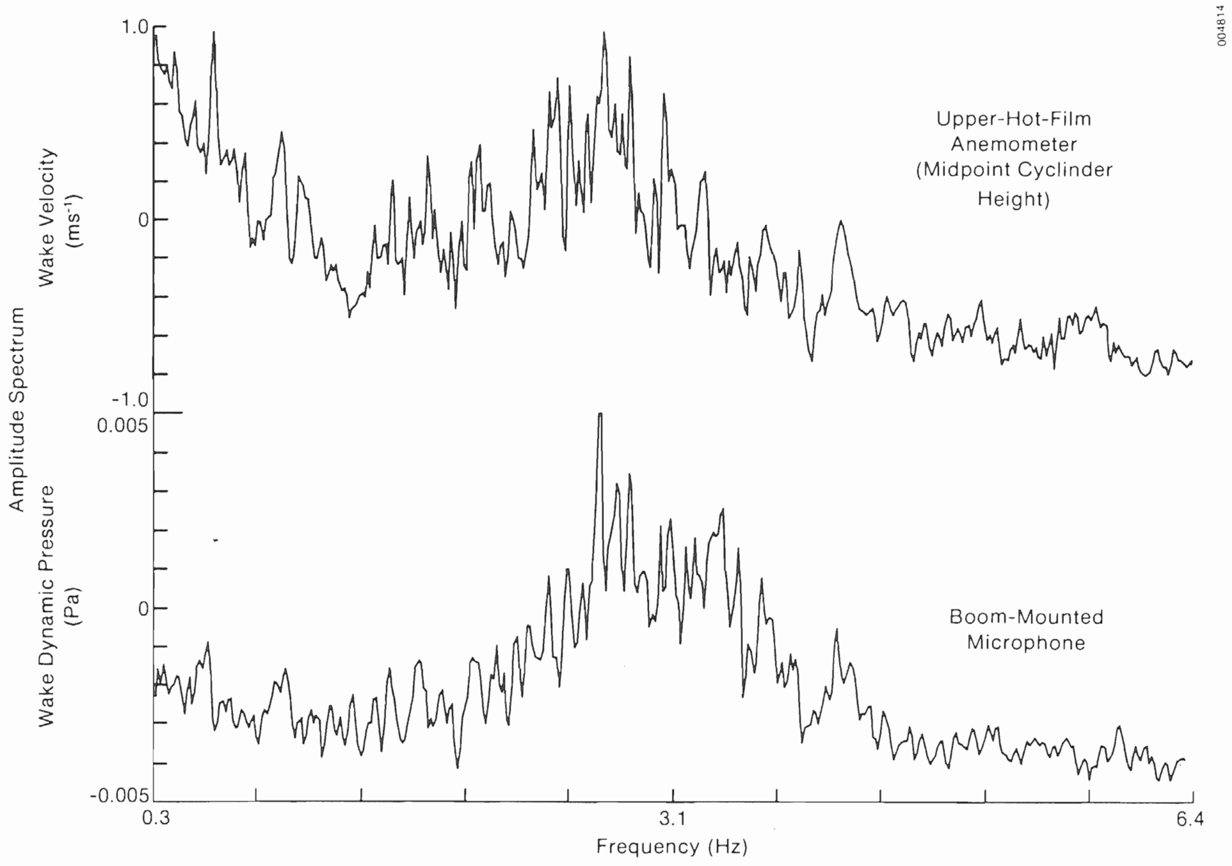

Figure 8-5. RMS Spectra of Wake Velocity (Measured at Cylinder Midpoint) and Dynamic Pressure for Shrouded Cylinder at 1.5D Downstream

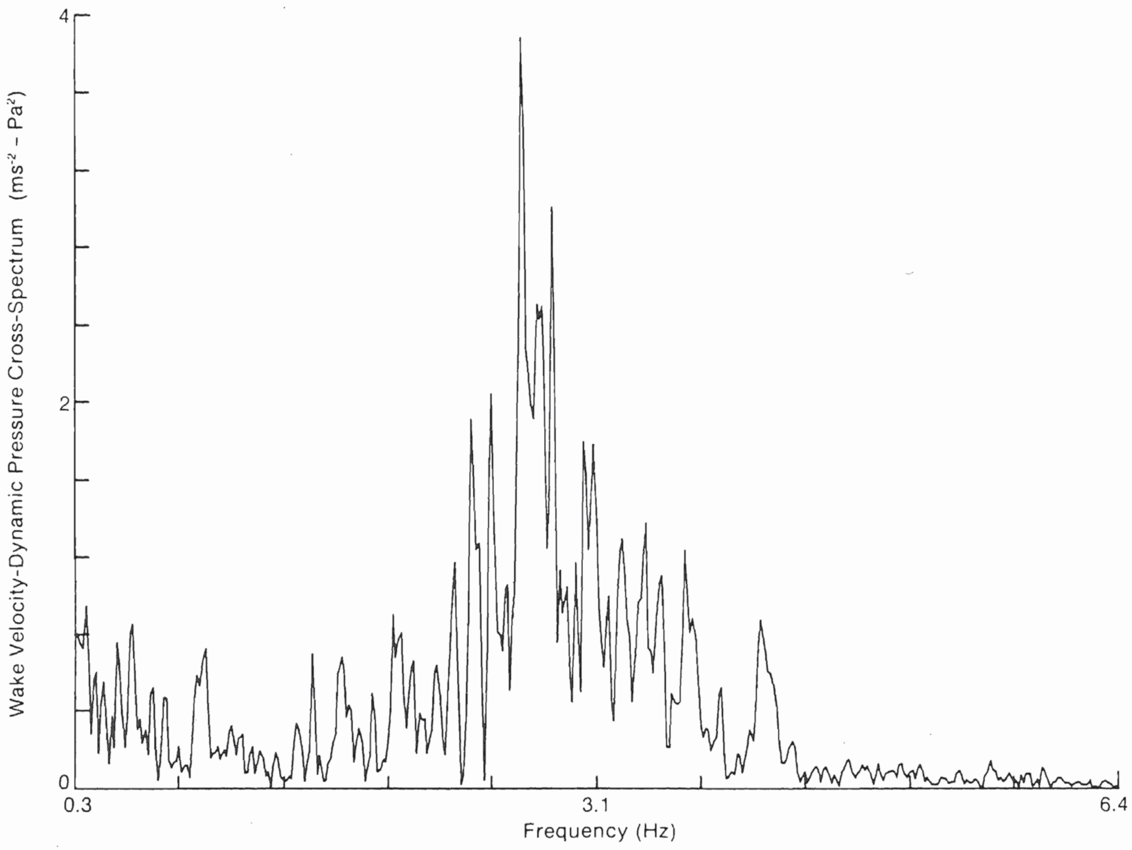

Figure 8-6. Cross-Spectral Magnitude of Wake Velocity and Dynamic Pressure of Figure 8-5
(Also appears as Figure 5-37)

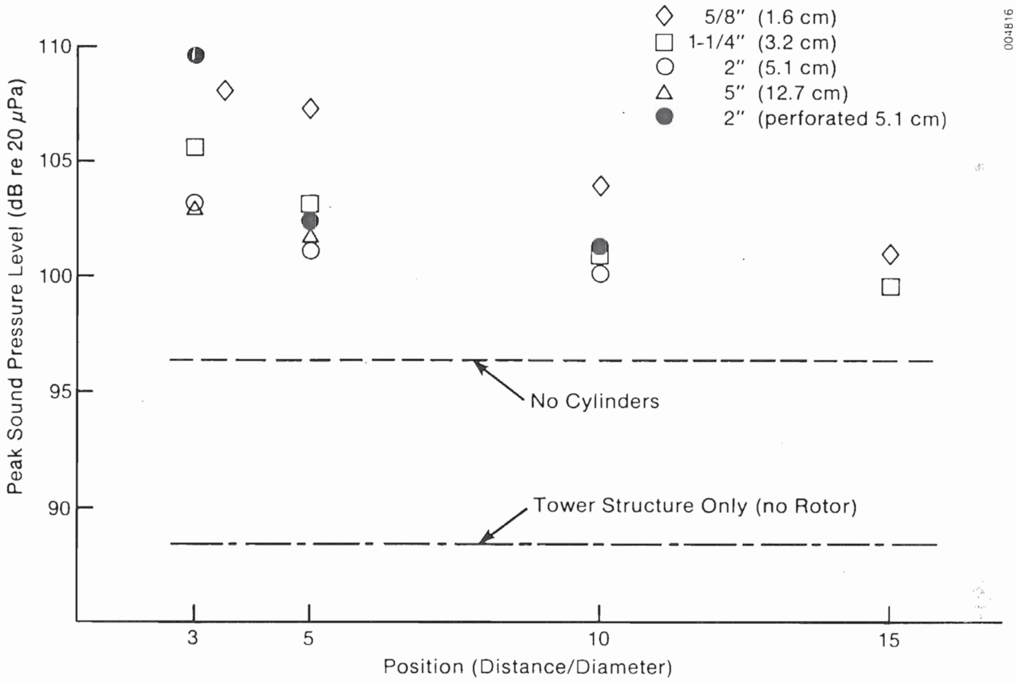

Figure 8-7. Peak Sound Level of On-Axis Microphone
Source: Ref. [15].

device was to evaluate its ability to destroy the strong 2-D shedding of a bluff body (cylinder) by direct mechanical means. Because of the complexity of this type of device (i.e., the making and mounting of so many "turbulator" vanes) it may be not practical to employ it on large tower members such as those of the MOD-1.

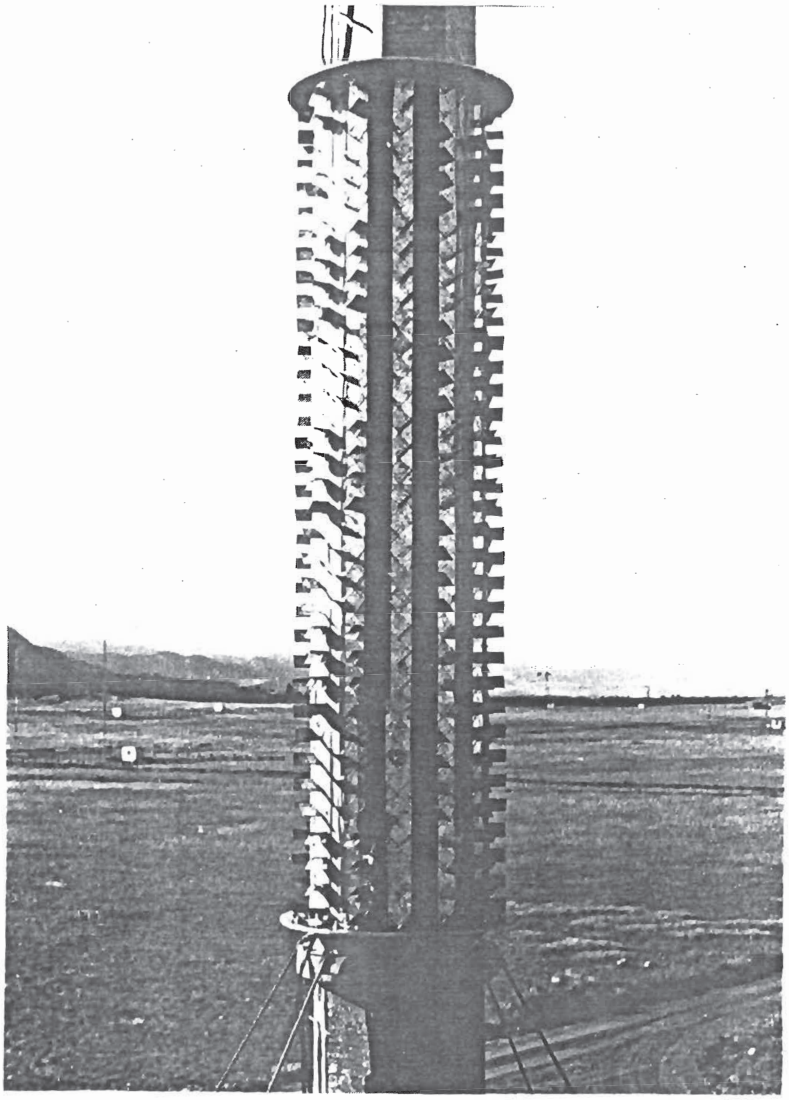

Figure 8-8. View of Vortex Generator or Turbulator Spoiler Installed on 0.5-m Cylindrical Test Section. (Note microphone installed at cylinder base.)

8.3.2.1 Acoustic Results

In cylinder-height winds averaging 7-9 ms^{-1}, no strong impulsive behavior was aurally detected similar to that observed with the perforated shroud and, to a lesser extent, to the bare cylinder in the same wind-speed range. A coherent power analysis of the tower-mounted microphone and freestream turbulence signals in Figure 8-9 shows that the tower shedding is locked into a Strouhal-type excitation in the inflow with a peak at 1.51 Hz. A detailed acoustic analysis of these data, however, remains to be done.

8.3.2.2 Wake Characteristics

This test revealed a very important characteristic of WECS tower wake flows. The photograph of the test configuration shown in Figure 8-8 indicates that our spoiler section occupied only that portion of the support tower immediately upwind of the rotor disk with no treatment above or, more importantly, below the tip of the blade. The consequences of treating only a portion of a bluff body with a spoiling device are evident in Figure 8-10, in which averaged wake velocity spectra are presented from the upper hot-film anemometer (positioned about half-way up the cylinder) and its lower counterpart (near the cylinder base). The upper velocity spectrum indicates, as expected, a generally incoherent, broadband turbulent flow demonstrating that the spoiler was operating in a desirable mode. However, when we examine the lower spectrum, we find that discrete shedding is evident. The coherent power analysis of Figure 8-11 for these two velocity signals indicates that some vertical structure does exist from the cylinder base to the midpoint at a discrete frequency of 1.58 Hz, which is close to the coherent Strouhal shedding frequency indicated in Figure 8-9 at 1.51 Hz. This vertical coherence also appears in the correlation between the wake dynamic pressure and the velocity field as indicated in the coherent power analyses with the upper and lower hot-film signals in Figures 8-12a and 8-12b.

8.3.2.3 Interpretation

The acoustic and wake characteristic analysis has indicated that the vortex generator spoiler was at least partially functioning. The general broadband nature of the wake turbulence spectrum as measured at the cylinder midpoint indicates an effective destruction of the vertical separation line found on the base cylinder. The presence, however, of relatively strong, discrete components near the cylinder base, along with weak vertical coherence extending up to the midpoint, demonstrates the substantial influence of the unaffected shedding process above and below the treated portion of the cylinder. We attribute this phenomenon to the cogency of the pressure forces present and to their influence extending vertically, most likely through the strong central pressure gradients present in the shed vortices. Snyder and Wentz [14] found a wake shed from a polygonal shaped bluff body (an eight-sided body in our case) tended to be more periodic or discrete than a comparably true cylindrical shape. This indicates that the vortex elements are probably much stronger due to the well-defined vertical separation lines afforded by the edges on the body itself.

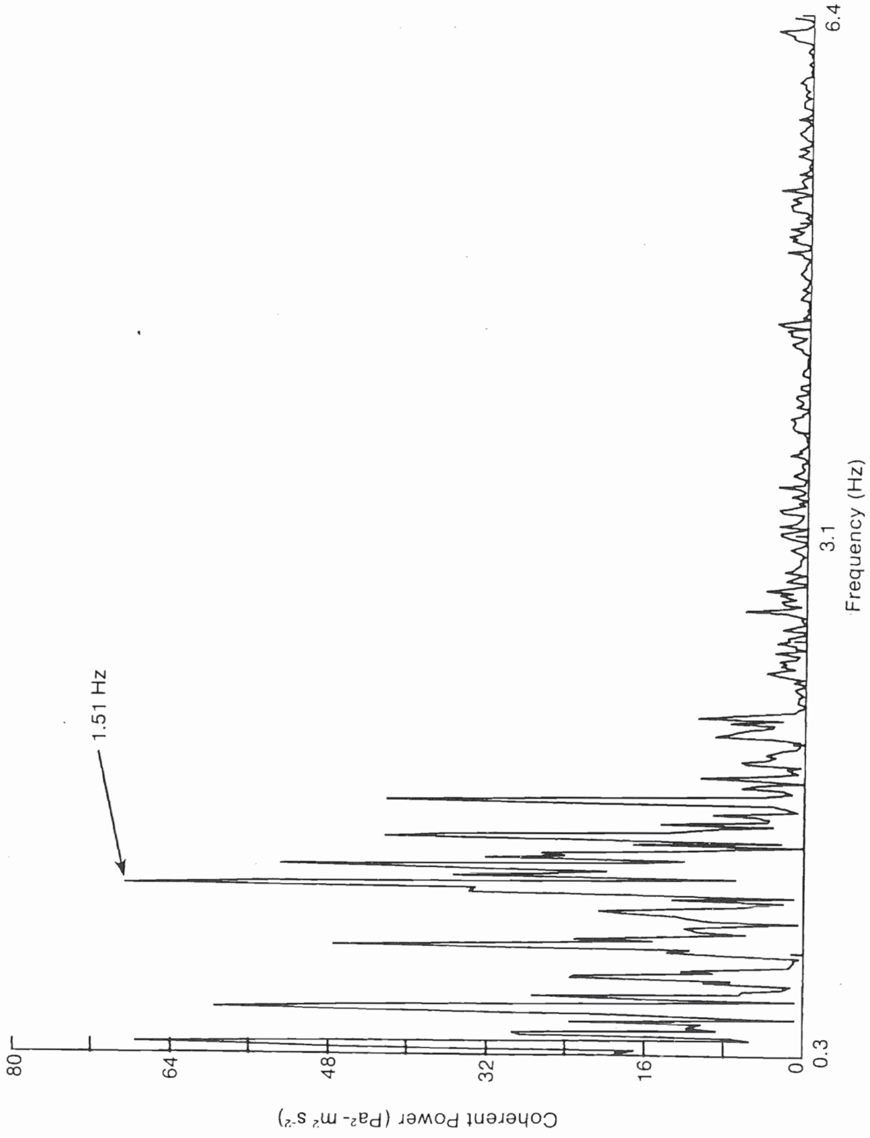

Figure 8-9. Coherent Power Analysis of Freestream Turbulence and Tower Base Dynamic Pressure

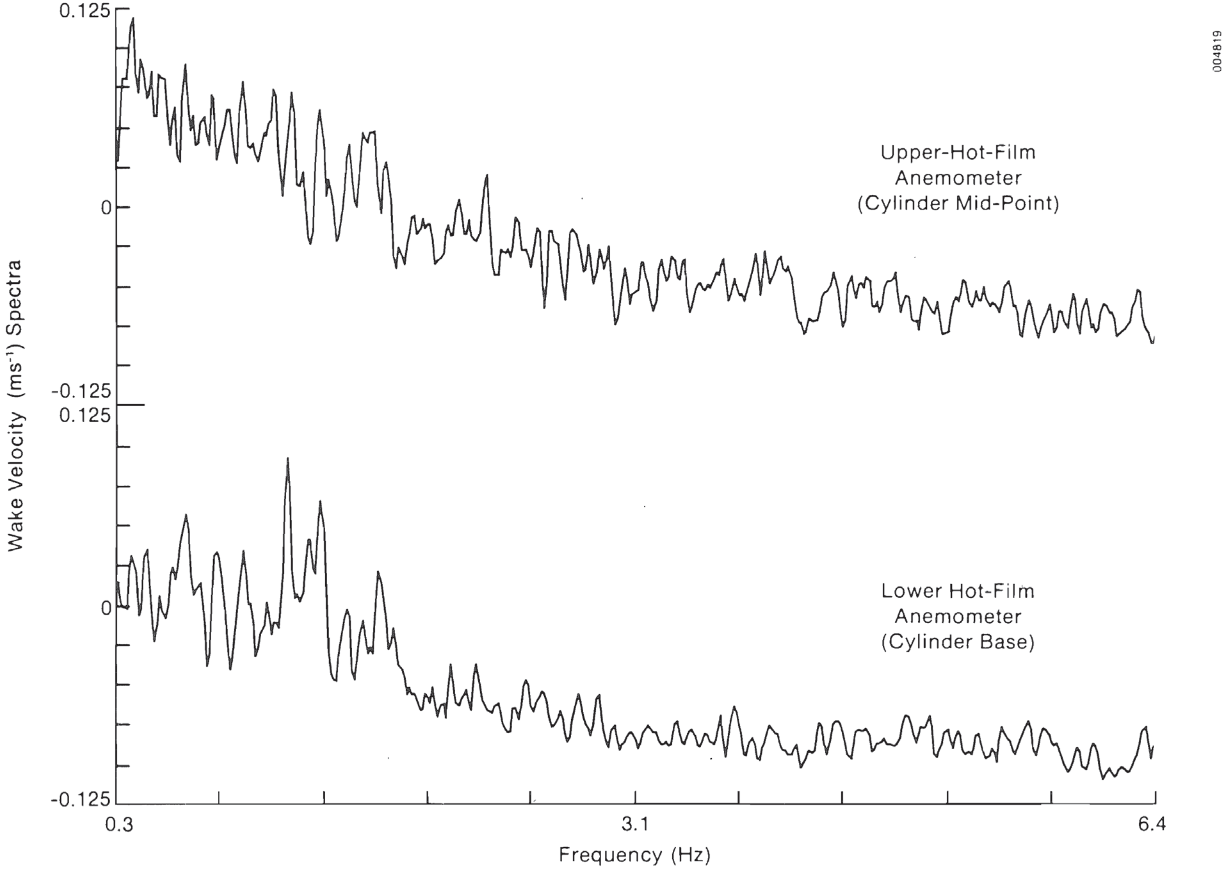

Figure 8-10. Upper (Cylinder Midpoint) and Lower (Cylinder Base) RMS Velocity Spectra at 1.5D Downstream of Vortex Generator-Modified Cylinder

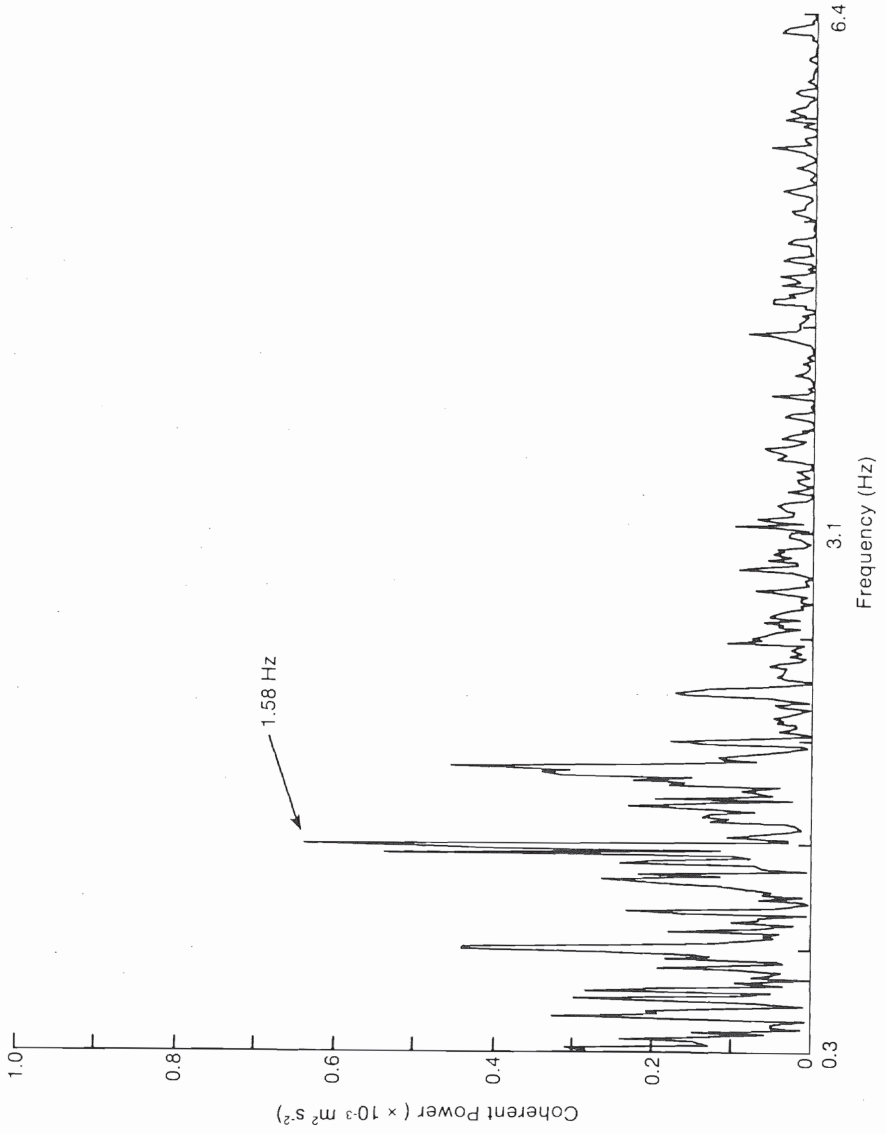

Figure 8-11. Coherent Power Analysis of Upper and Lower Wake Velocities of Figure 8-10

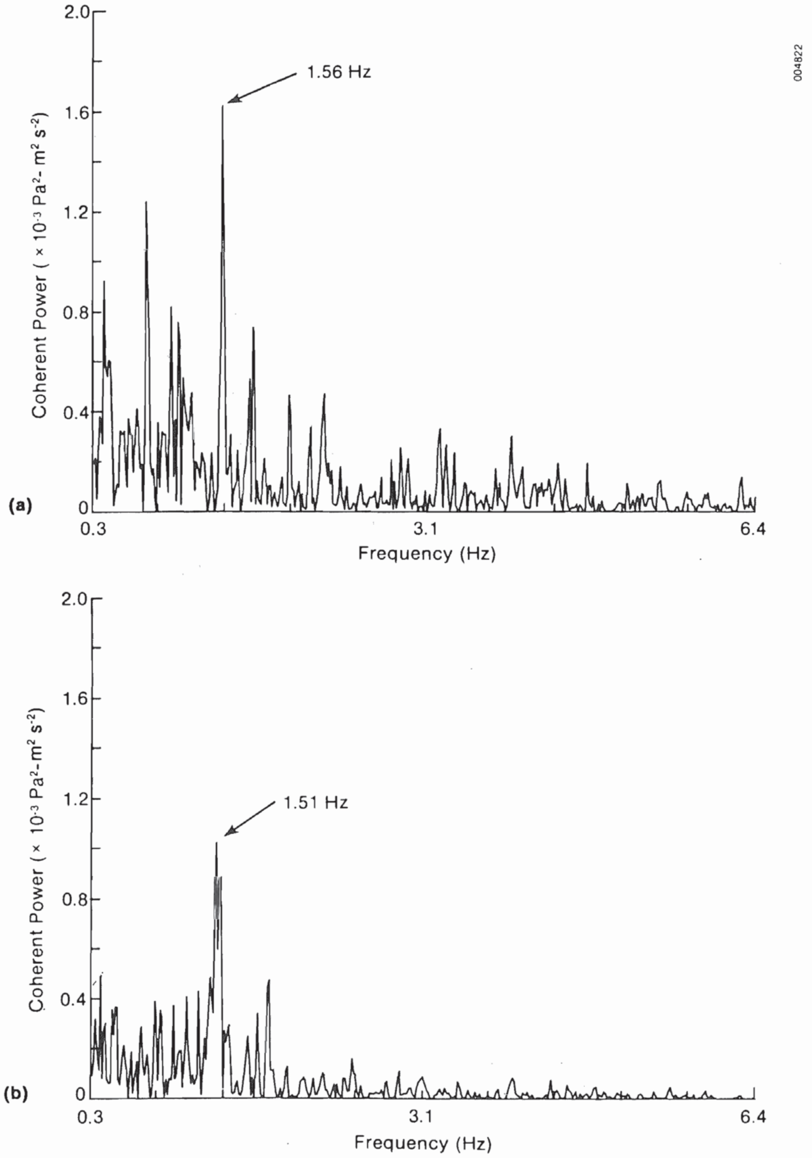

Figure 8-12. Coherent Power Analysis of Upper (a) and Lower (b) Wake Velocities and Dynamic Pressure at 1.5D Downstream of Vortex Generator-Treated Cylinder

We conclude that the vortex generator or turbulator type of spoiler will provide the separation line distortion required to prevent strong 2-D wakes from developing in the lee of cylindrically shaped support tower elements. This particular experiment, however, has shown the need to treat not only the portion of the tower element immediately upstream of the rotor plane, but also at least the length of the rotor below the blade tip in order to minimize effects of untreated areas and thus reenergize the spoiler-derived portion of the wake with discrete structures.

8.3.3 The Helical Strake Spoiler

The third type of aerodynamic spoiler investigated has been the helical strake (or spiral fence). This device was first proposed by Scruton and Walshe [42] as a means of preventing aeolian instabilities which, if coupled to lightly damped modes, could be responsible for failures of cylindrically shaped structures such as tall smokestacks. The advantage of the strake, and the two previous devices discussed, is that they are omnidirectional in their effectiveness. We have considered other devices that have been suggested (such as airfoil sections, upstream fences, etc.), but all suffer from the disadvantage of needing to be moved with the wind azimuth to be effective. This ability to follow the wind necessitates additional mechanical devices such as low-friction bearings and complicated mounting devices, which, if they fail to function properly, may make the noise problem more severe than if the problem were left untreated.

The theory behind the helical strake, as shown in Figure 8-13 installed on our cylindrical test section, is that it continuously distorts the parallel or vertical separation line from which the 2-D wake is generated. Woodgate and Maybrey [43] performed extensive testing to determine the most effective strake configuration (in terms of minimizing aeolian instabilities) and found the optimum to be three strakes (fences), a screw pitch angle equivalent to about 5 cylinder diameters (D) (30°-40°), and a height of about 0.1D. Our test item, which was manufactured by a special machine designed to make auger elements, was constructed of 5 x 0.1 cm (2 x 0.25 in.) steel bar stock formed into a spiral with a 10 pitch (the shape most readily available). We also reinstalled short sections of the vortex generators below the base of the test cylinder in an effort to minimize "crosstalk" between the treated and untreated portions of the support tower, as pictured in Figure 8-13.

8.3.3.1 Acoustic Results

In winds averaging 7-8 ms^{-1} and with a good indication of the Strouhal excitation of the tower wake, no impulsive-type noise could be audibly detected. A more quantitative analysis of the available data remains to be done, however.

8.3.3.2 Wake Characteristics

The wake characteristics, as measured in the rotor plane 1.5D downstream, are exemplified in the velocity spectra derived from hot-film anemometers placed at the cylinder midpoint height and near the base of the test cylinder as

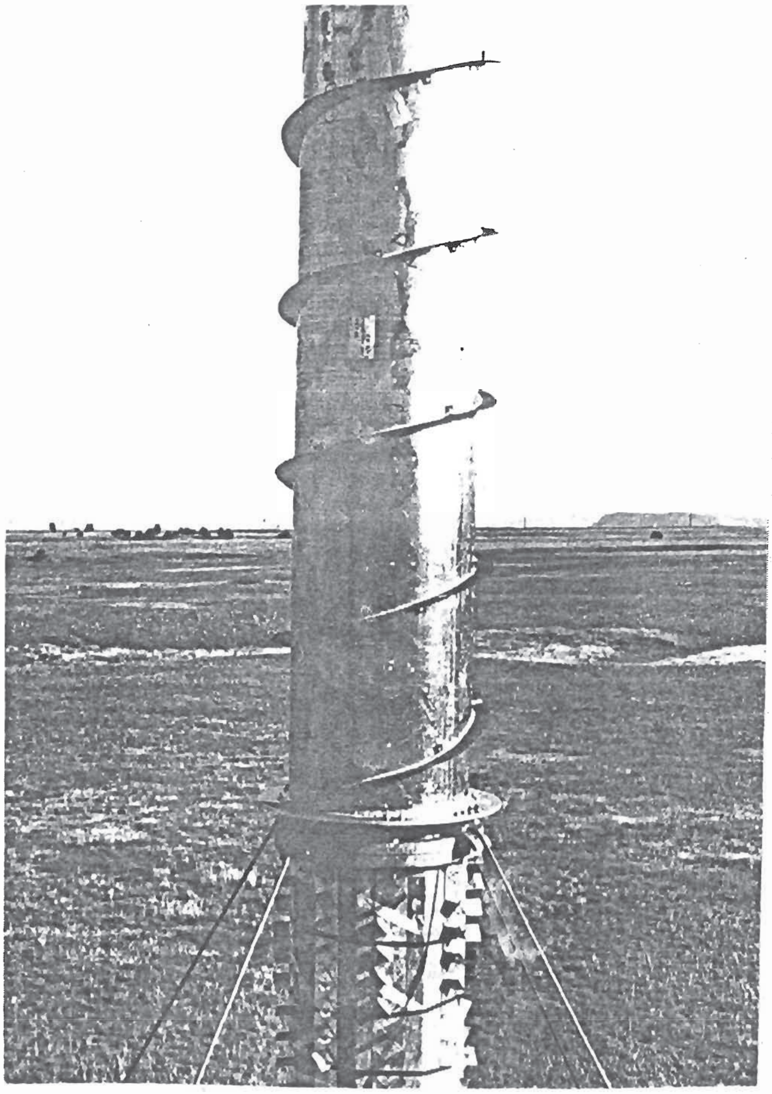

Figure 8-13. View of Helical Strake (Spiral Fence) Spoiler with Vortex Generator Sections Installed Below on 0.5-m Test Cylinder

shown in Figure 8-14. The upper probe spectrum is essentially broadband with a mean-square value of 0.868 m^2s^{-2}. The flow at the cylinder base is more energetic (probably influenced by the vortex generators immediately below), with a mean-square value of 4.16 m^2s^{-2} but with what appears to be a discrete component at 2.31 Hz. The coherent power analysis of Figure 8-15 does, however, indicate some vertical coherency between the base and midpoint of the straked cylinder, which we believe to be the result of influences from either below or above the treated area, or both. The coherent power analysis between the wake velocity and dynamic pressure fields strengthens the argument that the wake at midpoint height is broadband chaotic, as evidenced by Figure 8-16a and with some discrete elements in the wake near the base, as indicated by Figure 8-16b.

8.3.3.3 Interpretation

The wake measurements at the cylinder midpoint height, where the influence of the untreated tower sections appears to be minimal, confirms the effectiveness of the helical strake in converting a discrete 2-D flow into a chaotic 3-D circulation--the desired goal. These results are in agreement with those of Snyder and Wentz [14] who found a similar wake structure downstream of a straked 0.5 cylinder in their full-scale Reynolds number wind tunnel test.

There has been some criticism of using spoiling devices such as the strake because of the potential for an increased wake deficit caused by the high drag coefficient in the supercritical Reynolds number ($Re > \sim 300,000$), as plotted in the data of Figure 8-17 from Ref. [44]. We believe this may only be a consideration for turbines whose rotors pass in the near-wake region or closer than about 3D because the strong 3-D circulation prevalent in the far-wake region tends to diminish the mean deficit rapidly by being re-energized by freestream turbulence entrainment. Further, the space-scale spectrum of the wake turbulence created by strake action appears not only to be broadband but also dominated by a scale that removes much of the remaining perturbations from the critical unsteady excitation range discussed in Section 8.2. It is also known that a predominance of small-scale turbulence can be beneficial, because it has a stabilizing influence on the airfoil boundary layer and delays separation, something we found to be true in our analysis of the MIT anechoic wind tunnel tests reported in Section 5.2.1.

8.4 CONCLUDING REMARKS

In this section, we have reviewed our results in evaluating the effectiveness of various aerodynamic spoiler designs whose purpose is to (1) destroy the parallel or vertical separation line of a cylinder wake responsible for vertically coherent, 2-D vortex wakes in the lee of the MOD-1 tower legs, and (2) convert the wake turbulence from narrowband discrete to a broadband characteristic with a chaotic 3-D circulation. While we cannot yet be sure about the perforated shroud (which needs more study), the vortex generator or turbulator and the helical strake spoilers (if installed properly) do perform the required functions. The strake, however, appears to be the most desirable, based on construction and installation simplicity. We suggest, therefore, the installation of appropriately configured strakes to almost the entire height

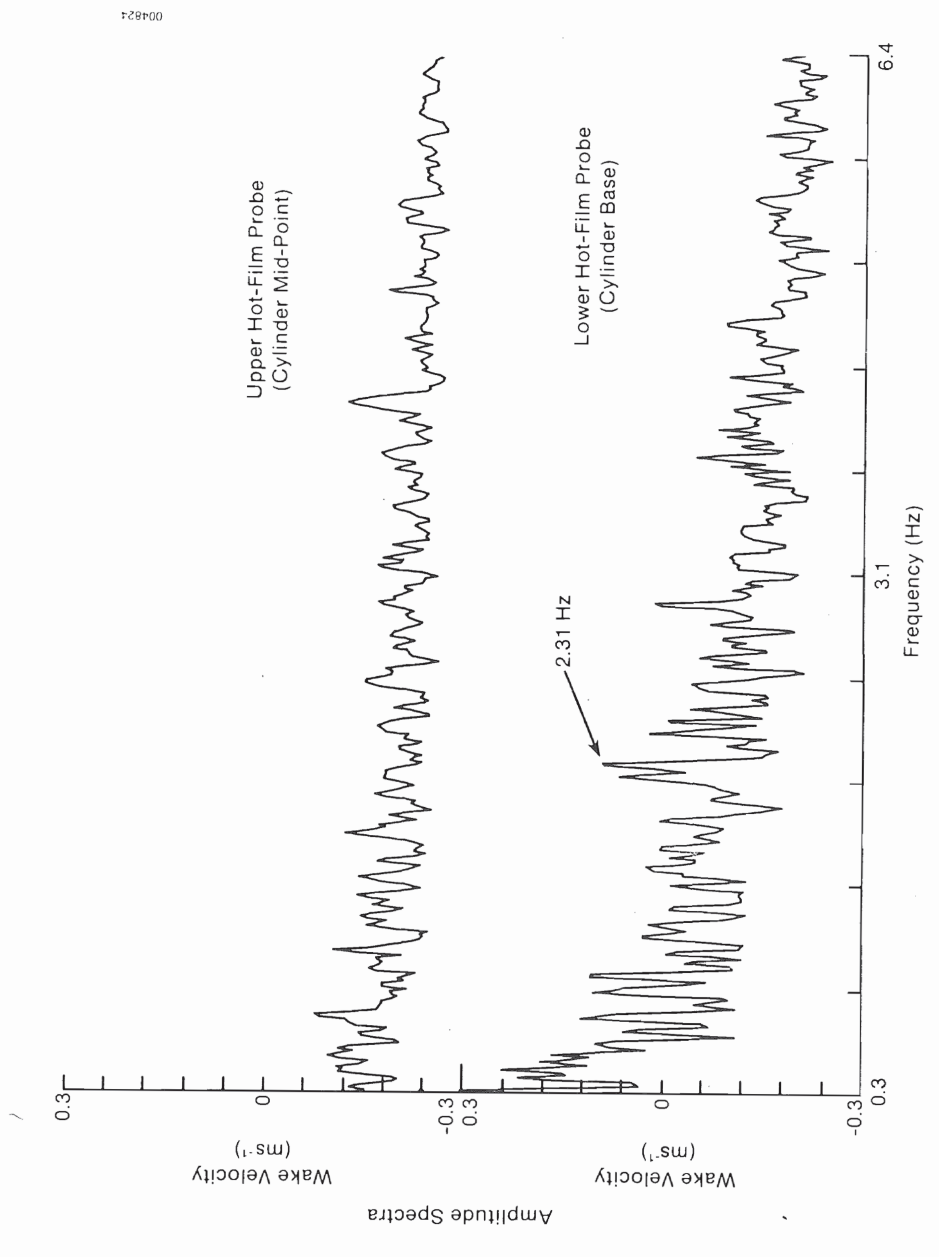

Figure 8-14. Upper and Lower RMS Wake Velocity Spectra Measured 1.5D_r Downstream of Cylinder Treated with Helical Strake

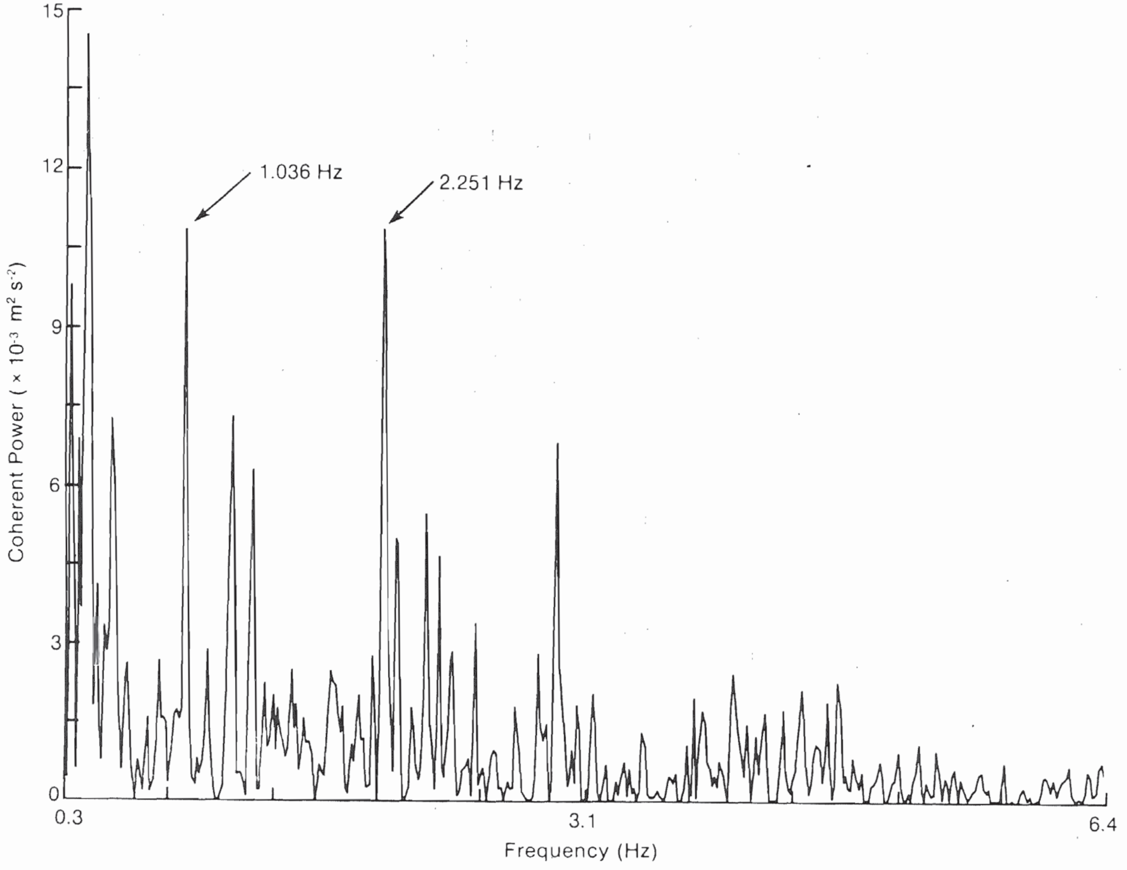

Figure 8-15. Coherent Power Analysis of Upper and Lower Wake Velocities of Figure 8-14

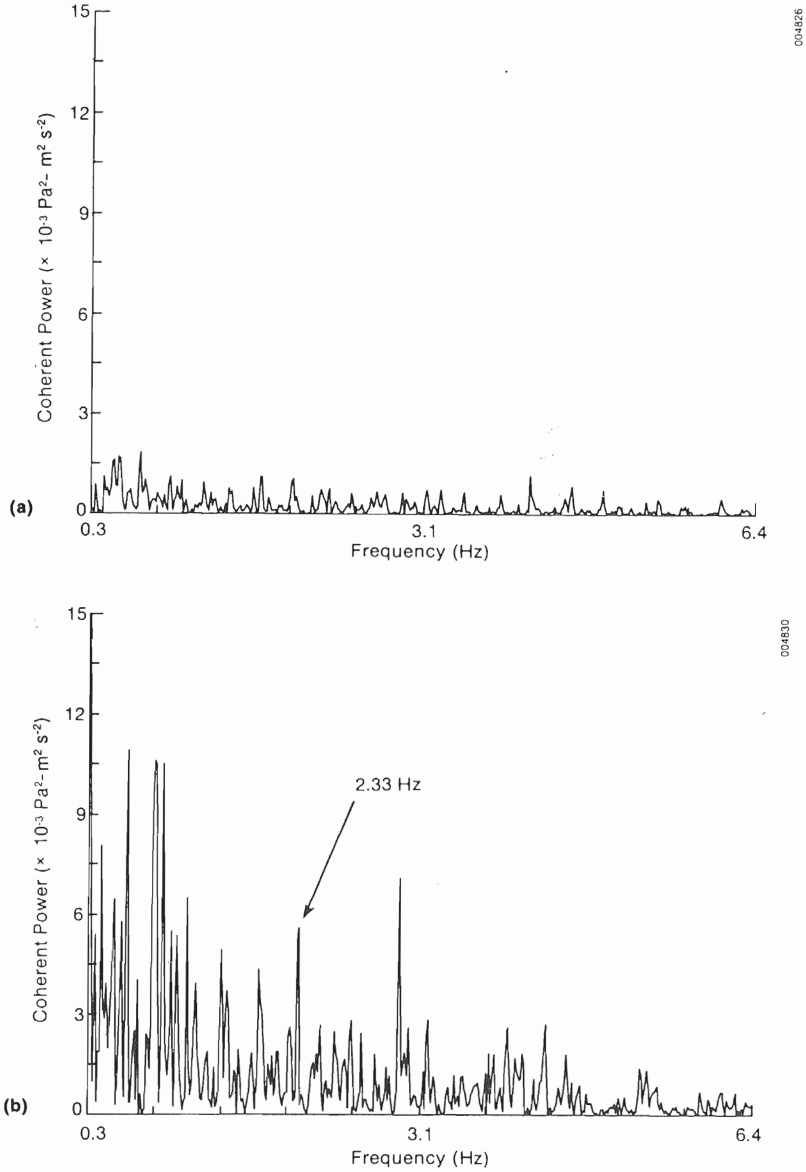

Figure 8-16. **Coherent Power Analysis of (a) Midpoint Wake Velocity and Dynamic Pressure and (b) Base Velocity and Wake Dynamic Pressure**

of the large 0.5-m-diameter vertical MOD-1 tower members. We suggest that these devices be installed over the large cylindrical members shown in Figure 8-18 before a turbine of this design is operated in the future.

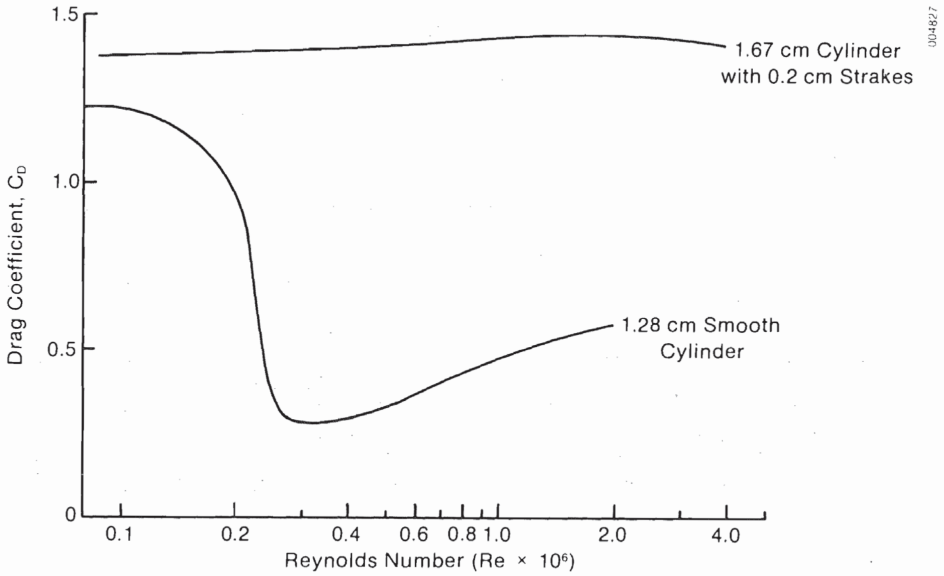

Figure 8-17. Drag Coefficients vs. Reynolds Number for Smooth and Straked Cylinders

Source: Ref. [44].

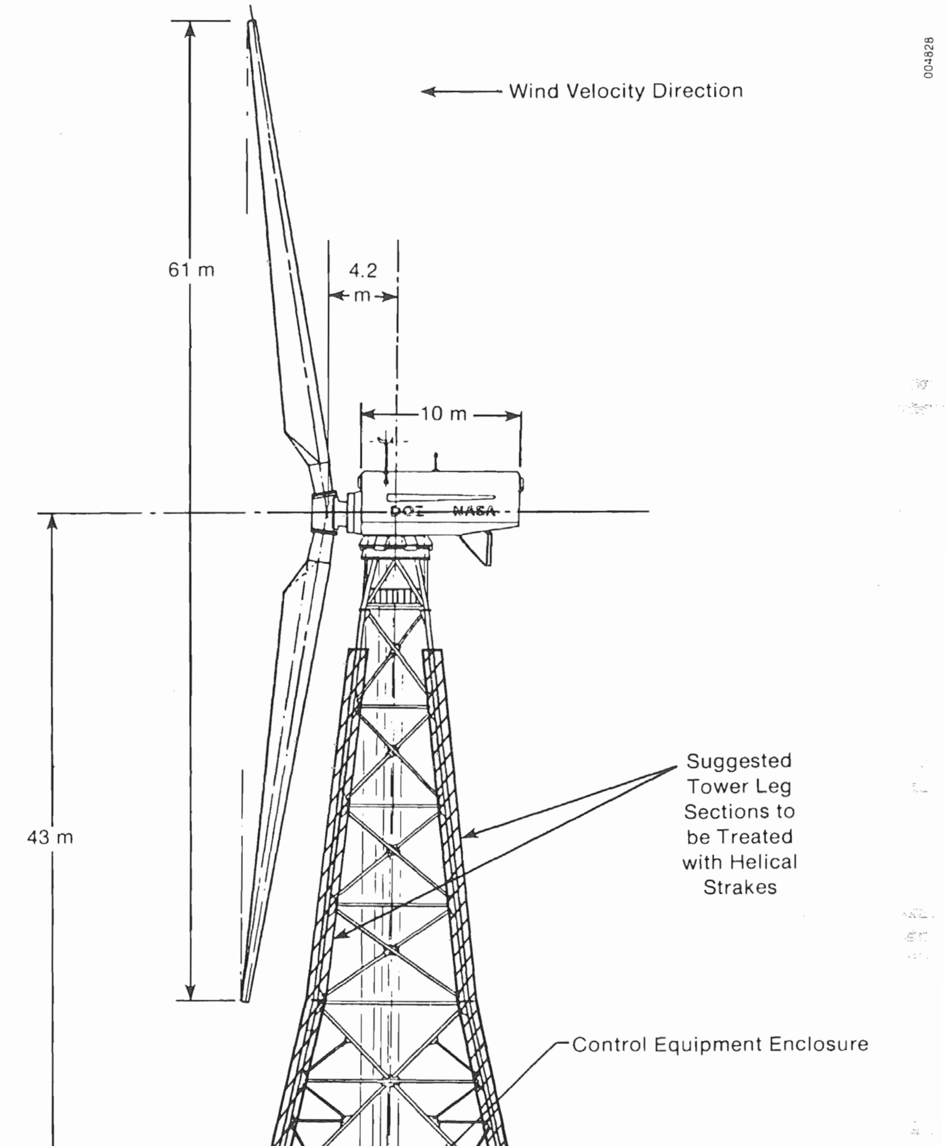

Figure 8-18. Suggested Helical Strake Treatment of MOD-1 Tower Legs

SECTION 9.0

CONCLUSIONS

The objectives of this study have been to investigate the physical mechanisms responsible for the generation, propagation, and impact of the annoyance associated with the operation of the MOD-1 wind turbine near Boone, North Carolina. It was necessary to develop a definitive knowledge of each of these areas in order to (1) best decide on the most effective abatement procedure to employ on the MOD-1 itself, and (2) apply this knowledge to noise control in other wind turbine designs, both large and small.

9.1 A PROPOSED PHYSICAL MECHANISM RESPONSIBLE FOR HUMAN ANNOYANCE

In this section we summarize our conclusions in defining proposed physical mechanisms responsible for the annoyance (impact) of the dozen families involved in the study and the process involved in the generation and propagation of the noise to the affected homes.

Our detailed field investigation of the effect of the MOD-1 noise on two of the affected houses during March 1980 corroborated and confirmed the nature of the annoyance. We have found strong evidence that the major causal agent responsible for the annoyance of the complaining residents was the excitation of highly resonant structural and interior air volume modes by the acoustic impulses generated by the operation of the MOD-1 turbine. The coherent, low-frequency acoustic radiation indicative of these impulses coincides almost perfectly with the fundamental and higher resonant structural modes of the homes. Comparison with a nonimpulsive, low-frequency source affecting residential structures has supported the existence of the annoyance situation perceived by the Boone residents and has shown the same strong acoustic-structural dynamic interaction.

The audible-range sounds perceived indoors by the Boone residents appear to have had at least two sources: (1) secondary emissions from the vibrating of loose objects or very lightly damped structural elements, and (2) direct radiation from the turbine impulses transmitted through the structure. We believe that source (1) was dominant at Boone. The general lack of audible-range sounds present in the homes undergoing nonimpulsive acoustical loading appears to be a consequence of the low emission levels at these higher frequencies and the nontransient, temporal characteristic (low coherence) of the radiation source.

The coherence (impulsiveness) of the emitted low-frequency acoustic radiation has been identified as a major factor in determining not only the level of potential annoyance to residents within a structure, but perception as well. We developed a joint probability technique to assess the level of impulsiveness in wind turbine acoustic radiation using four contiguous octave-frequency bands covering the structurally sensitive range of 5-100 Hz. Using this technique, we were able to make a rough estimate of external joint band intensity levels which can cause perception (not annoyance) within a typical residential structure. The joint radiation levels (expressed in terms of acoustic intensity and measured external to a structure) in the 8, 16, 31.5, and 63 Hz standard (ISO) octaves should not exceed band intensity threshold limits of 60, 50, 40, and 40 dB (re 1 pWm^{-2}) more than 20% of the time. These figures compare favorably with a summary of low-frequency annoyance situations by Hubbard [32]. Thus, these figures provide the basis for an acoustic figure of merit of the annoyance potential of a particular wind turbine design when compared with actual measurements of joint band levels made at an on-axis reference distance of 1.5 rotor diameters up or downwind of the machine.

9.2 AERODYNAMICS GENERATING MECHANISM RESPONSIBLE FOR MOD-1 IMPULSIVE NOISE

The intersection of the MOD-1 rotor blades and the vortex tubes contained in the downstream wakes of the large, 0.5-m-diameter cylindrical tower legs have been shown to be the most likely source of the intense acoustic impulses responsible for the annoyance of the nearby residents. The scale of these disturbances (which is controlled by the tower's major support leg diameter), their vertically coherent structure, and the vortex strength (a function of the freestream velocity) when coupled with the 44xx-series airfoil shape create a strong, transient lift change possibly related boundary to layer separation on the turbine blades, which radiates as a dynamic pressure wave or impulse. We have also shown that the character of the leg wakes is strongly influenced by such environmental factors as the freestream velocity, vertical wind shear and stability, and upwind fetch properties. For these reasons, the severity of the impulses is not simply related to the mean wake deficit, and they exhibit a probabilistic distribution in their physical properties. As a consequence, we have determined that the impulse generation is a result of two narrowband stochastic processes: one is related to boundary layer instabilities in the airflow around the tower legs which controls the downstream wake embedded vortex characteristics and the other, a somewhat similar situation, involves the stability of the boundary layer of the rotor leading edge as it cuts through these wakes.

We have shown that a reduction in impulse intensity below nominally perceptible limits is only possible by (1) making the rotor blade loads insensitive to the 2-D wake disturbances (which would require, in all probability, a different shape and therefore a new rotor), or (2) converting, by some suitable means, the strong, 2-D narrowband wake characteristics into 3-D broadband chaotic throughout the critical perturbation reduced frequency range of $0.5 \leqslant k \leqslant \pi$. Slowing the rotation rate, which has been tried, has been shown to be only partially successful, since no modification of the wake characteristics takes place and the improvement is strictly related to the decrease in the magnitude of the quasi-steady lift. In this regard, we suggest installing an appropriate aerodynamic spoiling device such as the helical strake or fence on each of the four major legs.

9.3 ROLE OF ATMOSPHERIC PROPAGATION IN THE SEVERITY OF THE MOD-1 ANNOYANCE

As a result of an analytical and field measurement effort, the Penn State Group [3,30] has found that a combination of terrain reflection and atmospheric refraction is responsible for focusing the turbine impulses into locations occupied by several of the affected homes. They have estimated, and it has been experimentally verified, that this focusing is capable of raising local incident levels to more than 25 dB above the figure expected from the spherical spreading of the source alone. They also found that ground propagation was insignificant in comparison with reflection and refractive airborne propagation. These results underscore the need to control the noise at the source, not only in the case of the MOD-1, but where any large wind turbines are installed near human populations.

9.4 ANSWERS TO QUESTIONS POSED IN SECTION 1.5

Three specific questions were posed in Section 1.5 of this report, and our answers are presented here.

1. Why did the noise not reach annoying levels each time the turbine was operating? We have shown that the characteristics of the tower leg wakes were very important in whether or not strong impulses were produced. These characteristics (vortex strength, in particular) are functions of the freestream velocity, turbulent energy levels in the critical Strouhal shedding frequency range, vertical shear and stability, and upwind fetch. Further, certain wind directions tended to orient the turbine and its radiating lobes away from the most frequently affected homes at times, or a combination of terrain and atmospheric refraction failed to focus the sound sufficiently to be heard.

2. Why were some families annoyed more often than others and why did the situation confine itself to such a small fraction of the overall population living within 3 km of the machine? Again, the reason why certain homes were affected more frequently was because of three factors: (a) the orientation of the turbine (which positions the lobes of the acoustic dipole in their general direction) (a function of the site climatology); (b) the terrain along the centerline of these dipoles; and (c) the vertical variation of wind speed and temperature. By far, factors (a) and (b) appear to be the most influential, since they both subsequently have an influence over (c). Figures 6-5 through 6-9 show sound ray paths for various radial directions from the turbine, and the importance of the terrain is clear. The small population fraction bothered by the turbine happened to live in locations where a combination of terrain and refractive focusing reached maximums, or caustics, a good portion of the time.

3. Why did the noise appear more noticeable inside the affected homes and why did it become more persistent and perhaps louder during the evening hours? The noise was more noticeable within the homes because of the dynamic amplification and resonances created in the internal acoustic pressure field because of the interaction between the external transient acoustic loading and the lightly damped elastic response of the residential structure. This dynamic interaction serves to extend the impulse time period from a few milliseconds outside to more than a second indoors. There were two reasons why the sounds became more persistent and perhaps more severe at night. The first reason again relates to the site's climatology, in which the diurnal variation in wind speed tends

to reach a maximum during the period slightly before local sunset and continues up to the early hours of the next morning, with a secondary peak occurring just after local sunrise and continuing for one or two hours thereafter. A coupling of this evening wind-speed maximum with the second reason, the transition from a daytime to nocturnal atmospheric surface layer, in which the surface to hub-height stability increases and encourages the development of turbulent shear layers, resulted in a greater degree of Strouhal excitation of the tower leg wakes. This combination of higher wind speeds and Strouhal excitation increased the intensity and 2-D structure of the embedded wake vortices and, subsequently, the severity of the impulse generated by the turbine rotor blades. These conditions may have persisted for up to four or five hours, depending on conditions, and therefore appeared more severe and persistent to the affected residents during those periods of the day. Furthermore, generally lower ambient noise levels occur during the early evening hours, which perhaps also contributed to the increased sensitivity of the affected residents.

SECTION 10.0

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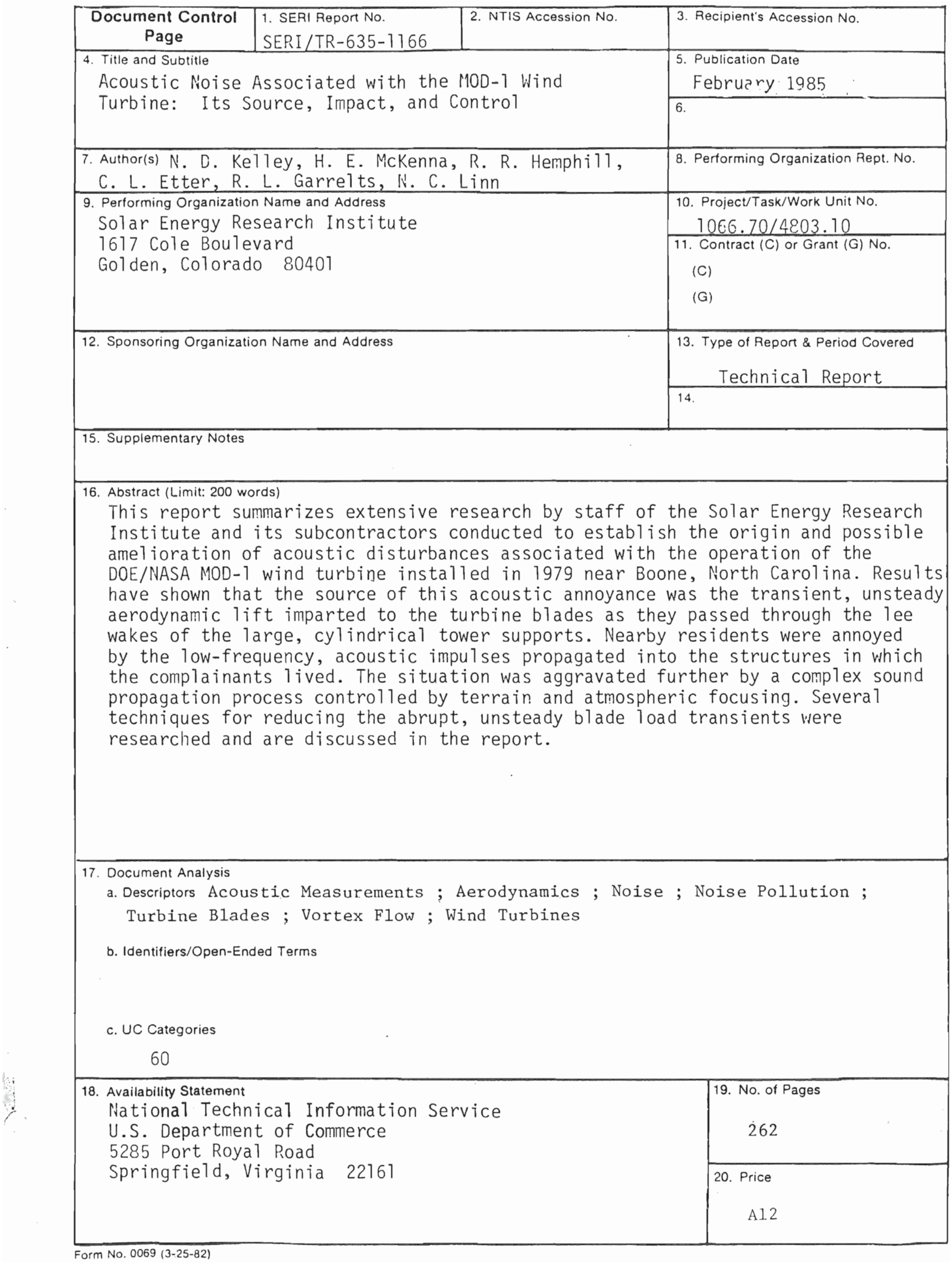

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This report summarizes extensive research by staff of the Solar Energy Research Institute and its subcontractors conducted to establish the origin and possible amelioration of acoustic disturbances associated with the operation of the DOE/NASA MOD-1 wind turbine installed in 1979 near Boone, North Carolina. Results have shown that the source of this acoustic annoyance was the transient, unsteady aerodynamic lift imparted to the turbine blades as they passed through the lee wakes of the large, cylindrical tower supports. Nearby residents were annoyed by the low-frequency, acoustic impulses propagated into the structures in which the complainants lived. The situation was aggravated further by a complex sound propagation process controlled by terrain and atmospheric focusing. Several techniques for reducing the abrupt, unsteady blade load transients were researched and are discussed in the report.

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Subject: Fwd: The dirty secret of Britain's power madness: Polluting diesel generators built in secret by foreign companies to kick in when there's no wind for turbines - and other insane but true eco-scandals | Mail Online

I came across this article in the Daily Mail and thought you would find this of interest.

The amount of evidence and reports into the scam that is the wind industry is substantial, with reports coming out practically on a daily basis from all around the world.

It is now time to stand up for the people you represent and say enough is enough.

This so called "green energy" is a complete farce and waste of money and has numerous serious consequences. Division among families and rural tight knit communities, adverse health impacts on people as a result of industrial wind turbines being sited too close to their homes, damage to wildlife and the killing of bats and birds, the damage to the environment and to streams and rivers, the negative visual impact of our beautiful countryside much of which are Areas of Outstanding Natural Beauty and widely promoted as a popular tourist destination and the loss of jobs in this sector as a result, the devaluation of property as a result of industrial wind turbines / wind farms being sited too close to their property, this will also have a negative impact on any future planning applications for any dwellings and this will lead to a fall in revenue in the amount of rates being paid by these properties, the list goes on.

The environmental damage carried out by and hidden by the wind industry was also exposed by Channel 4 News. Please take the time to google "Rare Earth Elements" (John Snow's picture is on the home page).
This tells the story of the extraction of rare earth elements required in the manufacture of a wind turbine. Each wind turbine requires two tonnes of these rare earth elements. The story uncovers how the local farmers were deprived of their land and promised to be relocated to new settlements, another empty promise, they are now left with land they cannot use with no running water and lakes of toxic waste, but no one was meant to find this out because this is suppose to be "Free and Green".

Increasing electricity bills, almost 40% increase since the renewable energy programme was launched, this madness is driving more people into fuel poverty and businesses facing closure or relocating overseas with further job losses as they cannot compete with their competitors overseas because their running costs are much higher.

The front page of the Sunday Telegraph recently ran the story that subsidies paid out to the wind industry equates to £100,000 per employee. This is staggering and hard to believe but it's true.
If the wind industry was so great as they would have us believe, surely then the wind industry would be able to stand on it's own two feet and NOT depend on any subsidies at all, which was over £140 Million alone in Northern Ireland in the last 3 years, never mind the constraint payments they receive.
This point proves that the wind industry is Unsustainable and Unreliable because it is depending on substantial subsidies. This money would be better spent on our schools and hospitals where

it Will be able to keep A&E departments open with proper staff and not have scenes like we witnessed recently at the A&E at the Royal Hospital in Belfast, where that money will do some good and we can see the benefits.

In this day and age people are more aware of their spending and looking for value for their money, more so than ever before.

Ask yourself this question: Are we getting value for our money which is being paid in subsidies to the wind industry to do all the damage and all the hidden costs which I mention above?

People are now waking up and starting to question what is being pulled over their eyes and what is being taken out of their pocket.

Why does the wind industry gag their landowners?
Why does the wind industry bribe people by offering their neighbours £200 off their electricity bill?
Why does the wind industry bribe the councils by so called "community benefits" when the money is coming from that community through hidden charges in their electricity bills in the first place?

How do you determine community as to who benefits?

I asked this question to the members of the working group from the Omagh and Strabane District Councils at a meeting with them in January last, they could not give me an answer. We now know that it is 8 miles from the perimeter of a wind farm according to their recent discussion document.

The reason I mention this point is because a recent advert in a local newspaper relating to a wind farm in Castlederg said that community groups from within a 10km radius of that wind farm could apply for this so called "community benefit".

Is that an admission of liability from the wind farm developers that people living from within a 10km radius of that wind farm are effected in a negative way as a result of that wind farm being sited too close to heir homes?

"Free and Green" they proclaim!

Well the truth is, It's certainly not Free and It's far from Green!

Best regards,

Owen McMullan Chairman
West Tyrone Against Wind Turbines

Hi Sheila,

Please see below Addition No.9 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

\>> Subject: Council of Europe
\>>
\>> Please see the link below for the Council of Europe relating to culture heritage and landscapes.
\>>
\>> The UK & Irish governments have signed up to this.
\>>
\>> Don't be put off by the 257 pages.
\>>
\>> Pages of note are pages: 17, 153 - 167 , 175. 243 - 248
\>>
\>> On page 160 it states that the Sperrins Walking Festival celebrates the landscape of the region
\>>
\>> It also states the the NITB recognises the importance of the landscape to the tourist industry.
\>>
\>> One wonders how these energy companies are actually sponsored by state via substantial subsidies which is taken from consumers in hidden charges on their energy bills, come into our beautiful countryside and do the damage they do with NO regard whatsoever for the environment or for anything living in it and that includes us
\>>
\>> Yours sincerely,
\>>
\>> Owen McMullan, Chairman
\>> West Tyrone Against Wind Turbines,
\>>
\>>
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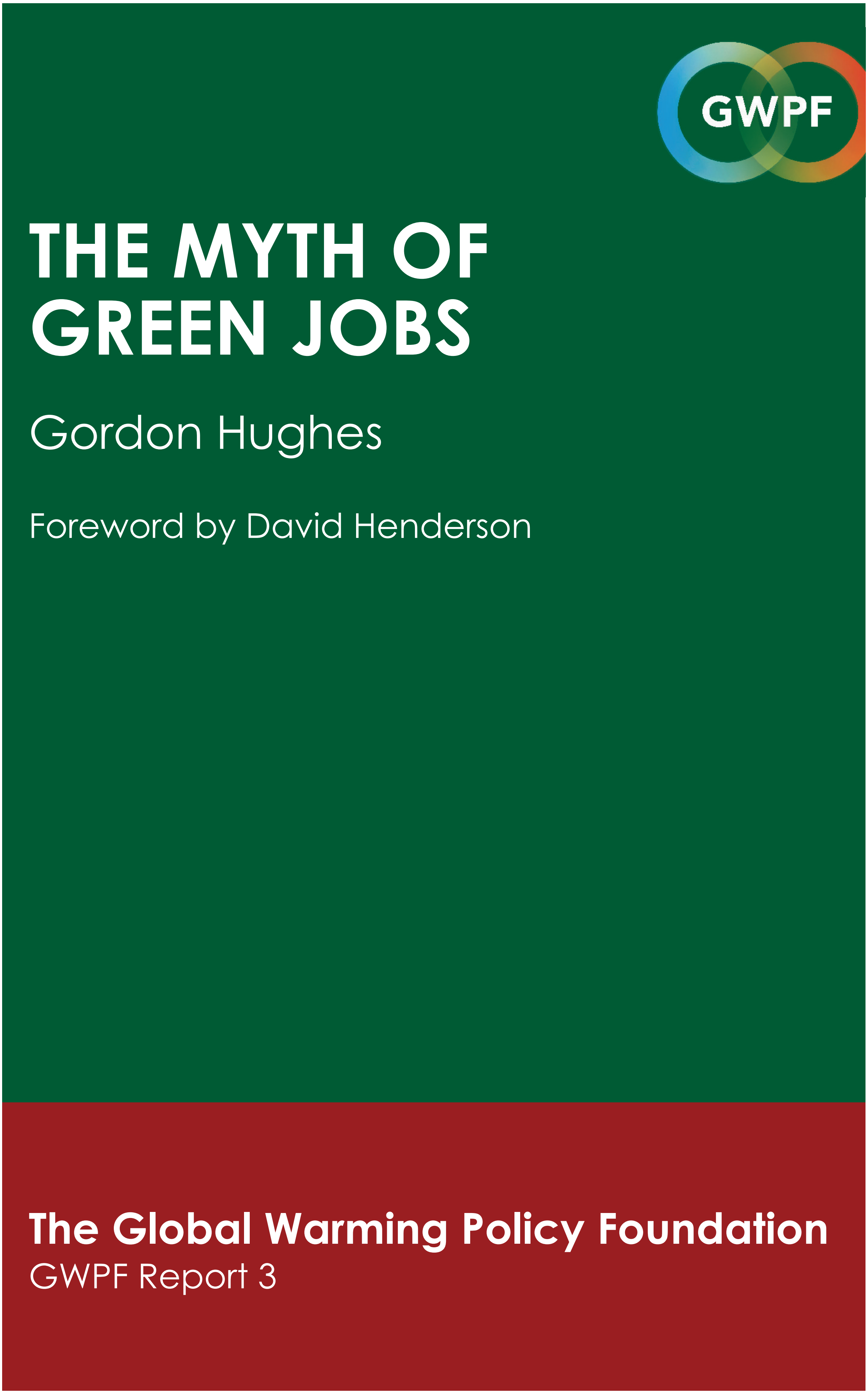

GWPF

THE MYTH OF GREEN JOBS

Gordon Hughes

Foreword by David Henderson

The Global Warming Policy Foundation
GWPF Report 3

GWPF REPORTS

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Dr Benny Peiser

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Contents

Professor Gordon Hughes
Dr Gordon Hughes is a Professor of Economics at the University of Edinburgh where he teaches courses in the Economics of Natural Resources and Public Economics. He was a senior adviser on energy and environmental policy at the World Bank until 2001. He has advised governments on the design and implementation of environmental policies and was responsible for some of the World Bank's most important environmental guidelines.

Professor David Henderson
David Henderson was formerly Head of the Economics and Statistics Department of the Organisation for Economic Cooperation and Development (OECD) in Paris. He is the Chairman of the GWPF's Academic Advisory Council.

Foreword

In relation to climate change issues, there is an official policy consensus. The consensus is virtually world-wide, and has now been in place for over 20 years. The measures which reflect it have largely focused on 'mitigation' – that is, on curbing emissions of (so-called) 'greenhouse gases'. Ambitious long-term targets have been set for 'decarbonisation' of economies, and an array of policies is already in place with more of the same in prospect. A transformation of world energy systems is envisaged.

The generally accepted rationale for these far-reaching actions is that they are necessary, or at any rate highly desirable, to avert the threat of dangerous global warming. Within this approach, it is admitted that the required mitigation measures involve higher costs, of energy in particular: in themselves, in isolation, they would make the world somewhat poorer. But the official policy consensus holds that these costs, while uncertain and possibly substantial, are known to be greatly outweighed (or overshadowed) by what would without them be the costs (or risks of disaster) from global warming. Mitigation policies, despite their costs, are thus seen to yield a clear net benefit to the world.

In recent years, however, a different way of thinking has emerged and gained ground. Within it, mitigation policies are seen as involving not just costs to be borne for reasons of prudence, but rather a new path to prosperity. 'Green growth' is put forward as the key to sustained economic progress and the creation of new jobs.

Gordon Hughes's paper offers a powerful critique of this way of thinking, focusing chiefly on the claims made for job creation. He deals with the arguments on two different levels.

The first level is that of projects or programmes. Here he makes the fundamental point that in appraising these, prospective labour inputs are to be viewed as a cost not a benefit: labour costs should be counted as such, along with other inputs (such as energy). Hughes notes that if the objective of policy is to reduce CO2 emissions, the right course of action is to minimise the costs of any such reduction; and these include the costs of labour.

A second level is that of the economy as a whole – the possible macroeconomic effects of green energy policies. It is here in particular that green growth (and green energy) policies are now seen as intrinsically positive, through creating new opportunities for productivity-enhancing investments linked to a combination of rapid technological advances, higher energy efficiency, and expanding international markets.

In that context, Hughes makes a key point which is often overlooked. He says, correctly, that 'there is no general reason to assume that future technical progress and improvements in efficiency will favour renewable sources of energy over non-renewable sources'. As to the notion of gaining a new range of profitable exports, he reviews specific areas and finds that they 'provide no evidence that the UK can acquire a long-term comparative advantage in the manufacture of renewable energy equipment by any combination of policies that are both feasible and affordable'.

While the supposed large gains from green energy policies appear as illusory, the costs are well authenticated and heavy, for reasons that Hughes spells out in relation to power generation. He concludes that, on present plans, 'the wholesale prices paid for electricity by industrial and other large users will increase by at least 100% and more likely 150% over the next 5-8 years'. He notes the obvious and worrying implications for output, exports and employment in British manufacturing industry.

An indirect but potentially serious consequence of continuing officially-induced higher energy prices, as Hughes points out, is that the trend rate of inflation is pushed up. Meeting official inflation targets will thus require stricter monetary policies to hold in check other forms of price increases, with probable negative effects on aggregate output and employment.

Current renewable energy policies are no more than an unnecessarily costly means of achieving given emissions reductions. The idea, now embraced by Her Majesty's Government, that officially-created higher energy costs open up exciting new prospects for growth and jobs, is an illusion which this paper dispels effectively.

David Henderson

August 2011

Summary

1. Meeting the UK Government's targets to reduce CO2 emissions by relying upon green energy will be very expensive. To mobilise support for this spending, government bodies and lobby groups have been making increasingly extravagant claims about its supposed economic benefits. The usual formula is to claim that a proposal or policy will "create" some number of jobs and, perhaps, stimulate the future development of competitive industries.
2. The first observation is that job creation has no merit as a basis for judging policy. Total income, or value-added, or welfare is what matters, not the number of jobs. If this were not the case, why not employ 50% more workers to produce the same output and reduce all wages by one-third? Employing more people involves costs including loss of leisure or alternative output, travelling to work, extra consumption, etc. This is only worthwhile if the extra output produced by the workers is valued more highly than these costs.
3. A second observation is that there are no sound economic arguments to support an assertion that green energy policies will increase the total level of employment in the medium or longer term when we hold macroeconomic conditions constant. Yes, more people may be employed in manufacturing wind turbines and constructing wind farms, but this neglects the diversion of investment from the rest of the economy. We must look to macroeconomic and labour market policies to influence the level and composition of employment.
4. Careful investigation of the impact of green energy policies on the labour market shows a very different picture from that depicted by enthusiasts and lobbyists. The key lies in the fact that green energy is highly capital-intensive. As an illustration, the target for generating electricity from renewable energy sources will involve a capital cost that is 9-10 times the amount required to meet the same demand by relying upon conventional power plants. There is not even a substantial saving in operating costs because the limited reduction in fuel consumption is largely offset by higher operating and maintenance costs.
5. Naturally, spending £120 billion - mostly on offshore wind farms - rather than £13 billion on conventional power plants will increase demand for labour in construction, turbine manufacture and related sectors, provided we ignore the diversion of funds from other spending to finance renewable energy projects. About 35% of total investment is translated, directly or indirectly, into wages and salaries. This is similar to other business investment, but the equivalent share for other forms of infrastructure or government services is nearly 70%.
6. If green energy projects are entirely financed by diverting money

from other forms of business investment, the immediate impact will be approximately neutral but both productive capacity and employment incomes will be lower in the medium or longer run. In practice, however, a significant part of the cost falls on the taxpayer, through a variety of disguised subsidies, with the consequence that spending on public services and capital projects will be lower. This will reduce either employment or employment incomes in the short and long run.

7. It is argued that green energy policies will promote innovation and the development of new industries. Almost every country in the world wants to claim the same benefit, so the numbers do not add up. Total employment in manufacturing wind turbines, solar cells, etc is small when compared with employment in the manufacture of conventional equipment for power generation and transmission. Some small countries – Denmark or Israel – have gained an initial advantage but this is rapidly disappearing as factors such as skills, transport costs, local demand and existing patterns of specialisation reassert themselves. For the longer term, there is little doubt that the primary beneficiary will be China. That is already apparent from the way the market is developing.

8. The focus on capital spending in the short and medium term gives a very partial view. The wholesale prices of electricity and other sources of energy must rise by 100% or more to cover the much higher capital and operating costs of renewable energy. Since other countries are not following the same route, the burden of adjustment will fall heavily upon workers in sectors producing traded goods and services. In sectors accounting for about 40% of employment in manufacturing and related industries, the prospective increase in energy costs amounts to more than 10% of current wages and salaries.

9. Manufacturing activities account for little more than 10% of total employment in the UK and they do not set the general level of wages, so the response to this change is likely to be contraction and relocation of production rather than a reduction in wages. In terms of the labour market, the gains for a small number of actual or potential employees in businesses specialising in renewable energy has to be weighed against the dismal prospects for a much larger group of workers producing tradable goods in the rest of the manufacturing sector.

10. A further consideration is that the Bank of England is required to set monetary policy to meet an inflation target. Policies to promote renewable energy will add 0.6-0.7 percentage points per annum to core inflation from now to 2020. To meet the inflation target, non-energy core inflation must be lower than would have been the case without these policies, requiring tighter monetary policies, which will cause a significant loss of GDP over this period.

11. The cumulative impact of current policies will amount to a loss of 2-3% of potential GDP for a period of 20 years or more. In the next 5-8 years a part of this cost may take the form of higher unemployment, because that

is an important element of the mechanism by which tighter monetary policies lower the core rate of inflation. After 2020 the main effects will fall on incomes rather than employment.

12. The merits of policies to promote a switch to renewable energy should be assessed by considering the average cost of reducing CO2 emissions in this way. This average cost exceeds £250 per tonne for the shift from conventional to renewable electricity generation without considering the macroeconomic consequences.

13. The decision to sacrifice at least 2% of GDP to reduce the UK's emission of CO2 by about 23 million metric tons per year, less than 4% of total emissions of greenhouse gases in 2008, is a choice that must ultimately be made by the public. They will have to bear the costs via lower real disposable incomes and higher prices. Claims by politicians and lobbyists that green energy policies will create a few thousand jobs are not supported by the evidence. More importantly, they are irrelevant when considering the choice that has to be made. Sadly, the claims seem intended to divert attention from the consequences of setting arbitrary and poorly-considered targets for renewable energy.

1. Introduction

In recent months the public has been bombarded with claims that some environmental policy or project will "create" hundreds, thousands or millions of jobs, in addition to reducing emissions of carbon dioxide. These claims are made by a variety of official bodies as well as by groups or businesses interested in promoting particular policies or projects. Examples of such claims made by politicians and official bodies include assertions that:

- meeting targets for renewable energy in the Europe Union will create 2 million jobs across the EU (the EU Commission);
- a Green Deal involving insulation of houses, the installation of smart meters and other energy saving measures will create up to 250,000 jobs in the UK (Chris Huhne, Secretary for Energy and Climate Change); and
- the development of renewable sources of electricity generation in Scotland will create 7,000 jobs (the Scottish Government).

Even worse, the claims are becoming steadily more hyperbolic with an escalation in the numbers of green jobs being claimed for various policy initiatives being multiplied by 2, 4 or even 10 times.

With such over-heated rhetoric it is necessary to take a step back and consider what basic economic principles tell us about claims for large scale job creation linked to policies intended to promote renewable energy, energy conservation or generally reduce CO2 emissions. There are three key questions that have to be addressed:

Question 1 – Why would or should the creation of jobs be seen as a reasonable basis for assessing the merits of economic or, even more, environmental policies?

The point of environmental policies is to achieve a higher level of environmental quality. Some people take the view that a pristine environment has an inherent value without consideration of any impacts on our well-being. Economic analysis has tended to focus on environmental quality as a factor determining human welfare. In either case, it is possible to assess the extent to which particular policies contribute to one or more goals that can be identified and, in principle, measured.

From this perspective, whether or not environmental policies lead to higher employment is entirely incidental to the main goals of green energy policies. Indeed we can go further. Job creation is a cost, not a benefit, of such policies. It involves the use of resources which could have been devoted to other ways of improving the environment or human wellbeing.

Question 2 – If job creation is a relevant basis for assessing the potential impact of environmental policies, are there sound reasons to believe that green energy policies can lead to an increase in the total level of employment?

This goes beyond the conventional calculus of employment in industries that are directly or indirectly engaged in the supply of renewable energy or other green goods and services to take account of the diversion of finance and other resources from other activities.

Question 3 – Is there any convincing evidence that the green energy policies being implemented in the UK and the EU will actually lead to higher levels of total employment, either in the short term or long run?

This is an empirical question, which can only be answered by careful consideration of the impact of green energy policies on the energy sector, energy users and the whole economy. Claims about green energy and job creation rely heavily upon anecdote, speculation and assertion, so no weight can be attached to figures that are not supported by a proper analysis of the mechanisms by which green job creation is supposed to occur.

The economic reasoning required to answer these questions is outlined in the sections that follow, but the simple answer may be summarised as No in each case. But, then, if (a) job creation is not a sensible goal for economic or environmental policies, and (b) there is little doubt that green energy policies are both expensive and more likely to destroy rather than create jobs, the obvious follow-up question is why so much weight is given to claims about green jobs.

One view is that such claims offer an optimistic vision for uncertain times. Proponents believe that a rapid transition to reliance upon renewable energy is essential for environmental and other reasons. However, the costs of the transition will be high and there seems to be no widespread public acceptance of the consequences of the adjustments involved, especially in hard economic times. So, the logic is that the costs of adopting renewable energy will be offset by job creation, which is simply assumed to be a good thing without explaining why.

Another point must be kept in mind. Few proponents will devote much time to the jobs created by their favoured policies or projects when these appear to have a good justification in their own right. No one points to the number of jobs created by improving the quality of education or health care. It is only when we encounter proposals whose merits are somewhat more questionable that vigorous efforts are made to construct arguments about the associated economic benefits.

Claims about green job creation offer a story about our economic future. In simple terms, the story is that the future economic prospects of rich market economies will be undermined by the economic success of countries like China, India and others. The suggestion is that the solution lies in promoting innovation and it is claimed that green technologies offer an opportunity for such innovation. The whole argument is nonsense and is based on the worst kind of "do-it-yourself economics". Countries are not companies and do not compete with each other in any meaningful way. There is no UK plc. In the medium and longer term, the average level of real incomes in any country depends upon investment and factor productivity, while economic history shows that (typically) more than 90% of the benefits of innovation accrue to consumers through lower prices rather than to producers. Nonetheless, the vision appeals to politicians and commentators when there has been a general loss of confidence in economic prospects, so it is necessary to examine whether it has any relevance to the UK's future economic prospects.

In the sections which follow I will consider each of the questions that were outlined above. The assessment of the actual impact of green energy policies on UK employment relies upon detailed empirical work presented in a separate paper titled '*Why is wind power so expensive?*' which will be published by the Global Warming Policy Foundation in September 2011.

2. Is job creation a good basis for assessing economic policies?

I will start with a simple parable. Suppose we are considering the adoption of two varieties of wheat. The varieties are identical in all respects – yield per hectare, fertiliser and machinery requirements, environmental impact, nutritional value, ease of use, etc – except that Variety A requires an input of 50 hours of labour per hectare of land over the course of a crop year, whereas Variety B requires an input of 100 hours of labour. Thus, planting 100,000 hectares of land to Variety A would "create" half the number of jobs as planting Variety B. Does this mean that economic policy should encourage the adoption of Variety B in preference to Variety A? Of course, the question answers itself: it would be an absurd distortion of economic criteria to argue that Variety B should be preferred on the grounds that it has a higher labour requirement. Anyone inclined to dispute this statement should first replace all references to labour by references to energy or capital and explain why it would be more desirable to adopt a technology that requires more energy or capital without any reduction in other costs.

Yet this is exactly the argument that is being put forward by the promoters of green energy, albeit in a disguised form. The central point of my parable is that the labour inputs required to grow the wheat are a cost – both for the farmer and for the whole economy. Even if there is widespread unemployment or under-employment, there is still a cost to planting the more labour-intensive variety. At the very least there is a loss of leisure, but more usually the employment of more labour will involve a variety of additional costs including transport, higher consumption of other goods and services, lower household production, etc. In economic terms, the opportunity cost of employing labour is not zero.

The real income – and ultimately the well-being - of a country depends upon the productivity of the labour, capital, land and natural resources used to produce goods and services, provided that those goods and services are valued either in the market or by the final users in the case of non-market activities. Using more labour – or capital - than necessary to produce wheat or electricity serves no purpose and simply reduces net incomes and the benefits of economic activity. It cannot be a sensible goal of policy to achieve that outcome.

The objection to this parable may be that I am interpreting the effects of job creation in too literal a manner. From this perspective, the real point of job creation is not using more labour inputs to produce the same output but that either (a) it is the route by which the total level of income and economic activity can be increased, or (b) the future productive capacity of the economy will be enhanced even if there is no immediate increase in output. A fashionable variant of this argument is that having a (useful) job is an important element in determining an individual's happiness and, thus, collective well-being.

Still, none of these arguments imply that job creation is a proper basis for judging economic policy. It is the things which are associated with employment – the production of valuable goods and services, the acquisition of useful skills or self esteem, the contribution to family or society – that may or may not justify projects or policies. Net job creation provides a mechanism by which the goals of economic or social policy may be achieved; it is not an end in itself.

One reason why employment on its own is not a suitable goal for economic policy is that it is easy for any government to create jobs. If tax revenues can be raised or money borrowed, workers can be added to the public payroll or otherwise contracted to provide a whole range of services from providing care to the elderly to filling potholes in roads. The constraint on the level of overall employment is not the capacity of the public sector to create jobs, but the willingness of the public to pay for these jobs through their taxes or charges for the services provided.

Green energy programmes are intended to meet basic requirements for electricity, heat, transport and other purposes while reducing the impacts on the global environment and natural resources associated with conventional energy production and use. At present, all forms of green energy tend to be substantially more expensive than conventional energy, so there is a trade-off between higher costs and lower emissions. This trade-off is not specific to green energy, since there are many ways of reducing emissions of greenhouse gases. Hence, the starting point of any assessment of such programmes should be the total cost per tonne of carbon dioxide saved – or its equivalent - which will be incurred by relying upon different measures or policies to reduce emissions.

The labour inputs required, for example, to manufacture wind turbines enter this assessment as a cost not a benefit. To reformulate the parable, let us suppose that we have two designs of wind turbine which have the same performance and reliability and can be manufactured and maintained at identical costs of materials and other inputs. However, Design A requires 10,000 hours of labour input (directly or indirectly) per MW of capacity while Design B requires 20,000 hours. Again, it would be absurd to suggest that Design B should be chosen in preference to Design A on the grounds that it will create more employment.

Public policies with respect to green energy ought to focus on reducing emissions at the lowest cost. This should be the position of both advocates for environmental improvements and those doubtful about their benefits. For the first group, lowering the cost of reducing emissions will make it more likely that greater reductions could be considered. For the second group this will, at least, minimise the economic cost of policies that may be considered misconceived. Thus, without taking any position on the merits of green energy policies, any appeal to employment creation as a justification for such policies does not assist in identifying which forms of green energy offer the most cost-effective ways of improving the environment.

That, of course, may be the whole point. A sceptic about such lobbying for public support might reasonably conclude that any policy advocate or project promoter who relies upon claims about job creation to justify their favoured form of green energy has a weak case to make on the fundamental merits and economics of the policies or projects that are being promoted.

3. Can green energy policies create jobs?

Despite the strong arguments for concluding that employment creation is not directly relevant to a proper assessment of green energy policies, the appeal to do-it-yourself economics is remarkably resilient. Almost every project promoter in the green energy sector makes some claim about the number of "additional" jobs that would be "created" by its project. So the next question is whether such claims can have any substance as a general proposition, i.e. before we examine the details of the specific claims.

It is easy for lobbyists to claim that they are "creating" jobs which are, in practice, nothing more than the by-product of economic growth or demographic change. For example, the total population of the UK is growing slowly while the proportion of the population aged 65+ is also increasing. Businesses that provide goods and services for the elderly – from shops to nursing homes – are bound to expand and there is likely to be an increase in the total number of people employed by such businesses. In the energy sector, the replacement of old power plants by new plants – a regular and inevitable process linked to technological change and the physical or economic life of equipment – is used to justify claims about job creation. Of course, in all such cases the decline in employment at plants and/or activities that are being displaced is studiously ignored, so that the “creation” of new jobs may not reflect trends in employment – either in aggregate or in the sector concerned.

To understand whether claims for job creation could be valid it is necessary to put the issue in a macroeconomic context. Is there any reason to believe that green energy policies could increase total employment in the national economy in the medium or long run? We know the macroeconomic framework – including inter alia fiscal policy, monetary policy and exchange rates – does have an effect on total employment. Further, certain policies which affect the structure and operation of the labour market may have quite long term effects on total employment.

In contrast, green energy policies will have no permanent effect on how the labour market functions. Their effects are manifested in other ways – primarily in the level and distribution of real incomes and consumption. To illustrate the point, consider current policies to encourage the development of wind farms to produce electricity, replacing power from gas or coal plants. These policies affect many people in the longer term – i.e. after construction is complete:

- Landowners with windy sites will receive rents for leasing their land to wind operators.

- Local workers will be employed to maintain the wind turbines, while those who might have been employed at gas or coal plants will have to seek other employment.

- Domestic and industrial customers will pay higher prices for their electricity. This will teduce spending on other goods and services. In some cases, companies may close down their operations in the UK or invest elsewhere.

- Higher electricity prices will reduce company profits, so companies will pay less in corporation and other taxes. In addition, they may be less inclined to increase wages or take on new employees.

- Imports of coal and gas will be lower so that the long run exchange rate will be higher, reducing incomes and profits for businesses which export goods and services or which compete with imports. On the other hand the users and consumers of imported goods and services such as travel and consumer durables will be somewhat better off.

None of this will have any significant effect on the level of employment in the longer term. If the UK meets its target for renewable energy in 2020, it will not have higher or lower unemployment than it would have had if no such targets had been promulgated. Workers and shareholders in companies that have to pay higher electricity prices will be worse off. Some workers may lose their jobs, but other job opportunities will be created by companies taking advantage of the lower level of real wages. The overall impact of the policy will fall on incomes and the real standard of living of different groups in the population.

Since green energy policies do not affect the level of employment in the medium and long run, claims that such policies will create jobs are either misconceived or refer to a temporary impact on employment while the economy is experiencing cyclical unemployment during an economic downturn. Such temporary effects are possible because macroeconomic shocks can cause substantial unemployment while labour markets adjust to new economic conditions. The period since 2008 has shown how the collapse of a credit bubble leads to a rapid increase in unemployment due to the loss of jobs in construction and related activities without offsetting adjustments in other sectors. But neither past experience nor the current situation gives any reason to believe that the increase in unemployment is permanent.

Under normal macroeconomic conditions the level of job flows – workers leaving jobs and others starting new jobs – is much higher than the stock of unemployed workers. Most workers who change jobs are never registered as being unemployed. Nonetheless, small variations in the average length of time between leaving one job and finding another can lead to large variations in the number of people who are temporarily unemployed while looking for work. This type of unemployment is often referred to as "frictional unemployment", reflecting the fact that no market can perfectly match people looking for jobs with employers looking for workers.

Frictional unemployment may persist if employers lose confidence in their capacity – or do not have the resources required - to deploy additional workers usefully. Further, workers may resist a reduction in real earnings even when the market-clearing level of earnings has fallen. These factors will slow the process of adjusting to macroeconomic shocks. Nonetheless, over a period of months or years frictional unemployment will tend to return to its normal level. Green policies will do nothing to accelerate such adjustments if we hold general macroeconomic conditions constant. Indeed, they are only likely to slow up the process of adjustment by creating additional uncertainty and costs for potential employers.

Not all unemployment is purely or predominantly frictional. The term "structural unemployment" is used to refer to a longer term mismatch between the skills, location, and other characteristics of job seekers in relation to what employers are looking for. This is partly reflected in the number of long term unemployed – people who have been looking for work for a minimum of 6 or 12 months. Another component of structural unemployment consists of people who have given up looking for work - including some who may be registered as suffering from various disabilities plus others who have retired early or who are engaged in unpaid activities but might prefer to take on a paid job. Again there are no reasons to believe that green energy policies will have a significant impact on the level of structural unemployment. This will only occur if the requirements of any new jobs match the skills, location, etc of those who are unemployed. Otherwise, the policies will simply lead to a displacement of jobs with a minor or zero effect on unemployment.

An alternative route by which these policies may generate additional employment in the short run is if they serve as a vehicle for delivering a broad macroeconomic stimulus to the national economy. In that case, the proviso of holding macroeconomic conditions constant does not apply. But no disinterested economist would regard investment in renewable energy or housing insulation as a good way of boosting aggregate demand. Fiscal changes, such as the 2008 cut in VAT, or a temporary boost to public spending on transfers or fixing social infrastructure are much more effective in this respect. The period required to get significant investments in renewable energy off the ground is a minimum of 3 years and more typically 5 years.

These arguments imply that, at best, green energy policies may have a very small impact on the total level of UK employment in the short run and little or no impact in the medium or longer term. Applying any reasonable economic criteria, such policies are a really poor way of allocating public money (through subsidies) or private resources (through higher energy prices) to create jobs at the macro level – i.e. for the UK as a whole or for the EU.

All, then, we are left with is the possibility that green energy policies may have an effect at local or regional level in areas with high structural unemployment. But this argument presumes that the job opportunities associated with green energy arise in locations where people with suitable skills are experiencing high levels of unemployment. If that is not the case, the "creation" of new jobs will actually amount to a displacement of other employment opportunities.

Consider the example of Scotland, which is most enthusiastic about the potential benefits of job creation associated with the development of renewable energy. Its unemployment rate in 2010-11 has been very close to the average for the UK as a whole. Within Scotland the highest unemployment rates by local authority are in North Ayrshire, Glasgow City and West Dunbartonshire – none of them candidates for the development of onshore wind farms and all of them at some distance from the primary sites for offshore wind farms. Neither is there any strong evidence that Scottish manufacturing businesses, who account for little more than 7% of Scottish jobs, would gain a significant boost from the capital spending on wind farms.

Another region with high expectations of job creation associated with renewable energy is the North East, but again the figures don't add up. It has the highest unemployment rate in the UK with particular concentrations along the coast in districts such as Middlesbrough, South Tyneside and Hartlepool. Still, the notion that there is a large pool of unemployed or discouraged skilled workers who could be employed in manufacturing wind turbines is not consistent with the development of the regional labour market over the last 30 years. Manufacturing now accounts for only 11% of total jobs in the region. As elsewhere in the UK, most unemployed or discouraged workers have limited skills and require substantial training or other assistance to hold down skilled jobs in manufacturing.

For the UK as a whole, we need to apply a basic test of cost-effectiveness. Is the number of jobs generated by green energy policies greater than if equivalent funds had been allocated to direct intervention in the labour market, for example through spending on job-related training and other measures? At local level there is a concern that spending on training and other labour market interventions might ultimately benefit other regions because workers with improved skills might choose to move elsewhere in search of work. Linking support to specific investments reflects a view that not all benefits – or jobs – should be weighted equally. In such cases, local impacts are treated as being more important than spill-over effects outside the locality. From a national perspective that cannot be right, but it is a very strong element in the arguments concerning support for specific projects.

The observation that training and similar labour market measures may be more effective ways of reducing structural unemployment than support for specific environmental or industrial projects leads on to another important point. Training and similar policies stimulate outcomes that go far beyond their impact on the level of unemployment. Their benefits may take many forms including (a) higher incomes for those who receive the training, (b) higher output of goods and services from the same inputs of labour and other factors, and (c) improved quality of personal or community services. Often, the division of the aggregate benefits between more jobs and higher real incomes or quality of life is difficult to predict and may be affected by unforeseen exogenous factors.

Two conclusions follow for any assessment of green energy policies.

- If the primary objective of such policies is to reduce CO2 emissions, then we should seek to minimise the costs of meeting that objective, including any wages for jobs directly or indirectly linked to the project.[1]
- If, instead, the goal of the policies is to increase real incomes and improve human wellbeing, then job creation is an irrelevant measure of their benefits. The criterion should be to select the options which generate the highest level of net benefits, treating both employment and environmental externalities as costs to which appropriate weights are applied to reflect the social opportunity costs of paying wages or emitting CO2 and other greenhouse gases.

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[1] There is an argument, which is sometimes used in cost-benefit analysis, that the "social" cost of employing workers or paying wages is less than the money cost. The argument may be relevant when there is large structural unemployment, but most careful assessments suggest that any gap is likely to be small and would only apply to limited categories of unskilled employment. This does not alter the basic fact that job creation is a cost, not a benefit, of such policies.

4. How might green energy policies affect incomes and the labour market?

The conclusion that green energy policies will not have any significant impact on the level of total employment in the medium and longer term is less important than the broader impact of such policies on incomes and the labour market. For anyone with an interest in the future development of the UK economy, a key issue may be put as follows:

Given a standard set of assumptions about macroeconomic variables – GDP, investment, inflation, etc – how will the implementation of green energy policies affect the demand for labour? If they are likely to increase the overall demand for labour, then this will tend to increase real wages and the share of employment income in GDP. If they are likely to reduce the overall demand for labour, then real wages will be lower in future along with the share of employment income in GDP.

As explained above, claims about job creation rely upon a faulty description of the way in which labour markets work. It is adjustments in real wages that matter in the medium and longer term, whereas changes in the total level of employment are transient and depend upon the way in which labour markets respond to external shocks. Changes in labour market policies will affect the speed and nature of the adjustment to shocks of all kinds, including those associated with the adoption of green energy policies. However, the nature and direction of those shocks matter because policies that tend to reduce the demand for labour will leave most people worse off, even if the level of employment does not change.

Hence, in the remainder of this paper I will consider how green energy policies will affect the demand for labour and, thus, the total level of employment income holding GDP constant. I will build up the analysis in stages by widening the scope of the impacts considered, starting with the direct demand for labour in the energy sector and culminating by considering economy-wide effects. For purposes of illustration I will concentrate mainly on policies that are designed to promote electricity generation from renewable sources of energy instead of fossil fuels. Green energy policies are only relevant if the renewable option would not be viable without some form of support, so the nature and level of any support is crucial. It may take the form of explicit subsidies or a variety of indirect subsidies linked to mechanisms designed to meet targets for generation from renewable sources.

Any analysis must be based upon some clear basis for comparing like with like. This is not straightforward when considering types of electricity generation that differ in terms of their load factors, intermittency, capacity to meet fluctuations in demand, etc. Most comparisons published by advocates of green energy adjust generating capacity for differences in assumed load factors.[2] The average load factor for onshore wind farms in the UK is significantly less than 30% - in some cases it is less than 20%. In contrast, a new gas-fired unit operating on base load may be expected to operate for up to 85% of hours in a year. Adjusting for differences in typical load factors but nothing else, one might compare a gas plant with a generating capacity of 500 MW with wind turbines with a capacity of at least 1400 MW producing the same amount of electricity over a typical year.

Unfortunately, as explained in detail in the background paper, this is only a part of the story. Most forms of renewable energy are intermittent sources of generation – you get electricity when the wind blows or the sun shines, and not otherwise. To meet hour-to-hour variations in demand for electricity, for every 100 MW of wind generation capacity it is necessary to have backup capacity, usually provided by gas-fired plants, of 80-100 MW to meet demand during periods when demand is high and the wind is not blowing, as in the UK during December 2010. Backup electricity tends to be expensive per MWh, because the plants do not run much, and the plants have low thermal efficiency because of the costs of starting up and running down.[3]

There is not just a requirement for backup capacity. Nuclear and clean coal plants are designed to operate almost continuously – on base load - for economic and technical reasons. With large amounts of wind capacity there may be surplus power when the wind is blowing and demand is low, so either wind or nuclear plants will be constrained in the amount they can operate. Relying upon wind power will undermine the financial viability of nuclear and clean coal, but allowing such plants to run will further reduce the load factor for wind plants.

The heart of the problem is simple and inescapable. Electricity demand varies greatly over time – daily, weekly and seasonally. Renewable and other low carbon sources of generation are highly capital-intensive and relatively inflexible. The attraction of fossil fuels has always been that they provide the flexibility required to meet fluctuations in demand. There are alternative sources of flexibility – e.g. pumped storage - but they are expensive and/or unattractive for the UK. The figures in the background paper demonstrate that a proper like-for-like comparison requires an investment of about £9.5 billion in wind generation plus associated infrastructure per £1 billion of investment in gas-fired generation.[4] The costs of operations and maintenance excluding fuel are also much higher for renewable energy than for gas-fired plants, especially for offshore wind plants. Higher non-fuel operating costs may be offset by a saving in fuel costs, but the extent of the saving is far from certain because

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[2] The load factor for a generating plant is calculated as the total electricity generated in a year (in MWh) expressed as a percentage of the amount of electricity that it would generate if it operated at full rated capacity for 24 hours a day, 365 days a year. No plant achieves a load factor of 100% because of interruptions for maintenance or seasonal variations in demand. Base load plants are electricity plants that operate practically all of the time that they are not being maintained. Typically this will correspond to a load factor of 85-90%.

[3] The problems of backing up intermittent supplies of renewable electricity are not unique to wind power. Two major electricity markets that rely heavily upon hydro power – Brazil and California - have experienced major disruptions in the last decade because of a combination of droughts, mismanagement and a lack of alternative sources of generation when hydro sources could not meet peak demand for electricity. All electricity systems require a margin of spare capacity in reserve to meet peaks in demand or plant breakdowns. However, the margin has to be much greater for most renewable sources of generation than for systems based on fossil fuels.

gas-fired plants used as backup consume up to twice as much gas per MWh of electricity as the most efficient type of gas-fired plants and the fuel cannot be purchased in the most economic way.

There is another dimension to comparisons between alternative ways of generating electricity. Advocates of renewable energy often rely upon projections of performance and costs in future rather than as they are today. In such cases we must be very careful to use such projections in a consistent way. As a matter of fact, the thermal efficiency and overall reliability of new fossil fuel generating plants are much higher than the equivalent parameters for their predecessors 10 or 20 years ago.[5] For example, the thermal efficiency of new gas-fired generating plants has improved from less than 50% to close to 60% over 20 years, but similar improvements have occurred for coal plants as well. New design standards and better operating performance mean that emissions of various pollutants have fallen even more. Experience has shown that such improvements are likely to continue and this must be taken into account when carrying out comparisons. Thus, there is no general reason to assume that future technical progress and improvements in efficiency will favour renewable sources of energy over non-renewable sources.

Proper like for like comparisons put a rather different complexion on claims that investments in renewable energy will generate X thousand jobs – or, more accurately, increase the demand for labour by this amount. We must start with some broad numbers. In order to meet the UK government's target for renewable electricity generation for 2020, it will be necessary to invest about £120 billion at 2009 prices in renewable generation over a period of 8 years in addition to the replacement and/or expansion of non-renewable generation capacity. Over 2006-09, total investment in electricity, gas and water averaged £7.6 billion per year at 2009 prices, while the average value of total business investment over the same period was about £142 billion per year at 2009 prices. Hence, the additional investment required to meet the renewable generation target is close to 1 year's business investment outside the electricity sector. This is bound to have important macroeconomic consequences.

First, adding 200% to historic levels of investment in the energy sector will create supply bottlenecks and demand-driven inflation for capital goods. Either the planned increase in capacity will not occur or it will prove to be much more expensive than the base costs suggest. Second, this amount will represent a diversion of more than 10% of non-electricity business investment into renewable energy, unless there is a significant reduction in household or government consumption to finance an increase in total investment expenditure.

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[4] This estimate is conservative because it does not allow for the reduction in the average load factor for wind plants if new nuclear and/or clean coal power plants receive guarantees that they will operate on base load as suggested in recent government proposals.

[5] The thermal efficiency of a generating plant is the proportion of the total energy content of the fuel that is converted into electricity. Holding other parameters constant, a higher thermal efficiency translates to lower costs and lower emissions of CO2 or other pollutants per unit of electricity.

At this scale, the classic assumptions of a small intervention in a large economy do not apply. These permit economists to assume that any macroeconomic effects can be set aside, thus focusing attention on the immediate direct or indirect consequences of the policy. However, in this case the consequences of who is to pay for the policy, and how, are crucially important because the economic effects arise from a shift in business investment from other activities to renewable energy. Thus, analysis of the impact of green energy policies on the labour market has to proceed in a series of steps.

Direct and indirect effects. The starting point is the demand for labour in the construction and operation of electricity generating plants. This covers (a) employment in the construction industry when the plant is being built, (b) employment in the manufacture of capital goods – wind or gas turbines, boilers, generators, associated transformers and switching equipment, transmission lines, controls, etc – required for the programme, and (c) employment in operating the plants and providing the inputs they consume These calculations apply not only to renewable energy plants but also to other sectors of the economy from which investment has to be diverted. They are examined in Section 5 below.

Technology and comparative advantage. It is claimed that promoting the adoption of renewable technologies will lead to the development of experience, skills and long term comparative advantage in the industries which supply the technologies. This is, of course, simply a modern variant on the old "infant industry" argument for protection and/or industrial subsidies. The traditional argument was that providing financial support or protection for an industry today will enable it to achieve economies of scale or improvements in efficiency (learning by doing) that will confer a (more or less) permanent advantage in future.

The modern variant of the infant industry argument in the environmental context is known as the Porter hypothesis since Michael Porter has argued that the early adoption of strict environmental standards – for example, low emissions of air pollutants such as sulphur dioxide or nitrogen oxides – had enabled countries such as Japan and Germany to acquire a comparative advantage in supplying environmental technologies. Thus, the initial costs of early adoption were offset by the longer term contribution to national income from the comparative advantage they acquired. The classic version of the infant industry argument is viewed with considerable scepticism by most economists because the conditions under which it provides a genuine case for financial or other assistance are very restrictive. Yet it remains popular among those who wish to advocate public support for new or old industries. I will return to this in Section 6.

Changes in production and spending. The Porter hypothesis is only one element in the larger set of adjustments that will follow the implementation of policies to promote renewable energy. With no change in overall economic activity, investment in wind farms, accompanied by higher energy prices, must result in lower levels of real income, investment and consumption in the rest of the economy. The path of adjustment will depend upon a variety of internal and external factors, but the inevitable outcome will be a reduction in economic activity in sectors that are relatively energy-intensive (relative to the outcome with no intervention), together with lower spending on non-energy consumption and investment.

Renewable energy is highly capital-intensive, so once the initial program of investment is complete the diversion of spending required to cover its costs will certainly reduce the demand for labour in other sectors of the economy, though the adjustments may be complex. Further, labour income will be lower than it would have been without intervention, simply because there is an economic cost – called its deadweight loss – involved in promoting specific outcomes or technologies beyond what would be efficient after allowing for external costs. As an illustration, the current renewables obligation is simply a disguised tax which transfers resources from energy users to landowners and others who control renewable energy assets that count under the scheme. Since the scheme is essentially arbitrary, it involves a substantial deadweight loss that is reflected in real incomes.

Macroeconomic impacts – inflation. Up to this point the analysis has rested on an assumption that the overall level of economic activity is not affected by policies to promote renewable. For most microeconomic policies this is a reasonable basis for examining their effects. However, in this case there is a significant macroeconomic impact that must be examined.

The green energy policies proposed by the UK government will have a large and permanent effect on energy costs in the UK. These must be passed on to consumers if the policies are to achieve their goals, so the underlying rate of consumer price inflation will be significantly higher than would have been the case had the policies not been implemented. Under a monetary regime in which the Bank of England is required to target a 2% rate of inflation, this means the rate of inflation excluding energy costs must be reduced in order to meet the target. Hence, it is necessary to consider the impact on GDP of monetary policies designed to restrain non-energy price inflation in order to achieve to the Bank of England’s target.

5. Direct and indirect employment

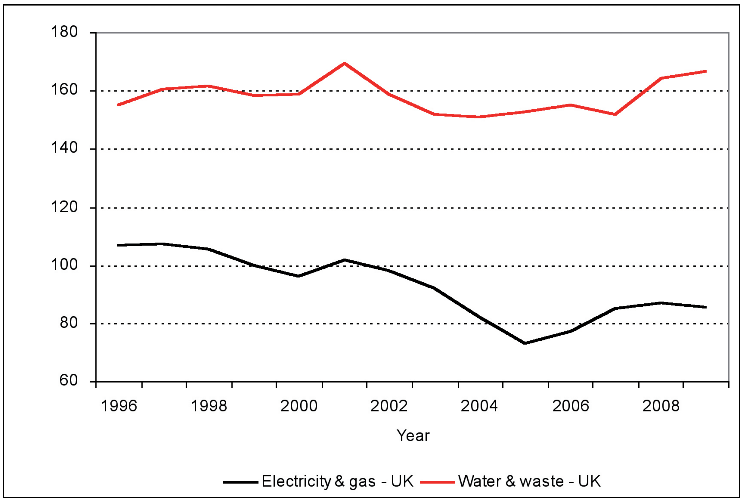
As a starting point it is important to have a sense of the actual number of people who are directly employed in sectors that would be affected by renewable energy or other green projects. The main sources of data are incomplete and use definitions that have changed over time. Figures from the Quarterly Labour Force Survey show that UK employment in electricity & gas, which covers both electricity generation and networks, fell by about 20%, from 106,000 in 1996-98 to 86,000 in 2007-09 – see Figure 1. As a comparison, employment in water and waste services was stable at about 160,000. Figures from the Annual Business Inquiry/Survey show that electricity production accounts for about 25% of the total for electricity and gas – with reported employment of 20-25,000 for 2003-07. In terms of direct employment, this is a very small sector, while recent trends suggest it is likely to get smaller rather than larger.

In rich, post-industrial economies, it is very unusual for new technologies to lead to an increase in the number of people directly employed in providing energy services if the amount of energy consumed is held constant. A simple illustration is the introduction of "smart" electricity meters and their extension to "smart" electricity networks. The essence of the investment in both metering and network management is to provide both consumers and network operators with better information on electricity use. This would allow them better control over both the amount and timing of consumption in a way that reduces the total amount of energy use and the peaks in consumption that lead to very high costs, often associated with the use of generating plants that emit the most.

FIGURE 1

Employment in energy has fallen since 1996, whereas it has remained stable for water and waste

Employment in energy, water and waste in '000s, 1996-2009



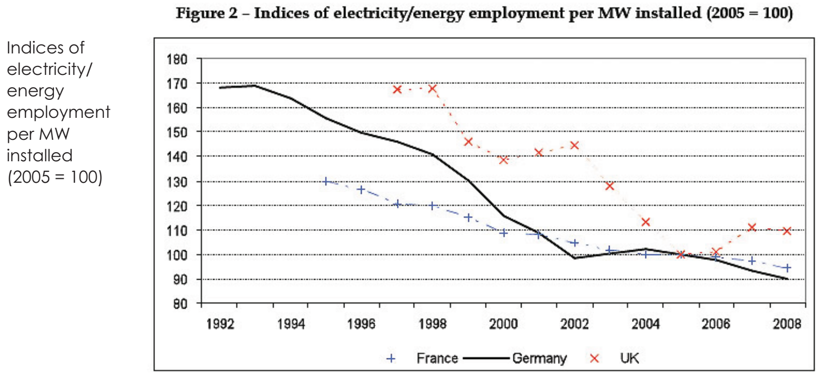
Source: Based on Quarterly Labour Force Survey

Investment in smart metering has been presented as a way of generating green jobs and the US stimulus program of 2009 included funding of about $4 billion for the installation of smart meters. Some simple calculations by a specialist in the field – Sharan (2010) – show that the net effect of this spending over any period longer than 1-2 years would lead to a significant fall in total employment in electricity metering, including installation and production. Even allowing for different practices in the UK, the same conclusion applies to the proposal to install smart meters for UK electricity customers before 2020. In Italy, Enel undertook a large program of installing smart meters, which are not accessible to customers, simply because of the saving in the costs of meter-reading and maintenance.

For electricity generation there has been a clear trend in OECD countries towards fewer but more skilled employees per MW of generating capacity over the past two decades. Detailed analysis for the US shows that the average number of employees per MW fell by about 50% from 1990 to 2003 after controlling for other factors – Shanefelter (2008). This is equivalent to a trend increase in productivity of 5.2% per year. The trend was accompanied by a rather slower increase of 2.0% p.a. in real terms in the average annual wage of employees. A part of this shift in employment was associated with the deregulation of electricity markets and the separation of generation from network operations, which encouraged operators to reduce costs. Nonetheless, the same trends are apparent even in states that did not restructure their utilities.

The decline in average employment per MW of generating capacity has occurred in Europe as well, though the data is not so precise. Figure 2 shows indices of labour hours worked per MW with 2005=100 for France, Germany and the UK. In Germany the labour input refers to the electricity generation, transmission & distribution, while for France and the UK the coverage is electricity and gas. Except in France, with its strong public sector culture, employment per MW of installed capacity has fallen at 4-5% per year, considerably faster

FIGURE 2
Employment per MW of generating capacity in Europe has fallen since the mid-1990s



Source: Based on Eurostat data.

than the increase in demand for electricity. This trend is likely to continue, so any expectation of an increase in direct employment in the electricity sector must depend upon an increase in the level of installed capacity per MWh of electricity demand, i.e. on a fall in the utilisation of generating capacity.

Turning to indirect employment, the crucial issue is the demand for labour associated with investment in generating plants, including any transmission that may be required. Table 1 provides basic information on the costs of building and operating different types of power plants, including an indicative breakdown of costs between various components. This is used to estimate the employment income generated in the UK by the construction of power plants as shown in Table 2.

The direct employment income generated by investment in power plants is about 20% of total investment for all technologies other than solar power – Part A of Table 2.[6] Given the differences across projects and the inevitable uncertainties in the raw data, the amount of direct employment income per £1 billion of investment is similar for renewable energy (other than solar power) and conventional forms of electricity generation.

Part B of Table 2 looks rather deeper by taking account of induced spending, i.e. not just employment income associated with the construction of plants and the manufacture of turbines, generators and other equipment but also the wages and salaries paid by domestic (UK) suppliers of parts and equipment

Table 1 – Indicative capital and O&M costs for electricity generation

Technology	Operating life	Overnight capital cost	Fixed O&M cost	Variable O&M excl fuel	Indicative composition of overnight capital costs (%)				
	Years	£ mln per MW	£ 000 per MW per year	£ 000 per GWh	Construction	Boilers, turbines, etc	Mechanical & electrical	Solar equipment	Other
Nuclear	60	2.68	43	2.3	15-20%	50-55%	5-10%		20-25%
Coal - advanced	35	1.47	28	1.6	15-20%	55-60%	15-20%		5-10%
Gas - combined cycle	35	0.61	14	1.6	20-25%	50-55%	10-15%		10-15%
Gas - single cycle	30	0.40	9	3.9	20-25%	50-55%	10-15%		10-15%
Wind - onshore	25	1.30	13	0.0	15%	60-65%	15%		5-10%
Wind - offshore	25	2.72	63	0.0	25-30%	50-55%	15-20%		5-10%
Solar photovoltaic	20	4.00	20	0.0	10-15%		25-30%	45-50%	10-15%
Solar thermal	20	3.35	50	0.0	5%	15%	10-15%	55%	10-15%
Biomass	35	2.58	49	5.2	15-20%	55-60%	15-20%		5-10%
Reservoir hydro	50	2.58	13	5.5	50-60%	10-20%	10-15%		15-20%
Pumped storage hydro	50	2.58	13	5.5	50-60%	10-20%	10-15%		15-20%

Source: Capital and O&M costs based on Mott Macdonald estimates for DECC. Composition derived from detailed project costs.

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[6] The estimates in Part A of Table 2 cover wages, salaries and other labour costs for employment directly generated by investment projects – i.e. paid to workers directly employed in construction or the supply of equipment and services.

[7] The estimates in Part B of Table 2 cover wages, salaries and other labour costs for all types of direct and indirect employment including, for example, those working for the suppliers of construction materials or in producing inputs directly or indirectly used in manufacturing equipment for the plants.

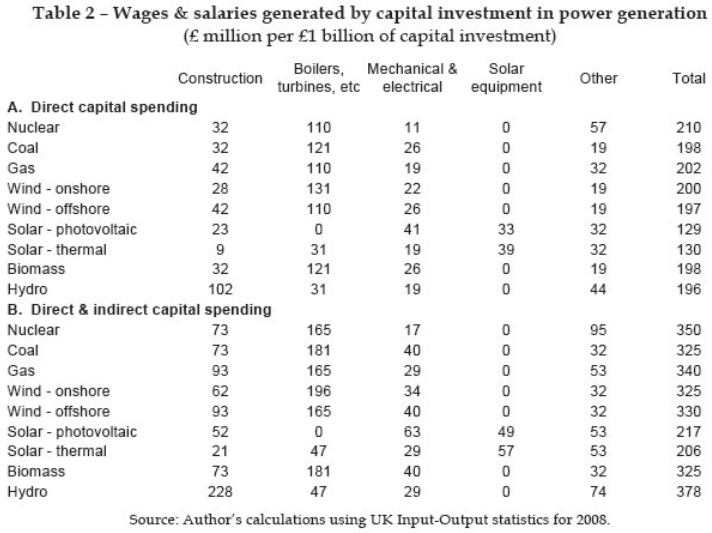


Table 2 – Wages & salaries generated by capital investment in power generation
(£ million per £1 billion of capital investment)

	Construction	Boilers, turbines, etc	Mechanical & electrical	Solar equipment	Other	Total
A. Direct capital spending						
Nuclear	32	110	11	0	57	210
Coal	32	121	26	0	19	198
Gas	42	110	19	0	32	202
Wind - onshore	28	131	22	0	19	200
Wind - offshore	42	110	26	0	19	197
Solar - photovoltaic	23	0	41	33	32	129
Solar - thermal	9	31	19	39	32	130
Biomass	32	121	26	0	19	198
Hydro	102	31	19	0	44	196
B. Direct & indirect capital spending						
Nuclear	73	165	17	0	95	350
Coal	73	181	40	0	32	325
Gas	93	165	29	0	53	340
Wind - onshore	62	196	34	0	32	325
Wind - offshore	93	165	40	0	32	330
Solar - photovoltaic	52	0	63	49	53	217
Solar - thermal	21	47	29	57	53	206
Biomass	73	181	40	0	32	325
Hydro	228	47	29	0	74	378

Source: Author's calculations using UK Input-Output statistics for 2008.

to turbine manufacturers and so on along the chain of economic activity.[7]
The primary difference between the direct and total effects of investment is the substantial increase in wages and salaries for hydro power plants. This is a consequence of the large share of construction in the total cost of hydro plants. The way in which figures are recorded means that direct demand for labour by construction firms is modest, but they rely heavily upon purchases of inputs and services which are quite labour-intensive.

Again, the figures do not justify any conclusion that investing £1 billion in renewable energy projects will create a higher level of employment income than spending the same money on conventional power plants. Solar power stands out as having a relatively low share (20-22%) of total employment income in investment while hydro power has a relatively high share (38%). The shares of total employment income for other forms of generation fall in a narrow range for 32% to 35%.

Translating these figures to estimates of the demand for labour depends upon the distribution of skills and average earnings across sectors. In 2008 average labour costs per employee were relatively high in the manufacture of boilers & turbines at about £32,000 per year per full-time employee and lowest in construction and business services (Other) at £26-27,000 per year per full-time employee. These differences imply that the total demand for labour for hydro plants is about 13,600 job-years per £1 billion of investment – while it is significantly lower for wind plants at about 10,700 (onshore) – 11,100 (offshore) job-years per £1 billion of investment. Overall, the differences in labour-intensity between different renewable technologies are much more important than the differences between renewable and conventional forms of generation.

Two simple conclusions follow from this analysis.

- If stimulating the demand for labour is really an important consideration in shaping future policies towards power generation, then priority ought to be given to the development of hydro plants. For example, a combination of nuclear and pumped storage hydro plants would meet demand for electricity with lower CO2 emissions and greater employment income than relying upon wind turbines with gas backup. Of course, there are many difficulties of land use for pumped storage schemes, but it is odd to favour the use of land in upland and scenic areas for wind turbines but to resist its use for hydro plants.
- Claims that the impact of renewable energy on the demand for labour must rest on the scale of the investment that is required. Naturally, spending roughly £9.5 billion on building wind farms or other forms of renewable generation to meet the UK's future electricity demand to match £1 billion spent on gas-fired power plants will lead to higher payments of wages and salaries linked to investment in electricity generation. However, since the cost has to be funded by diverting resources from other investments, this tells us nothing about the net effect of investing in renewable energy for the economy in aggregate.

The net effect of reallocating finance from other investment to renewable energy will depend on what kinds of investment are displaced by the capital requirements of renewable energy. If all of the finance is reallocated from business investment, then there will be a small increase in employment income from about £310 million per £1 billion of investment to about £330 million. Alternatively, the government seems to view investment in renewable energy as making up for capital spending in the public sector and on housing. In that scenario, employment income will fall by 15-20% from £380-410 million per £1 billion of investment. Overall, it is reasonable to conclude that the net impact on employment income may be relatively small and is quite likely to be negative under current economic conditions. There is no basis for making the suggestion that investments in renewable energy will lead to significant increase in the total demand for labour in the UK.

The economic effects of Mr. Huhne's Green Deal, a programme to upgrade building insulation, are even more transient and uncertain. The whole point of insulation is that it is passive and requires no continuing expenditure after the initial cost has been incurred. Any impact on the demand for labour will be purely temporary during the period of installation, so this leads us on to the indirect employment linked to the purchase of materials and any investment in capital assets. Even these effects are likely to be quite small because it will be financed by reallocating money that might otherwise have been spent on construction services and similar activities.

The employment data in Figure 1 have another lesson if the impact of environmental policies on the demand for labour were to be used as a serious criterion in selecting policies. The environmental sector which employs the largest number of workers is waste management and recycling. Direct employment for 2005-07 in recycling alone was very similar to that for all electricity generation and much larger than for renewable electricity. If recycling makes economic sense, then it would be worth paying workers to separate and manage waste of various types. Instead, authorities responsible for waste management attempt to rely upon unpaid labour inputs from households, companies and others. The labour input for waste separation alone is similar to the transitory increase in employment claimed for Mr. Huhne's Green Deal. This example demonstrates that arguments about job creation in relation to green energy are both incoherent and opportunistic, because no attempt is made to apply them systematically across a range of green policies.

6. Infant industries and the Porter hypothesis

Talk of smart networks, wave power, geothermal engineering, and similar technologies seem intended to give the impression that green projects involve investments in new technologies of a highly sophisticated character. This is largely wrong, as may be illustrated by a few examples.

(a) The most expensive environmental investments in the power sector over the 30 years have involved the (retro-)fitting of equipment to reduce the amounts of particulates, SO2 and NOx emitted by coal-fired plants. While some of the components involve highly sophisticated engineering, the majority of the costs have been incurred for conventional civil works and chemical engineering. These projects are no more, but no less, high tech than modern chemical plants or oil refineries.

(b) Modern wind turbines may look more sophisticated than old windmills, but the basic technologies are mature and widely available around the world. Most of the cost of building new onshore wind farms is spent on civil works, transformers, switchgear and transmission lines – all standard bits of modern industrial technology. For offshore wind farms you have to add the element of anchoring the turbines to the sea bed, technology that originates in offshore production of oil and gas.

(c) Carbon capture and storage (CCS) involves a combination of chemical engineering and gas transmission & storage but in the opposite direction.

(d) As noted, the Green Deal is largely a programme of building insulation combined with the installation of smart meters. Insulation has been promoted by UK Governments consistently over the last 40 years. The materials are standard and the additional employment differs little from any other forms of building maintenance.

These examples make a simple point. Even sophisticated environmental technologies are rarely new because they involve a direct extension of existing technologies from well-established industries. In most cases they require major investments in large scale but conventional civil works or construction. There are a few technologies that can be characterised as genuinely different

– certain forms of solar power, wave power, and nuclear fusion – but, sadly, many of them have remained technologies of the future for several decades. Environmental technology is not new in the sense of quantum computing or genetic engineering. If it is to work reliably on a large scale, it must be based upon established engineering principles and practice.

This observation matters because green programmes do not, as is often claimed, create new sources of competitive advantage for industries and countries. Most civil works and construction is local and will generate employment for suitably qualified workers living close to the investment. On the other hand, many types of machinery and similar capital goods can easily be traded over long distance. Even though wind turbines may initially be manufactured in countries with local demand due to investment in wind farms, this factor is rapidly overtaken by a re-assertion of conventional manufacturing skills and economies of scale in the relevant industries – electrical or mechanical equipment, chemical engineering, building materials, etc. It is easy to mistake a temporary bias in favour of local suppliers while experience is being built up and equipment is being standardised with a permanent source of comparative advantage.

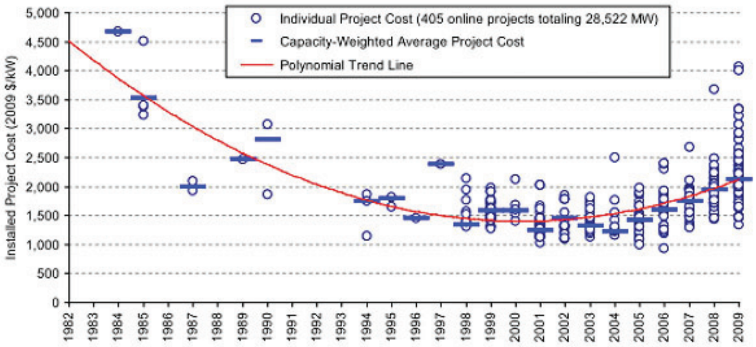
This leaves variants of the Porter hypothesis. As explained earlier, this is a version of the infant industry argument for protecting or subsidising industries, so it is not special to environmental technologies. An essential element of the hypothesis is the assertion that the real cost of producing inputs or capital equipment will fall relative to other technologies and/or other countries. This leads to the claim that a manufacturing industry may be uncompetitive today but will become competitive – in some sense – in future. In such cases, the correct economic test is to treat support as an investment that is required to generate a proper rate of return from higher employment, taxes or incomes in future.

There are two reasons why costs might fall as claimed. One is by gaining economies of scale as production increases. The second is through what economists call learning by doing. The idea is that producers learn how to organise production more efficiently and perhaps how to produce better or more reliable products. The phenomenon is well-documented and has certainly operated in the manufacture of equipment such as combined cycle gas turbines (CCGTs).

The unit cost of wind turbines and solar photovoltaic modules has certainly fallen over the last decade. The difficulty for advocates of the Porter hypothesis is partly that the same process has occurred for other technologies as well – notably for gas-fired plants – and may be expected to continue. Second, the relevant industries are much larger today than they were 10 years ago and there is little evidence that there are large additional economies of scale or learning to be gained, except perhaps for solar thermal equipment. Indeed, US figures suggest that the average cost in real terms of both wind and solar power installations stabilised and/or has been increasing since the middle part of the decade 2000-09 – see Figures 3 & 4. It is unlikely that there is some large reduction in the costs of renewable energy which can be achieved without a major shift in technology.

FIG 3

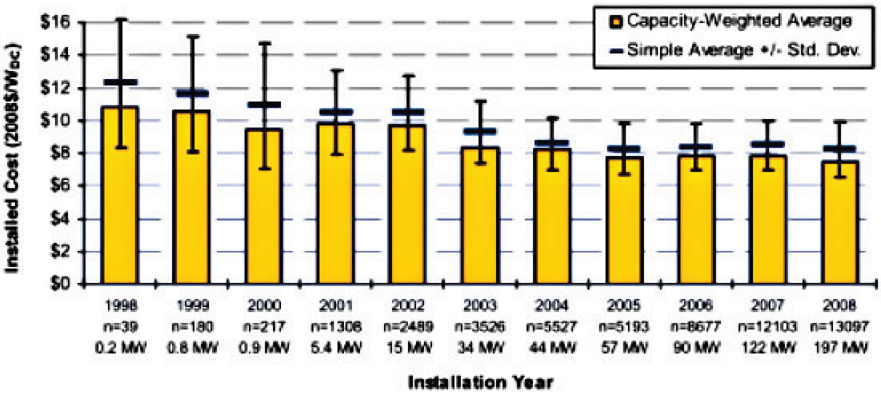
Wages & salaries generated by capital investment in power generation (£ million per £1 billion of capital investment)



Source: Figure 27 in Wiser & Bolinger (2010).

FIG 4

Average real cost per W of photovoltaic installations in US, 1998-2008



Source: Figure 4 in Wiser et al (2009).

The argument that an opportunity exists to acquire country-specific comparative advantage, leading to substantial job creation, is even weaker. The US provides the clearest example.

A. *Wind turbines.* In terms of total installed capacity, the largest global manufacturers of wind turbines have been based in Denmark, Germany, Spain and the US. In the US, the market for new capacity is dominated by American firms, followed by firms based in Denmark, Germany and Spain. The rapid growth of new capacity in China propelled three Chinese companies into the top 10 manufacturers in 2009. These characteristics indicate that wind turbine manufacturing operates in a manner similar to the markets for other power generation equipment. Small countries – Denmark for wind turbines, Sweden and Switzerland for conventional turbines and generators – can establish and retain comparative advantage in specific niches, but larger economic factors determine the broad structure of the industry. Large markets such as the US, China or Europe tend to be served by domestic suppliers, while components may be purchased either from low cost manufacturing centres or from suppliers with specialised skills that are often not specific to any one industry.

- Total employment in manufacturing wind turbines in the US was reported as 20,000 at the end of 2008, corresponding to new capacity of 8,400 MW installed in 2008 and 10,000 MW in 2009. The size of the domestic market and transport costs mean that US wind farms are more likely to buy from domestic manufacturers than would be the case in Europe, so this figure sets an upper limit on the plausible level of employment in the UK. Currently, the UK has about 2,300 MW of capacity under construction and it is reasonable to expect that the installation could increase to 5,000 MW per year on a sustained basis. The highest projection of employment in manufacturing wind turbines would be 10,000. To put this number into context, total UK employment in the manufacturing sectors covering thermal power plant equipment was about 46,000 in 2007. Growth in the manufacturing of wind turbines would have to be large simply to make up for the loss of employment in existing activities.

B. *Solar power.* The US has always been one of the dominant producers of solar power equipment since much of the technology is based upon US electronics and related innovations. In addition, the climate in some regions of the US is favourable for solar power generation – especially in California and the South-West. Thus, this ought to provide the best conditions for the Porter hypothesis to apply, but that is not what has happened.

- *Photovoltaic (PV) cells and modules.* Until 2005, exports of PV cells and modules exceeded imports. However, despite rapid growth in domestic production in 2008, imports were significantly greater than exports and accounted for more than one-half of all domestic deliveries. The trend is clear: US manufacturers are gradually being displaced by low-cost producers – particularly from China, Japan and the Philippines – as production costs overtake technology as the driving factor in the market. Total employment in manufacturing PV cells and modules will increase for a period – it was about 11,000 in 2008 – as the overall market grows, but this trend will eventually reverse as market growth slows and imports continue to increase.[8]

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[8] There is a common misrepresentation of the situation for PV installations. The cost of PV modules has fallen and may continue to fall due to technological change. At the same time, this is a cyclical industry, price changes are often driven by the balance of supply and demand – the same applies to gas turbines as well. Even then, PV modules do not account for the bulk of the cost of PV installations, since inverters, transformers, civil works and supports, and grid connections are more important in cost terms. These are conventional technologies used in a wide range of other generating plants. Lower costs for PV modules do not translate directly to lower costs for PV installations.

- *Solar thermal equipment.* The manufacture of solar thermal collectors in the US is a much smaller industry than PV cells and modules, with employment of about 1,100 in 2008. Exports represent 15% of total production and imports have captured about 30% of the domestic market – a share that has been increasing gradually since the early 2000s. The main source of imports is Israel, so the key factor in this case is not production costs but technology.

These examples illustrate the circumstances under which the Porter hypothesis is more or less likely to be relevant. The primary beneficiaries from the initial phases of learning by doing and economies of scale in renewable energy are small countries that gain a first mover advantage due to a combination of local conditions and innovation – e.g. Denmark for wind turbines and Israel for solar thermal equipment. Over time, however, these initial advantages are eroded as international markets expand and conventional economic factors such as transport and manufacturing costs reassert themselves.

The examples discussed – and others such as geothermal or biomass – provide no evidence that the UK can acquire a long term comparative advantage in the manufacture of renewable energy equipment by any combination of policies that are both feasible and affordable. This would be true even if other countries – whether in Europe or the rest of the world - had no interest in such an objective. In practice, many countries face lobbies for industrial support and market intervention that rely upon the Porter hypothesis to justify financial assistance today on the promise of economic benefits tomorrow. Even if the logic was correct for one country on its own, it cannot possibly be correct when extended to many countries in a open global economy. This is just a fools' competition in which taxpayers and energy consumers must lose.

7. Impact on spending and production

The previous sections focused on the immediate impact of programmes to promote renewable energy on employment, looking at sectors that may benefit directly or indirectly from such investments. The background paper demonstrates that the true cost of renewable energy – calculated on a proper like for like basis – is extraordinarily high. The UK Government has suggested that electricity prices will have to rise by 40% to recover the costs of restructuring market incentives and investments required to meet its targets for reducing CO2 emissions up to 2020. This is likely to be a substantial under-estimate when considering the impact on the economy as a whole, partly because the figures focus on retail rather than wholesale prices and partly because the analysis does not take full account of the investments required to accommodate intermittent sources of electricity generation.

Increasing the investment required to meet future electricity demand by 9-10 times relative to reliance on modern gas-fired plants will approximately triple the average cost of generation. Savings in fuel use are almost entirely offset by the higher costs of operations and maintenance (O&M). After allowing for transmission and distribution costs, the wholesale prices paid for electricity by industrial and other large users will increase by at least 100% and more likely by 150% over the next 5-8 years. Further, this assessment makes no allowance for other measures such as the cost of ETS emission permits, the Climate Change Levy, the Renewable Transport Fuels Obligation, etc – none of which will apply to a manufacturer who relocates to China or any number of other countries.

To understand the potential impact of these changes I have estimated how much employment income by sector would have to fall to offset the impact of (a) an increase of 150% in wholesale electricity prices, and (b) an increase of 100% in total energy costs. The analysis focuses on sectors which produce traded goods, competing with imports or selling in export markets. Inevitably, different assumptions can be made, but my estimates reflect a situation in which producers cannot pass on higher energy costs via higher prices but their input costs, other than for electricity or energy, are similarly fixed. If firms compete for investment funds in the international market, higher energy prices which reduce total value-added must ultimately be translated into lower wages and salaries because investors do not and will not have to accept lower returns.

Table 3 shows the traded sectors which are worst affected by potential increases in electricity and other energy prices. The criterion for inclusion was that the increase in electricity prices is equivalent to 10% or more of current employee compensation. A few sectors may be partly protected by relatively high transport costs – e.g. building materials including structural clay products and cement, lime & plaster or animal feed. Total employee compensation in the sectors identified in the table amounted to about £39 billion in 2008. This is only 5% of the total employee compensation for all sectors, but it is nearly 40% of employee compensation for traded sectors that compete in international markets.

The figures highlight a crucial issue. Suppose we take the commitment to reduce emissions of greenhouse gases as given. Does the UK government wish to achieve this by contracting the traded sectors of the economy? Total employment in the sectors that will be severely affected by the higher costs of electricity and energy is about 1.3 million full-time equivalent jobs. The prospective increase in electricity costs is 17.4% of employee compensation in all of the sectors listed in Table 3, while the increase in total energy costs is 31.5%.[9] A part of that burden may be translated into lower wages and/or higher prices in the UK market, but it is inevitable that many businesses will simply contract or close down their operations – transferring activities to more attractive locations. The consequences for manufacturing employment in the medium and longer term will far exceed any temporary boost due to investments in renewable energy.

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[9] These are weighted averages of percentages in colums 2 and 3 of Table 3 with employee compensation in column 4 used as weights.

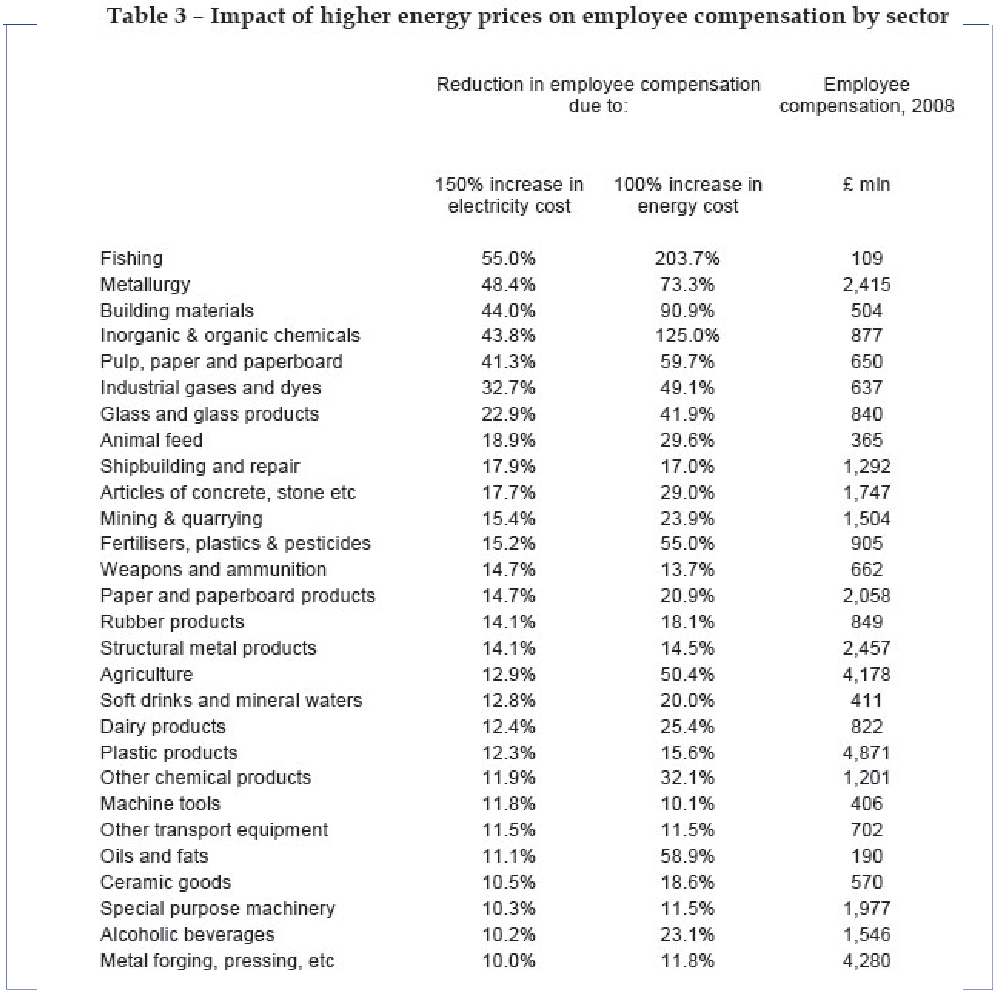

Table 3 – Impact of higher energy prices on employee compensation by sector

	Reduction in employee compensation due to:		Employee compensation, 2008
	150% increase in electricity cost	100% increase in energy cost	£ mln
Fishing	55.0%	203.7%	109
Metallurgy	48.4%	73.3%	2,415
Building materials	44.0%	90.9%	504
Inorganic & organic chemicals	43.8%	125.0%	877
Pulp, paper and paperboard	41.3%	59.7%	650
Industrial gases and dyes	32.7%	49.1%	637
Glass and glass products	22.9%	41.9%	840
Animal feed	18.9%	29.6%	365
Shipbuilding and repair	17.9%	17.0%	1,292
Articles of concrete, stone etc	17.7%	29.0%	1,747
Mining & quarrying	15.4%	23.9%	1,504
Fertilisers, plastics & pesticides	15.2%	55.0%	905
Weapons and ammunition	14.7%	13.7%	662
Paper and paperboard products	14.7%	20.9%	2,058
Rubber products	14.1%	18.1%	849
Structural metal products	14.1%	14.5%	2,457
Agriculture	12.9%	50.4%	4,178
Soft drinks and mineral waters	12.8%	20.0%	411
Dairy products	12.4%	25.4%	822
Plastic products	12.3%	15.6%	4,871
Other chemical products	11.9%	32.1%	1,201
Machine tools	11.8%	10.1%	406
Other transport equipment	11.5%	11.5%	702
Oils and fats	11.1%	58.9%	190
Ceramic goods	10.5%	18.6%	570
Special purpose machinery	10.3%	11.5%	1,977
Alcoholic beverages	10.2%	23.1%	1,546
Metal forging, pressing, etc	10.0%	11.8%	4,280

It is easy to characterise such arguments as special pleading and that the sectors affected should come to terms with the reality of higher energy costs by improving efficiency, etc. Undoubtedly, there are cases in which the rhetoric of economic damage due to policy changes is overstated, but policymakers should beware of making that assumption in this case. I can illustrate the point by a very important example based upon personal knowledge.

During the transition from socialism in Central Europe and the break-up of the former Soviet Union from 1989 to 1992, I carried out a series of studies of industrial competitiveness in all of the countries affected using the methods underpinning the analysis presented here – Senik-Leygonie & Hughes (1992), Hare & Hughes (1994). A crucial issue was the potential effect of moving to market prices for energy and other natural resources on a wide range of industries. The studies highlighted the fact that a significant portion of industrial activity in all countries (more than 50% in some cases) was operating at negative or very low value-added – i.e. the cost of their inputs at world prices exceeded or was close to the value of their outputs at world prices. The inevitable consequence was that the industries concerned would collapse once they were required to pay international prices for their inputs and were exposed to competition in international markets. That is exactly what happened: industrial output and employment fell by amounts varying from 20% at the low end to 60% at the high end over a period of 3-4 years and our work correctly identified the sectors that were at most risk.

The adjustment that occurred in the transition economies was unavoidable, even though it had a massive human cost, because the industries affected were very inefficient and relied upon extravagant use of under-priced oil, gas, and other resources. The same considerations do not apply in the UK today. Electricity, energy and other natural resources are not under-priced in the UK today, even when external environment costs are properly taken into account. The Government's proposals will impose substantial costs on energy users for environmental benefits that are absolutely minimal in relation to trends in the world economy and total emissions of greenhouse gases. It is hard to understand why a Government which claims to believe that the UK cannot continue to thrive solely by selling financial and other services to the rest of the world should adopt policies that will substantial damage or close down sectors that account for nearly 40% of employment income from traded goods.

8. Macroeconomic arguments

In this section I will consider two consequences of green energy policies for macroeconomic management. They imply that the assumption that the effects of such policies should be assessed within a static macroeconomic framework has to be modified for a dynamic approach. The first element is a consequence of the reallocation of investment funds from other sectors to finance the additional costs of renewable generation. The diversion is far from marginal, amounting to about 10% of business investment over a period of 8 years. This means that the productive capacity of the economy will be lower than it would have been without the policies. Under any macroeconomic policy regime this must reduce the level of GDP in the longer term.

The reduction in non-energy investment will amount to £105-110 billion, at 2009 prices, up to 2020. Using a marginal capital-GDP ratio of 3, which is typical for developed countries, this will translate to a reduction of about 2% in potential output in 2020. Provided that the labour market remains relatively flexible, this will not affect the overall level of employment but it will be reflected in lower value-added per worker and thus lower incomes. It is roughly equivalent to the loss of one year's growth in total factor productivity. This may not seem a lot but the aggregate impact is 40% of the total reduction in the planned level of public spending announced by the Chancellor in October 2010.

The second element concerns monetary policy. The Bank of England is required to set its monetary instruments to achieve a target rate of inflation of 2% per year in terms of the CPI. The effect of the Government's policies will be to increase the trend rate of inflation between now and 2020 because of their impact on (a) the electricity and other energy prices paid by consumers, and (b) non-energy prices, as the effects of high energy costs are passed on by non-traded sectors. The combined effect of these factors will be an increase in the CPI of about 6.5% up to 2020. Again, this may not seem too serious until the implications for monetary policy are examined. If Bank of England maintains its inflation target, the effect of the renewable policy implies that the general rate of inflation can be no more than 1.3% per year up to 2020 in order to accommodate the policy-driven increase in energy and energy-related prices.

Macroeconomists use a concept called the "sacrifice ratio" to measure the reduction in capacity utilisation – i.e. the permanent loss in GDP - required to reduce core rate of price inflation by 1 percentage point. Most current estimates suggest that the sacrifice ratio is at least 2 and may be substantially higher. At the lower end of the scale this means that the Bank of England would need to operate monetary policy to reduce the level of economic activity by 1.5% relative to what it would have been. Cumulatively, this translates to a loss of GDP over the period up to 2020 amounting to about £250 billion.

Adding these two elements, the macroeconomic impact of the policies to promote renewable energy will be to reduce GDP by 2-3% for at least 10 years. The loss of income from this reduction will greatly outweigh any possible non-environmental benefits from the promotion of green technologies. To put it in context, it is equivalent to sacrificing all net investment in the public sector – i.e. the part not funded out of depreciation – or about 60% of total spending on education for the UK as a whole. These are not small sums and illustrate the costs of implementing a misguided and poorly designed set of policies.

9. Conclusion

The UK Government has set a target which implies that by 2020 more than 30% of the country's electricity will come from renewable sources of energy, in practice mostly from onshore and offshore wind farms. Because of the technical characteristics of wind generation the capital cost of building the generation capacity required is 9-10 times the capital cost of meeting the same demand from modern gas-fired power plants. In money terms the extra capital cost is roughly £105 billion at 2009 prices and will be equivalent to nearly 10% of total business investment up to 2020. There will be some saving in fuel costs from reliance on wind power, but this gain will be largely offset by the much higher costs of operation and maintenance for wind farms.

The justification for promoting the use of renewable energy is that it will contribute to meeting the UK's goal of reducing CO2 and other greenhouse gas emissions by 34% relative to 1990 in 2020. However, once the effects of economic growth are taken into account, the reduction in CO2 emissions as a consequence of the programme to promote renewable electricity generation will be just 8% of the reduction that has to be made between 2010 and 2020. The average cost of CO2 saved will be about £270 per metric ton, nearly 20 times the average price of CO2 traded under the European Union's Emissions Trading System.

Whatever one's view of the urgency of reducing emissions of CO_2, it is clear that the public and its political representatives have never signed up to the proposition that the UK should sacrifice a minimum of 4-5% of GDP annually in order to meet climate change targets that will have a minimal effect on global warming, even if all other EU countries adopt the same targets. Goals that may be acceptable if the cost of reducing CO2 emissions is £20 or even £50 per metric ton have an entirely different complexion if the best available policy, according to the Government, will cost a minimum of 5 or 10 times more per unit of reduction.

It is possible that the true costs of relying heavily upon renewable electricity generation were not recognised when the current targets for CO2 reductions and renewable energy were originally considered. This is unfortunate, but it reflects the fact that it is quite easy to accommodate small amounts of wind generation in a system with a substantial margin of mid-merit coal and gas power plants. Analysis of the actual performance of wind farms and the difficulties of managing large amounts of intermittent generation ought to prompt a reconsideration of the targets rather than an even more vigorous digging of policy black holes.

As the potential costs of the UK's policy commitments have become clearer, the political rhetoric has shifted to emphasising the alleged economic benefits of greater reliance on renewable energy. The argument is that the promotion of renewable energy will "create" jobs in manufacturing or maintaining wind turbines and similar equipment. Of course, the fact that practically every other developed country in the world makes the same claim is studiously ignored.

In this paper I have explained that there are two broad objections to these arguments. The first is that real incomes levels, not employment, provide the criterion by which to judge economic policies. If the level of aggregate real income is held constant, then higher employment is, usually, worse rather than better because of the loss of leisure and other job-related costs. Claims about green job creation seem to rely upon a casual assumption that higher employment is necessarily associated with a higher level of aggregate real income or welfare. Not only is this not true as a general proposition, there are strong macroeconomic grounds for believing that green energy policies will not affect the long run levels of aggregate employment. Instead, the non-environmental impact of such policies will fall on the real level of employment income. In as far as they have short term, transient, effects on the labour market, the same impacts can be met at much lower cost by other interventions.[10]

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[10] The conclusion that green energy policies will not increase – and could decrease – total employment is supported by a substantial number of studies. Examples include a recent paper that the programs act as a form of macroeconomic stimulus whose effects could be mimicked in a number of different ways, eg by Gulen (2011), an analysis of the impact of policies with respect to renewable energy in Germany by Frondel *et al* (2009) and in Spain by Alvarez *et al* (2009), and a review of arguments about the US fiscal stimulus and green jobs for a general audience by Levi (2009). The consistent theme is that claims for green job creation (a) fail to take account of adjustments outside the sectors directly or indirectly affected, and (b) do not standardise macroeconomic activity and thus assume that the programs act as a form of macroeconomic stimulus whose effects could be mimicked in a number of different ways.

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Acknowledgements

I am grateful to Ian Byatt, David Henderson, Nigel Lawson and Alan Peacock for comments on earlier drafts of this paper. The views expressed in this paper are strictly my own and do not represent the position of any organisation with which I am affiliated.

The Global Warming Policy Foundation is an all-party and non-party think tank and a registered educational charity which, while open-minded on the contested science of global warming, is deeply concerned about the costs and other implications of many of the policies currently being advocated.

Our main focus is to analyse global warming policies and their economic and other implications. Our aim is to provide the most robust and reliable economic analysis and advice.

Above all we seek to inform the media, politicians and the public, in a newsworthy way, on the subject in general and on the misinformation to which they are all too frequently being subjected at the present time.

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Hi Sheila,

Please see below Addition No.11 to our Submission by West Tyrone Against WindTurbines on Wind Energy.

This article explains the deceitful tactics used by wind farm developers to directly mislead the planners, public elected representatives and the general public with their photo montages on how wind turbines would look.

Yours sincerely,

Owen McMullan
Chairman
West Tyrone Against Wind Turbines

Subject: Photo trickery makes wind farms smaller | Wind Energy News

https://www.wind-watch.org/news/2012/07/15/photo-trickery-makes-wind-farms-smaller/#.UuAc57ljxL4.facebook

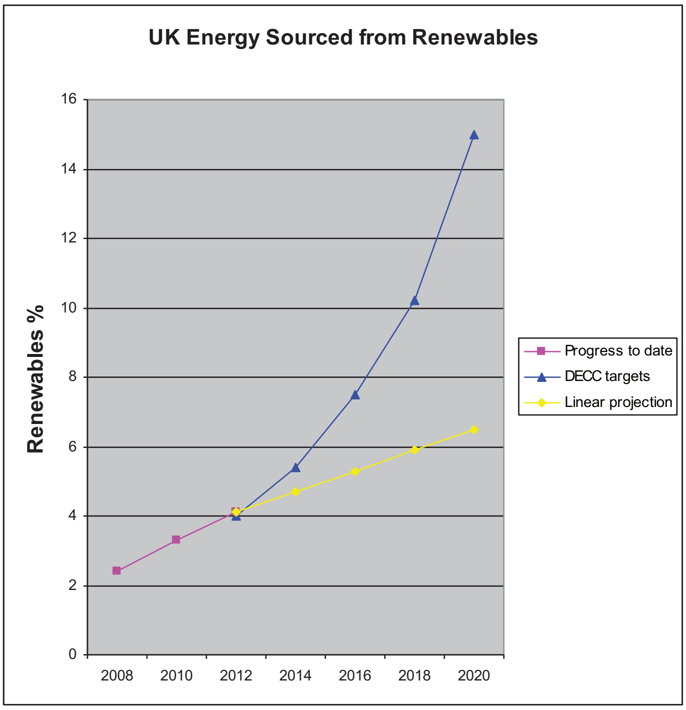
Sent from my iPad

Decarbonisation isn't working

Under the 2009 EU Renewable Energy Directive, the UK is mandated to produce 15% of its energy requirements from renewable sources by 2020. However, in 2012, the latest year for which figures are available, the actual contribution from renewables was only 4.1%. In his recent article Decarbonisation isn't working, the widely respected blogger Paul Homewood forensically dissects the policy options for reaching the 15% target by 2020 and concludes:

> "… we will be lucky to get to half of the target of 15%. It seems we will be paying out ever increasing subsidies, in order to attempt to hit targets that we have not got a cat's chance in hell of reaching."

My own analysis of renewables is more subjective than Mr Homewood's but comes to the same conclusion. The following graph of UK energy sourced by renewables shows progress to date (from Dukes 2013 Chapter 6, Table 6B), a linear extrapolation of that progress and the DECC targets to 2020 (from UK Renewable Energy Action Plan para 4.7.4 table 9). The linear projection from the 4.1% reported value for 2012 is calculated at the rate of increase achieved from the 2011 value of 3.8%.



The graph shows that actual progress to date has been more or less linear. In contrast, the DECC interim targets towards 2020 get progressively more demanding as the years go by, actually a compound increase of over 17% per year.

However there is no logical reason why annual compounding should apply in this scenario, since what is added each year in future does not depend on what has been achieved in the past. The opposite could well apply, as the "low hanging fruit" of easy implementation options gets used up in the early years. The government is also facing many difficult new circumstances, for example:

- the risk of a investment strike on renewables as a result of Ed Miliband's pledge to freeze energy prices and Ed Davey's threat to break up Centrica and SSE,
- uncertainty over the outcome of the Scottish independence referendum, especially in view of the Scottish government's plans to create a grossly unbalanced electricity generation mix,
- the EU Competition Commissioner's plans to limit subsidies on renewables,
- the recent cancellations of the huge Atlantic Array and Tiree Array offshore windfarm projects, despite the sky-high strike prices on offer,
- public opposition to rising energy prices and further spending on highly subsidised renewables,
- climate science doubts created by the ongoing 17-year "pause" in global temperatures which the IPCC is unable to explain coherently.

The graph shows that continuing the linear trend of actual achievement from 2011 to 2012 would only reach 6.5% by 2020. Being more generous, continuing the linear trend set since 2008 would only get to about 8% by 2020. It seems to me that the bureaucrats at the DECC have failed to take on board the exponential increase in progress that would be needed to achieve their final 2020 target. It looks as if an embarrassing policy failure is looming, with a potential fine to be paid to the EU.

To make matters worse, some of the claimed "progress" to date has only been achieved by dubious accounting methods. On transport energy it has been achieved partly through the directive on biofuels, which is increasing global CO2 emissions by causing forests to be cleared (one study has shown that 92% of the CO2 "saved" is just emitted elsewhere) and pushing up world food prices. Some of the claimed progress on electricity is being met by burning biomass, felling forests in North America and shipping the wood in pellet form all the way across the Atlantic. Even the environmental group Friends of the Earth says this a nonsense which actually increases CO2 emissions overall, yet by the perverse accounting standards of the EU and the UK government it still counts as a "renewable".

With regard to the targets on greenhouse gas emissions, the annual progress reports of the Committee on Climate Change show that UK greenhouse gas emissions fell by just 0.5% over the three years to 2012, the latest year for which figures are available, despite all the newly commissioned windfarms. It will be a struggle to make substantial progress by 2020 given that new nuclear is at least a decade away and all but one of the old, zero-emissions nuclear plants are due to be shut down by then. In addition, there is ongoing denial as to what level of net emissions savings, if any, is achieved by wind power. Yet politicians continue to believe that the Committee's targets are feasible, e.g. "a reduction of 40% on 1990 levels by 2030 on the path to an 80-95% reduction by 2050".

On top of all the above:

- Cutting UK CO2 emissions will make negligible difference globally as UK CO2 emissions are less than 2% of global emissions.
- Cutting UK CO2 emissions unilaterally is futile because the developing countries have repeatedly made clear that they will not accept international constraints on their ability to use cheap, reliable, efficient fossil fuels to take their people out of poverty. The Kyoto Protocol expired in 2012 with no successor treaty. There are plans to build more than 1,000 coal-fired power stations worldwide.
- We now know that the earth is awash with fossil fuels, enough for centuries. We also know that we have huge reserves of shale gas in the UK. The "peak oil" argument is no longer an urgent issue. We have ample time to develop sensible, cost-effective sustainable energy supplies. The energy-sparse, expensive, unreliable technology of wind power is exactly what we should not be embracing.
- The ongoing 17-year "pause" in global temperatures despite steadily rising levels of atmospheric CO2 shows that CO2 is nothing like the main driver of climate change that the IPCC claims it to be. The IPCC reports always say that global temperatures will rise by a steady 0.2°C per decade, with never any mention of the possibility of such a "pause". In fact the "pause" has developed into a cooling trend since about 2005, most probably due to the natural variability of the Pacific Decadal Oscillation 60-year cycle, which the IPCC studiously ignores because it is non-anthropogenic in origin. Based on the global temperature record of the last 150 years which shows repeating 30-year periods of natural global warming followed by 30-years of natural global cooling, this new cooling trend will probably last into the 2030s. There is growing public realisation that the IPCC hypothesis of dangerous global warming due to man-made CO2, based entirely on failing computer models, is seriously flawed, i.e. there is growing doubt as to whether there is any urgent need to save on CO2 emissions at all.

It is encouraging to see that the main-stream media is finally starting to understand the utter shambles of our energy and climate change policies. See the recent article Collective madness is gripping European energy policy.

The conclusion is clear: decarbonisation isn't working. In the face of the reality that current policies are failing to achieve their objectives and are simply impoverishing the nation, it is surely time for a complete change of direction on energy policy. The sooner we abandon the pointless targets for renewables and CO2 emissions and the state subsidies that go with them, the better. We need to stop covering the countryside with expensive, useless wind turbines and instead concentrate on the deployment of cheap and reliable forms of energy to allow the nation to prosper.

Doug Brodie
14th February 2014

Decarbonisation isn't working

Web References:

If the links above do not function, then please copy and paste the addresses below directly into your browser.

Page 1

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Hi Sheila,

Please see below Addition No.13 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

Subject: Wind company hid water contamination evidence | EPAW - European Platform Against Windfarms

These wind energy companies wouldn't lie to us sure they have our best interest at heart! Well that is if they had a heart.
Scottish Power hid evidence that drinking water has heavily polluted by their wind farm.
As I have said to you in previous emails, these wind energy companies have no regard whatsoever for the environment or for anything living in it and that includes us. Another massive cover-up exposed on the dirty tactics and lies by the wind industry.

Their sole aim is just to cash in on the obscene subsidies that is driving thousands of homes into fuel poverty and forcing people to choose between eating or heating.
According to a BBC report today, the UK's big 6 energy companies have also over £400 Million of consumers money that they have yet to refund. On a recent Which Report the same energy companies featured high on the list of companies that "Failed You Most" in 2013.

There are loads of other stories from all around the globe on the dirty tactics of the wind industry and the destruction they leave and the lives they ruin.

Please have a look at www.epaw.org
This is the website for European Platform Against Wind with around 630 action groups from 27 countries from all around Europe with one thing in common:
All they want to do is protect their families and their homes from industrial wind turbines, pylons and substations.

I am sure you will find this very interesting.

Yours sincerely,

Owen McMullan Chairman
West Tyrone Against Wind Turbines,

http://www.epaw.org/documents.php?lang=en&article=cont1

Hi Sheila,

Please see below Addition No.14 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

Owen McMullan, Chairman
West Tyrone against Wind Turbines,

Dear All,

You might be interested in this new video entitled '*Wind Energy: Chalk it up as a loss*'. It is an excoriating analysis of industrial wind energy, presented by my policy adviser, Ben Acheson. It may be useful for everyone running individual anti-wind campaigns.

The link is here: http://www.youtube.com/watch?v=kxmltKaTroY

Please feel free to spread it far and wide, embed it on your websites or share on social media sites. If you haven't seen the article that accompanies the video, it is available on the Huffington Post website: http://www.huffingtonpost.co.uk/ben-acheson/wind-energy-chalk-it-up-a_b_3974632.html

Thanks,

Struan

Struan Stevenson MEP

Chairman of the Iraq Delegation

Senior VP of the Fisheries Committee

European Parliament

Brussels

From: owen mcmullan
Sent: 28 February 2014 15:37
To: +Comm Environment Public Email
Subject: Addition No.15 to our Submission by West Tyrone Against Wind Turbines in Wind Energy

Hi Sheila,

Please see below Addition No.15 to our Submission by West Tyrone Against Wind Turbines on Wind Energy.

Yours sincerely,

Owen McMullan, Chairman

Subject: Lawrence Solomon: Fossil fuels now beat wind and solar on environmental as well as economic grounds | Financial Post

Good evening,

I would like to share this article from the Financial Post with you.
So much for renewable energy, the truth always comes out in the end.
Time to stop this madness on wind energy.
With £140Million paid out to the renewable sector in Northern Ireland in the last 3 years and increasing year on year and with £500 Million required to upgrade the grid,
where is this money going to come from and how many more homes will be driven into fuel poverty and how many businesses will close with thousands more out of work.

There are NO Benefits to be had here despite the claims from the wind industry.
If this business was so great as they would have us believe,
then they should be able to stand on their own two feet
and NOT BE DEPENDING ON SUBSTANTIAL SUBSIDIES.
That money would be far better spent in our schools and hospitals
where it will do some good and we can see the benefits.

As people are starting to realise what is going on here and how they are paying for this massive destruction of our landscape, fingers will be pointed at our elected representatives and the planning department, which is following government policy, for letting this happen.
This wind energy business is not in the best interest of the citizens of this country and their claims that they will decrease our dependancy on fossil fuels and deliver cheaper electricity is nothing but lies. All we get from the wind industry is misleading information and higher energy costs and a trail of destruction left behind them.

Yours sincerely,

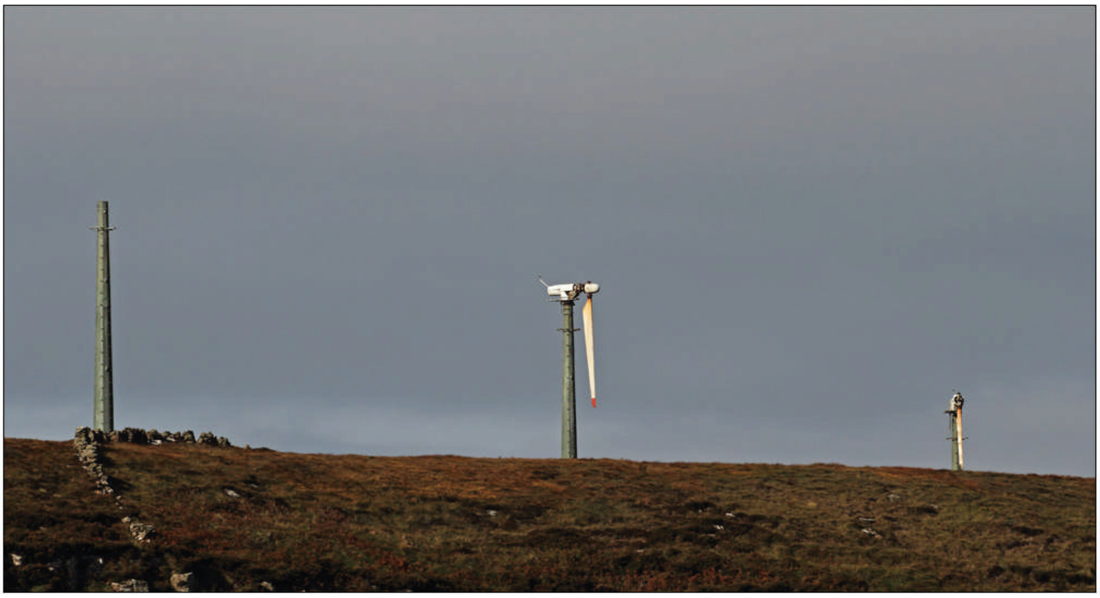
Owen McMullan Chairman

http://opinion.financialpost.com/2013/11/14/lawrence-solomon-fossil-fuels-now-beat-wind-and-solar-on-environmental-as-well-as-economic-grounds/

Windwatch NI

Devastation and Delusion

Sacrificing Rural Communities for unfulfilled promises



Response to the Environment Committee
Inquiry into Wind Energy

by

Windwatch NI

28 February 2014

Devastation and Delusion

Sacrificing Rural Communities for unfulfilled promises

Response to the Environment Committees investigation into Wind Energy

Windwatch NI

About Windwatch NI

Windwatch NI is a collective title for a rapidly expanding network of numerous groups and individuals across Northern Ireland who are suffering from, or are threatened with the destruction of their amenity, health and well-being by the imposition of industrial wind energy in their midst either against their will or with consent obtained through a failure to adequately disclose the true nature and scale of the impacts.

Amongst its aims and objectives we would emphasise two for the current review:

To represent, lobby and promote the views of all who are affected by existing or future wind energy development and to promote the introduction and advantages of a citizen-centred approach to all scales of wind development;

To promote a presumption in favour of the protection of the health and well-being of the public who will be exposed to the impacts of wind energy developments, such presumption to take precedence over economic benefits - Health before Wealth, and the application of the precautionary principle.

Daniel Kane
On behalf of
Windwatch NI

Introduction

There is an unexpected parallel between our energy policy and the self-deception and wishful thinking exhibited by the mishandling of intelligence in the run-up to the invasion of Iraq in 2003. The Blair government ignored warnings about the reliability of sources, some of whom were fantasists, and "sexed up" whatever evidence it thought it did have. In an alarmingly similar fashion, successive British governments since the White Paper of the same year have been basing energy and climate change policy on questionable evidence, much from visionary green NGOs, dubious assumptions about future oil and gas prices and flawed reasoning about the beneficial effects of current renewable generation technologies. The thrust of this policy — unfortunately supported by all three main parties on the mainland— is to offer heavy subsidies, mostly for wind power, by means of levies on energy bills: a regressive wealth transfer from consumers to investors in renewables and to large utilities. The scale of these burdens, already significant at about £2.2 billion a year, is set to grow dramatically as we struggle to reach the 2020 targets set by the European Union's Renewables Directive.

"Instead of a science-based approach, our energy and environmental policies are typically written by those who stand to economically or politically profit from them. As a result, anything genuinely science-based in these policies is usually inadvertent and accidental."

Democratic deficit and inhuman treatment

The emergence of a democratic deficit can be traced to a general belief amongst local politicians that wind power gives us "energy security", that it creates jobs and that it reduces CO_2 emissions. To achieve such 'benefits', it seemed acceptable to subordinate the need for planning policy and Government to protect the quality of life of communities and rural dwellers from the adverse consequences of the technology. The only role for the general public in Northern Ireland, it seems, is to swallow the propaganda, pay those ever-soaring bills — and wait for our lights to go out. It would also appear on the face of it that little attention was given to the possible implications of renewable energy policies on Human Rights law, European law, European Environmental law and the principles of the Aarhus Convention. An addendum on this issue is attached to this section.

Perhaps the most perplexing aspect is the failure to recognise the effect of energy price on the resilience and competitiveness of economic activity and the impacts on well-being, employment, creativity and, for those on low incomes, the more immediate threat of premature death or illness from cold. Sacrificing the population here on the altar of expensive electricity, when it is known that the most vulnerable can lose their lives in cold winters due to the fuel poverty in a weakened economy, is a sure recipe for ruin and is utterly immoral.

The Northern Ireland government aspires to human rights ideals, yet they indirectly endorse the inhuman treatment suffered by some families, stemming directly from Government policy that allows construction of wind turbines in close proximity to family homes. The protection of family life and its amenity and health are less important to Government and its policy-makers than corporate welfare, which is favoured over human and environmental well-being.

The lack of debate, and information about the negative effects of wind power, means that people and the environment in Northern Ireland are being treated by the government as a form of collateral damage. Due regard is not being given to the growing scientific evidence which shows that wind turbines have a profoundly damaging effect on the local ecology and on people's health. The industry has also successfully diverted attention away from its 'dirty little secret' - the true cost of the technology in terms of the pollution it causes in parts of the world from source materials such as rare earth metals. The wind industry are the true NIMBYs since the worst polution has been displaced out of sight to China's 'backyard', not to ours.

Planning system 'not fit for purpose'

The nature of wind energy as a technology has also exposed long-standing tensions in the institutional design of planning. Participation is often identified as a core value of planning, yet it is just this openness to wider viewpoints that most seems to threaten the narrow, instrumental, unaccountable delivery of renewable energy under PPS 18. Decision-makers lack the specialist knowledge to effectively weigh the impacts caused by the technology, or to judge the efficacy of the information provided by many developers. Planners have been politicized to the extent of subordinating professional planning judgement to renewable targets, since the application of the same professional judgement on the mainland results in significantly higher rejection rates.

One particularly disappointing aspect is the absence of any principled independence amongst government departments and agencies, consultees, NGOs and those charged with the protection of the public. Consultees are straitjacketed by the Planning Service in how they can consider and respond to wind energy applications,usually following a desk top exercise on their part, and in some cases are compromised by accepting financial contributions from the wind industry. Any form of independent judgement that does not promote the wind paradigm is rejected outright and the assurances of the wind industry as to the benign nature of its activities are left unchallenged. Indeed, the whole system is perceived as being subservient to the goal of achieving the unproved assertions of economic, environmental and social benefits of wind energy, and no one is prepared to establish the reality of these claims. As Ed Milliband once said, 'The wind industry knows best'.

Our broken planning system has undoubtedly failed rural communities, who see it as a 'rubber stamping exercise' which does not protect members of the public from the residential amenity, health or safety impacts of wind energy. Indeed, Planning is seen as an Agency of the wind industry, and this was humorously confirmed by a recent example involving a local resident from mainland Europe, who rang the wind energy section at Planning Service headquarters. Before he could even state the purpose of his call, he was literally assailed and brow-beaten by a sales pitch on the advantages of bringing his wind farm proposal to Northern Ireland, on the mistaken assumption that he was a possible incoming developer!

However, in a clear abandonment of the precautionary principle, not only do the majority of decision-makers and consultees display a disturbing renewables sycophancy, thus maximizing approval rates for wind energy, but they have failed to put in place a robust methodology for addressing any reported adverse impacts on the rural public. For example, both planners and Environmental Health claim that they cannot monitor or police or enforce any issues relating to noise from wind farms because of the Penalty that would be applied to the developers by Power NI for interrupting the supply – a strange argument for an energy source characterized by intermittency. So the affected residents are left to suffer. Similarly, both planners and Environmental Health have admitted to having no competence in the assessment and resolution of problems caused by shadow-flicker.

By ignoring the history of such community experiences with renewable energy, therefore, the message is sent that there is an unwillingness to listen to the public at large, no matter how loud they shout, or research their grievances.

The burden is real – what about the benefits?

This response does not comment on every aspect of how wind energy interacts with people and the environment. Other colleagues will comment in more detail on the effects on health, the electricity grid, habitat and wildlife and other aspects in separate submissions. However, we wish to make the point that the burden placed on rural communities by the administration of the present renewables policy under PPS 18 is not matched by any commensurate benefits to the community as a whole.

As Dr. Patrick Moore, co-founder of Greenpeace, told more than 1,000 farmers in Ontario in 2012, the industry destroys more jobs than it creates, and causes energy prices to climb for all users. "The industry is a destroyer of wealth and negative to the economy."

There are two words that should be tattooed on the chest of every energy minister: cheap and reliable: subject all policies to those criteria. Who will invest in an economy that can't guarantee its electricity or gas supply or in which the price is no longer competitive?

Those who forget history are destined to repeat it. Catastrophe can be avoided but only with a clear understanding of the failures of the past.

One seminal failure is highlighted by Professor Tony Trewavas of Edinburgh University, and very relevant to this review. Prophesies of the end of 'scarce' fossil fuels were made without looking at the available information, but these views, were widely distributed in newspapers and magazines.

"From EIA assessments, we are several centuries away from any substantive depletion in gas, oil or coal.

Shale and methane hydrates between them put gas even longer term. There are 7 trillion tonnes of world-wide coal and even in the UK, gasification of the known 17 billion tonnes of off-shore coal offers over three centuries worth of energy.

99% of world uranium lies dissolved in the oceans and can be recovered, thus powering the future well beyond the survival of our species. Nuclear currently is the real future. And then there is thorium. We need not be complacent, oil substitution seems the most pressing because so much technology depends on it; but equally we should not descend into meaningless hysteria. Look at the facts, not the hubris."

It is simply facile to say, as the wind industry often does, that "the wind is free". Coal and gas are free in the ground; but we have to extract, convert, and deliver the usable energy to a consumer, all of which have costs.

Exactly the same is true of wind power, and for renewables the extraction, conversion, and delivery costs remain extremely high compared to fossil fuels.

The crude subsidy levels confirm this point. Even onshore wind, a relatively cheap renewable, needs a near 100% income top-up, and if systems costs, extra grid and balancing costs (a hidden subsidy since these costs are socialized over the entire system), are taken into account the cost to the consumer of onshore wind is three times that of fossil fuels, and offshore wind is still more expensive, perhaps four or five times as expensive as conventional energy. Furthermore, these cost estimates may well be too low, since there is emerging evidence to suggest that the economic life of current wind turbines is only half that claimed by the industry, roughly doubling the levelised costs of the energy generated.

Conclusion – Don't Panic!

The symptoms of decay are only too obvious, threatened blackouts, failure to advance replacement of old power stations when needed, policies constructed out of hysteria and ideology, grossly expensive electricity with bills threatened to rise for another decade, a dysfunctional market system dependent on public subsidy for its survival, inadequate gas storage, etc.

It is likely that George Washington was killed by his doctors. With good intentions they met each new symptom with the routine of blood-letting and almost certainly bled him to death.
There are certain parallels with the present feeble state of our generating policy: Ideological meddling, poor leadership and failure to act on expertise have all taken their toll and without some radical changes we too may end up like Washington, remembered but no longer extant.

Can we therefore make a heartfelt plea to our politicians to take a more detached view of the whole energy issue. There is time to look at the costs and benefits of the various alternative policies available, and, indeed, this is a requirement of the Aarhus Convention. We ask that people and the 'real' environment are placed at the centre of deliberations. Even if global warming is true - and the temperature has not risen over the last 17 years - the feared increase of two degrees over a century for a species that can acclimatise to temperature differentials of 50 degrees, or more, does not require that simply any solution, no matter how costly and injurious, is applied. We do have time to take a more balanced approach to climate change and the future of our energy supply. Therefore, as an organisation that sees the effects of hurried and irrational planning policy on families and communities in the countryside, in all sincerety we would ask the Environment Committee to accept the advice given on the front cover of Douglas Adam's famous book, 'The Hitchhiker's Guide to the Galaxy', and DON'T PANIC! There is still time to take good decisions that will benefit ALL the members of the community.

Breach of European law and other international agreements and standards

Introduction

PPS 18 does not fulfill the requirements of, and is in conflict with, a number of European and international laws and agreements.

Public participation

In this regard, two main considerations apply. Firstly in implementing these renewable programmes at such a rapid pace, the authorities have by-passed the legally binding procedures related to environmental assessment and democratic accountability. As the recent legal ruling from the United Nations Economic Commission for Europe (UNECE) has demonstrated, major failings have occurred in relation to the obligations under the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, which is a binding component of EU and Member State law.

With regard to the implementation of the renewable energy programme, the EU is now required to put in place the necessary measures, such that they ensure that the arrangements for public participation in a Member State are transparent and fair and that within those arrangements the necessary information is provided to the public. In addition, such a legislative framework must ensure that the requirements of the Convention are met, in relation to reasonable time-frames, allowing for sufficient time for informing the public and for the public to prepare and participate effectively, allowing for early public participation when all options are open, and ensuring that due account is taken of the outcome of the public participation.

Implications of failure to complete an environmental assessment

1. European Directives

While this effectively demonstrates the planning approvals and funding arrangements for renewable energy projects to date have been implemented without ‘proper authority’, and hence are open to legal challenge, there are further implications related to the failures to complete the necessary environmental assessments. Since 2004 EU legislation required that a programme, which led to the development consent of wind farms, should have been subject to Strategic Environmental Assessment. This required the preparation of a detailed Environmental Report, followed by an in-depth public consultation. This was by-passed, a situation which also occurred in other Member States. Therefore in Northern Ireland, no such Environmental Report exists.

The Environmental Report should have addressed the effects of the renewable energy programme on biodiversity, population, human health, fauna, flora, etc. It should also have addressed the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the programme. Member States should have monitored the significant environmental effects of the implementation of the programme in order to identify at an early stage unforeseen adverse effects, and to be able to undertake appropriate remedial action.

Requirement to undertake an independent environmental assessment

Not only did none of this happen, but at the individual project approval stage, European law is clear in that the planning authority cannot simply rely on the developer's documentation, such as his Environmental Impact Statement. The 1985 Directive on Environmental Impact Assessment, which regulates all significant projects, including wind farms, is very specific in Article 3 of this Directive, that the competent environmental authority must undertake both an investigation and an analysis to reach as complete an assessment as possible of the direct and indirect effects of the project concerned on the factors:
(a) Human beings, fauna and flora;
(b) Soil, water, air, climate and the landscape;
(c) Material assets and the cultural heritage;
(d) The interaction between the factors referred to in points (a), (b) and (c).
However, Northern Ireland failed to transpose and implement this measure. It also adopted a noise standard in PPS 18 that does not fulfil the requirements in the EU Directive. It does not appear to be recognised that it is a legal requirement that a noise assessment forming part of an Environmental Statement must supply "the data required to identify and assess the main effects which the project is likely to have on the environment", and that the "direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project must be described".

ETSU-R-97 does not fulfil the requirement of a description of the likely significant effects of the development and so residents do not know whether the impact is small or great – merely that it meets a target noise level.

Failure to transpose Article 3 of the EIA Directive

According to settled case-law, the transposition of a directive does not necessarily require the provisions of the directive to be enacted in precisely the same words in a specific, express provision of national law and a general legal context may be sufficient if it actually ensures the full application of the directive in a sufficiently clear and precise manner (see, to this effect, inter alia, Case 29/84 Commission v Germany [1985] ECR 1661, paragraph 23, and Commission v Ireland, paragraph 54).

In particular, where the relevant provision is designed to create rights for individuals, the legal situation must be sufficiently precise and clear, and the persons concerned must be put in a position to know the full extent of their rights and, where appropriate, to be able to rely on them before the national courts (see, to this effect, inter alia, Case C-233/00 Commission v France [2003] ECR I-6625, paragraph 76).

As the European Court of Justice stated in its March 2011 ruling in case C-50/09 against Ireland; the competent authority may not confine itself to identifying and describing a project's direct and indirect effects on certain factors, but must also assess them in an appropriate manner, in the light of each individual case. While Ireland's failure to comply with this ruling has now led to the situation where the European Commission is calling for it to be fined, there are other implications. Namely countless wind farms have been approved throughout the country, where both at the national level and at the individual project level, there has been a complete failure to assess properly the environmental impacts associated with these turbines and ensure that the necessary mitigation measures are in place.

Further confirmation of illegality

It should be noted that, on 13 February 2014 the European Court of Justice declared that:

"by failing to transpose correctly Articles 3(7) and 4(4) of Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice Council Directives 85/337/EEC and 96/61/EC, inasmuch as they provide that the judicial proceedings referred to must not be prohibitively expensive, the United Kingdom of Great Britain and Northern Ireland has failed to fulfil its obligations under that directive;"

Renewable energy projects in Northern Ireland to date have been implemented without 'proper authority', and hence are open to legal challenge under the access to environmental justice procedures through the courts, with the assistance of the Costs Protection (Aarhus Convention) Regulations (NI) 2013, which may now require further amendment to the benefit of appellants.

2. World Health Organisation

Noise is also about residential amenity. Many noise complaints made about wind turbines relate to sleep disturbance. Yet the noise standard used by PPS 18 is the only noise guidance in the entire world that recommends higher levels of noise during the night than during the day;

This guidance is quite unsuitable for quiet rural areas because, particularly at night, it sets noise limits not by what is acceptable or reasonable to protect amenity but by what is the upper limit that can be tolerated. For example it often permits turbine noise levels four times as loud as the background noise level at night and just into the region where the World Health Organisation says that it may cause sleep disturbance. Since it was written, the WHO has revised its guidance 5dB lower. So the PPS 18 night standard is now higher than WHO says is required to get back to sleep;

This updating of the night time level to 38dB as a result of the later WHO guidance was recently confirmed by the reporter in the Spittal Hill decision in Caithness in his recommendation to Scottish Ministers who accepted his recommendation to refuse the application.

The British Institute of Acoustics (IOA) will soon be the only organization left trying to defend a night time level of 43dB, and this is included in their recent 'Good Practice Guide', which has just been accepted by the Environment Minister in Northern Ireland. There is no credibility in this position or in the document supporting it.

3. The United Nations Aarhus Convention

The international legal basis for wind energy disappeared in December 2012 when the Kyoto Protocol ceased being legally binding and now the Aarhus committee have ruled the UK is acting illegally.

The Aarhus Convention Compliance Committee has ruled unequivocally that the UK is non-compliant with Article 7 of the Convention.
That ruling will have a profound effect on planning applications for wind farms right across the UK. This will call into question the legal validity of any further consents.

As noted by environmental lawyer, David Hart, QC,:
'This ruling means that consents and permissions for further wind-farm developments in Scotland and the UK are liable to challenge on the grounds that the necessary policy preliminaries have not been complied with and that, in effect, the public has been denied the chance to consider and contribute to the NREAP [National Renewable Energy Action Plan]':

Until such time as the NREAP is fully compliant with the requirements defined under National and Community law and International Treaty Arrangements with regard to environmental democracy and public participation, there should now be a moratorium on such consents.

The opportunity to comment on a planning application is not “public participation” since neither Planning Authorities nor appeals mechanisms will countenance any discussion, never mind criticism, of “Government Policy”.
A halt to further consents until recommendations are implemented should now be automatic.

drk 27 Feb 2014

History of PPS 18 'Renewable Energy'

Three documents were published in the PPS 18 process. The policy statement itself is a general criteria-based approach for all forms of renewable energy development. It is accompanied by a Best Practice Guide and, specifically for wind energy, Supplementary Planning Guidance about how the technology looked on the landscape."

How balanced was this policy?

The section of PPS 18 relating to wind energy is in our view a seriously flawed and unbalanced policy which has resulted in effects on the health and wellbeing of everyone living adjacent to industrial wind turbines in Northern Ireland. This lack of balance is particularly evident in the inadequate protection given to the general public in relation to amenity, noise, shadow flicker and health and safety. Why was this the case?

As well as submitting a substantial document to the consultation exercise, including the most recent research on health and safety, Dr. D. Kane had also written to Environment Minister Mr. Sammy Wilson on 16 October 2008, and, in addition to raising the issue of the unrepresentative stakeholders group, two paragraphs of his letter are particularly relevant to the minister's position versus that of the Department of the Environment:

"…I fear that in the frantic desire to appear to be acting against global warming, wind energy with all its problems, will be presented to you as an issue free and effective panacea. In particular, it may be claimed that the safeguarding of the health and safety of the general public has been adequately addressed when it most certainly has not."

And, further:

"I have had much contact with the planners on wind farm applications over the last four years, and they have openly admitted to a general ignorance on many of the core issues. It is my observation that, with respect to wind farm applications, they have been acting in the role of facilitators rather than as guardians of the public interest."

It is against these statements, that Mr. Wilson's response, dated 29 October 2008, should be understood:

"Thank you very much for your letter regarding the draft PPS 18 on Renewable Energy. You may well be aware from press comments that I have made that I am not totally sold on the renewable energy argument and feel that planning policy needs to ensure that our landscape and the interests of those who live close to wind farms are taken into full consideration when deciding on the policies which will apply to wind farms. You are quite right that there is an attempt to try and have policy written so that it is much more favourable towards wind farms but I believe that we have got to get the right balance. We cannot allow the arguments about climate change to result in a policy which gives the wind farm industry a relaxed set of rules." (Emphasis added).

Who originated the wind energy section of PPS 18?

This is a critical question given the general perception that PPS 18 is an 'industry-friendly' policy, whose restrictions are only loosely adhered to and through which approval is usually expected with confidence by developers – not without reason.

It is in this context that we would draw to your attention comments made by Mr. Stephen Hamilton on behalf of the Department of the Environment on 11 November 2010 to the Committee for Enterprise, Trade and Investment as part of its Renewable Energy Enquiry and officially recorded in Hansard.

"The project was initiated mainly by the wind industry, which was aware that the existing policy was old and had to be revised. There was lobbying of different Ministers, and DOE formed an internal working group — internal to government, not just to DOE."

It is worth noting here that a local lack of balance had already emerged in an unstructured but promotive approach to the assessment and approval of wind farm applications, as demonstrated by the very low rejection rate when compared to the rest of the UK. In 2007 some 24.8% of wind farm applications across the UK had been rejected, compared to 1.6% in Northern Ireland. In 2008 the position worsened considerably with a 41% rejection rate across the UK, but 0% in Northern Ireland. As a result, with only 3%of the population of the UK and 5.7% of the land area, we had 14% of the operating turbines. It is therefore difficult to identify what problem PPS 18 was designed to address, since the approval rate was already 100%. Any pretence to applications being subjected to rigorous scrutiny had already been exposed as disingenuous.

Mr. Hamilton continues:

"separate criteria were produced for wind technology to accompany the generic criteria for all forms of renewable energy. Those were brought together through a stakeholder group. The wind industry sat on that group and provided invaluable help and advice to those of us who did not have the competencies to deal with certain issues."

2

It should be noted that amongst those not invited to participate in the stakeholders group, were representatives of Environmental Health, the only consultee used by the Planning Service for issues related to noise from wind energy applications. It would appear that the wind industry was able to write its own policy in this regard, unchallenged by any other competent authority. It is therefore no surprise to learn from Mr. Hamilton that:

"Generally speaking, the wind energy industry has been very content with the policy throughout the entire consultation process."

The reasons for this 'contentment' were revealed by the minutes of a meeting held at Stormont on 16 June 2009 at which Dr. Kane, Alderman Paul Girvan, now an MLA himself, and the then Environment Minister, Sammy Wilson, were present.

"Alderman Girvan reminded Mr. Wilson that they had both previously attended an event at the Ross Park Hotel sponsored by the wind industry. Although the Department had made a presentation on that occasion, he noted the apparent absence of any significant underpinning knowledge and the Department appeared to be depending very much on the industry guiding them on the issues associated with PPS 18. In effect, the industry seemed to be telling the Department what to include and therefore was basically permitted to write its own charter.

The department, in his opinion, had started from an initial position of overreliance on the industry to come up with their policies as opposed to a balance of the industry position and contrary arguments proposed to protect the public interest from these facilities and there were a number of questions that had to be answered as to the economic benefits."

Mr. Girvan's opinion is fully borne out by a further statement by Mr. Hamilton to the Committee for Enterprise, Trade and Investment on 11 November 2010:

"One issue that really put the cat among the pigeons was that of the supplementary planning guidance, which related to how the technology looked on the landscape. When it was published, it was felt that it was too prescriptive. It went into policy issues when it was only meant to supplement the policy. As a consequence, when the Minister published PPS 18 in August 2009, he asked that the SPG be held pending some analysis of how it would impact on the then draft SEF [Strategic Energy Framework]. Colleagues from NIEA and I have worked very hard with the industry to make sure that we have something that can protect the amenity of third parties but can still help the industry realise the targets set in the SEF. The SPG was published in August 2010, and the industry has sent letters to the Minister thanking him for the process that he has brought forward and for producing a guide that they feel they can work with while still protecting the amenity of Northern Ireland."

How the Wind Industry censored the SPG

Although the public consultation on the SPG had concluded on 5 June 2008, the wind industry continued to have full access to the process of creating the final version. The nature and degree of that involvement has been uncovered from their own documentation, and reveals a disturbing and completely inappropriate level of influence on the creation of public policy and guidance. Their timetable went as follows:

5 June 2008 submission to DoE on SPG
28 July 2008 present findings of Enviros report to DETI and DoE
August 2008 submit comments on draft SPG text
4 September 2008 meet with DoE Planning Service and NIEA to discuss text of SPG
October/November 2008 DoE response to industry position expected
November 2008 expected final meeting with DoE

According to their own information, the industry engaged the Department at these meetings with a list of ‘Key issues’:

“The publication of the draft SPG raises a number of key issues for the Wind Industry in Northern Ireland
Policy is extremely prescriptive in terms of turbine heights and groupings
Planning policy is prepared without due regard UK energy policy
Policymakers do not appreciate industry constraints in terms of turbine size, availability and the commercial viability of small turbines
Policymakers do not treat the Wind Industry as an indigenous industry to be promoted
Policymakers did not adequately consult the industry during the preparation of policy”.

The industry then set out a series of objectives to be achieved before they saw the SPG as being suitable for publication:

“Industry objectives
Changes to draft SPG to include:
Remove turbine height constraints
Removal of turbine grouping specifications
Revisions to negative language used in draft SPG
Significant changes to LCA sensitivity ratings
Alignment of SPG and PPS 18 with energy policies
Acknowledgement of the role of EIA in design and planning process”.

PPS 18 and its Best Practice Guide were published in August 2009, but at the insistence of the Industry, the SPG was held back until August 2010. When it was finally published, the scale of the wind industry's influence can be gauged by their achieving all of the above objectives and more. For example, under the 'key principles of good siting, layout and design', given in Table 8 on page 50 of the draft SPG, the two statements below are given. Compare this with the final version of the SPG, were Table 5 on page 48 shows the underlined portions to have been removed:

Siting

"Optomise separation of commercial wind farm sites from settlements to reduce impacts on the amenity of residents. At distances less than around 2 km, wind turbines are likely to be prominent in the landscape and turbine movement will be clearly visible."

Layout

"Adequate separation from walking, riding and other recreational routes is important to prevent adverse impacts in the landscape experience, amenity and safety of recreational landscape users. 500 m. is generally regarded as a sensible mimimum."

As can be seen, the wind industry have an aversion to any form of separation distances that might impinge on their activities. It is also clear that the trade associations of this industry have a degree of control over the creation and final form of public policy that is inimical to the public good.

Broken Promises on adverse impacts

At the meeting on 16 June 2009 alluded to above with Sammy Wilson, then Minister for the Environment, concerns about the health and safety issues for neighbours of wind farms were raised through the medium of a detailed presentation by a delegation from residents, accompanied by Dr. William McCrea, MP and Ald. Paul Girvan. At the conclusion of that meeting, concrete assurances were given by the minister that he would consider a number of suggested alterations and that the draft policy would be released for further public consultation in which we were to be specifically involved.

In clear breach of that commitment, PPS 18 in its final form, was published on 14 August 2009 without further consultation and apparently without even the knowledge of the Assembly's Environment Committee.

Conclusion

It can now be more easily understood why the results of the meeting of 16 June 2009 were not to the liking of those whom Mr. Wilson stated were attempting '… to try and have policy written so that it is much more favourable towards wind farms' within the Department of the Environment. The proposals submitted in writing by Dr. Kane and his colleagues and then presented by their delegation to Mr. Wilson, would have provided significant support for his expressed desire that, '…We cannot allow the arguments about climate change to result in a policy which gives the wind farm industry a relaxed set of rules.' Our proposals in relation to noise, shadow-flicker and health and safety, proper definitions and adequate separation distances would have had a significant impact in curbing the excesses of the more irresponsible elements of the wind energy sector operating in Northern Ireland, without unduly hampering responsible development.

It may be seen that the observations and concerns expressed by Dr. Kane, Mr. Wilson and Alderman Girvan in 2008 and 2009 are fully borne out by Mr. Hamilton's statements to the Committee for Enterprise, Trade and Investment. The final version of PPS 18 and its Best Practice Guidance was not published by a skeptical Mr. Wilson, but by his much more accepting successor and thus we have the unbalanced, seriously flawed and promotive policy of today. The equivalent policies on the mainland have resulted in approximately 50% of wind farm applications being rejected. In Northern Ireland in 2009 to 2011 inclusive, only one application was rejected.

After fruitless efforts to obtain a response from Sammy Wilson, attempts were made in 2009 to bring the fallacies in PPS 18 to the attention of the Assembly's Environment Committee. No acknowledgement or reply was received to the three letters sent.

A meeting was sought and eventually obtained on 26 October with Edwin Poots, successor to Sammy Wilson as Minister of the Environment. He claims that PPS 18 was 'slipped through' by civil servants in the hiatus between Sammy Wilson's departure and his arrival as Minister to replace him and that they never advised him of the commitment he had inherited. However he was not prepared to fulfil the obligation entered into by Sammy Wilson that further public consultation should take place. Indeed, Mr. Poots believes that we needed to 'grin and bear it' with wind farms because of planning mistakes in the past which pepperpotted housing development across the province preventing larger separation distances. He ignored evidence of health and safety issues when these were presented to him.

Further attempts to bring new research on health and safety matters to the attention of the next Minister of the Environment, Mr. Alex Attwood on 7 November 2011, brought the response that

"I remain satisfied that the safeguards contained within PPS 18 are adequate to ensure that the health, safety and amenity of occupants are adequately assessed through the planning process; and from the consultation responses received from statutory bodies to wind energy developments, that significant harm to the safety or amenity of any sensitive receptors arising from noise: shadow flicker; ice throw; and reflected light will not result."

This is a breathtakingly complacent statement and contrary to the evidence provided to him. For example, the noise standard which is supposed to protect amenity, itself states that its noise limits are set above those required to protect amenity and, by its own admission, it is not a method of assessing impact. Indeed, in terms of night time noise standards, it allows a level substantially higher than the World Health Organisation say is necessary to permit return to sleep.

Mr. Attwood's comments on shadow-flicker and reflected light are also baseless since the appropriate section of PPS 18 misquotes the research it is apparently based upon. Finally, with regards to safety, instead of the "very few accidents" causing "injury to humans", stated by PPS 18, there had by that time in fact been at least 133 fatalities and the annual accident rate was increasing.

To therefore summarise, this history of PPS 18, after a slow start in which the planners did little to develop their understanding of the issues surrounding wind energy over 16 years, the industry itself asked for a new policy which they had a major part in creating. This policy has the same outcome as before in assuring a tiny rejection rate and the industry remains the main source of advice to the planners on any research that challenges the paradigm that it is a clean, green and safe supplier of cheap electricity and CO2 reductions. In the same way, at the most basic local level, communities are being exposed to the health and safety impacts of wind energy partly because no one feels able to challenge the wind industry paradigm and because local authority officers do not have the expertise or working knowledge of the noise standard to establish why it is limited and should not be applied directly. They also automatically apply it as the developer's consultants use it, therefore permitting the developer to become the arbiter in its interpretation.

Terms of Reference 1:

“To assess the adequacy of PPS18 and related supplementary guidance in regulating proposals for wind turbines on a consistent and strategic basis, with due regard for emerging technologies and independent environmental impact assessment;”

> "To assess the adequacy of PPS18 and related supplementary guidance in regulating proposals for wind turbines on a consistent and strategic basis, with due regard for emerging technologies and independent environmental impact assessment;"

Introduction

The most striking aspects of the planning procedures for wind energy are the absence of knowledge amongst decision-makers, and the absence of principle amongst the agencies tasked with advising them. There is no element of caution, no application of due diligence and no acknowledgement of a duty of care. At no time have the underlying assumptions ever been submitted to independent scrutiny. The rural public have been abandoned to the depredations of an unscrupulous industry which is permitted to be the arbiter in its own court.

Context and constraint in wind energy policy

It is important to briefly remind ourselves of the key aspects of the policy set out in PPS 18 for wind energy, in order to appreciate how this is being so blatantly disregarded. These can be seen in the two passages from PPS 18, below, with underlining added for emphasis:

Policy RE 1

Renewable Energy Development

Development that generates energy from renewable resources will be permitted provided the proposal, and any associated buildings and infrastructure, will not result in an unacceptable adverse impact on:

(a) public safety, human health, or residential amenity;
(b) visual amenity and landscape character;
(c) biodiversity, nature conservation or built heritage interests;
(d) local natural resources, such as air quality or water quality; and
(e) public access to the countryside.

The wider environmental, economic and social benefits of all proposals for renewable energy projects are material considerations that will be given significant weight in determining whether planning permission should be granted.

Wind Energy Development

Applications for wind energy development will also be required to demonstrate all of the following:

(i) that the development will not have an unacceptable impact on visual amenity or landscape character through: the number, scale, size and siting of turbines;

(ii) that the development has taken into consideration the cumulative impact of existing wind turbines, those which have permissions and those that are currently the subject of valid but undetermined applications;

(iii) that the development will not create a significant risk of landslide or bog burst;

(iv) that no part of the development will give rise to unacceptable electromagnetic interference to communications installations; radar or air traffic control systems; emergency services communications; or other telecommunication systems;

(v) that no part of the development will have an unacceptable impact on roads, rail or aviation safety;

(vi) that the development will not cause significant harm to the safety or amenity of any sensitive receptors[1] (including future occupants of committed developments) arising from noise; shadow flicker; ice throw; and reflected light; and

(vii) that above-ground redundant plant (including turbines), buildings and associated infrastructure shall be removed and the site restored to an agreed standard appropriate to its location.

Any development on active peatland will not be permitted unless there are imperative reasons of overriding public interest.

For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply.

The policy is obviously promotive, but there are to be certain constraints. Renewable Energy Development, including wind energy, will be permitted provided the proposal will not result in an unacceptable adverse impact. To this constraint for all technologies, wind must also demonstrate that the proposal will not cause 'Unacceptable impacts' and 'significant harm'.
Unacceptable adverse impacts are now acceptable.

The Planning Service have turned this policy on its head and removed all protection from the rural public in the manner revealed in these statements from a recent Professional Planning Report:

“Following additional training and guidance from the headquarters in February 2012 staff were advised to adopt a more flexible approach and it was emphasised that as RE1 states ; "The wider environmental, economic and social benefits of all proposals for renewable energy projects are material considerations that will be given significant weight in determining whether planning permission should be granted."

"The amplification of the Policy also explains even though there may be unacceptable adverse impacts - these can still be outweighed by the local and wider environmental, economic and social benefits of the proposal.
"This includes wider benefits arising from a clean, secure energy supply; reductions in greenhouse gases and other polluting emissions; and contributions towards meeting Northern Ireland's target for use of renewable energy sources."

The Powerpoint slides for this 'training and guidance' continually emphasise that PPS 18 is a 'promotive' policy, and this has been used to justify the elevation of the material considerations of 'wider environmental, economic and social benefits' to be given significant weight, to the level of being the decisive arbiters. This is critical to an understanding of why PPS 18 has failed so completely in preventing unacceptable adverse impacts and significant harm.

Quite simply, there are two very different standards applied to how the costs and benefits of an application are assessed. On the one hand, there is a refusal to apply robust measures to fully reveal the cost to be paid by an individual or community from the location or operation of a wind energy proposal, for example, from noise, health impacts and property devaluation. We find that even that detriment will be reduced further through comparison with purported benefits, primarily economic. The burden of proof for the economic benefits to be set against those costs is much lighter. For example, economic considerations often cannot give rise to effective planning conditions. Similarly, if we do not assess or otherwise audit, carbon payback claims made by developers, how can we verify the carbon footprint of their turbines?

Yet in the absence of such economic and environmental evidence, communities and individuals are being exposed to 'unacceptable adverse impacts' from noise, shadow-flicker and loss of amenity, impacts that are both easily measured, and very, very real.

Abandonment of minimum separation distances

PPS 18 seems clear when it states that "…a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply."

But it would appear that this is getting in the way of the 'promotional' aspects of the policy. Take, for example, the following statement dated 24 February 2014 from the Western Area Planning Office:

"Planning Policy Statement 18 'Best Practice' suggests a minimum separation distance of 500m between proposed wind farms and the nearest noise receptor. This proposal however is for a single wind turbine and as such this suggested separation distance does not apply in this instance."

It would be simple to prove the error of this statement from the original draft PPS 18 responses to the public consultation and other subsequent correspondence with its authors, but this will only prolong this document. Suffice to say:

Definition of a wind farm

> "The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2012 Schedule 2, Category 3(j) defines wind farms as "Installations for the harnessing of wind power for energy production (wind farms)" where:
>
> > "the development involves the installation of more than 2 turbines; or
> >
> > the hub height of any turbine or height of any other structure exceeds 15 metres."
>
> Thus the definition of a wind farm has already been established in Northern Ireland's legislation as having either more than two turbines or where the hub height of any turbine or height of any other structure exceeds 15 metres. This means that a single turbine is classed as a wind farm if its hub height is more than 15 metres, and thus the 500 m. minimum separation distance in PPS 18 must apply.

Freedom to depart from 'Guidance'?

The Western Area Planning statement, and this is a common practice, treat the guidance in PPS 18 and its associated documents, as somehow optional. The complete lack of logic in their argument that only policy that uses the term 'wind farm' applies solely to wind farms and not to single turbines, was again demonstrated in their statement dated 10 December 2013:

"Planning Policy Statement 18 (PPS 18); Policy RE 1 states that for wind farm development, a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m will generally apply. For operational purposes, in applying PPS 18 the Department regards a planning application for more than 2 No. wind turbines to constitute a wind farm, not a single wind turbine."

Now compare this to the noise methodology applied by PPS 18 to both wind farms and single turbines:

"1.3.46 The report, 'The Assessment and Rating of Noise from Wind Farms'

Recommended Good Practice on Controlling Noise from Wind Turbines From 'The Assessment and Rating of Noise from Wind Farms' (ETSU for DTI 1997).

The current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach."

So if ETSU-R-97 referring to wind farms, can be applied to single wind turbines, separation distances for wind farms in PPS 18 can also be applied to single wind turbines.

It is a concern that the guidance is treated in such a cavalier fashion and that by simply using a non-defined term such as 'operational purposes', the planning guidance can be simply set aside. There is also an unacceptable ignorance of the provisions of The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2012.

It is a common claim by professionals of all kinds, which obscures the reasoning for some of their more controversial decisions, that they are applying 'professional judgement'. It should be pointed out that the same planning professionals applying the same planning judgement in England, reject a far higher proportion of wind energy applications than in Northern Ireland.

The Planning Service is one of the organisations which falls under the jurisdiction of the Office of the Northern Ireland Ombudsman and it is therefore bound by the Parliamentary Ombudsman's Principles of Good Administration. The Ombudsman is clear that these Principles are intended to promote a shared understanding of what is meant by good administration and to help public bodies provide adequate and efficient public service to citizens. What is important is that they have been accepted as a benchmark by government representing the standard of performance expected of public officials. They are not aspirational but must be followed. They are therefore a benchmark of good administrative practice against which the standard of service provided by a public body can be tested.

The first Principle of Good Administration is called, "Getting it right". This states that the public body must act in accordance with its policy and guidance (published or internal). There is no flexibility here, it is an obligation. The Ombudsman further goes on to state that a novel approach should only be followed when this will bring a better result or service, and that when public bodies decide to depart from their own guidance recognised quality standards or established good practice they should record why?

These are clear rules that do not allow the Planning Service to cherry pick what part of Policy or guidance they choose to follow or not. They must follow all of it.

The issue is not whether it right or wrong that a wind turbine should be erected, nor is it that the Ombudsman should challenge the opinion of the Planning Service but whether the Planning Service have followed their own processes correctly. A finding of maladministration against the planning service, defined as delay, wrong action, inaction or decisions arrived at due to improper consideration or motives, would raise the issue of compensation for financial loss.

Material Factors

As the residents of rural areas across the province have found to their cost, when an application for wind energy is considered by the Planning Service, different material considerations are given different weight with different burdens of proof.

It is not proposed to examine every material consideration, but some examples will illustrate these problems.

Noise

If we consider noise as an example, the methodology applied is ETSU-R-97, 'The Assessment and Rating of Noise from Wind Farms'. This openly states that its noise limits are set above the level required to protect the amenity of residents, since a level to protect amenity was seen as being very restrictive on the development of wind energy. This noise methodology is therefore in conflict with the part of Policy RE 1 entitled Wind Energy Development, where an applicant will also be required to demonstrate, "vi) that the development will not cause significant harm to the safety or amenity of any sensitive receptors arising from noise;"

Other renewable sources such as biomass plants may have to meet levels of 25dBA at night in quiet countryside whilst wind turbines can operate at over 40dBA when background noise may be well below 30dBA. Usually this would be an accepted cause for complaint, but wind noise receives special treatment. The most bizarre result is that night time noise can be up to 8dBA more than the day time noise. No other standard anywhere in the world has a night time limit higher than a day time limit, and often permits turbine noise levels four times as loud as the background noise level at night. The ETSU night standard is now higher than the World Health Organisation says is required to get back to sleep. We could postulate, therefore, that if the noise level was predicted to be likely to give rise to complaints then this would constitute a major loss of amenity.

However, by using the ETSU standard instead of the more protective BS 4142, rural residents are already being asked to pay a noise penalty for wind turbines. There is no recognition of this in the weighing of material considerations.

Shadow-flicker

The claim that 'flicker effects have been proven to occur only within ten rotor diameters of a turbine' is one of a number of unsubstantiated statements made in the Best Practice Guide to PPS 18.

The research paper on which the statement is based, does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The research also contains a fundamental and demonstrable error that restricts its application.

So the standards on which the preventative separation distance are based, if properly applied, would actually considerably increase those distances. Again, the rural community is being asked, in this case through a misapplication of the research and the German standards with which it has been associated, to bear a heavier adverse impact than they will be given credit for in the weighing of material factors.

Residential Amenity and Human Rights

Whilst it is acknowledged that the planning system must seek to balance competing interests, and that Paragraph 52 of PPS 1 states that 'the planning system does not exist to protect the private interests of one person against the activities of another', this point has been explored in some detail by the Planning Appeals Commission.

In the 'Langley Hall' Appeal (Ref: 2000/A127 & 2000/A128) Commissioner Rue commented:

'The first sentence of Paragraph 52 of PPS 1 seems to suggest that the planning system will not protect private interests. I consider any such suggestion to be unlawful in the light of the Human Rights Act. It seems to me that the possibility of occupiers of neighbouring properties experiencing financial or other loss from a particular development must be a consideration material to the determination of a planning application for development. There is, in any event, an obvious connection between the devaluation of, or the loss of a view from, a property and the amenity of that property. It follows that a development that would unacceptably affect the right of an owner or occupier of adjacent land to the peaceful enjoyment of his or her possessions would not measure up to the yardsticks of good neighbourliness and fairness referred to in the last sentence of paragraph 52'.

Two very important points emerge from this.

First, financial loss is a material consideration in planning decisions. In relation to financial loss, it has been enough in the past for a developer simply to state that no financial loss would occur from property devaluation, and the planners took no account of it in any case. The Advertising Standards Authority (ASA) have upheld complaints about such claims made by developers, who have then had to withdraw them. A heavier burden of proof should not be placed on residents, some of whom have now obtained independent valuation reports by RICS registered valuation surveyors. These conclude that the proposed wind energy proposals will have an impact upon the amenity of their properties and will reduce the value by, in some cases, 25% if permission is granted. This is incontrovertible evidence that residents right to their possessions and the peaceful enjoyment of their property will be significantly affected, contrary to the provisions of the Human Rights Act.

Second, development which will unacceptably impair the peaceful enjoyment of a person's property would clearly be contrary to the policy requirements of paragraph 52 of PPS 1, and would provide a sustainable reason for refusal.

There is an increasing list of cases in GB where applications for turbines have failed because of the impact upon residential amenity. These include:

i) - APP/X2220/A/08/2071880 - Enifer Downs - 'an unpleasantly overwhelming and unavoidable presence in the main view from a house or garden, there is every likelihood that the property concerned will become regarded as an unattractive and thus unsatisfactory (but not necessarily uninhabitable) place in which to live. It is not in the public interest to create such living conditions where they did not exist before'(Para 66)

ii) - APP/E0915/A/12/2168121 - Newlands, Carlisle - 'the presence of a commercial wind turbine, with no intervening screening and in such proximity to dwellings (c400 metres) would be likely to undermine the enjoyment of domestic properties to such an extent as to result in intolerable living conditions for residents of the farm complex'. (Para 21-26)

iii) - APP/D0515/A/12/2181777 and APP/A2525/A/12/2184954 - Fenland and South Holland - 'At The Birches, a bungalow, the main living area window looks directly east towards T2 at 695 metres........I consider the occupants would suffer an overwhelming adverse impact on their outlook and their day to day lives that could not be adequately mitigated'. (Para 27)

iv) - APP/X1118/A/12/2189089 - Tiverton, Devon - the determining issue was the 'severe and unacceptable impact' upon living conditions in a bungalow 400 metres from the site. (para 11)

Residents of rural properties have an expectation that the planning system will protect not just their health, but their amenity. As PPS 1 notes, 'good neighbourliness and fairness are among the yardsticks against which development proposals can be measured'. This major detriment to amenity has generally been ignored completely in the weighing of material considerations in the past.

The wider economic benefits

The burden of proof for the economic benefits to be set against some of the costs discussed above is much lighter than for them. For example, economic considerations often cannot give rise to effective planning conditions. It is not possible to secure through planning conditions how many people can be employed in a business or its profitability, yet these may become reasons that form the basis of an approval.

Several Planning Policy Statements and guidelines have been published recently that align planning policy with an overly narrow concept of conventional economic development. The definition of 'economic benefits' is unclear as it has not been defined and neither are its objective intentions. There must be a clear definition of what the economic and social benefits actually are. These must be real, as opposed to aspirational, since the adverse impacts are real. It is not enough to permit a certain level of noise because an applicant claims that the proposal will create 100 jobs. Such claims are often aspirational and unfulfilled. The planning system has no role in ensuring that those 100 jobs actually appear. It is solely about land management.

In Planning (Statutorily) the definition of 'development', ties it specifically to development of land [Pyx Granite vs Minister of Housing and Local Government 1958]. In this sense development or promotion of economic development generally implies an identified area of development whether that is national, regional or local. Does this mean, for example, that the cost a community will be asked to pay from additional noise, will be compared with an increase in the GDP of that area?

There is a need for a complete review of what constitutes an economic benefit to provide a robust cost/benefit analysis of the tangible and realistic factors relevant to the application. Expected benefits must be based on realistic assumptions about future economic activity resulting from the project, and against which adverse impacts can be measured. The Addendum on Economic Considerations at the end of this section lists basic flaws and faulty assumptions, including a number identified by the Economics Branch of the DRD, that should be taken into account when considering the robustness of claimed economic benefits.

Similarly, a second addendum addresses the issue of supposed CO2 savings, which not only form part of the environmental assessment, but since carbon is assigned a monetary value, has an effect on the balance sheet.

Need for an audit of the past

There is an increasing suspicion in rural communities about the veracity of the claimed benefits from a proposal for which they are being asked to sacrifice their environment, amenity and health.

On the basis of job creation alone, the more than 70 wind farms already approved seem to have grossly exaggerated the numbers to be employed on a permanent basis. There is therefore an urgent need for a retrospective audit of claims about economic, environmental and social benefits of specific wind farms. This must be carried out by an independent consultant with no links either to the wind industry, the government or the various consultees whose impartiality has become so compromised. The object would be to establish if the future benefits projected by the applicant and accepted by the planners, ever materialize, and was this cost effective for the community as a whole?

Terms of Reference 2:

“To compare the perceived impact of wind turbine noise and separation distances with other jurisdictions and other forms of renewable energy development;”

The Problem of Noise from Wind Turbines

"Only when the public can trust the Government and wind farm developers on noise issues will there be a chance that the public will accept them without a fight ..." (Editorial, Noise Bulletin, Issue 15, Aug/Sept. 2007).

Preamble – Why so much emphasis on Noise?

The Committee will note that a very substantial part of this response concerns aspects of noise from wind turbines, as we see this as one of the major adverse impacts on those living around them. In an attempt to make this lengthy response more palatable, it has been broken up into an introductory section ending in our proposed solution to the problem, and seven major questions and answers (numbered 1 to 7 with an addendum), each with a short supporting rationale and a more detailed commentary.

Surely Noise is just Noise?

For years, the scientific community looked on noise as only affecting a person's ears. That is why what is termed the '(A)-Weighted decibel', or dB(A), unit was created to measure noise, since there was an interest only in measuring the noise that will cause hearing damage.

If we compare noise with light, we find that we separate light into, for example, x-rays, Ultra Violet and infra-red,. We know that x-rays are a form of light that cannot be seen but, in sufficient quantity, can cause harm. We know that ultra violet is not visible yet harms the skin. If we use dark glasses for x-rays or ultra-violet light, they will not protect the eyes. Thus different types of 'light' can cause harm in different ways. This is similar to what happens with noise.

The present noise methodology applied in PPS 18 does not take this same approach to acoustics. This has two main effects.

Firstly, in identifying if a noise problem exists. If analysts are measuring for one type of noise, on a particular scale, but what is being heard is not recognised by this scale, this will underestimate any problems.

Secondly, if we treat noise as a single entity, how do we measure the agent of disease to identify which part is affecting, for example, a person's heart, or his lungs?

If we consider low frequency noise, it is about 10 keys below the lowest note on a piano and does not cause hearing damage. Very low frequency noise, known as infrasound, is characterized by very long wavelengths that stimulate the outer hair cells, the ear's amplifiers. The inner hair cells, responsible for hearing, do not respond to infrasound. Therefore, like ultrasound, infrasound is generally outside the range of human hearing. It is still stimulating the ear and the brain, but is doing it in a way that is not auditory. Even though it is affecting the body, it is not measured by the dB(A) unit used in PPS 18.

Neither does PPS 18 adequately protect residents from aerodynamic modulation noise, because the specified noise descriptor ignores the noisiest 90% of each ten-minute measurement period and gives a result based on the loudest noise during the quietest 10% of the period.

These are just two examples of categories of noise that are not adequately addressed under PPS 18, but which give rise to marked physiological effects, disturb sleep and impair health.

Currently the Northern Ireland Planning Service do not require measurement of the full sound and vibration spectrum, do not require measurement inside homes and workplaces, do not require evaluation of sleep or other disturbances, but instead limit almost all assessment to audible noise (dBA) only, outside homes and workplaces. Obviously they are either under the misapprehension that the population of Northern Ireland sleeps outside at night, or they have no inclination to identify and resolve the adverse impacts they have inflicted on wind turbine neighbours.

Introduction

Adverse health effects in people living near or within the footprint of industrial scale wind turbines are being reported by researchers and medical professionals from countries around the world. These reinforce the self-reported descriptions from people living around wind turbine sites who commonly report high levels of annoyance and sleep disturbance. In some cases the reports are of other adverse health effects. In response to this information, the wind industry uniformly disclaims any responsibility. Instead, the problems are blamed on sublimated fear and anxiety; disapproval of the "visual" impact; concern about property value loss; or other issues that cause the symptoms. It is never the sound from the wind turbines that might be the cause.

Is there an explanation for this conflict between the developers safety assurances and the subsequent widespread complaints from those affected by wind farm noise? How can wind turbine noise be both ‘unbearable’ and ‘undetectable’?

Why is the full impact of wind turbine noise not properly assessed?

It is important to appreciate that the guidelines applied to wind energy applications are problematic and controversial in themselves, since they were not just about noise measurement, but reflected an implicit political agenda when they were written. Their method of assessing the noise effects of their developments is not based on generally accepted acoustical measurement and prediction procedures, but is based instead on a 1996 document entitled 'The assessment and rating of noise from wind farms by the Working Group on Noise from Wind Turbines' and more commonly known as 'ETSU(Energy Technical Support Unit)-R-97'. Independent acoustical consultants across the world have found it to be seriously flawed and its use in place of the generally accepted procedures codified in ANSI and ISO standards, explains why projects that appear to be compatible with a community during the planning process later produce complaints of noise annoyance, sleep disturbance and other adverse health effects once operation commences.

For example, the noise standard which is supposed to protect amenity, itself states that its noise limits are set above those required to protect amenity and, by its own admission, it is not a method of assessing impact.
. Indeed, in terms of night time noise standards, it allows a level substantially higher than the World Health Organisation say is necessary to permit return to sleep.

This deniability does not end with the Wind Industry and the authors of the methodology. , as can be seen by a report in the Sunday Times on 13 December 2009:

"Civil servants have suppressed warnings that wind turbines can generate noise damaging people's health for several square miles around.

The guidance from consultants indicated that the sound level permitted from spinning blades and gearboxes had been set so high — 43 decibels — that local people could be disturbed whenever the wind blew hard. The noise was also thought likely to disrupt sleep.

In their draft report the HMP researchers recommended that "Consideration be given to a revision of the night-time absolute noise criterion", noting that this would fit with World Health Organisation recommendations on sleep disturbance.

It has now emerged that officials removed the warnings from the draft report in 2006 by Hayes McKenzie Partnership (HMP), the consultants. The final version made no mention of them.

It has also been used by ministers and officials to support the view that there was no need to revise official wind farm noise guidelines and that erecting turbines near homes posed no threat to people's health and wellbeing.

In Northern Ireland, Planning Policy Statement 18 on Renewable Energy (PPS 18) requires that ETSU-R-97 methodology be used. However, this 'industry best practice', promoted by the Wind Industry, can be seen as permitting the introduction of wind farms into inappropriate low background noise locations where they and other comparable industrial installations could not meet planning conditions derived from the long established BS 4142 standard. This has led to wind turbines being built too close to residential areas resulting in an increasing amount of noise nuisance, whilst preventing local authorities from exercising duty of care responsibilities with respect to wind energy.

Obscuring the Impacts to the Environment Committee?

When the Environment Committee met with NIRIG on 12 September 2013, thus avoiding the possibility of an informed challenge to their statements by Windwatch NI, questions were asked of them by members about the ETSU-R-97 noise methodology used in PPS 18. The following excerpts from Hansard are of particular interest:

Ms Hitchins: I ask you to remember that the ETSU noise limits during the day are set to protect people's amenity of their gardens, so that, on a Sunday afternoon, after a good lunch, you can have that snooze in your garden or on your patio. However, at night, the guidelines assume that you will be indoors asleep — with an open window. So, that is all taken into account in the guidelines.

To show just how disingenuous this statement is, we reproduce from a document on these same points, comments by renowned independent acoustician, Dick Bowdler, a former member of the Noise Working Group:

"it is a thoroughly flawed document and does not deserve the prominence it has been given." Its conclusions are '…so badly argued as to be laughable in parts (the daytime standard is based on the principle that it does not matter if people cannot get to sleep on their patio so long as they can get to sleep in their bedrooms). It is the only standard where the permissible night time level is higher than the permissible day time level" and it "bears no resemblance to standards used for other industrial developments."
the compromise reached by the NWG is so lacking in basis, so full of unfounded assertions and so badly thought out and argued that it comes up with standards for wind farm noise that are quite unlike any other noise standards. It cannot, therefore, even by its own admission, be used as a standard to protect the health and amenity of those most affected by wind farm development, as this was not part of the DTI's remit. Yet that is how PPS 18 attempts to use it.

Turbine noise has a character that makes it far more annoying and stressful than other sources of noise at the same A-weighted sound level. The reasons for this include the amplitude modulation associated with the blade passage past the tower, the quiet rural environment in which turbines are placed, the turbulence of the air that blows past the blades, the variability of manufacture and assembly, and the dominance of low frequencies in the received sound spectrum.

Community noise studies consistently show that public annoyance increases substantially when there is a noise source with unpredictable variability and unusual sounds. Wind turbine noise satisfies these criteria. It has a unique and visceral sound character, which may be perceived as being twice as loud as measured.

The Industry 'Filter'

When public attention first turned to smoking as a health hazard, the tobacco industry tried to defend itself by pointing to the fact there were no large-scale studies that "proved" a direct causal connection between smoking and illness. Making a causal link between a health hazard and its impact can be difficult, costly, and time-consuming. As a result of these obstacles, Big Tobacco was able to hold its critics at bay for decades. The strategy of insisting on almost absolute certainty also provided Big Tobacco with the time it needed to mount a massive PR campaign and aggressively lobby policymakers for legal protections. Meanwhile, despite public posturing to the contrary, Big Tobacco knew full well just how dangerous and addictive its product truly was.

Similarly, Big Wind's call for indisputable certainty about turbine health impacts has bought years for its epic lobbying campaign to extend the government subsidies. It too, knows that there are side-effects resulting from its product.

In the summer of 2011, a crack in the wall of silence surrounding wind turbine low frequency noise emissions occurred as a result of the Danish EPA intention to add low frequency criteria to their wind turbine noise regulations. A letter dated 29 June 2011 from CEO of Vestas Wind Systems A/S to the Minister of Environment for Denmark's Department of Environment (DoE) sheds some light on why the wind industry directs permitting authorities away from regulations requiring low frequency or C-weighted analysis. Denmark's DoE had been undergoing the steps of the regulatory process to include a requirement limiting low frequency sound from wind turbines. This requirement is the same one that Denmark uses for general industry and is a well conceived and tested method although it does not utilize the dBC scale. The Danish government had concluded that larger utility scale wind turbines shift sound energy downward and increase the potential effect of low frequency noise on people inside their homes. This is consistent with the Vestas letter, which acknowledges that it will take some time to make the design changes needed to reduce the low frequency sound emissions. It states:

> "In fact according to our analyses the most economical turbines, the 3 MW category, are the ones that will be strongly affected by the new rules. This applies to open terrain in particular, where in future low frequency noise will dictate and increase the distance requirements to neighbours for close to half of the projects that we are already aware of over the next 2 to 3 years.".

"At this point you may have asked yourself why it is that Vestas does not make changes to the wind turbines so that they produce less noise? The simple answer is that at the moment it is not technically possible to do so, and it requires time and resources because presently we are at the forefront of what is technically possible for large wind turbines, and they are the most efficient of all.".

The recent discovery of a 2004 Powerpoint presentation, demonstrating that Vestas knew a decade ago that safer buffers are required to protect neighbours from noise, that their pre-construction noise models are not accurate and that "we know that noise from wind turbines sometimes annoys people even if the noise is below noise limits" is a disturbing contradiction to their rhetoric. It is also confirmation that the global wind industry have in fact been peddling misinformation rather than facts.

When NIRIG met with the Environment Committee on 12 September 2013, in answer to a question by Mr. McElduff they gave assurances that there was conclusive evidence that there are no negative health impacts from low-frequency noise, specifically citing the Hayes-McKenzie (HMP) Report from 2006.

However, as noted earlier in this introduction, in their draft report the HMP researchers recommended that "Consideration be given to a revision of the night-time absolute noise criterion", noting that this would fit with World Health Organisation recommendations on sleep disturbance. It later emerged that officials removed these warnings from the draft report and the final version made no mention of them. It is, therefore, clear that relying on the conclusions of this report, as published, is unwise as they are, at best, misleading.

Even so, this final version has been used to support the view that there was no need to revise official wind farm noise guidelines and that erecting turbines near homes posed no threat to people's health and wellbeing.

The lack of physiological expertise in the investigators was a major methodological flaw rendering the conclusions in the original draft unreliable. Even with this weakness, and there are others, for NIRIG to suggest that there is no health problem when faced with the large body of evidence presented in the original draft of the Hayes-McKenzie 2006 report is perverse.

Since this apparent attempt to mislead the Environment Committee is so serious, an Addendum has been added to Question 2 dealing with Low Frequency Noise to directly address this claim that there is no evidence to support health impacts from this source.

Even so, this tedious digression has one salutary outcome. It demonstrates the dangers of permitting the Wind Industry to remain the main source of advice to the planners on any research that challenges the paradigm that it is a clean, green and safe supplier of cheap electricity and CO2 reductions. In the same way, at the most basic local level, communities are being exposed to the health and safety impacts of wind energy partly because no one feels able to challenge the wind industry paradigm and because local authority officers do not have the expertise or working knowledge of the noise standard to establish why it is limited and should not be applied directly. They also automatically apply it as the developer's consultant use it, therefore permitting the developer to become the arbiter in its interpretation.

Industry Acousticians acting beyond their roles

Governments continue to rely on acoustic engineers to prepare official guidance both on exposure to wind turbine noise, including the upper limits of dosage and duration, and on the separation distances of wind turbines from homes. It is ironic that several experts on noise and health are on faculty at British universities -- yet perplexingly, Britain continues to rely upon acoustic engineers to advise on the complex problem of noise and health.

Acousticians acting for developers routinely exceed their area of expertise in noise assessments; their reports often contain claims in relation to wind farm power output, meteorological factors or impacts of noise on sleep and health of neighbours. The acoustician's role is to do no more than gather and interpret the necessary acoustic data, providing the public and decision makers with a clear and accessible description of the noise impacts.

It is not the acoustician's role to make value judgements about the merits or otherwise of applications in the planning system. Similarly, calculating power output does not lie within the area of expertise of acousticians and should not form part of their deliberations.
Acousticians instead should concentrate on quantifying the likely duration and level of exposure by calculating the percentage of time in a year that complaints would be likely or marginal based on the BS4142 metric. This information could then be used by the Planning Service or local authority to decide if a proposal is satisfactory and what noise limits would be acceptable given the site-specific results.

The Solution

The constant refrain of, 'this is what is done in England', by policymakers in the Department of the Environment and by the Northern Ireland Planning Service , is the strongest argument imaginable for not having an Assembly in Northern Ireland at all. It displaces responsibility for the protection of residents living around wind turbines onto anonymous officials in England, or on Ed Davey, Secretary of State for Energy and Climate Change. When the origins of the policies uncritically espoused by these principals are uncovered, they usually reside with lobbyists from the wind industry. Thus at times indirectly, but at others through direct intervention, the wind industry has constructed a framework that is permitted to control the amenity, health and wellbeing of everyone residing around a wind turbine.

On behalf of the increasing number of people in Northern Ireland, suffering acute and chronic health damage from living near wind turbines, Windwatch and its many constituent groups across the province demand that the Northern Ireland Assembly take the following action as a matter of urgency:

- Initiate full frequency spectrum acoustic monitoring inside and outside the homes and workplaces of people claiming health problems caused by the proximity of operating wind turbines;

- The monitoring must be conducted for sufficient time, under the weather and wind conditions indicated by victims as being contributive to their symptoms;

- Measurements must specifically include, amplitude modulation, infrasound and low frequency noise, (dBZ or dBLin, dBA, dBC, & dBG);

- The noise monitoring must be performed by accredited acousticians demonstrably independent of the wind industry, approved by the sufferers, and in a manner that will avoid any deliberate manipulation of turbine operation to reduce the acoustic emissions during testing. The results (including all the raw data and associated sound files) must be made available to all parties;

- Excess Amplitude Modulation (EAM) of the aerodynamic turbine noise is neither rare nor minor. Planning conditions following the Den Brook metric should now be applied to all future approvals;

- Wind energy and the wind industry have flourished in Germany with noise limits of 35 dBA at nighttime and, where applicable, 40 dBA for daytime, despite a population density twice that of Northern Ireland. At the very least, the World Health Organisation’s night-time noise limits of 38dB LA90 (40dB LAeq) in the absence of Amplitude Modulation must be implemented. This will help bring setbacks to those recommended by health authorities;

- Initiate parallel assessment between the methodologies for assessing noise impacts contained within ETSU-R-97 and BS4142, to identify the additional noise burden on rural communities from wind turbines;

- Regulation without compliance testing is unethical. Therefore, urgently initiate independent routine testing for post-construction noise compliance. A fully automatic environmental noise measurement system for compliance testing of wind turbine noise is currently available.

- Initiate as a matter of urgency an independent academic, epidemiological clinical study of the effects of wind turbine noise on host communities;

- Introduce a mandatory 2 kilometre minimum separation distance from any wind turbine, and a greater distance for turbines over 2 MW, until robust and independently-assessed evidence is produced that a smaller distance will not have health impacts;

- Introduce a requirement that applicants for wind energy projects should provide tangible proof that their applications will not cause any short or long-term health impacts to the host community.

The plight of people made ill by wind turbine acoustic pollution has been generally ignored in many jurisdictions, including Northern Ireland, as have other negative medical impacts from this technology. The current noise assessment practices and standards in the province, based on the discredited and obsolete document known as ETSU-R-97, are incompetent and unacceptable, and must be urgently reviewed. Future procedures must include full spectrum acoustic monitoring inside homes and workplaces with separation distances being applied that are appropriate to increasing turbine scale and acoustic emissions. Both the allocation of modest funding for independent research and an adherence to the precautionary principle, are an urgent necessity. Only in this manner will the health of those living around wind turbines be adequately protected.

1. Noise Levels

Question: Is the noise standard in PPS 18 adequate to protect residents from wind turbine noise?

Answer: No.

Reason: Noise from wind turbines is permitted to be far greater than for any other renewable source and the noise guidance on which it is based is seriously flawed, thus exposing the public to even greater noise levels.

Comment: The guidelines applied to wind energy applications are problematic and controversial and the noise assessment methodology is not based on generally accepted acoustical measurement and prediction procedures, but is based instead on a 1996 document known as ‘ETSU-R-97’. Independent acoustical consultants across the world have found it to be seriously flawed and it’s use in place of the generally accepted procedures codified in ANSI and ISO standards, explains why projects that appear to be compatible with a community during the planning process later produce complaints of noise annoyance, sleep disturbance and other adverse health effects once operation commences.

Other renewable sources such as biomass plants may have to meet levels of 25dBA at night in quiet countryside whilst wind turbines can operate at over 40dBA when background noise may be well below 30dBA. Usually this would be an accepted cause for complaint, but wind noise receives special treatment. . The most bizarre result is that night time noise can be up to 8dBA more than the day time noise. No other standard anywhere in the world has a night time limit higher than a day time limit.

There are a number of difficulties with the ETSU-R-97 guidance.

It is out of date and it stated in 1996 that a revised report would be required in two years time. No such review has ever taken place, yet turbines are at least five times larger than those on which ETSU-R-97 was based;

The guidelines state that there should be separate noise limits for day and night time, and that the permitted noise level from turbines can be higher at night than during the day; yet many noise complaints made about wind turbines relate to sleep disturbance. ETSU-R-97 is the only noise guidance in the world that recommends higher levels of noise during the night than during the day;

The main difficulty with ETSU-R-97 is that it is quite unsuitable for quiet rural areas because, particularly at night, it sets noise limits not by what is acceptable or reasonable to protect amenity but by what is the upper limit that can be tolerated. For example it often permits turbine noise levels four times as loud as the background noise level at night and just into the region where the World Health Organisation says that it may cause sleep disturbance. Since it was written, the WHO has revised its guidance 5dB lower. So the ETSU night standard is now higher than WHO says is required to get back to sleep;

Consultants working for the Business Department (now the DECC) in 2006 indicated that the sound level permitted from turbines had been set so high — 43 decibels — that local people could be disturbed in particular wind conditions and likely to disrupt sleep. The report said the best way to protect locals was to cut the maximum permitted noise to 38 decibels, or 33 decibels if the machines created discernible "beating" noises as they spun. However, it later emerged that officials removed the warnings from the draft report by the consultants. The final version made no mention of them;

Any measurements at night are underestimated due to incorrect assumptions about the masking effects of wind near ground level, and turbines will therefore be producing more noise precisely when background noise levels are low. Atmospheric conditions at night mean higher pulse levels (producing 'thumping' noises), but investigations generally take place during the day. Likewise, the guidelines state that measurements should be taken outside properties, whereas complainants are usually more troubled by noise penetrating inside their homes;

Absolute noise level is less important than the character of the noise produced. Similarly, research suggests that wind turbine noise has special characteristics which are easily perceived, even as low sound pressure levels. This is also something that noise measurements do not take into account. Rather than noise being simply related to volume, perception of a noise as unpleasant, neutral or pleasing is much more complicated;

The Best Practice Guide to PPS 18 compares the likely noise levels from a wind turbine to those from a car or an office environment, missing the critical points that the quality of the sound, the appropriateness of the noise, and the source from which it arises are just as important as the level;

The current noise assessment practices and standards in the province, based on the discredited and obsolete document known as ETSU-R-97, are incompetent and unacceptable, and must be urgently reviewed. Future procedures must include full spectrum acoustic monitoring inside homes and workplaces with separation distances being applied that are appropriate to increasing turbine scale and acoustic emissions. Both the allocation of modest funding for independent research and an adherence to the precautionary principle, are an urgent necessity.

drk 9 Sept 2013

2. Low Frequency Noise

Question: Does the noise standard in PPS 18 protect residents from the effects of low frequency noise?

Answer: No.

Reason: The noise methodology ignores this type of noise.

Comment: As turbine sizes increase, pushing the blades into increasingly turbulent winds, the associated low frequency sounds increase and shift downward in the frequency spectrum. Because of this downward shift some larger wind turbines have lower dBA ratings than their smaller siblings. This has led to the incorrect conclusion that larger turbines are quieter.

One of the criticisms of the noise standard used by PPS 18 is that the 'A'-weighted scale it uses to measure noise mostly excludes low frequency noise. But much of the noise produced by wind turbines is low frequency and it seems strange to use a scale that does not take into account fully, noise from an offending source.

Large wind turbines generate very low frequency sounds and infrasound (below 20 Hz) when the wind driving them is turbulent. The amount of infrasound depends on many factors, including the turbine manufacturer, wind speed, power output, local topography, and the presence of nearby turbines (increasing when the wake from one turbine enters the blades of another). The infrasound cannot be heard and is unrelated to the loudness of the sound that can be heard. Infrasound can only be measured with a sound level meter capable of detecting it (and not using the A-weighted scale). Infrasound at the level generated by wind turbines cannot be heard, but the human ear is indeed detecting and responding to it, as research clearly demonstrates.

The situation has been exacerbated by bad siting, poor measurement, and the fact that the ear is most sensitive to infrasound when other audible sounds are at low levels or absent. It has been known for many years that maximum stimulation of the ear with infrasound will occur inside the home, because the audible sound of the turbine is blocked by the walls of the house, but infrasound readily passes through. The infrasound will be strongly stimulating the ear even though this is unheard. But it can be felt as a resonance, typically in the chest or through the feet etc.

This problem has been recognised by the World Health Organisation, which has said that special attention should be given to noises in an environment with low background sound levels, where there are combinations of noise and vibrations; and where there are noises with low frequency components.

The factors listed above can lead to differing views about the existence of noise problems. If analysts are measuring for one type of noise, on a particular scale, but what is being heard is not recognised by this scale, this will underestimate any problems. What has been revealed by recent research is that wind turbines do produce significant levels of infra and low-frequency sound at great distances, even when the sound pressure levels do not rise to the thresholds of audibility, and that the greatest effect is indoors.

drk 20 Feb 2014

Spinning the Environment Committee a Low Frequency Yarn?

Addendum to Question 2 on Low Frequency Noise

When the Environment Committee met with representatives of NIRIG on 12 September 2013, the following exchange took place between Mr. McElduff and Ms Hitchins of NIRIG, as recorded by Hansard. This is such a distortion of the actual position concerning the adverse health impacts of low frequency and other categories of noise, that a full rebuttal is given in an excerpt by Dr. Christopher Hanning, the acknowledged expert on Sleep Disorders Medicine in the UK, and in a fully-referenced consideration of The growing evidence of the health impacts of wind turbines.

Mr McElduff: Could Gail point us in the direction of conclusive reports that say that there are no negative health impacts from low-frequency noise?

Ms Hitchins: Yes. Numerous reports reach those conclusions. I refer you to probably the most cited of those, which is the 2006 report that was issued on behalf of the then Department of Trade and Industry and carried out by the Hayes McKenzie Partnership. It concluded that, yes, low-frequency noise can be measured indoors at properties in the vicinity of wind turbines, but that it is well below the guidelines that are permitted by the Department for Environment, Food and Rural Affairs (DEFRA). Wind turbines are not the only source of low-frequency noise. There are guidelines that aim to control it from a variety of sources. Wind turbines are not unusual in that regard, and, as I said, the levels measured were well below the DEFRA guidelines.

Statement byDr Christopher Hanning. BSc, MB, BS, MRCS, LRCP, FRCA, MD, Honorary Consultant in Sleep Disorders Medicine to the University Hospitals of Leicester NHS Trust, based at Leicester General Hospital having retired in September 2007 as Consultant in Sleep Disorders Medicine.

Hayes McKenzie Report 2006

The UK Department of Trade and Industry (DTI) commissioned a report from the Hayes McKenzie Partnership (HMP) in 2006 which investigated low frequency noise at three UK wind farms. As far as can be determined, no medical or physiological expertise was used in the design of the study. Sound measurements were taken at three of five sites where complaints had been recorded over periods from 1-2 months. Communication with residents other than those who complained was minimal. However, they did confirm that “some wind farms clearly result in modulation at night which is greater than that assumed with the ETSU-R-97 guidelines”. Measured “internal noise levels were insufficient to wake up residents at these three sites. However, once awoken, this noise can result in difficulties in returning to sleep.

The lack of physiological expertise in the investigators in not recognising that noise can disturb sleep without actual recalled awakening is a major methodological flaw rendering the conclusions unreliable, as is the short recording period. It is well recognised also that not every resident affected by a nuisance such as noise will actually register a complaint (Health Protection Agency 2009). Many will not be sufficiently literate or confident so to do and others may wish to avoid drawing attention to the problem to protect property prices. They may assume also that protest is futile, which seems to be the experience of many with wind turbine noise. The WHO and other research by DEFRA suggest complaints may represent between 5-20% of sufferers with others seeking alternative coping strategies. Recorded complaints are thus the tip of the iceberg.

It will be claimed also that only 5 of 126 wind energy developments at the time of the study had attracted complaints of noise and thus the matter is trivial. This assertion is, to say the least, disingenuous. Many of the developments at that time were of small turbines set in isolated areas of the countryside, well away from habitation. In addition, as noted above, the proportion of those affected by wind turbine noise who formally complain to their local authority is very small. Research into wind farm noise and health issues in the UK is virtually non-existent and of poor quality. To suggest that there is "no problem" when faced with the large body of evidence presented here is perverse. The conclusion is also contradicted by Moorhouse's study (vide infra) which showed a complaint rate of 20%.

Draft versions of the report (DTI 2006 a,b,c) have recently come to light as a result of Freedom of Information requests. They show that HMP had recommended a reduction of the ETSU-R-97 permitted night time limits to 38dB LA90 (40dB LAeq) in the absence of AM with a further penalty of up to 5dB in the presence of modulation. These recommendations were removed from the final version of the report. No scientific explanation for their removal seems to have been offered. An example of removed text follows:

"The analysis of the external and internal noise levels indicates that it may be appropriate to re-visit the issue of the absolute night-time noise criterion specified within ETSU-R-97. To provide protection to wind farm neighbours, it would seem appropriate to reduce the absolute noise criterion for periods when background noise levels are low. In the absence of high levels of modulation, then a level of 38 dB LA90 (40 dB LAeq) will reduce levels to an internal noise level which lies around or below 30 dB LAeq with windows open for ventilation. In the presence of high levels of aerodynamic modulation of the incident noise, then a correction for the presence of the noise should be considered."

Similarly, references to WHO guidance for the protection of sleep disturbance which supported HMP's recommendations for a reduction in ETSU-R-97 night time noise limits were removed. The removed text follows:

"If one takes the guidance within the WHO for the protection against sleep disturbance of 30dB LAEq, and apply a 5 dB correction for the presence of high levels of [aerodynamic] modulation within the incident noise, then this gives rise to an internal noise criterion of 25dB LAeq. Based upon the measured building attenuation performances at Site 1 & 2, then an external level between 35 – 40dB LAEq (33-38 dB LA90) would provide sufficient protection to neighbouring occupants to minimise the risk of disturbance from the modulation of aerodynamic noise."

It is quite clear that relying on the conclusions of this report, as published, is unwise as they are, at best, misleading.

Dr. Chris Hanning, 'Wind Turbine Noise, Sleep and Health', November 2010.

The growing evidence of the health impacts of wind turbines

- Most health practitioners are well aware of the links between chronic severe sleep deprivation[1] chronic stress[2] and poor physical and mental health. This is exactly what residents living near wind turbines are experiencing[3,] together with other specific symptoms strongly correlating with acute exposure to this sound energy[4,5,6,7].

- Knowledge of the damage to health from exposure to infrasound[8] and low frequency noise [9] (ILFN) has been known for many years. Despite this, little is known about the current ILFN exposure levels inside people's homes since this is not required for wind turbine planning applications.

- The link between chronic exposure to low frequency noise and chronic physiological stress, even when asleep, was clearly highlighted by Professor Leventhall et al in 2003 [10].

- Most medical practitioners have been unaware of the problems associated with exposure to ILFN. This ignorance has not been helped by acousticians and others calling such problems "annoyance" without any accurate clinical diagnoses[11].

- These symptoms have been reported to occur specifically with exposure to wind turbine noise by medical practitioners since 2003 [12,13,14,15,16,17]. Symptoms have been reported by acousticians, health practitioners and residents from countries including Denmark, Sweden, Germany, United Kingdom, France, United States, Canada, New Zealand and Australia.

- Symptoms have been reported up to 4 km from the nearest wind turbine, and more recently characteristic symptom patterns have been reported at distances of up to

10km [18]. These are associated particularly with larger wind turbines (e.g. 3MW), and on occasions are reported at even greater distances, where turbines are sited on hills above dwellings [19] or near expanses of water.

- These health problems consistently worsen over time, until the exposure ceases. A relationship between reported adverse health effects and distance has now emerged [20.] Families in other jurisdictions are being advised by their medical practitioners to leave their homes in order to regain their health. Others remain trapped due to lack of an economic alternative, unable to move to reduce exposure [21].

- Professors Moller and Pedersen, from the University of Aalborg in Denmark, have confirmed that larger more powerful wind turbines emit more low frequency sound waves as a proportion of their sound emissions [22, 23] and this has been confirmed by the world's leading turbine manufacturer [24]. These emissions are known to easily penetrate the walls, foundations, roofs, and windows of homes and workplaces, due to the lesser transmission loss of low frequencies.

- In Falmouth, USA [25], Australia (NSW) [26] and Shirley,USA [27] low frequency noise and pulsatile infrasound emitted by wind turbines have been measured inside the homes and workplaces of people suffering ill health effects. Both LFN and infrasound are present when they are experiencing the symptoms of what has been termed 'Wind Turbine Syndrome'.

- Professors Salt and Lichtenhan have shown that inaudible low frequency sounds do indeed stimulate the ear and produce marked physiological effects [28]. A large body of evidence now exists to suggest that wind turbines do disturb sleep and impair health at distances and sound pressure levels that are permitted in the United Kingdom [29].

  In Canada the research team headed by Roy D. Jeffery, MD, advised family physicians to recognize the symptoms of patients complaining about adverse health effects from wind turbines. "The documented (medical) symptoms are usually stress disorder-type diseases … and can represent serious harm to human health," [30].

- Currently the Northern Ireland Planning Service do not require measurement of the full sound and vibration spectrum, do not require measurement inside homes and workplaces, do not require evaluation of sleep or other disturbances, but instead limit almost all assessment to audible noise (dBA) only, outside homes and workplaces.

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3. Amplitude Modulation

Question:	Is Excess Amplitude Modulation from turbines rare and will PPS 18 protect residents from it?
Answer:	No to both.
Reason:	All wind turbines generate AM and PPS 18 misrepresents the noise it measures.

Comment:

1. The noise most commonly associated with wind turbines, and frequently complained of, is the repetitive swishing beat occurring at turbine blade rotation frequency, which is known as Amplitude Modulation (AM) of the aerodynamic turbine noise. This becomes audible at a considerable distance from the wind turbines.
2. The fluctuating (amplitude modulated) noise caused by aerodynamic modulation is more noticeable and annoying than broadband noise of the same sound level.
3. The noise monitoring recommended in ETSU-R-97, the noise standard used in PPS 18, is totally ineffective in protecting residents from aerodynamic modulation noise, because the specified noise descriptor LA90, 10min) ignores the noisiest 90% of each ten-minute measurement period and gives a result based on the loudest noise during the quietest 10% of the period.
4. ETSU-R-97's recommendation that noise monitoring is carried out at the nearest noise sensitive properties fails to take account of the fact that aerodynamic modulation noise can be heard at considerable distances from a wind farm and can be difficult to detect closer to the wind farm.
5. It is highly likely that one form of aerodynamic modulation is caused by stable atmospheric conditions.
6. The noise limits recommended by ETSU-R-97 will over-estimate the level of wind-induced background noise near ground level during stable atmospheric conditions. Therefore, when the atmosphere is stable, the ETSU-R-97 noise limits will allow wind turbines to generate noise significantly above the background noise level.
7. During stable atmospheric conditions wind turbines will generate higher levels of noise than would be predicted from the wind speed at 10 metres above ground level and the logarithmic wind speed profile equation.

Recent research presented at three Planning Inquiries in England that were conducted in September, October and November 2013 (Starbold, Bryn Lleweln and Shipdham - decisions awaited) have hopefully exposed the misconceived arguments made by the Industry's acousticians' which have successfully avoided controls over wind farm noise impact for many years.

After more than 4 years of smoke screens, obfuscation and erroneous objections raising unrealistic concerns and placing barriers in the way of necessary controls over the wind farm noise called "Excess Amplitude Modulation", industry acousticians have finally admitted a planning condition is "necessary" and "reasonable". Excess AM is now shown to be neither rare nor only causing minor effects as claimed over the last few years, arguments that have successfully blocked planning controls leaving many communities exposed to serious noise impact. Research by noted British acoustician, Mike Stigwood, and a three-year Japanese study of 34 wind farms by a team under Hideki Tachibana Chiba Institute of Technology have exposed this as a common and serious problem.

Dr Matthew Cand of Hoare Lea is part of the Renewables UK research team on EAM who were due to report their findings over 2 years ago but have continuously deferred this. He finally admitted after 2 hours of cross-examination, when being questioned over the need for a condition at the Shipdham Inquiry, that one was both ‘necessary and reasonable’. Dr Cand was also questioned over the Den Brook condition metric which was accepted in 2009 but rejected ever since and that was formulated by MAS Environmental with a 3dB(A) EAM limit. This has been subject to widespread industry attacks over the last four years, leading to its rejection by planning inspectors ever since the Den Brook decision. In response Dr Cand said "If I had to pick a number I don't think 3dB(A) is…a bad number". In effect the Renewables UK research must support what Mike Stigwood's team found four years ago.

These admissions follow years of unpublished work by Renewables UK, coupled with statements that no one knows the appropriate level. In September at the Starbold Inquiry arguments that the Den Brook condition was triggered by extraneous noise were dropped by the appellants and they accepted it was an incorrect argument. Following the Bryn Llewelyn appeal in October 2013 Dr Jeremy Bass of RES, the main opponent of the Den Brook condition said during a meeting:

> "foolishly ... we went along the industry line that amplitude modulation is rare". He accepted the argument that it can be dealt with by statutory nuisance was wrong. He continued "I think that argument is completely exploded by the weight of evidence presented by Mike Stigwood in particular .... we are in a difficult position now ... the landscape has changed and I suspect .... in the future developers will no longer try the argument that AM is rare".

It is hoped decision makers will no longer receive erroneous arguments about the control of EAM and that conditions following the Den Brook metric are now applied to all future consents. There also needs to be a mechanism developed by Government for applying it to existing wind farms. Emerging evidence from the Japanese studies suggests a stricter limit may arguably be necessary but at the present time it is safe to consider the Den Brook metric as a means of controlling wind farm noise.

We also hope decision makers will now exercise particular caution with respect to arguments made by wind industry acousticians and that those who raise concerns over wind farm noise, in the main, do so legitimately.

These findings should be welcomed by both wind-farm neighbours, developers, and decision makers in the planning process. AM noise provokes complaints and heated debates, and an enforceable, objective, condition to cap such noise gives all parties clarity, as well as sparing neighbours and developers the trouble, expense, and uncertainty of private nuisance actions. The Den Brook condition appears to be a readily workable solution to this very real problem.

It should now be accepted that a planning condition to prevent excessive AM noise is both necessary and reasonable in every turbine approval. If AM does not exist, it will never be called upon.

Drk 26 Feb 2014

4. Good Practice Guide to ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms'

Question: Does the Institute of Acoustics Good Practice Guide improve the protection of neighbours from wind turbine noise?

Answer: No. It weakens it substantially.

Reason: The data on which it is based does not support its claims.

Comment: After nearly two decades of insisting that ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms', is fit for purpose DECC commissioned the Institute of Acoustics (IOA) to carry out a review of this standard and develop good practice guidance (GPG). However, this was not a proper independent review by the IOA as the limits which, we were told, "are government policy", were excluded from it's remit.

Pre-determined Outcomes

Indeed, the review was not truly independent from it's inception since, as was stated by the chair of the working group itself at the Wind Farm meeting in January 2013, the work of the group "would be in vain if government did not feel they could endorse it at the end of the day".

Flawed Remit

This absence of real independence and the exclusion of the indicative noise limits from consideration, were not the only problems faced by the review. The character of turbine noise was also placed outside the remit and the actual environmental impacts of the noise standards in terms of audibility and likelihood of complaints were not addressed. Moreover, the guidance diverges from ETSU-R-97 in a number of key areas resulting in a reduction in protection from noise for wind farm neighbours.

The working group was, therefore, not able to tackle the real problems of the assessment of wind farm noise.

The very restricted remit from DECC, was describe in the following terms by the IOA itself:

> "The terms required us to look at the technical elements of the methodology, but did not allow us to consider the noise limits, which are a matter for Government, or to discuss the potential health effects."

Flawed Membership

A major concern with the consultation process was the lack of transparency and potential conflict of interest, since the working group was dominated by the wind industry supply chain.

The working group had no statisticians, meteorologists or others not involved with wind farm planning applications to provide balance or a check mechanism. Further, the majority of members had previously signed up to a method that had not been tested and so were committed to a particular method before taking on the role.

Flawed Methodology

Contrary to the IoA's own professional Code of Conduct, the primary data relied on in the report is not publically available, so the claims concerning the validity of the recommended guidelines cannot be independently verified.

It appears that none of the members of the working group (other than Matthew Cand as part of Hoare Lea) saw the research data they say supports the main element of the GPG. Independent acousticians have been refused the data contrary to IoA rules and now have good evidence to show it does not support its findings. In essence the GPG should not rely on research that cannot be validated but in fact it does appear to do so.

Flawed Scrutiny

The GPG has allegedly been peer reviewed but, incredibly, the reviewers have also not actually seen the research data on which it is based. They appear to have accepted its findings on trust! Thus the peer reviewers, as well as the other members of the working group, appear to simply accept the unverified statements of Industry acousticians on the efficacy of their methods, whilst meekly accepting their exclusion by those same Industry acousticians from the raw data that would allow them to test the validity of those claims.

Undue Influence?

As if all of the above was not enough to invalidate any reliance in the GPG, as journalists discovered, the lobby group for the turbine industry was able to influence the final wording of the guide.

Internal energy department emails released following a freedom of information request show the lobby group met ministry officials and were assured that their input was "reflected in guidance". In particular, an e-mail from an energy department official to RenewableUK on May 10 said: "I understand you met with [name removed] and […] to discuss your concerns about the IoA noise good practice guidance – in particular sound power levels and cumulative impacts. I'm aware that […] has spoken to […], who has confirmed that the majority of R-UK's input has been reflected in the guidance."

Indeed, RenewableUK was invited on to a peer review panel.

Failure to Meet Legal Requirements

The purpose of the GPG is to help ensure that local planning authorities and planning inspectors receive reliable information on the noise impacts of a proposed wind farm in order that a robust planning decision may be made.

The GPG does not appear to recognise that it is a legal requirement that a noise assessment forming part of an Environmental Statement must supply "the data required to identify and assess the main effects which the project is likely to have on the environment" (EIA Directive 2003/35/EC, Article 5 paragraph 3)
and that the "direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project must be described". (Annex IV, paragraph 4)

A noise assessment is required to describe the 'levels and effects of noise from the development'. (Environmental impact assessment: guide to procedures DCLG) There is an obligation that the 'democratic right of a member of the public to make representations must be meaningful and therefore the information which is made available must be sufficient to enable a member of the public:
a) to respond to the significant effects on the environment to which it is suggested the project may give rise;
b) to examine the project to see whether it is likely to give rise to significant effects which have not been identified.' (Newman J. in R(Burkett) v London Borough of Hammersmith and Fulham, [2003] EWHC 1031 para 8 (vii)

As a consequence of this fundamental flaw, a developer who followed the guidance indicated in the GPG would nevertheless fail to comply with over-arching legal requirements, and neither the neighbours of the proposed application, nor the decision maker, would have access to non-technical noise information that would allow them to understand the effects that would result. This is obviously an absurd outcome.

Not Fit for Purpose

We also believe that the IoA document, like ETSU-R-97 itself, is not fit for purpose. The GPG allows more noise than ETSU-R-97.

Every wind farm causing complaints (over about 80 we know about and probably double that) is considered to comply or be within 0.5dB with ETSU limits and especially when using the GPG. Thus either everyone living near them is unreasonable or ETSU and the Guide are both wrong.

The major deficiencies are as follows.

- The new guidelines deviate from the previous guidance by recommending a change of methodology which permits wind farms to make more noise during quiet evening and night hours when high wind shear conditions prevail.

- The IoA's - suggested noise condition permits additional headroom for wind farms to make more noise under specific wind conditions that are common during quiet evening and night hours.

- The IoA guidance on theoretical turbine noise predictions at neighbouring dwellings permits turbines to be built even closer to dwellings.

There are also a significant number of unsubstantiated assertions throughout the IoA documents.

Research by independent acousticians similarly confirms the data on which the GPG is based does not support its claims and as time goes on the evidence grows. A paper to be presented on this is imminent.

Dr John Constable, director of REF, said: "Almost unbelievably, the IoA's wind farm noise committee report has actually increased the risk of serious noise problems for neighbours to new wind farms, and the risks were already quite unacceptably high."
Dr Constable continued: "The report may represent current wind industry practice but it is very poor guidance and fails in its duty of care. The government and the acoustics profession should ignore it, as should responsible wind developers who do not wish to antagonise wind farm neighbours."

There can be no confidence in good practice guidance unless it is rigorous and its claims are capable of independent verification using publically accessible data.

Drk 26 Feb 2014

5. ETSU-R-97 and the protection of residential amenity

Question: Does the noise methodology in PPS 18 protect the amenity of residents?

Answer: No.

Reason: A level to protect amenity was seen as being very restrictive on the development of wind energy.

Comment: ETSU-R-97 was written by a Noise Working Group (NWG) of developers, noise consultants, environmental health officers and others set up in 1995 by the Department of Trade and Industry through ETSU (the Energy Technology Support Unit). The DTI's mission was prosperity for all by working to create the best environment for business success in the UK. It has no brief for the protection of the environment or for the protection of the citizen from nuisance or loss of amenity.

As Dick Bowdler notes, "The first paragraph of the executive summary says this document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. It is thus, by its own admission, not a method of assessing impact. What is more, the compromise reached by the NWG is so lacking in basis, so full of unfounded assertions and so badly thought out and argued that it comes up with standards for wind farm noise that are quite unlike any other noise standards."

Thus comments will be seen such as that underlined below:

It is proposed that the background noise levels upon which limits are based, and the noise limits themselves, are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels, but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions. (Page 61).

This is one example of how protection of amenity is set aside in the document. It is the spikes in noise that frequently cause the annoyance to neighbours of wind turbines. People's perception of intruding noise is based on what they hear in the quiet times, not what they hear on average.

Another example of this process is seen in the two sections below, parts of which are underlined for emphasis:

Margin above background

It is proposed to limit the noise from a wind farm relative to the existing background noise but with special consideration given to the very low noise limits this would imply in particularly quiet areas. Noise from the wind farm will be limited to 5dB(A) above background for both day and night time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different. (Page 62).

Lower limit

Applying the margin above background approach to some of the very quiet areas in the UK would imply setting noise limits down to say 25-30dB(A) based upon background levels perhaps as low as 20-25dB(A). Limits of this level would prove very restrictive on the development of wind energy. As demonstrated below, it is not necessary to restrict wind turbine noise below certain lower fixed limits in order to provide a reasonable degree of protection to the amenity. (Page 62).

For someone living in a rural environment, the level of background noise would be very low, yet the minimum level of noise for a single turbine is permitted to be 35 dB(A). Immediately you will be exposed to a noise increase of probably 10 or more decibels, which is certainly a loss of amenity. Indeed, the reasonableness of the degree of protection is not defined, nor should it be assumed that the use of the term 'amenity' refers to the defined term in planning.

The document then resorts to 'sleight of hand' by introducing the night-time noise limit of 43 dB(A) before it addresses the day-time noise limits, thus giving the impression that they are somehow being generous by having a lower day time limit. In fact, the reverse is the case. The result is that night time noise can be up to 8dBA more than the day time noise, and up to four times higher than the original background noise level. No other standard anywhere in the world has a night time limit higher than a day time limit.

The document then attempts to set up 'straw men' such as in the following statement:

The Noise Working Group believes that the external levels around 50dB(A) suggested by some of these documents for the protection of external amenity would be entirely inappropriate in the quiet rural locations of the UK. Furthermore, even the 43dB(A) limit (LA90,10min) derived above to protect sleep disturbance inside the property does not offer sufficient protection to the external amenity in quiet areas of the UK during the day.

2

It is also the opinion of the Noise Working Group that there is no need to restrict noise levels below a lower absolute limit of $L_{mo,10min}$ = 33dB(A); if an environment is quiet enough so as not to disturb the process of falling asleep or sleep itself then it ought to be quiet enough for the peaceful enjoyment of one's patio or garden. This level would however be a damaging constraint on the development of wind power in the UK as the large separation distances required to achieve such low noise levels would rule out most potential wind farm sites. There are however the following justifications for relaxing this limit:

- Wind farms have global environmental benefits which have to be weighed carefully against the local environmental impact.

- Wind farms do not operate on still days when the more inactive pastimes (eg sunbathing) are likely to take place. Etc.

- The absolute lower limits will only come into force when the turbine noise is more than 5dB above the background noise level and when this level of 5dB above background is below a figure in the range discussed below. The period of greater exposure to noise will therefore be limited and on some sites will not occur at all. (Page 64).

For periods during the day the Noise Working Group has adopted the approach that external noise limits should lie somewhere between that required to avoid sleep disturbance even if the occupant is outside of the property and the higher level that would still prevent sleep disturbance inside the property.
The Noise Working Group has therefore concluded that in low noise environments the day-time level of the $Lmo_{,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). We believe that limits within this range offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development. The levels are low compared to some of the advisory documents reviewed and this is because of our concern to properly protect the external environment. (Page 65).

As Dick Bowdler again comments, “The conclusions of ETSU-R-97 are so badly argued as to be laughable in parts (the daytime standard is based on the principle that it does not matter if people cannot get to sleep on their patio so long as they can get to sleep in their bedrooms)...

ETSU-R-97 bears no resemblance to standards used for other industrial developments. Other renewable energy developments have to meet stricter standards. At several points the Noise Working Group that drew up the document decided that a particular standard was appropriate and then, without putting forward any evidence said that such a standard would restrict development of wind farms and so relaxed it further.”

This is only an introductory look at the document, but it will be seen that the abandonment of protection of amenity is quite subtle in places and this is only a selection.

Drk 22 Feb 2014

6. BS 4142 – An alternative to ETSU-R-97 that works

Question: Does the noise standard in PPS 18 enable local authorities to exercise duty of care responsibilities concerning wind turbines?

Answer: No.

Reason: The noise standard used by PPS 18 permits the introduction of

wind turbines into inappropriate low background noise locations where they and other comparable industrial installations could not meet planning conditions derived from the long established BS 4142 standard.

Comment: A standard does exist for the assessment of the impact of environmental noise that both complies with EU law and UK regulations, and sets out the impact of noise from the development on people and the environment. It also provides a more robust methodology than that used in PPS 18, known as ETSU-R-97.

BS 4142 Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas is a British Standard that has been in existence for over 40 years. It is widely used throughout the UK as an assessment tool for planning purposes. It is so widely used that hardly any local authority in the country does not use it for some types of assessment and most require it for assessments of developments where a new non-transportation noise is introduced into an area – even such noise sources as football pitches. It has been and is still regularly used to assess noise impact and experienced practitioners know of no case where it has been suggested that BS4142 gave an anomalous result.

The standard was endorsed by DEFRA in September 1998, the department of government concerned with the environment at that time. They submitted their Noise and Nuisance Policy under Health Effect Based Noise Assessment Methods to the EU. This said that BS4142:1997 provides a technical means of assessing whether or not 'complaints are likely'. The result of an assessment carried out to BS4142 would normally be relevant to the deliberations of any court considering whether or not a nuisance exists.

It seems common sense that the impact of a new noise on existing residences is related in some way to the background noise. For example if the background noise level at present is 45dBA then a level of 35dB from a new industrial source would probably be inaudible. If the background noise level at present is 20dB then an industrial noise of 35dB will clearly be heard and would be very likely to produce complaints. Indeed it is normal to set a noise limit relative to the pre-existing background noise when a new industrial noise is to be introduced into a residential area. Typical planning conditions imposed by rural local authorities require that the new noise be no more than 5dB above the pre-existing background.

BS4142 indicates that a difference of around 10dB or higher will likely result in complaints. We could postulate that if the noise level was predicted to be likely to give rise to complaints then this would constitute a major loss of amenity. BS4142 also includes a penalty to reflect the nature of the noise. If it is tonal, has clicks and bangs or is otherwise likely to attract attention then a penalty is applied of 5dB.

This then must be accompanied by a narrative to describe the likely subjective impact that the noise will have on each sensitive receptor. That narrative will include those factors that are not taken into account by the objective test – for example for how long do particular levels of impact last, is the noise likely to be masked by the background noise or are the frequency characteristics quite different, does the intruding noise have significant levels of low frequency. This is all set out in such a way that everyone understands the position and then a proper planning decision can be made.

The critical advantage in using BS 4142 is that it enables local authorities to exercise duty of care responsibilities denied to them under ETSU-R-97.

In summary, BS 4142 can be characterized as follows:

- First published in1967, amended 1975, 1980, 1982, and revised 1990, 1997

- Concise 19 page document easily understood and applied by local authorities and developers (compared to 175 pages for ETSU)

- Applicable for a range of wind speeds up to 5m/s

- Applicable when rating levels are above about 35dB

- Background surveys not required if rating level is below 35dB

Overall BS 4142 provides enforceable, robust noise assessment guidance and reintroduces the concept of protection for residents living adjacent to wind turbines.

Drk 26 Feb 2014

7. Separation Distances and Noise

Question: Does the noise standard in PPS 18 ensure adequate separation distances between turbines and rural residents?

Answer: No.

Reason: The need was ignored for epidemiological and laboratory research by health professionals and acousticians concerned with public health and well-being to develop effective and precautionary setback distances for industrial wind turbines that would protect residents from wind turbine sound.

Comment: The normal Noise protocol is to base the siting of turbines on the prediction of the noise at a receptor. There is no routine testing for compliance postconstruction and therefore no feedback on the planning of future wind farms. In cases where complaints have led to noise audits that have demonstrated noncompliance, the receptors have sometimes been compensated but no feedback has informed the compliance process.

Applicants and regulators should have foreseen the very negative noise response from neighbors living near wind turbine sites. By their not adequately understanding the sound character generated by wind turbines, appropriate corrections to prevent annoyance were not included in the noise predictions.

Residents are being annoyed, are suffering sleep deprivation and disturbance, and in many cases, are suffering adverse health effects.

Yet, in comparison to other sources of environmental noise, annoyance due to wind turbine noise was found at relatively low noise exposure levels, which for other noise sources appeared reasonable.

We now know that turbine noise has characteristics that contribute to this situation. We also know that there are factors not considered when applying the noise regulations. Finally, there is a reluctance to test for compliance. Unlike industrial machinery there is no possibility of shielding the noise at source. Nevertheless, regulation without compliance testing is unethical.

The characteristics of turbine noise that contribute to annoyance and sleep disturbance are as follows:

The sound from turbines is amplitude modulated at the blade passage frequency. The modulation level is typically 3 to 5 dBA (van den Berg, 2005) but higher levels have been measured (Moorhouse, Hayes, von H erbein, Piper, & Adams, 2007). Two things arise: The peak sound is higher than the average used for noise regulation and the modulation enhances the audibility of the sound to such an extent that the turbine noise can be detected even when the sound is below ambient (Hanning, 2010). The noise emitted by a turbine is broadband; however, at a distance of 500 meters and more, the higher frequencies have been absorbed by the atmosphere so that it is predominantly low-frequency noise that reaches a receptor. This low-frequency noise enhances annoyance and is more readily able to penetrate walls and resonate inside rooms. Many people report a thumping, rumbling, or impulsive character to the turbine noise (e.g., Frey & Hadden, 2007, 2012; Harry, 2007); the reason is not clear.

Deficiencies With Present Noise Regulation

As noted above, the character of turbine noise makes it especially intrusive. This is exacerbated by the fact that wind turbines are sited in rural areas where the ambient noise level can be 25 dBA or less. An intrusion of 15 to 20 dBA is too large. Germany has a night time noise limit of 35 dBA; this should be the international absolute maximum, but that in Northern Ireland is 43 dBA.

Also, the standard algorithm for predicting noise at a receptor is ISO-9613-2. But, this was never designed for turbine noise. The ISO manual is specific in limiting its use to noise sources close to the ground such as “road or rail traffic, industrial noise sources, construction activities, and many other ground-based noise sources.” Turbine noise derives from blades rotating, typically, between 35 to 125 meters above ground level. When used without compliance, testing the results of the predictions have little meaning.

The authors of noise prediction algorithms appreciate that there is uncertainty in the calculations. For instance, the manual for ISO 9613-2 puts the uncertainty at 3 dBA for a source to receptor distance in the range 100 to 1,000 meters.

The turbine makers know that there is variability in manufacture; this is put at 1 or 2 dBA.

Combining these, the predictions can be no better than 4 dBA. This uncertainty is ignored by the wind energy developers and by the regulatory authorities. This is despite the fact that the final siting plans are signed off by professional engineers and approved by professional engineers.

All prediction algorithms assume spherical spreading of the sound from the turbines. This is not necessarily always so, especially when more than one turbine is involved. Sound propagation experiments over hard surfaces, such as water or packed sand, have demonstrated a transition from spherical to cylindrical spreading even for distances of less than 1 kilometer (Bou 2007; Hubbard & Shepherd, 1991). Packed snow would be another example of a hard surface. The cylindrical spreading is a result of refraction of sound in the atmosphere and channeling of sound between the atmosphere and the ground (S dergaard & Plovsing, 2005).The distance at which the transition occurs depends on the wind speed and temperature gradients in the low atmosphere and will vary with time of year, time of day, and weather.

Turbines leave behind them a turbulent wake and a wind speed deficit. Turbulence is known to exacerbate turbine noise (Amiet, 1975; Moriarty, 2004; Moriarty, Guidati, & Migliore, 2004, 2005; Moriarty & Migliore, 2003; Romera-Sanz & Matesanz, 2008). Turbulence occurs naturally in the atmosphere but the wake turbulence can equal this natural turbulence out to 5 blade diameters (Barthelmie et al., 2003). Experiments with an isolated turbine at the National Renewable Energy Laboratory in the United States have demonstrated this excess noise for measured natural turbulence and compared it with turbulent inflow noise calculations (Moriarty, 2004). Below 200 Hz, the turbulent inflow noise dominates over all other aerodynamic sources for turbulent intensities above 10%. No account of this excess noise is included in any noise regulation.

The use of masking noise to justify an increase of the noise limit with wind speed was laid to rest by the pioneering work of van den Berg (2004). He argued that in a stable atmosphere there can be a large vertical wind speed gradient such that the turbine is generating power and noise while at ground level there is insufficient wind to generate masking noise. He supported his argument with meteorological tower wind speed measurements. The pity of it is that so many wind farms have been built with setbacks based on the allowance years after van den Berg had so clearly made his case.

The Way Ahead

At a minimum, the following need to be introduced into noise regulation of wind turbines.

The noise limit needs to be reduced to 35 dBA at night time and, where applicable, reduced to 40 dBA for daytime. This is still intrusive in rural areas but will help bring setbacks to those recommended by health authorities. Wind energy and the wind industry have flourished in Germany with these regulations, despite a population density twice that of Northern Ireland.

A penalty of 5 dBA needs to be added to the time-average predicted noise levels; this is to compensate for the enhanced audibility of the amplitude-modulated and impulsive character of turbine noise.

Uncertainty in design calculations is the norm in engineering practice. The 4 dBA is real and should be tolerated in the noise prediction calculation. For the wind developers, erring on the side of caution could protect their very large investments when testing for compliance does become the norm.

A great deal is known about the excess noise due to turbulent inflow. Wind energy developers need to make test tower measurements of local natural turbulence and make calculations of wake turbulence to predict this excess noise.

Compliance is not so difficult. It is common practice to check for compliance in all manner of industrial situations. Atkinson & Rapley Consulting (2011), in association with Astute Engineering, in New Zealand has developed a fully automatic environmental noise measurement system. This is in service in New Zealand for compliance testing of wind turbine noise. Compliance testing is vital because it leads to reconsideration of noise prediction calculations. Where noise audits have been done, such as that at a home near Shelburne in Ontario, turbine noise well in excess of the noise limit has been demonstrated. In such cases, the wind energy company pays compensation or buys out the home-owner; no iterative use is made of the audit.

With the above changes to the regulation of noise:

- a 35 dBA night time noise limit;
- penalties of 5 dBA for the periodic or impulsive character of turbine noise;
- 4 dBA for uncertainty in noise prediction, and;
- a penalty for turbulent inflow noise;

the setback from homes will approach the 1.5 to 2 kilometres recommended by health authorities.

Drk 26 Feb 2014

The Inadequacy of Separation Distances

Introduction

There are a number of aspects that must be considered in setting an adequate separation distance. To simplify this document, it has been divided into a main discussion, ending with a proposed minimum separation distance, and three major questions and answers (numbered 8 to 10), each with a short supporting rationale and a more detailed commentary covering Residential amenity, shadow-flicker and reflected light, and safety impacts. All of these have significance in deciding how close to a residence a turbine should be permitted to approach, as do a number of those already considered under the earlier section on ‘Noise’.

Separation distances in PPS 18 - Origins and Faulty Basis

It is surprising but true that there is no scientific basis to the statement within PPS 18 that, “For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply.”

As will be seen below, the statement is the result of the conjunction of three errors:

- Failure to fully understand the application of the noise standard adopted by PPS 18;

- Failure to identify the limitations and shortcomings inherent in a restricted piece of research concerning shadow-flicker, not capable of verification or repetition; and

- Failure to objectively examine wind industry assertions concerning the safety of their technology.

No research had been conducted nor was independent expert advice ever sought to assess if these separation distances would be adequate to protect residents from the effects of noise, shadow-flicker and component failure. In short, it appears to be a civil servant’s approach to controlling impacts by combining two misread and misunderstood standards, the adequacy of which individually and in concert, have never been established, and ignoring a third impact completely.

Why a 500 metre minimum separation distance and what does it apply to?

This is first stated in the summary of consultation responses to the draft of PPS 18 in 2009:

"In response to points raised through the public consultation, the Department has decided to amend the policy text to include reference to a recommended separation distance that should be applied as a general rule to applications for wind energy development. The distance is expressed as 10 times rotor diameter or a mimimum distance of 500 metres to occupied property."

Note in particular that this minimum is to be applied '…as a general rule to applications for wind energy development', and not only to wind farms. However, the reason for the size of the actual distances themselves is not given.

Further investigation into the efficacy of these separation distances brought the following clarification from Stephen Hamilton, one of the authors of PPS 18, on 14 May 2010: It is partly reproduced below without correction:

"I would like to draw your attention to the complementary Best Practice Guidance to PPS18. This guide was initially published as Annex 1 to draft PPS18 and provides guidance for other amenity considerations outside of the established ETSU noise standards applied across the whole of the UK. Paragraphs 1.3.76 and 77 of the Guidance (paragraphs A107/8 in the consultation draft) provides a separation distance to mitigate against the potential for shadow flicker. While this document is referenced in the text of policy RE1, only limited weight can be applied to this in setting a minimum standard in the protection of public safety, human health or residential amenity. Taking the comments received to the public consultation exercise from the Chief Environmental Health Officers Group (CEHOG) proposing a minimum distance of 500m on the issue of noise, the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds.

So the separation distance is the combination of two methodologies, applying to noise and shadow-flicker respectively, and slightly increased at the recommendation of CEHOG. Note also that '…the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds' and does not refer specifically to wind farms.

This understanding of the sources from which the separation distances were derived, is further confirmed in correspondence dated 18 June 2010 with Anne Lockwood, Deputy Director of the Planning and Natural Resources Division.

In her reply, Ms. Lockwood states:

'In your email, you stated "You have not revealed the origin of the "10 diameters is sufficient to prevent noise impacts". The department FEELS that this is right. Have they conducted research? Have they sought expert advice? Or is it just in their bones? Perhaps you would advise us of the basis for this intriguing assertion". In response, I would like to refer you back to Mr Hamilton's email dated 14 May 2010. Taking on board the CEHOG comments to the PPS 18 public consultation, a minimum separation distance of 500m has been introduced to accommodate the differences in noise emissions between different types of turbine. Generally speaking, 500m is approximately the same distance as10 times rotor diameter to a turbine of 80m in height. On general amenity grounds, the 10 times rotor diameter separation distance has been introduced with particular regard to taller turbines. This increases the separation distance to sensitive receptors beyond what is required by national guidelines set out in ETSU.'

In this regard it is useful to record what ETSU-R-97 actually says on the matter of separation distances:

"The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms", (ETSU-R-97, page 46).

In effect, what the Chief Environmental Health Officers and Anne Lockwood are saying is that, because turbines are now bigger and noisier than those considered under the adopted noise standard of ETSU-R-97 which was written in 1996, then the separation distance should be increased above the 350 to 400 m. which ETSU-R-97 states is not adequate to resolve noise problems. The CEHOG recommended a minimum of 500 m. Although ETSU-R-97 clearly applies also to single turbines, neither the CEHOG nor Ms. Lockwood refer to any lesser distance for these. So 500 m. is the minimum separation for any turbines, either singly, in clusters or farms.

Unfortunately, neither the Chief Environmental Health Officers Group nor the Planning and Natural Resources Division, seem to have been aware that, in a major presentation to the British Wind Energy Association and the Department of Trade and Industry in 2004, Andrew Bullmore, one of the original authors of ETSU-R-97, the noise methodology applied under PPS 18, advised his audience:

"All other things being equal, original 350 m. separation distance on grounds of noise should now be 700 m."

So, in summary, even by the time the minimum separation distance of 500 m. was inserted into PPS 18 to address all adverse impacts, it was already five years out of date as a protection of noise from larger turbines. Further, in adopting a minimum separation distance related to rotor diameter, no scientific corroboration had been obtained that there was a direct relationship between rotor size and noise output.

Separation distances on the Mainland

When NIRIG met with the Environment Committee on 12 September 2013, thus avoiding the necessity of having to substantiate their statements before the public at Omagh, they portrayed the position relating to separation distances in the following two exchanges with members, as recorded in Hansard. Our response is given after each exchange.

Mr Elliott: Apologies for missing part of your presentation. If this point has been addressed, that is fine. One of the issues that came up consistently at the Omagh meeting was the distance from which wind turbines can be built from a dwelling. People referred continually to the Scottish policy and guidance. I cannot remember; was it 3 kilometres or something like that? It was quite a long distance anyway. I am sure that you are very much aware of that policy and guidance. How do you react to the suggestion that Northern Ireland should move to a policy similar to Scotland's?

Ms Whitford: I think that that is under consultation at the moment. I will have to triple-check with my colleagues in Scotland, but, as far as I am aware, it is a consultation and it relates to villages. My understanding is that it is not individual properties; it relates to villages. It is an ongoing consultation. As far as I know, there is not a set policy anywhere for a separation distance, apart from what is detailed in PPS 18 and policy RE 1 for residential amenity, which is 10 rotor diameters, and a minimum of 500 metres.

This statement is contradicted by the following, from 18 April 2009:

The Stop Highland Windfarms Campaign wrote to Jim Mather, Minister for Enterprise, Energy and Tourism, for clarification. In reply, the Directorate for the Built Environment wrote: "The 2km separation distance is intended to recognise that, in relation to local communities, visual impacts are likely to be a prominent feature and this should be taken into account when identifying the most suitable search areas. However, impacts will clearly vary considerably depending on the scale of projects and the proposed location. That is why SPP6 confirms that, in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby. This principle applies to houses within and outwith 2km of the proposed development and regardless of whether they are single dwellings or part of a settlement."

Similarly, NIRIG do not appear to be aware that The Welsh Affairs Select Committee, after investigating wind farms concluded, "for existing wind farms we are satisfied that there are cases of individuals being subject to near-continuous noise during the operation of the turbines, at levels which do not constitute a statutory nuisance or exceed planning conditions, but which are clearly disturbing, unpleasant and may have some psychological effects". "We recommend that such limits should be set both in respect of a standard distance from the development and separately for all dwellings within a certain radius (say 1.5 km). It should be the intention of those limits that wind farm noise of mechanical origin is inaudible at any neighbouring dwelling."

Moving on now to the second exchange:

Ms Hitchins: I am aware of local authorities in England that have tried, in the context of their local plans and development frameworks, to introduce stand-off distances of varying amounts, but those have been rejected when the policies have gone for examination. They have been found not to be appropriate.

Mr Elliott: By whom? Was it the courts?

Ms Hitchins: I will have to check. Milton Keynes is the example that I am thinking of. We can certainly get back to you on who exactly rejected it.

In fact, in contrast to this misrepresentation, the real outcome of the Milton Keynes case is neatly summarised below, and has a totally different meaning for the introduction of separation distances :

"The Renewable Energy Foundation (REF) regrets the misreporting of the High Court ruling on the RWE Judicial Review of Milton Keynes Borough Council's attempt to set a minimum separation distance between wind turbines and residential dwellings. Milton Keynes Borough Council is to be congratulated on the judgment reached in the High Court case on their Wind Turbine Supplementary Planning Document (SPD) on Monday 15 April 2013. The judgment confirms that local authorities can set exclusion zones to protect local people from inappropriate development. Press reports and press statements from the wind industry suggesting that the judgment prevents local authorities from doing so are incorrect."

"The judgment in the Milton Keynes case shows that the law in fact supports Local Authorities that wish to set minimum separation distances, although it also shows that these must be designed and worded carefully."

Milton Keynes is not the only English council to adopt significantly larger separation distances. Stratford-on-Avon, Cherwell, in Oxfordshire, Wiltshire and Staffordshire councils are using the planning system to create "separation zones", banning new turbines within up to 2 kilometres

A particularly good example is Lincolnshire County Council, aspects of whose Wind Energy Position Statement of June 2012, is reproduced below:

c) Residential Amenity

Amenity of existing residential occupants must be maintained at an acceptable level, therefore the following criteria shall be applied:-

no wind turbine developments shall be constructed in close proximity of a residential property (the accepted distance for separation is 700 metres) however, noise and amplitude modulation issues can be present up to 2km away. Therefore, unless through assessment, it can be demonstrated that there would be acceptable noise levels within the 2km radius of a residential property, the minimum distance should be 2km:

no wind turbines shall be constructed within a distance of a factor of ten times the diameter of the blades of a residential property to mitigate against flicker, unless intervening topography/structures negates the impact.

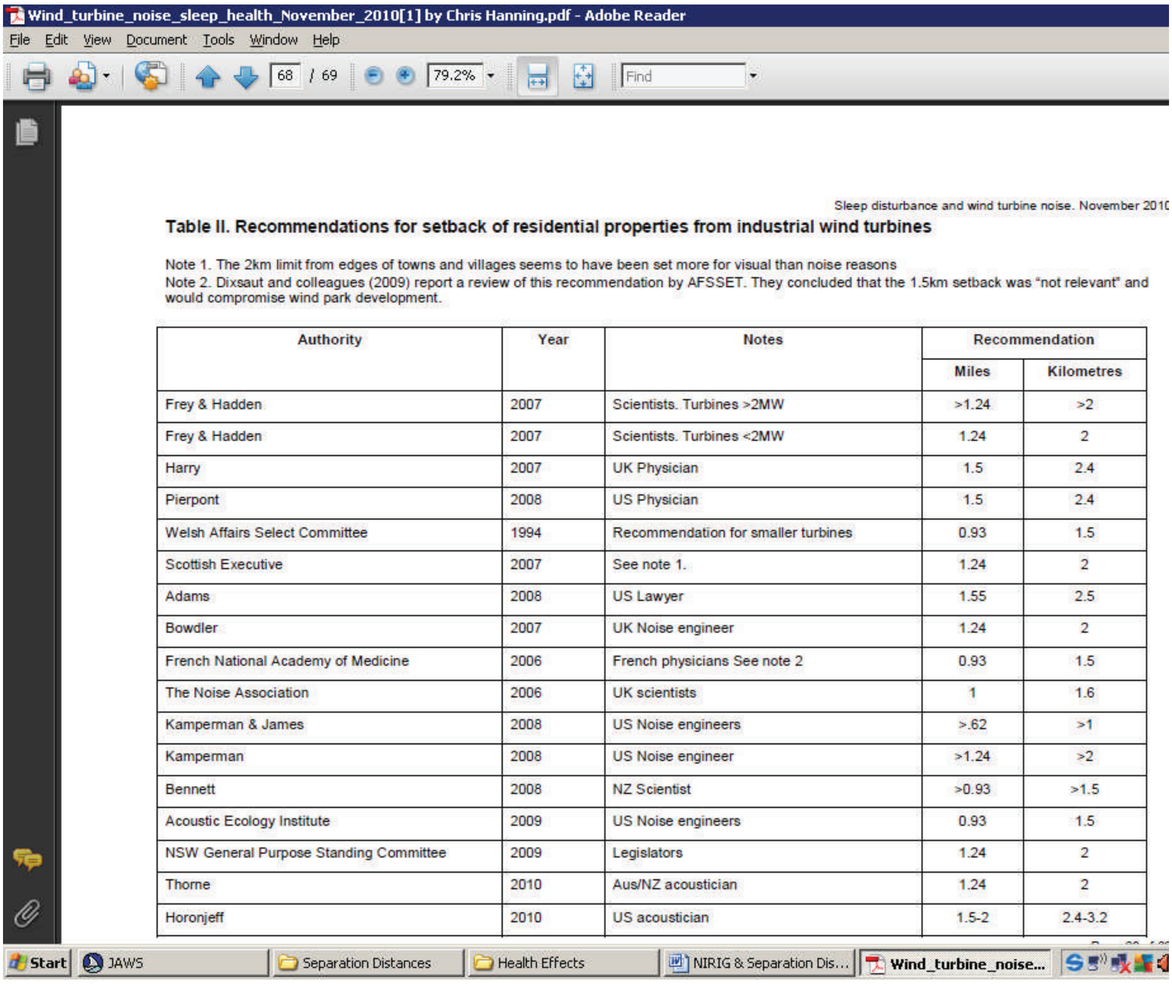
wind farm developments must demonstrate that they would have no unacceptable impact due to noise, amplitude modulation, low frequency sound or vibration on residential amenity.

Wiltshire county council has gone further. Its draft "core strategy", awaiting approval by the government's planning inspectorate, has proposed separation zones of 2km for turbines up to 150 metres high and 3km for anything taller. South Cambridgeshire district council has brought in a 2km separation zone while others considering similar moves include Rutland, Staffordshire, and Northumberland county councils. South Kesteven, in Lincolnshire, has proposed a 2km "search area" around any proposed wind-farm site, where prospective developers must prove turbines will not generate disturbance or visual intrusion.

This is enough to demonstrate that the desire for greater separation distances, usually at least 2 kilometres, is not confined to Milton Keynes, and has not been denied by the courts or the government.

What is happening in other jurisdictions?

Table II (see below) shows recommendations for setback distance by a number of authorities, although some of these have increased the recommended minimum distance and more have emerged since then. In general, noise engineers recommend lesser setback distances than physicians. The former rely more on measured and/or calculated sound pressures and the latter on clinical reports. It is logical to prefer the actual reports of the humans subjected to the noise rather than abstract calculations, even if the latter accurately measure ambient noise and allow for the low frequency components of wind turbine noise. Calculations can not measure annoyance and sleep disturbance, only humans can do so.



Sleep disturbance and wind turbine noise. November 201

Table II. Recommendations for setback of residential properties from industrial wind turbines

Note 1. The 2km limit from edges of towns and villages seems to have been set more for visual than noise reasons
Note 2. Dixsaut and colleagues (2009) report a review of this recommendation by AFSSET. They concluded that the 1.5km setback was "not relevant" and would compromise wind park development.

Authority	Year	Notes	Recommendation	
			Miles	Kilometres
Frey & Hadden	2007	Scientists. Turbines >2MW	>1.24	>2
Frey & Hadden	2007	Scientists. Turbines <2MW	1.24	2
Harry	2007	UK Physician	1.5	2.4
Pierpont	2008	US Physician	1.5	2.4
Welsh Affairs Select Committee	1994	Recommendation for smaller turbines	0.93	1.5
Scottish Executive	2007	See note 1.	1.24	2
Adams	2008	US Lawyer	1.55	2.5
Bowdler	2007	UK Noise engineer	1.24	2
French National Academy of Medicine	2006	French physicians See note 2	0.93	1.5
The Noise Association	2006	UK scientists	1	1.6
Kamperman & James	2008	US Noise engineers	>.62	>1
Kamperman	2008	US Noise engineer	>1.24	>2
Bennett	2008	NZ Scientist	>0.93	>1.5
Acoustic Ecology Institute	2009	US Noise engineers	0.93	1.5
NSW General Purpose Standing Committee	2009	Legislators	1.24	2
Thorne	2010	Aus/NZ acoustician	1.24	2
Horonjeff	2010	US acoustician	1.5-2	2.4-3.2

Are the separation distances in PPS 18 being adhered to?

The situation NIRIG are attempting to portray can be seen in this further comment to the Environment Committee on 12 September:

Ms Whitford: PPS 18 sets out a minimum of 500 metres or 10 rotor diameters. If a project goes forward for approval, it has to put its case for anything that is going to be under that, and then it is for the Planning Service to look at. That is certainly the policy context of PPS 18.

In fact, in contrast to this attempt to portray the existence of a regime of probity, scrutiny and quality assurance on the part of both planners and developers, we find that both the minimum and general separation distances are regularly ignored. Indeed, with respect to single turbines, the 500 metre minimum separation distance to sensitive receptors is being ignored by most Divisional Planning Offices.

Further, following additional training and guidance from headquarters in February 2012, planning staff were advised to adopt a more flexible approach even though there may be unacceptable adverse impacts. These can apparently still be outweighed by the local and wider environmental, economic and social benefits of the proposal, which although not calculated or evidenced, always appear to outvalue proximity to homes. Members of staff were reminded that PPS 18 is a promotive policy. So bad is the current situation, that turbines are being erected at a little over 100 metres from some homes.

There is no post-construction compliance testing, audit or 'policing for any aspect of turbines after erection, no assessment of the relationship between the range and severity of impacts occurring against those predicted by the developers in their original application, and no feedback from situations were problems have been identified. There remains a general subordination of due diligence and overarching duties of care to the achievement of targets for renewable energy AT ANY COST amongst planners, consultees and politicians

What separation distance should be used in future?

The original 10 times the rotor diameter, with a minimum of 500 metres, was a general separation distance on amenity grounds with no scientific basis. Since turbines are now substantially larger, with a range of adverse effects, this is no longer adequate and must be reviewed. Similarly, the use of the ETSU-R-97 methodology for the assessment of noise, has been shown to have numerous weaknesses that do not adequately identify, for example, the impact of amplitude modulation and low frequency noise, which travel further than higher-frequency broadband noise.

We have also seen that the research on which the use of the 10 times the rotor diameter for shadow-flicker is based, does not support the assertion that this will remove the problem. Further, research by Aston and Essex universities has demonstrated that seizure risk of flicker does not decrease significantly until the distance exceeds 100 times the hub height.

The effects of noise on sleep disturbance and symptoms of inner ear problems appear to be related to distance from the turbines. In addition, the night-time noise level remains above the level the World Health Organisation says is required to permit return to sleep. Finally, turbine component failures and accidents are much more common than the industry will allow, and blade throw distances identified by the government's own Health and Safety Laboratory, demonstrated that blade fragments were being thrown distances of up to1,462 meters.

All of these factors call for a significant increase in the minimum separation distance applied in Northern Ireland.

There are two other possible approaches to judging an appropriate setback distance.

The first is to determine a dose-response relationship between turbine noise and a health concern, for example, sleep disturbance. A dose level (turbine noise) that minimises the measured response (sleep disturbance) would be identified.

Examination of data from Swedish and Dutch studies suggests that an external predicted noise level of no more than 35dB(A) LA90 would be appropriate. This view is supported by a presentation by members of RIVM, the widely respected Dutch National Institute for Public Health and Environment, which recommends an outdoor Lden limit of 40dB(A) which corresponds to an external noise level of about 35dB(A). Thorne in 2010, from an analysis of noise complaints concludes that unreasonable noise occurs at noise levels above 30dB(A)LA90 in the presence of excess amplitude modulation. Together with van den Berg he states: “We believe annoyance and loss of amenity will be protected when the wind turbine noise limit would be 30 dBA L95 in conditions of low wind speed at the dwellings and modulation restricted to 3dB”.

Overall, as stated by Hayes-McKenzie in their 2006 report before it was emasculated by anonymous civil servants, it is apparent that the present ETSU-R-97 night time noise limits are too high to protect receptors from severe annoyance and sleep disturbance and that a level of 35dB(A) LA90 is appropriate, in the absence of excessive modulation.

The second approach is to correlate reports from those living in proximity to wind turbines to their distance to the turbines. This has the disadvantage that symptoms are generally self-reported and subjective. Nevertheless, it can be argued that it is logical to rely on the actual reports of human receptors in the same way that human opinions are used to judge visual amenity. It has the advantage also that it may better detect those subjects that are most sensitive to turbine noise than surveys. It has the merit also of simplicity. The New South Wales Legislative Council General Purpose Standing Committee No 5, under the Chairmanship of Mr Ian Cohen, a member of the Green Party, has recently published the report of an inquiry into rural wind farms (NSW 2009). Recommendation 7 to the NSW Planning Minister is for a minimum setback of 2 km. In the UK, Mr Peter Luff, MP for Mid-Worcestershire, was given leave to introduce a Bill to Parliament to establish a legal minimum setback distance. This Bill was unfortunately lost with the dissolution of Parliament and election.

Based on the reports cited in the table, and the introduction of a 2 km. minimum separation distance by more and more councils in England, the application of the precautionary principle would indicate a minimum setback of 2.0 km is appropriate.

8. Separation Distances & Long Term destruction of Amenity

Question: Are separation distances in PPS 18 adequate to protect residential and visual amenity?

Answer: No.

Reason: Minimum separation distances are totally inadequate, frequently ignored, often falsified and not policed.

Comment: For a single or group of turbines, The general rule in PPS 18 is that the minimum separation distance is the greater of 500 metres or 10 times the rotor diameter. This is being blatantly ignored by planners, Environmental Health Officers and developers, some turbines being placed just over 100 metres from a home. This compares badly with the situation in Scotland, where '<u>in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby</u>', and a general rule of 2000 metres applies.

Accuracy in the measurement of separation distances is fundamental to noise estimation, shadow casting and shadow flicker analysis and visual impact assessment. Yet many developers obscure the definition of the separation distance they are applying and there is no guidance in PPS 18.

The present planning system includes no proper vetting of applications for deliberate falsifications or accidental inaccuracies. In short, an applicant with a vested interest, is trusted, and is only required to state a 'candidate' turbine, not the turbine type and model that will finally be erected. Note also that some single turbine applications are for turbines bigger than in some wind farms.

Due to all the uncertainties involved, it is critical to introduce a mandatory 2 kilometre minimum separation distance from any wind turbine, and a greater distance for turbines over 2 MW, until robust and independently-assessed evidence is produced that a smaller distance will not have impacts on amenity and health.

PPS 18 fails in its stated intent to protect the amenity of those living in and using the countryside. For example, the noise standard used by PPS 18 itself clearly states that it is set above the level necessary to protect amenity, a statement corroborated by the Chief Environmental Health Officers Group. Similarly, no competent authorities are involved in the measurement of the impacts from shadow flicker, reflected light and safety hazards. Both Environmental Health and the Health & Safety Executive deny their responsibilities in such matters and the planners admit to having no expertise in all such areas, including noise.

The cavalier and uncaring attitude within PPS 18 to the amenity of neighbours of wind farms can be encapsulated in just two quotations. These demonstrate a fundamental disregard in Northern Ireland to the effects of visual impact.

Firstly, from PPS 18, section 4.14 (underline added):

‘Of all renewable technologies, wind turbines are likely to have the greatest visual and landscape effects. However, in assessing planning applications, the Department recognises that… some of these impacts may be temporary if conditions are attached to planning permissions which require the future decommissioning of turbines.’

Thus the term ‘temporary’ to the department means the expected life of the wind farm from approval to decommissioning.

Contrast this to the recognition of the human cost of such impact in Scotland where the Directorate for the Built Environment wrote in April 2009 under the direction of Jim Mather, Minister for Enterprise, Energy and Tourism (underline added):

“The 2km separation distance is intended to recognise that, in relation to local communities, visual impacts are likely to be a prominent feature and this should be taken into account when identifying the most suitable search areas. However, impacts will clearly vary considerably depending on the scale of projects and the proposed location. That is why SPP6 confirms that, in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby.”

In Scotland, with many more turbines, the life of a wind farm from birth to death is described as ‘long term’. In Northern Ireland, it is described as ‘temporary’. In landscape terms such structures are ‘temporary’, as are all man made structures. In human terms, they are most definitely not.

drk 9 Sept 2013

9. Shadow-flicker and reflected light

Question: Does 10 times rotor diameter prevent shadow flicker at a home?

Answer: No.

Reason: The original research on which this is based does not state this.

Comment: The claim that 'flicker effects have been proven to occur only within ten rotor diameters of a turbine' is one of a number of unsubstantiated statements made in the Best Practice Guide to PPS 18.

In correspondence with DECC, the source from which this statement was derived was confirmed as being from a paper by A.D. Clarke 1991 for Open University. However, this paper does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The research also contains a fundamental and demonstrable error that restricts its application.

This 10 rotor diameter assumption has also been decisively challenged by research from Delft University of Technology in the Netherlands, who, concluded that "there is no rule-of-thumb regarding the distance from a turbine where shadow flicker may be an issue", and by other comprehensive study. This is also confirmed locally, using the restrictive PPS 18 definition, identifying shadow flicker effects at distances of beyond 22 times the rotor diameter, the worst affected property being at 15 times the rotor diameter.

Other claims, such as the policy being based on a survey by PREDAC, an EU sponsored organisation, when examined, reveal a selective approach to the German model recommended by Predac itself. For example, not only does shadow-flicker occur inside a dwelling, German guidance clearly shows its existence outside the dwelling too. The 30 hours per year limit set by PPS 18 for shadow flicker through one window only, applies in the German standard to cumulative indoor and outdoor flicker.

The evidence indicates that the statement that only dwellings within 10 rotor diameters need to be considered likely to suffer shadow flicker is not correct and must be amended.

Finally, it should be highlighted that light nuisance powers held by councils within Northern Ireland under the Clean Neighbourhoods and Environment Act (NI) 2011 only relate to 'artificial light' produced by a luminaire (a light fixture or source) and hence cannot be used to address complaints of shadow or light flicker caused by a wind turbine. As a consequence, issues regarding shadow or light flicker associated with wind turbines would fall outside council's sphere of expertise. No competent authority therefore exists to scrutinize the often minimalist claims made by developers, in clear breach of EU legislation.

drk 22 Feb 2014

10. Safety Impacts.

Question:	PPS 18 states that 'There has been no example of injury to a member of the public.' Is this true? (BPG 1.3.50)
Answer:	No. It was not true when it was written and is even more untrue now.
Reason:	By 30th June 2008, a minimum of 48 people had been killed and 22 seriously injured as a result of wind farm operations. By 30 June 2013, this had risen to 136 deaths and 121 serious injuries. In the five years to 2011, 1,500 accidents occurred in the UK alone.

Comment: One impact of wind energy that has been generally ignored as almost irrelevant is that of the threat of injury due to a failure in the structure or components of a turbine. This is much more common than is generally known, and bears directly on the issue of separation distances.

Many accidents are not reported and examples of industry cover-ups abound since it is standard policy to obscure the frequency of turbine accidents. The lengths to which the industry will go to divert attention from the dangers of living too close to turbines were well illustrated on 10 February 2009 by Dale Vince of Ecotricity. As the Daily Telegraph noted at the time, he has been assiduous in spreading the story that the turbines which suffered catastrophic blade failure at his Conisholme power station might have been struck by a UFO or some other mysterious external agent:

Blade failure is particularly dangerous for neighbours of wind turbines because detached blades can 'plane' for long distances and fragments are cast using the velocity of the spinning blades to travel significantly further. As an example of the potential damage, a one centimetre slice through a 40 metre long turbine blade weighs 2¼ kg. Or 5 lbs. But how likely is this to occur?

According to the PPS 18 Best Practice Guide, 'Blade failure is therefore most unlikely. Even for blades with separate control surfaces on or comprising the tips of the blade, separation is most unlikely.' (BPG 1.3.51)

However, in one year in Germany, 36% of turbines suffered component failure.

A recent piece of EC - funded research by Loughborough University had the aim of identifying the problems of component failure and offering support to address it. This piece of UK based research estimated that from 8 to 10% of wind turbine blades will fail in some manner, the brakes controlling the speed of the blades will fail in another 7% of turbines, and the structure of 3% of turbines (which obviously support the blades) will fail.

A total of 265 separate incidents of blade failure were found to 30th June 2013, and pieces of blade are documented as travelling up to one mile. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why we believe that there should be a minimum distance of at least 2km between turbines and occupied housing or work places - in order to adequately address public safety and other issues including noise and shadow flicker.

The government's own Health & Safety Laboratory report entitled 'Numerical Modelling of Wind Turbine Blade Throw', demonstrated that blade fragments were being thrown distances of up to1,462 metres. The turbines in use in Northern Ireland are no different from those used in Germany or Denmark or England. Due to the unpredictability of such accidents, their significant scale and the high number of dwellings surrounding many wind turbine site, it is clear that safe separation distances are not being achieved.

Finally, neither the Health & Safety Executive, Environmental Health or any other local agency is prepared to take any responsibility for ensuring that accidents are recorded and that policy is informed by the results of experience.

drk 9 Sept 2013

Terms of Reference 3:

"To review the extent of engagement by wind energy providers with local communities and to ascertain how this engagement may best be promoted."

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Introduction – Distraction by Misdirection

The greatest tool of an illusionist, by means of which he seems to be able to perform the impossible, is through the misdirection of his audience, so that his 'sleight of hand' is not observed. The present preoccupation with community benefits, is a similar attempt at misdirection with the object of distracting attention from two signal failures.

Firstly, the entire community, rural and urban, were promised lower electricity prices from the introduction of wind energy. Secondly, if it is public policy that wind energy installations be 'hosted' by communities irrespective of their wishes, then it is a legal requirement that a compensation mechanism be put in place to address the adverse impacts they will suffer.

In the Programme for Government, the Northern Ireland Executive has committed to:

1. growing a sustainable economy and investing in the future;
2. tackling disadvantage;
3. improving health and well being;
4. protecting our people and building a strong and shared community; and
5. delivering high quality service.

It should be emphasised that Priorities 2, 3 and 4 have relevance here, which, taken together in the context of this review, can be summarized as stating that no citizen of Northern Ireland should be 'disadvantaged' by the imposition of unacceptable levels of adverse impacts.

In the effort to misdirect attention away from the failure to reduce electricity costs and protect those living around wind turbines, it would appear that these commitments have been abandoned.

Who are the 'community' and who decides?

As noted above, the entire community, rural and urban, were promised lower electricity prices from the introduction of wind energy.

The extent of the 'community' is defined by international law and by the application of other limiting factors.

Firstly, the Aarhus Convention and the Environmental Impact Assessment Directive apply to national units. Aarhus requires that an assessment of the alternative types of renewable energy, along with their costs and benefits, be provided before public consultation begins to finalise what will make up the Strategic Energy Framework. This has never been done, with an immediate move to wind energy taking place instead.

Within the national unit of the UK, regional targets have been completely removed. Indeed, as can be seen from the statement by Rt Hon Ed Davey MP, the Secretary of State in the Department of Energy and Climate Change, in the House of Commons on Thursday 8th March, 2012, the targets have already been achieved:

Mr Davey: "I thank my hon. Friend for his question. He and I may disagree about the significance of onshore wind, but I appreciate the measured way in which he has engaged with me and the Prime Minister on this issue. I can tell him that 5 GW of onshore wind power generation has already been built, that there is planning consent for a further 6 GW and that planning permission is being sought for 7 GW-worth of projects, only some of which will be approved. Given that the ambition was for 13 GW, most of the development that the country needs is indeed already on the table."

This gives substantial freedom to the Northern Ireland government in deciding what burden it is necessary to impose on its communities. However, with respect to local applications, the EU requirement (that full and meaningful community consultation is completed and that member state governments carry out independent Environmental Impact Assessments (EIA's) prior to approving major strategic infrastructural projects, has also been ignored.

When considering what constitutes the 'community', a number of other factors aid definition:

At what scale are economic and CO2 benefits calculated? Although developers will often present figures to support their application, the 'benefits' from CO2 savings and additional economic activity are usually set, with some local commentary, at national levels, since there are no measureable targets applied, for example, to each district council area. Indeed, no district council is considered in terms of having an individual gross domestic product. There is thus no adequate cost /benefit analysis below the national level.

Further, it can be argued that the entire population bears the costs of renewable energy through taxation and higher electricity bills. The population of Belfast, for instance, should not be disqualified from the 'benefits' of the renewable energy they have subsidized simply because they do not live in a rural location.

The Irish Wind Energy Association stated in 2009:

"More wind on the system will also result in lower and more stable energy prices for consumers while helping us achieve our energy and emissions targets."

Such unequivocal statements were common from the wind industry, but they are now disingenuously attempting to qualify them. This is due to the cost of a unit of electricity having increased from 9.38 pence per unit in 2003 to 17.18 pence now. This burden is shared by every household in the province, and it is a heavy burden indeed. How heavy can be illustrated by asking a simple question. Has Fuel Poverty in Northern Ireland increased?

"With 42% of households in Northern Ireland spending more than a tenth of their income on energy, compared to 15% in England, we have the highest level of fuel poverty in Western Europe." Pat Austin, Chair of the NIFPC.

More than seven out of ten people have been deprived of basic essentials such as food due to rising energy bills.

Eight out of ten struggle to adequately heat their homes.

The community in Northern Ireland were promised lower electricity prices as the benefit for accepting increasing amounts of wind energy. That commitment has not been fulfilled and to offer to pay a few crumbs to some and not all members of the community is an attempt to distract attention from that failure, whilst ignoring the vast majority who are providing the funding.

Lack of a Compensation Mechanism

The second aspect is the distraction from the moral responsibility to pay compensation to the most affected individuals.

> “If the state considers wind turbines are public policy, then the minority interest should be compensated. If wind turbines are not state policy, then decision makers may be challenged when they use the balance in favour of the state to justify giving an approval that risks a violation of basic human rights.” (Justice Buckley in Dennis & Dennis v. MoD, 2003).

This makes clear that, if wind farms are public policy, then the lesser interest, i.e., you and I, must be compensated by the greater interest. Community payments are simply a way of breaking democratic resistance against huge, noisy and unhealthy structures placed too close to homes. They are, in effect, an attempt to substitute token payments in place of compensation based on impacts.

Why do communities resist?

The well-known legal injunction, is that ‘In any context the essence of consultation is the communication of a genuine invitation to give advice and a genuine receipt of that advice.’ What communities find, however, is, to use a term now current, not ‘consultation’ but ‘insultation’.

Because of the way wind farms are procured, people quite simply see the process as unfair and this perception has been increased over the years by the actions of developers and government. Though there are some exceptions, developers have not involved communities and have been secretive and uncooperative. They may consult but only after the design and siting of their projects has been more or less established. Government has been dismissive of wind farm objectors and has put out and still does put out inaccurate and misleading information. When a minister boasts of approval rates of well over 90%, for wind energy projects, communities might be excused for asking what account will be taken of their interests?

The whole environment in which developers, landowners, planners and consultees interact with communities is characterized by inflated claims of benefits and a reductionist approach or outright denial of any adverse impacts. Numerous instances now exist of complaints against these exaggerated claims being upheld by the Advertising Standards Authority (ASA).

There is an absence of transparency throughout, including that the planners and some of the key consultees lack the expertise and equipment to accurately judge the extent of the impacts residents will be exposed to. Further, there is an apparent disregard by planning departments of the minimum separation distances included in PPS 18 to protect residential amenity.

In the absence of an independent Environmental Impact Assessment to verify claims of costs and benefits, as required by European legislation, the testing of the veracity of the claims by developers and their trade bodies, is left to ordinary members of the public.

It does not build confidence in either the developer or the efficacy of the planning system, to see impacts being underplayed, whilst claims about job creation and the number of houses that proposed wind farms will supply are grossly exaggerated, and no proper breakdown of the methodology used is ever given. For example, NIREG states that there are 1300 people directly employed by the wind industry in Northern Ireland whereas DECC figures state there are 239 jobs - a substantial difference and a figure also believed to be inflated.

There also are a number of significant non-quantifiable adverse effects directly attributable to the operation of wind farms which are generally not brought to the attention of rural communities:

- Property devaluation and resultant loss of rates revenue for local government;
- Fall in rural tourism as has been evidenced in Scotland and Cornwall;

- Acrimonious splits in rural communities and even within families;

- 3.7 jobs lost for every one renewable energy associated job created (Verso Economic Study in Scotland);

- The loss of CO2 retention capacity where wind farms are built on areas of raised bog-land;
- Forest clearance to make way for wind farms;
- Exposure of rural communities to accidents. There have been 1500 reported accidents to 2011 (Renewables UK statistics) some of which were fatal. Insurance industry statistics indicate that every turbine has a major incident every four years. Government held Health & Safety information has reported parts of turbines travelling up to 1600 metres.

None of the above are 'confidence-building measures that will contribute to the establishment of a basis of trust by developers who dismiss all problems caused by their technology.

There is one sure test that will reveal how true the statements on adverse impacts made by a developer or landowner actually are. Ask them to enter into a legally-binding Indemnity to protect the communities against impacts.

Can a community say 'NO'?

The present emphasis on community benefits seems to be part of a larger context in which public participation is being restricted or suppressed. The constant emphasis on economic development is given such precedence that many see an increasing 'democratic deficit' in Northern Ireland. This view is supported in three ways:

- The concept of 'well-being' appears to be defined as economic well-being. This definition is particularly important as it was a primary characteristic of the late failed Planning Bill 2013, which included 'promoting well-being' along with furthering sustainable development, and promoting economic development. It also features in the draft Noise Policy Statement 2014;

- The proposal for a third party right of appeal in planning cases, has been excluded from any revision to planning legislation;

- There is an absence of a Localism Act in Northern Ireland. When introduced in England in November 2011, it had the aim of devolving more decision making powers from central government back into the hands of individuals, communities and councils.

Applications for wind energy routinely exaggerate the economic benefits of the proposal and play down any adverse effects on visual or residential amenity, health, wildlife and habitat.

An ignorance amongst decision-makers, or a desire to achieve targets, has led to a dismissal of any negative effects of some of the renewable energy technologies being fostered. This, in turn, has led to a narrow 'one size fits all' approach to how a community benefit should be defined and assessed.

The starting point in all cases is that rejection of an intrusive, dangerous or economically disadvantageous energy source was not a choice open to a community and, therefore, not to their benefit. Thus, for example, a community which derived much of its economic activity from tourism and which wished to protect the unspoilt nature of its principle asset, would not in these terms be seen as providing a community benefit if it rejected intrusive renewable energy infrastructure. This is a very skewed view of what constitutes community involvement.

As per the Coughlan judgment, consultation must be undertaken at a time when proposals are still at a formative stage. It must include sufficient reasons for particular proposals to allow those consulted to give intelligent consideration and an intelligent response; adequate time must be given for this purpose; and the product of consultation must be conscientiously taken into account when the ultimate decision is taken.

Governments and large renewables companies may argue about global warming and targets but, as research has demonstrated, these are nothing more than distant and rapidly decreasing backgrounds in the context of the local decisions actually being taken on real renewable projects.

Collaborative processes work much better as has been found in waste power siting in some countries. Bad communication causes endless problems but it results from the way most decision -making is framed. There should be complete openness in the process and an avoidance of presupposition and predetermination in decision making. As research has conclusively demonstrated, consultation only after a plan is instituted is more of a trigger for opposition than an incentive for the design of suitable projects.

This is the inheritance that must be understood and addressed if meaningful community engagement is to occur. By ignoring the history of previous community experiences with renewable energy, therefore, the message is sent that there is an unwillingness to listen to the public at large, no matter how loud they shout. Thus reviews such as this are vulnerable to the charge of being part of an apparatus designed to be used as propaganda to put down opposition.

The supposition that the public will support whatever planners and industry want them to do, leads also to the simplistic belief that knowledge will change attitudes. It does not.

It is an inherent but false assumption, that when asked about the use of wind power in the abstract, the public is usually strongly in favour. Wind as a source of power is free at source (although not in exploitation) and supposedly green so is supported on that basis. But explicit (and local) proposals for wind farms in defined environments now remove it from the abstract and crystallise and focus attention on the reality of what wind power in the form of a farm or single turbine actually means to the landscape and to peoples lives. The cost-benefit analysis is no longer theoretical and distant, but factual, local and personal.

When theory meets reality, the dynamics of community engagement and the nature and perception of what constitutes a benefit to both community and individuals, changes. This review needs to demonstrate that this shift in perspective has been recognised and that communities objecting to renewable energy are no longer treated as somehow aberrant, rather than constituting the norm. While this continues to be the case, successful community engagement cannot occur.

Opposition and conflict – two effects of community payments

The existence of community benefit may in fact have the effect of increasing opposition to local wind farms. This is due to the phenomenon known as ‘motivation crowding effect’, where external intervention through monetary incentives is used in an attempt to undermine intrinsic motivation (in the case of wind farms to limit objections to proposals). There is compelling empirical evidence from many countries for the existence of crowding out and crowding in, based on circumstantial insight, laboratory studies by both psychologists and economists as well as field research by econometric studies.

Community benefit in the limited financial form offered by developers, fundamentally alters the perceived nature of a siting procedure. While external intervention, i.e. offering some financial recompense, manages to address some concerns regarding the costs of a noxious facility, it reduces the intrinsic motivation to permit the construction of such a facility. In some case studies, this latter effect outweighs even the benefits of external intervention, thereby reducing overall acceptance.

The ultimate objective of the community benefit payments made by the wind industry appears to be to muster support from those living further away from the wind farm hazards whilst at the same time isolating the lesser number living closest and most affected by shadow flicker, infrasound, loss of amenity and property devaluation – those who will suffer the pain whilst others gain. This is nothing less than a strategy of 'divide and conquer', with which many government agencies will be guilty by association.

That the industry is prepared to pay meagre sums to community projects within eight miles of their wind farms, appears to be an admission on their part that there are adverse effects up to that distance. The wider community in a 5 mile or 8 mile radius should not be permitted to benefit unless and until Northern Ireland's minimum separation distances between turbines and dwellings are updated and operated to safe international standards. Otherwise, this so-called 'community benefit' will prove to be merely a source of conflict and discontent. In particular, it will be seen as a lever whereby the wider community suffers no real adverse effects but is incentivised by the 'community benefit' to pressurise the unfortunate few in the centre zone whose amenity and health will suffer from the development.

Duration of community benefits

There are two major constraints that should be considered before the 'Faustian pact' of community benefits based on someone else's loss are entered into.

Firstly, the life expectancy of a wind turbine is not the 25 years of wind industry myth. Instead, as a number of recent studies have demonstrated, the life expectancy is 12 to 15 years, and there will be significant periods of 'down' time due to the need for repairs and replacement parts.

Secondly, as a recent case in Cornwall demonstrated, the agreements made between renewable energy developers and the communities they potentially damage are not legally binding. Legal opinion is that payment in any such agreement is entirely voluntary, and that the council had no lawful basis to refuse planning consent. In other words, Companies can refuse to pay and, if they change hands, their successors are certainly not liable for any commitments made. "Beware renewable developers bearing gifts."

The Sacrifice of the Rural Minorities?

Rural proofing is a process to ensure that all relevant Government policies are examined carefully and objectively to determine whether or not they have a different impact in rural areas from that elsewhere. We consider that the desire to promote community engagement through token payments, is not the way forward. Not only are the chief beneficiaries not those suffering the chief detriments from a proposal, but the amounts involved are tiny in comparison to the loss sustained by many families. A reduction in property value of even 10% cannot be accepted for an annual payment of £200 towards electricity costs.

Community benefits, as presently envisaged, are likely to have a differential impact in rural areas compared with that within any other sector of the community.

For this reason, the resistance to wind energy is growing across Northern Ireland. It is caused by a culture of false promises, lack of due diligence in identifying and preventing the adverse impacts, imposed to the disadvantage of a minority against the commitment made by the Executive.

When compared with the example of the procedures surrounding the redevelopment of housing, designed to protect the residents from the effects of planning blight in the public interest, wind energy is a policy 'on the cheap'. It is, in fact, nothing more than legalised intimidation and theft. In no other area of life in this community, can a developer freely destroy or seriously damage with impunity, the value of the single greatest asset belonging to any family – their home. That the same developer can, by the promise of tiny amounts from his vast profits, arrange for other parts of the same community to marginalise and ostracise these very victims for daring to object, is nothing more than an indirect form of bullying and harassment. The wind industry knows exactly what it is doing when it offers money to individuals so far from the wind energy installation. It has been trying to pin the perjorative term, NIMBY, on all who do not share their corporate vision for many years.

It is appalling that this is done with the complicity of a whole range of public agencies and NGOs, from those who ignore the blighting effect of nearby turbines when assessing Rates, to those who refuse to carry out research on reported health impacts, or simply look the 'other way'. Is it therefore surprising that rural communities feel abandoned by those they expected to protect them, and see themselves to be under siege?

Is there a way forward?

If wind energy is to be seen as public policy, then a robust compensation system must be introduced. But, given the disgraceful record of community engagement by the wind industry and allied government agencies and NGOs, there is presently no basis in trust. Indeed, the priority given to wind energy, and how this is manipulated through the planning process, is illegal under both the Aarhus Convention and the EIA Directive. It is expected that a judicial review will fully reveal this in the near future.

No matter what the technology chosen, there will always be occasions and locations where it is not suitable. Without an honest accounting of benefits and adverse impacts, a working relationship with communities cannot be built.

In addition, it is the role of those responsible for causing unacceptable adverse impacts and more particularly government, to ensure that these are managed properly. That is as important as ensuring that the impact levels themselves are low enough.

One way forward would be adherence, even initially on a voluntary basis, to a separation distance that will provide a significant cushion against impacts. For example, adoption of a 2 km. distance to the nearest receptor would be a major step by developers in starting to build credibility. Similarly, voluntary adherence to the World Health Organisation night-time noise guidance, would be another confidence-building move.

A system built on transparency, honesty, a realistic view of impacts and compensation for those most affected, would be the minimum for any future system. However, given the history, an 'honest broker' would be required, not only between the developers and local communities, but also between the local communities and the Planning Service, who are seen as the mouthpiece for the wind industry's demands.

Rural communities are not selfish, or inflexible. But they have found to their cost that the adverse impacts they were assured would not happen, have occurred and are sometimes impossible to live with. They have also found that the system they relied on for protection and post-construction policing, lacks both principle, integrity and belief in a duty of care. The message they are sending to the Environment Committee as part of its review, is that they do care about others who are yet to be affected. To them, NIMBY stands for, 'next it might be you'!

Addendum on Economic Considerations

Economic models often produce false or misleading outputs because (a) the model itself is faulty, and/or (b) unrealistic assumptions are “fed into” the model, with the result that the models overstate national, regional, and/or local job and other economic benefits.
In the case of wind energy models, basic flaws and faulty assumptions often include one or more of the following:

1. Ignoring the fact that much of the capital cost of “wind farms” is for equipment purchased elsewhere, often imported from other countries. An analysis by Deloitte for IWEA concerning Employment in Wind Energy identified that all investment in relation to turbine manufacture and installation is exported to continental Europe. EWEA analysis found that wind turbine and component manufacturing provides the majority of employment opportunities at circa 59% of direct employment. These elements represent 12.5 of the 15.1 jobs claimed to be created in the EU for every MW installed.

Northern Ireland has largely missed the opportunity to build a significant wind turbine and components manufacturing industry and the vast majority of turbines and components are being imported from the continent. Thus claims that wind turbines are “manufactured” in Northern Ireland when, in fact, they are merely assembled here using imported parts and components, are untrue. About 75% of the capital cost of “wind farms” is for turbines, turbine parts and components, towers and blades – so a large share of the “wind farm” cost is for imports. These add to the outflow of wealth from the UK, add to our balance of payments deficit and provide no economic or job benefits locally.

2. Assuming that employment during project construction results in new jobs for local workers. However, the international turbine companies typically install turbines in Ireland using their own internal teams rather than sub-contracting to local Irish firms.
Installation represents another 1.2 of the purported 15.1 jobs created in the EU for every MW installed. Therefore, it can be said that Ireland has not capitalised on 13.7 of the 15.1 jobs created in the EU for every MW installed.

3. Assuming that the very few permanent “wind farm” jobs are new jobs filled by local workers – when, in fact, these few permanent jobs are often filled by people brought in for short periods. Most “wind farm” construction jobs are short term (6 months or less) and the overwhelming share of them are filled by specialized workers who are brought in temporarily, usually from the Republic of Ireland or from mainland Britain. Some “wind farm” owners contracts with suppliers of wind turbines and other equipment for maintenance work with the result that no “new” jobs for local workers are added.

4. Job creation linked to renewables is subject to more and more doubt. There are now numerous reports which argue that jobs created in this sector are done so at the expense of jobs elsewhere in the economy. For example, a recent report suggests that for every job created in the UK in renewable energy, 3.7 jobs are lost or foregone in the rest of the economy. The key reasons for this are related to the grants and subsidies being paid, feed-in tariffs and the existence of the Renewables Obligation. Not only could this money have been spent on other projects (an opportunity cost), the price of electricity is artificially raised which means increased costs for households and businesses.

Wind energy applications do not analyse displacement of jobs, possible use of cross border workers, give no information on how many long term jobs will be created or how many of the jobs estimated are direct and how many are indirect. Worst of all, there is no retrospective auditing of the claims against fulfilment.

It is, however, worth recalling the oft quoted figure from NIRIG of 1,300 jobs from wind energy in Northern Ireland, a figure the Department of Enterprise, Trade and Investment seems unable to corroborate. This should be compared to the statement by Ed Davey, Secretary of State for Energy and Climate Change, that the 'industry has announced' 239 jobs in Northern Ireland. However, as Mr. Davey also announced 9,143 jobs in Scotland at the same time, and First Minister Alex Salmond was only able to confirm 2,235, the Northern Ireland figure of 239 is equally suspect.

High rates of employment are not characteristic of a highly productive energy sector, indeed quite the reverse.

5. Ignoring the fact that the higher true cost of the electricity from wind is passed along to ordinary electric customers and taxpayers via electric bills and tax bills which means that people who bear the costs have less money to spend on other needs (food, clothing, shelter, education, medical care — or hundreds of other things normally purchased in local shops), thus reducing the jobs associated with that spending and undermining local economies that would benefit from supplying these needs. The artificially raised price of electricity contributes to fuel poverty and the impact on households is another serious economic consideration, particularly in NI where fuel poverty is significantly higher than in the rest of the UK.

6. Assuming that temporary workers who are brought in for short periods live and spend their pay cheques — and pay taxes — locally when, in fact, these workers spend most of their wages where they and their families have permanent residences — where the workers spend most of their weekends and where they pay nearly all of their taxes. This was very evident with the recent Carn Hill wind farm above Belfast. The workers, including the night watchman, came from Co. Donegal, and even brought their food with them from home and cooked in their accommodation. There was virtually no benefit to the local economy.

7. Assuming that the full purchase price of the goods and services purchased locally (often minimal in any case) has a local economic benefit. In fact, only the local value added may have a local economic benefit. This truth is illustrated by the purchase of a litre of petrol, for about £1.35. Only the wages of the service station employees, the dealer's margin, and the taxes paid locally or nationally may have a local or national economic benefit. Economic benefits associated with the share of the £1.35 that pays for the crude oil (much of it imported), refining, wholesaling, and transportation generally flows elsewhere.

8. Assuming that land rental payments to land owners for allowing wind turbines all have local economic benefit. In fact, these payments will have little or no local economic benefit when the payments are to absentee landowners OR if the money is spent or invested elsewhere or is used to pay income tax or VAT that flow to the Inland Revenue.

9. Using "input-output" models that turn out "indirect" job and other economic benefits that, in effect, magnify (a) all of the overestimates identified above, and (b) use unproven formula and data to calculate alleged "multiplier" effects.

10. Ignoring the negative externalities that also need to be considered in the decision making process. Environmental and economic COSTS imposed by "wind farm" development, which include (a) environmental, ecological, and economic costs associated with the production of the equipment, and constructing and operating the "wind farm" (e.g., site and road clearing, (b) wildlife habitat destruction, noise, bird and bat kills and interference with migration and refuges, and (c) scenic impairment. From an economics perspective, these externalities have a value and only when the total cost of the proposal (including these wider costs) are compared against the potential benefits can we make a judgement about the net impact on the economy. This would ideally be done in the form of a cost benefit analysis or economic appraisal.

11. Ignoring the impact on property prices. It is now conclusively confirmed by recent research published by the London School of Economics that wind farms reduce property values for properties either in close proximity or within the range of visibility of turbines. Examination of over one million sales covering a 12-year period of properties close to wind energy installations found that values of homes within 1.2miles were being significantly affected. Independent valuation reports by RICS registered valuation surveyors in Northern Ireland, conclude that even single turbines will impact upon the amenity of nearby property and will reduce their values by some 25%. Owen Patterson MP has also commissioned research into this area.

12. Overstating the true value of payments made to local authorities. Contribution to local Councils through the payment of rates for the wind turbine is

always highlighted as bringing additional funds to the community but no account is taken of the negative benefit when sensitive receptors will demand rate reductions with a possible overall net loss in rates income. Arguably money received in rates as a result of any development may not be considered a benefit if it is used to cover the costs of servicing the site. Irrespective of being generated to local or national government, in net terms it remains unclear how much of the rates will be used to cover direct costs (e.g. road maintenance and other infrastructure costs) and how much, if any, is additional benefit locally or nationally.

13. Ignoring the fact that electricity produced from wind turbines, has less real value than electricity from reliable generating units — because that output is intermittent, volatile and unreliable. Also, the electricity is most likely to be produced at night, not during the day when demand is high and the economic value of electricity is high.

14. Ignoring the "backup power" costs; i.e., the added cost resulting from having to keep reliable generating units immediately available (often running at less than peak efficiency) to keep electric grids in balance when those grids have to accept intermittent, volatile and unreliable output from "wind farms."

15. Maintenance costs during non generation result in the wind farm taking electricity from the grid. Research confirms that wind turbines do in fact use electricity from the grid to turn the blades during periods of low wind and this is something that may need to be investigated further as it would have an impact on the perceived efficiency of the turbine and the running costs. As it stands, the Economic Statements in wind energy applications do not recognise that electricity from the grid is needed.

16. Ignoring the fact that electricity from "wind farms" in remote areas generally results in high unit costs of transmission due to (a) the need to add transmission capacity, (b) the environmental, scenic and property value costs associated with transmission lines, (c) the electric transmission "line losses" (i.e., electricity produced by generating units but lost during transmission and never reaches customers or serves a useful purpose), and (d) inefficient use of transmission capacity because "wind farms" output is intermittent and unpredictable and seldom at the capacity of the transmission line that must be built to serve the "wind farm".

For example, £44 million is being provided to upgrade the grid to accept another 800MW of wind energy. This is £55,000 per MW= £14,000 just for grid upgrade for a single 250 kW turbine.

17. The CO2 emission savings have often been calculated using the old style fossil generation power stations as opposed to the new generation of gas power stations, resulting in an over estimate of the economic benefits. Changes in the

energy mix have reduced the claimable CO2 savings of wind farms by over two-thirds in the past 20 years. However, even these figures are exaggerated as they make no allowance for CO2 expended in manufacture and installation, the mining of iron ore and limestone for steel and cement manufacture, the liberation of CO2 from peat which is damaged during construction, and the need to provide back-up of up to 90% of the installed wind capacity.

The Economic Statement usually does not disclose what the expected CO2 savings are or how they have been calculated.

In conclusion, most economic statements in wind energy applications are fairly basic and do not provide enough information or evidence to aid in decision making. They cannot be used to give an accurate and impartial indication of the total net economic benefit or otherwise. In order to make an informed decision, a full cost benefit analysis over the realistic capital life of the turbines would need to be completed and this would need to take into account all of the elements listed above to give a robust estimate on value for money. It need hardly be stated that this would need to be independent of the developer's estimates.

The viability of a proposal, in other words whether or not there would be sufficient revenue in the longer term to enable the proposal to survive commercially, is unknown since the economic statements do not usually examine this issue. The proposal would only have a positive economic impact if it continued to operate successfully, but this would be greatly affected if turbine life expectancy was not the 25 years usually claimed, but the 12 to 15 years revealed by recent research.

Perhaps most important, ignoring the fact that the investment pounds going to "renewable" energy sources would otherwise be available for investment for other purposes that would produce greater economic benefits. Indeed, on investigation we find that modern wind turbines are still extremely capital intensive, with low load factors, very high system integration costs and relatively low operating costs compared to generating units using traditional energy sources. They also create far fewer jobs, particularly long-term jobs, and far fewer local economic benefits. "Wind farms" are simply a poor choice if the goals are to create jobs, add local economic benefits, or hold down electric bills.

drk 26 Feb 2014

Addendum on CO2 reductions

If we consider the alleged environmental benefit of the Northern Irish renewable energy programme, then this should be; (a) related to specific verifiable reductions in greenhouse gas emissions and; (b) that these reductions should be associated with a defined environmental benefit. The combination of (a) and (b) actually amounting to something tangible is therefore of great importance. Yet when it comes to seeking data on what verified emissions have actually occurred and which can be expected to occur, no verification of emission savings with the wind energy installed to date appears to have been completed, and no estimation of greenhouse gas savings has been concluded.

Displacement of fossil fuels

It is claimed that 1 MWh input of electricity from wind energy directly displaces the emissions from 1 MWh of conventional generation using fossil fuels. In reality the power stations now have to operate in variable, stop start mode to balance the fluctuating wind energy input, such as like a car in city driving as opposed to on a motorway. As a result the fuel consumption of the power stations increases over the condition where they would otherwise be on steady load and not having to balance variable wind energy input.

Eirgrid in their 2004, engineering report on the impact of wind energy and its intermittency on the economics of operation of conventional plant concluded that:

"The adverse effect of wind on thermal plant increases as the wind energy penetration rises. Plant operates less efficiently and with increasing volatility". This Eirgrid report highlighted not only the practical limitations, but also the very high cost associated with wind energy given other far more cost effective alternatives available for carbon abatement. In fact this report predicted greenhouse savings from 1,500 MW of wind equivalent to 1 .42 million tonnes per annum, which equals 0.95 million tonnes per 1,000 MW.

Ireland is an isolated island with a limited amount of hydro-electricity available for balancing wind generation. It is therefore possible to analyse the performance of the thermal plants on its grid as the wind energy input varies, a position which is facilitated by Eirgrid, who not only publish wind energy input to the grid in 15 minute intervals, but also modelled emissions from the thermal power plants based on their theoretical loads. While this is not as precise as actual measured fuel consumption of the power plants, it is providing useful data for the interested public to analyse. This analysis of Eirgrid's data shows that emissions on the grid actually start to rise when the wind energy input exceeds 1,200 MW.

Indeed Dr Joe Wheatley, Biospherica Risk Ltd, completed an analysis of the CO2 performance of the Irish grid based on the modelled emissions available from Eirgrid, in order to better analyse the inefficiencies on the grid with increasing amounts of wind input. This was presented in March 2013 at a Seminar organised by the Economic and Social Research Institute (ESRI). Of relevance is that emissions savings from wind power are significantly lower than expected, 0.28 tonne CO2/MWh, relative to an implied average carbon intensity in the absence of wind of 0.53 tonne CO2/MWh, and the savings are decreasing as more wind power is added to the grid. In other words, actual savings are only about a third of what the wind industry frequently claims in its applications, usually 0.86 tonne CO2/MWh.

Disturbing peat releases CO2

The world's peatlands have four times the amount of carbon than all the world's rainforests, but they are a Cinderella habitat, completely invisible to decision-makers. Wind farms are typically built on upland sites, where peat soil is common. But peat is also a massive store of carbon, since they both contain and absorb carbon in the same way as trees and plants — but in much higher quantities.

Wind farms, and the miles of new roads and tracks needed to service them, damage or destroy the peat and cause significant loss of carbon to the atmosphere.

Scientists from Aberdeen University, contend that wind farms on peatlands will not reduce emissions and suggest that the construction of wind farms on non-degraded peats should always be avoided.

Peat only retains its carbon if it is moist, but the roads and tracks block the passage of the water. The wind industry insists that it increasingly builds "floating roads," where rock is piled on a textile surface without disturbing the peat underneath. But peat has less solids in it than milk. The roads inevitably sink, that then causes huge areas of peatland to dry out and the carbon is released. More than half of all British onshore wind development, current and planned, is on peat soils.

Windyfields

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28th February 2014

Committee Chairperson Anna Lo MBE
Committee for Environment
Room 247
Parliament Buildings
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By email to: committee.environment@niassembly.gov.uk.

Dear Chairperson Lo,

Ref: Committee for the Environment: Inquiry into Wind: Written response

1. Windyfields is a developer of medium sized onshore wind renewable energy projects in Northern Ireland. We have applications for a combined installed capacity of more than 110MW in the Northern Ireland Planning System at present. This represents a current investment to date of more than £5 million and should they be consented a further £100 million pounds of investment to include their construction and operation costs in the Northern Ireland.

To assess the adequacy of PPS18 and related supplementary guidance in regulating proposals for wind turbines on a consistent and strategic basis, with due regard for emerging technologies and independent environmental impact assessment

2. Both Planning Policy Statement (PPS) 18 and the related supplementary guidance were developed through collaborative working by Policy advisors and stakeholders over a considerable period of time. We believe that they are the result of industry and regulator discussions and they have been subject to the rigors of public consultation and as such they are suitably broad in their scope and reflect the various topical issues in a balanced way.

3. These documents have facilitated good progress by the private sector in their progress to support Government's Strategic Energy Framework target of 40% renewables by 2020, Clear policy and guidance has allowed confidence for developers to invest in Northern Ireland. Since August 2009 when PPS 18 was introduced some 33 windfarms have been consented (as of February 2014, 3.6 years), prior to this 35 windfarms had been consented between 1993 and August 2009, 16.5 years). These data, in part, reflect the changes in technology

which have allowed the economics of onshore wind generation to become more favourable, but in part underline the role that clear policy brings to providing a confidence to potential investors in the NI economy. This regulatory system underpins the Governments' commitment to renewable energy which is embodied in the Strategic Energy Framework 2010 (40% of our electricity to be provided from renewable energy sources by 2020) and this has allowed for the delivery of renewables on the ground and provided a strong basis for further growth.

4. Onshore wind energy is the most cost effective renewable energy option in the UK at present. In the context of the island of Ireland recent reports from the Transmission Systems Operator (TSO), Eirgrid and the Sustainable Energy Authority for Ireland have published information that indicates the presence of wind energy in the Single Energy Market (SEM) has provided a reduction in the wholesale price of electricity in the Irish market. As such it is important that a clear, transparent and consistent policy for the regulatory process is maintained.

5. PPS 18 and the related supplementary guidance also recognises the balance between environmental, social and economic considerations in making the decision to approve onshore wind projects and this is welcome as it supports the delivery of other related Government targets, specifically in relation to sustainable development, fuel poverty and energy efficiency.

6. We do not wish to comment on the range of technologies covered by PPS 18 as we are solely interested in the development of onshore wind projects.

7. The range of issues identified in PPS 18 required for consideration as part of the Environmental Impact Assessment (EIA) process is a fair reflection of the potential impacts of the technology even with advancements of the technology. The technical areas requiring assessment are extensive and not limited to the following: Landscape Character and Visual Impact, Acoustic performance; Hydrology and Hydrogeology, Shadow Flicker, Ecological and Avian, Aviation and Communications, Geology and Ground conditions, Cultural heritage, Transport and Health and Safety. Each of these assessments tests the development proposal in the context of the site specifics such as topography, neighbouring properties and existing development in the locality.

8. In conclusion PPS18 is the key planning policy document for renewable energy in Northern Ireland; it has resulted from extensive public consultation, and we believe that PPS18 and the associated supplementary guidance are balanced and fit for purpose in assessing wind farm developments in Northern Ireland

9. We strongly believe that the forthcoming Strategic Planning Policy Statement should maintain the current language and approach of PPS18 to enable the industry to reach our Strategic Energy Framework targets and beyond.

To compare the perceived impact of wind turbine noise and separation distances with other jurisdictions and other forms of renewable energy development

10. Noise and the impact of noise is currently defined in PPS 18 and related supplementary guidance. These documents recommend the use of "The Assessment and Rating of Noise from Wind Farms ETSU-R-97" to assess the potential impact of a windfarm on neighbouring properties. This guidance has been developed by a working group of environmental health professionals, wind farm developers and acoustic experts. The Institute of Acoustics (IoA) has most recently (in 2013) produced a Good Practice Guide as to how the ETSU document should be interpreted and used. The criteria used within these documents is wholly in line with World Health Organisation (WHO) recommendations on noise level restrictions necessary for the protection of human health.

11. There are no other jurisdictions in the UK that have defined the use of setback distances in legislation. A review of practice across Europe indicated that absolute noise limits at residential properties are the preferred means of regulation. Setback distances are used in some jurisdictions but usually in conjunction with the use of absolute noise limits.

12. Setback distances do not take account of local site specific information such as noise screening as a result of topography, wind shear or the number of turbines in the area. With the policy driver across Europe being to meet noise limits this has seen an industry focus on the reduction of noise from turbines by design and innovation, without this driver the momentum for quieter turbines is lost.

13. There are also difficulties in determining what an appropriate fixed minimum setback distance should be as by its nature the level will need to be sufficiently large to accommodate the noisiest turbines available on the market which again does not encourage the use of quieter models or drive design innovations further.

14. We consider the combined approach of setting fixed noise limits at residential properties in conjunction with planning conditions to ensure these limits are complied with to be the most effective means of managing wind turbine noise.

To review the extent of engagement by wind energy providers with local communities and to ascertain how this engagement may best be promoted.

15. Windyfields are committed to engaging with local communities during the development, construction and operational phases to ensure open and transparent dialogue. This means that local residents and communities are informed about proposals and have opportunities to comment on them.

16. There are currently no legislative requirements to engage with local communities and as such we endeavour to follow industry best practice. We are fully committed to NIRIG's Community Commitment Protocol published in January 2013.

17. Every effort is made to identify relevant stakeholders in the community and engage with these individuals and parties with appropriate information about the proposal.

18. Changes already made to our proposals in Northern Ireland after suggestions/comments from local stakeholders include;

    - Changing access routes and turbine delivery routes to avoid passing sensitive locations such as schools, riding facilities and residential homes.
    - Relocation of turbines away from residential homes;

19. Windyfields have tried a number of different approaches to community engagement at pre application stage. To date, we have engaged with communities living in proximity to our proposed windfarms through door to door visits (up to 2 km of the site); Information leaflets; press adverts; meetings with community groups; local interest groups and local councillors; hosting community events and appointing a dedicated Community Liaison Officer to each proposal.

20. Our experience has shown that early engagement can be difficult as some groups or individuals do not want to meet until proposals are more developed; there can be reasons why comments made cannot be integrated into design changes e.g. topography, access, communications, habitat and wildlife constraints can all provide constraints to design. Also at the early stages of a project there may be questions which cannot be answered because the answers are not available e.g. longer term surveys are not complete, land or turbine negotiations are not complete etc. The definition of community and local community can also be difficult to establish in the early stages of a project which increases the opportunities for stakeholders to be missed which can cause upset at a later stage.

21. Public events can be particularly difficult if non locals or even locals have come for the express purpose of objection. It is difficult in this context to engage with locals attending for information purposes. In these situations the objectors are highly motivated to ensure their opinion is heard and can be aggressive and intimidating in their manner.

22. We are supportive of the community consultation principles outlined in the Planning Act NI 2011 and the 2013 Planning Bill and will be interested in any consultation on secondary legislation that may come forth, outlining how these principles will work and will be delivered on a day to day basis.

23. We reiterate our commitment to effective community engagement with regard to the development of our projects.

Concluding Comments

24. The presence of a clear Government policy target for 2020 (and beyond) and Planning Policy Statement 18 which is broadly supportive of renewables development in the right context has provided a solid platform for the growth of the renewables sector and in particular onshore wind to date. Strong political leadership across the political spectrum will ensure that this foundation is built upon and that the benefits of renewable energy in terms of electricity costs, fuel security and jobs are realised for the benefit of the NI economy and people.

25. In conclusion we would like to thank the Committee for the opportunity to engage on this issue and look forward to their continued support for the development of our enviable renewable resources which we feel will enable the necessary progress towards meeting our low-carbon commitments.

Sincerely Yours,

*Sent electronically so no need for signature

Jeff Potter

CEO, Windyfields

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