

## 1 Wind Turbine Noise

2 Edited by Dick Bowdler and Geoff Leventhall  
3 Multi-Science Publishing Co. Ltd, Essex, UK, (2011).  
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6 Complaints regarding wind turbine noise are making  
7 headlines, as wind turbine development, once confined  
8 to remote areas, is making inroads in areas with higher  
9 population densities. The issue has polarized many  
10 communities and the debate often leads reasoned argu-  
11 ment astray. In part, this is a result of the internet age,  
12 where there is a large amount of information being  
13 offered, and it is difficult know what studies and claims  
14 are authoritative.

15 Given that the field has been developing rapidly,  
16 there has been lacking a modern text that brings together  
17 the diverse field of wind turbine noise, from sound  
18 generation to effects. Hubbard and Shepherd's Wind  
19 Turbine Acoustics (1990) is an excellent foray into  
20 the subject and covered much of NASA's pioneering  
21 research. It was updated in 2009. However, that update  
22 was only partial and did not bring us much new  
23 information.

24 Fortunately, the editors, Dick Bowdler and Geoff  
25 Leventhall, both highly regarded in the field of wind  
26 turbine noise, have put together an excellent text for  
27 professionals that details the many aspects of wind tur-  
28 bine noise, including sound generation, propagation,  
29 local effects, human health impacts, measurement, and  
30 criteria.

31 The book is primarily intended for scientists, regula-  
32 tors, and consultants. I could see this as being a useful  
33 text to others, including developers, community and  
34 environmental groups, and policy makers, but, with  
35 the exception of a short background chapter on basic  
36 acoustics and a review of international noise regula-  
37 tions, many of the chapters are not geared towards a  
38 lay audience.

39 The book is in eight chapters with two appendices,  
40 and each chapter is written by one or more of the top  
41 professionals in their field, including the two editors.  
42 The editors left each author to create their chapters in  
43 their own style, which they admit leads to some incon-  
44 sistency. However, they have done an excellent job with  
45 cross-referencing chapters and creating a consistency in  
46 information without duplication or conflicting  
47 arguments.

48 Chapter 1 of the book, written by Geoff Leventhall, is  
49 an introduction to basic acoustics. It covers sound pres-  
50 sure, frequency, the A- and C-weighting systems, sound  
51 power, decibel math, the differences between point and  
52 line sources, measuring sound, levels, and frequency  
53 analysis. In some sense this is a good review of the

basics of sound, but is not really needed given the level 54  
of sophistication of most of the book chapters. For ex- 55  
ample, somebody who wants to learn how to apply par- 56  
abolic equation modeling to wind turbines (Chapter 3) is 57  
unlikely to need an acoustics primer. However, for regu- 58  
lators and others with limited acoustical background, it 59  
is a handy reference. 60

Chapter 2, written by Stefan Oerlemans, deals with 61  
primary noise sources, or how sound is generated from 62  
wind turbines. The chapter deals with the potential 63  
sources of wind turbine noise, including a detailed ac- 64  
count of airfoil noise, localization of wind turbine 65  
sound emissions using phased microphone arrays, pre- 66  
diction of wind turbine sound emissions from informa- 67  
tion on airfoil design, and strategies for improving the 68  
design of wind turbines to reduce noise. I found this 69  
chapter to be highly informative and well-written. It is 70  
very detailed, giving equations describing the various 71  
mechanisms of sound generation, their directivity, and 72  
spectral characteristics. The written portion is well sup- 73  
ported with informative color graphics and photo- 74  
graphs. The references at the end of the chapter 75  
provide a good resource for those interested in further 76  
details of specific topics. 77

Chapter 3 concerns sound propagation from wind 78  
turbines and was written by Andrew Bullmore and 79  
Andrew Peplow. Like the previous chapter, it goes into 80  
extensive detail on the mechanisms of sound propaga- 81  
tion. This starts with an important section on accuracy, 82  
variability, uncertainty, and risk. It then goes into an ex- 83  
cellent discussion of the layers of factors that go into 84  
sound propagation modeling: characterizing the source, 85  
ground effects, atmospheric influences (temperature 86  
and wind profiles), turbulence, terrain, and barriers. 87  
Various modeling approaches are discussed, including 88  
the engineering methods of ISO 9613-2, Nord 2000, 89  
and Harmonoise, and full wave methods, such as para- 90  
bolic equation modeling, the WAVE model, and ray 91  
tracing. This chapter ends with a list of 43 references, 92  
which provide a wealth of further reading for those 93  
interested. 94

Chapter 4, "Wind Turbine Noise at the Receiver," is 95  
written by Bo Søergaard. It covers how sound changes 96  
by characteristics of the receiver position. For example, 97  
there is a good discussion of outdoor-to-indoor sound 98  
attenuation, interior sound reflections and resonance, 99  
and measurement techniques inside and outside homes. 100  
From these physical effects, it then goes into psycho- 101  
acoustics, covering ISO 226-2004 loudness, audibility, 102  
masking, tonality, and impulsiveness. The chapter is 103  
also supported with a list of excellent references. 104

Chapter 5 is a short chapter on amplitude modula- 105  
tion, written by Frits van den Berg and Dick Bowdler. 106  
It argues that the common swish of wind turbines is 107

108 primarily due to the directivity of trailing edge noise,  
109 but acknowledges other factors, such as stalling in high  
110 wind shear, can contribute to other types of amplitude  
111 modulation, such as the less common thumping sound  
112 that is sometimes reported.

113 Chapter 6 deals with one of the more controversial  
114 topics in wind turbine noise, the effects of sound on  
115 people. Written by Frits van den Berg, it takes a bal-  
116 anced approach to addressing claims of health effects  
117 and the research literature around it. The chapter first  
118 addresses the known health effects of noise, from all  
119 noise sources. It then discusses the personal and social  
120 factors that contribute to annoyance or other physiolog-  
121 ical and psychological effects. Finally, the author brings  
122 these factors into context with wind turbine noise, de-  
123 scribing the three European dose-response studies and  
124 other studies that offer clues into the perception of wind  
125 turbine noise. The special issue of low frequency noise  
126 and infrasound is addressed, where the author con-  
127 cludes that “as yet there is no evidence that inaudible  
128 (low frequency) environmental sounds can have so-  
129 matic effects. To guide further research with respect to  
130 environmental health effects, it is important to have  
131 clear indications to the contrary rather than specula-  
132 tions.” Several pages are devoted to sleep effects and  
133 sleep disturbance, where it appears that there is evi-  
134 dence that sleep disturbance may be related to annoy-  
135 ance from wind turbine noise. The author calls for  
136 more research into separate daytime and nighttime lim-  
137 its. Finally, he suggests several mitigation measures, in-  
138 cluding lowering nighttime sound levels, decreasing  
139 modulation, and “changing the meaning of the sound.”  
140 The chapter concludes with 62 references, providing a  
141 wealth of supporting information.

142 Chapter 7, written by David Hessler is “Measuring  
143 and Analyzing Wind Turbine Noise.” The measurement  
144 of environmental sound from wind turbines is made dif-  
145 ficult by the very fact wind turbines are noisiest in the  
146 highest winds. The standards that currently exist for en-  
147 vironmental noise measurement exclude windy periods.  
148 In addition, there is difficulty in quantifying back-  
149 ground sound, as windy periods tend to have higher  
150 background sound. Therefore, new methods must be

developed to quantify in situ long-term measurement 151  
of wind turbine sound. The author discusses the IEC 152  
61400-11 standard which is solely designed to estimate 153  
the sound power and other aspects of wind turbine 154  
sound near the turbine. For compliance testing, a test 155  
methodology is suggested which, the author suggests, 156  
works on a variety of wind project sites, but does not 157  
solve the above problems completely. As indicated, 158  
the method works very well where background sites 159  
can be found away from turbines that reflect the back- 160  
ground sound at the target site, and when the L90 crite- 161  
ria is used. It has limitations if one has to measure Leq, 162  
as short-duration local loud events can dominate the 163  
Leq. A good discussion is made of contaminating 164  
noise, such as insects and wind, and of windscreen at- 165  
tenuation, and how to correct for these. 166

The book concludes with Mark Bastasch’s review of 167  
sound criteria for wind turbine noise. Rather than 168  
recommending a criteria or approach to regulation, the 169  
chapter surveys various noise standards around the 170  
world. Standards in 18 jurisdictions are covered, includ- 171  
ing countrywide standards in Europe, New Zealand, 172  
South Korea, and Australia, and standards in various 173  
US states. By necessity, the description of each standard 174  
is short, and may leave out certain aspects, like averag- 175  
ing times. But readers wishing more information can 176  
refer to the comprehensive list of references provided. 177

Overall, I highly recommend *Wind Turbine Noise*. 178  
The authors have compiled information from almost 179  
200 papers on the topic and have done an excellent 180  
job in putting together a well-balanced and well- 181  
researched book. While it will be very useful as a basic 182  
text for students of acoustics, consultants, and engi- 183  
neers, I believe it may have the most use for regulators 184  
and policy makers looking for credible analysis on this 185  
difficult subject. 186

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