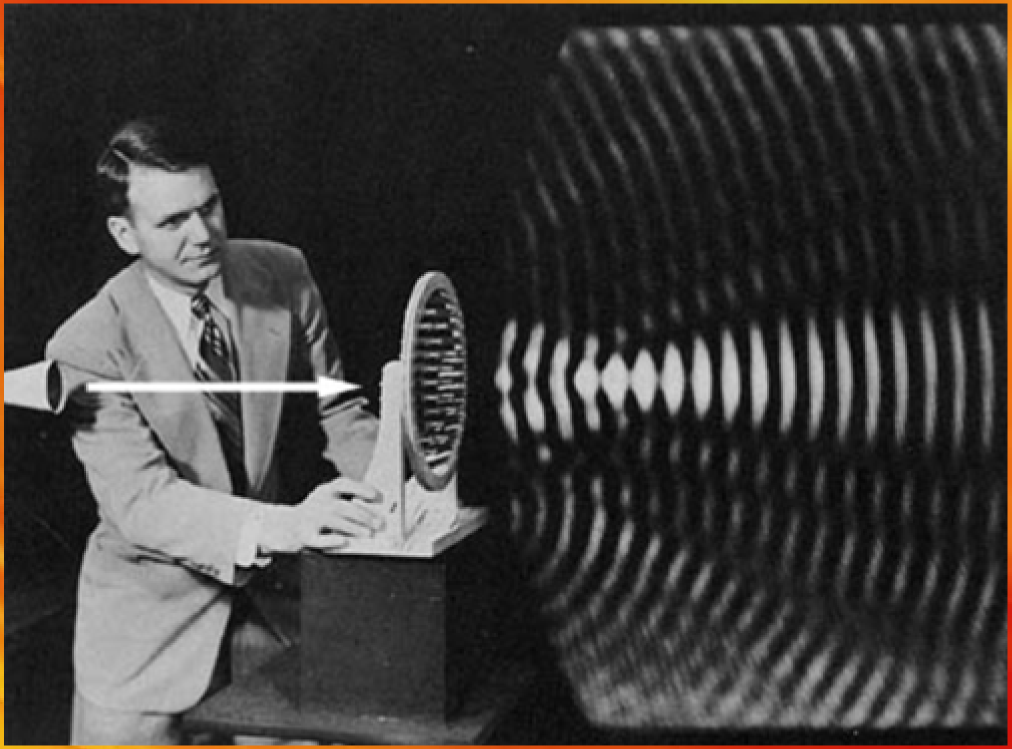
Wind Turbine Noise - from Source to Receiver
Far-field Noise Issues - AM, Tonality & Impulses

Dr Jeremy H Bass, MIOA, MInstP
SENIOR TECHNICAL MANAGER

11 – 12 December 2012 – EWEA Noise Workshop, Session 3



1. Introduction

2. Measurement & Analysis Techniques
   a) qualitative and quantitative

3. 'Other' Amplitude Modulation
   a) what is it & definitions
   b) methods for identification & quantifying
   c) possible theoretical explanations?

4. Other acoustic features
   a) Tones, Impulses, LFN & infrasound

5. Final Thoughts


An innovative sound level meter
A smart monitoring station
All-in-One
ACOUSTIC NOISE CONE 0°/90°
WEATHERPROOF MICROPHONE
INTEGRATED GPS ANTENNA
COLOUR DISPLAY
3-KEY KEYBOARD
WATERPROOF METAL CASING
RUBBER SIDE GRIPS
ACCESSORIES
DUO
01dB

- min
  to
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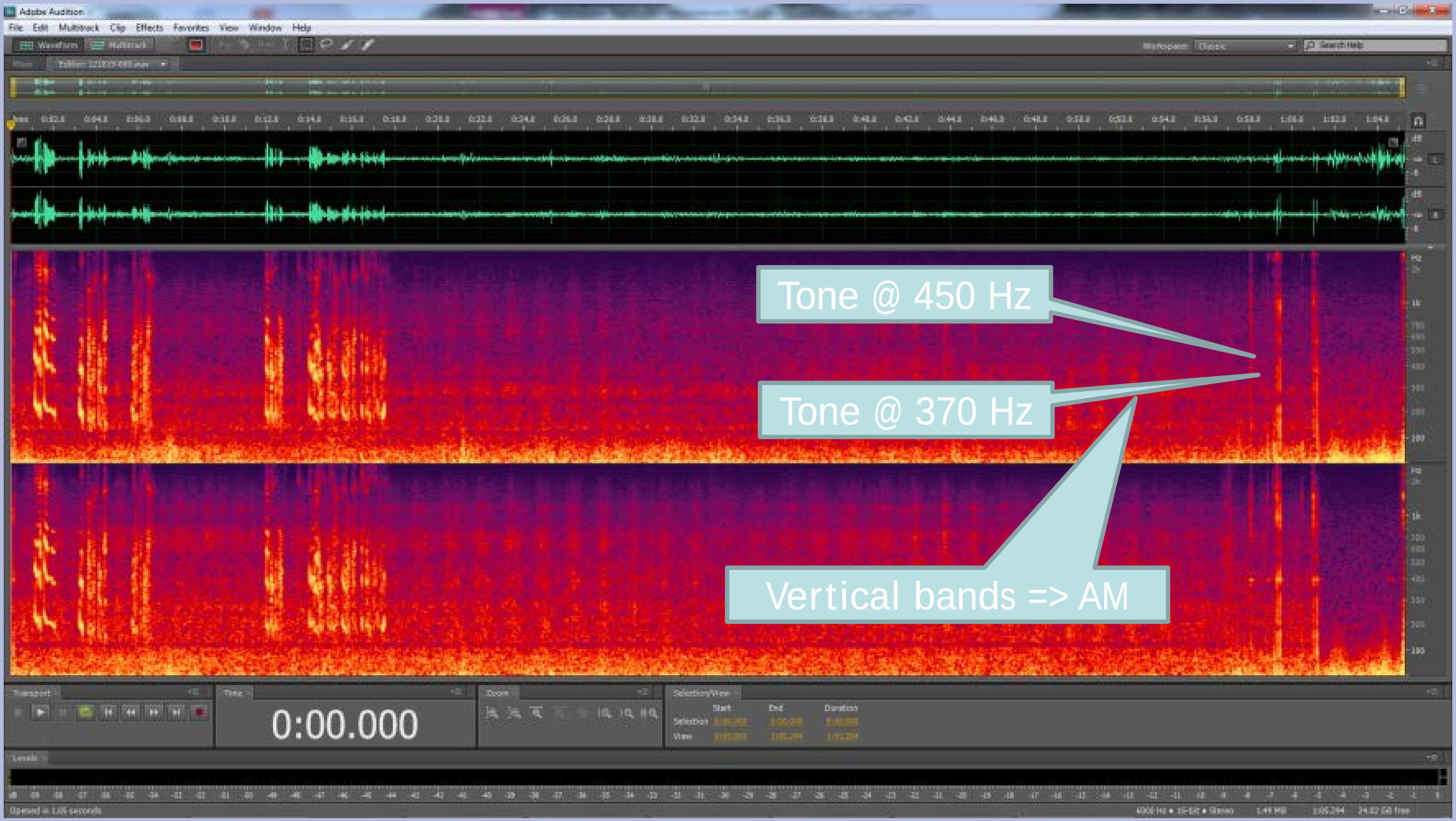
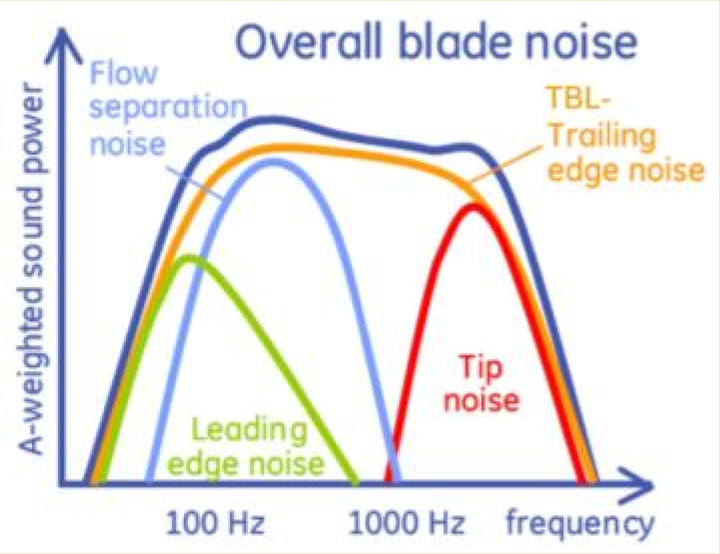
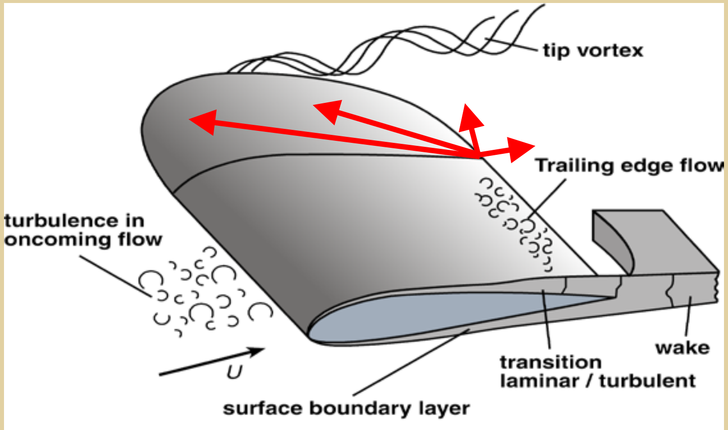
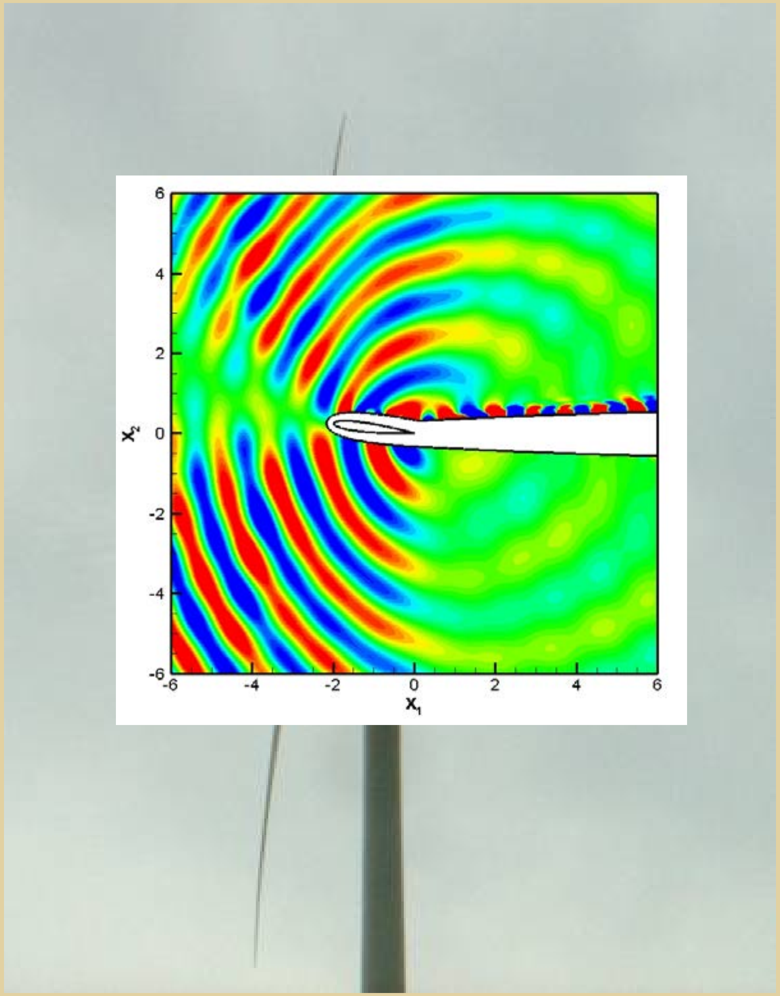

Tone @ 450 Hz
Tone @ 370 Hz
Vertical bands => AM
0:00.000


Overall blade noise
A-weighted sound power
Flow separation noise
TBL- Trailing edge noise
Tip noise
Leading edge noise
100 Hz
1000 Hz
frequency


tip vortex
Trailing edge flow
turbulence in oncoming flow
U
transition laminar / turbulent
wake
surface boundary layer


x_2
x_1
6
4
2
0
-2
-4
-6

3a ‘Normal’ Amplitude Modulation (‘NAM’ or ‘blade swish’)

What would an observer standing in near-field, downwind of a turbine hear?

Key points:

- occurs at blade passing frequency
- peaks when the blade is moving towards the observer, i.e. 3 am
- conflicts with common perception!
- only apparent close to turbine (ex. crosswind)
- theory suggests maximum predicted level variation ~5 dB (peak-to-trough)
- high frequency noise

[From Oerlemans, 2009]

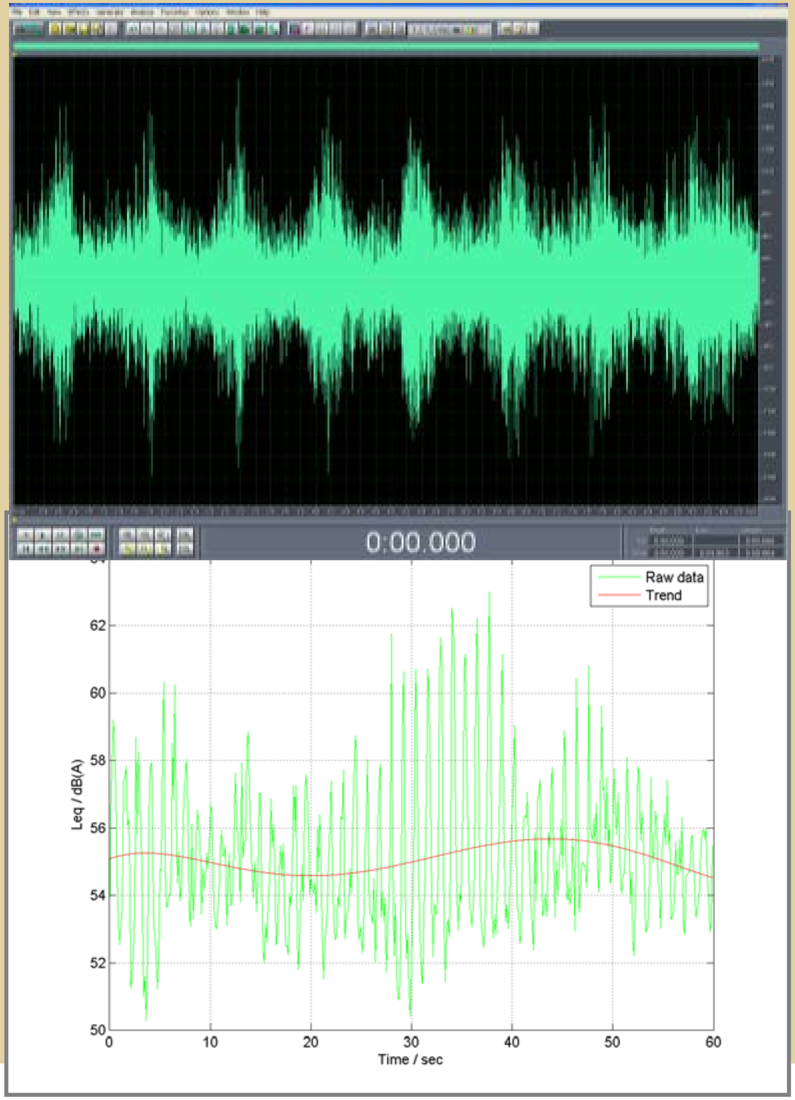
3a ‘Normal’ Amplitude Modulation (‘NAM’ or ‘blade swish’)

Key Points:

- ‘Normal’ AM occurs because of the directivity of the dominant boundary layer / trailing edge noise source combined with the rotation of the blades
- it is fundamental to the operation of all turbines
- it is predominantly a ‘near field’ feature

3a ‘Other’ Amplitude Modulation (OAM)

- at some sites, AM is apparent at residential distances (‘far field’)
- observed levels of 5 – 10 dB!
- despite it’s rarity, complaints have sometimes been vociferous and may reflect genuine nuisance
- potentially damaging to reputation of the wind industry, eroding public support and potentially reducing chances of planning success
- **‘other’ amplitude modulation - OAM**



Key Points:

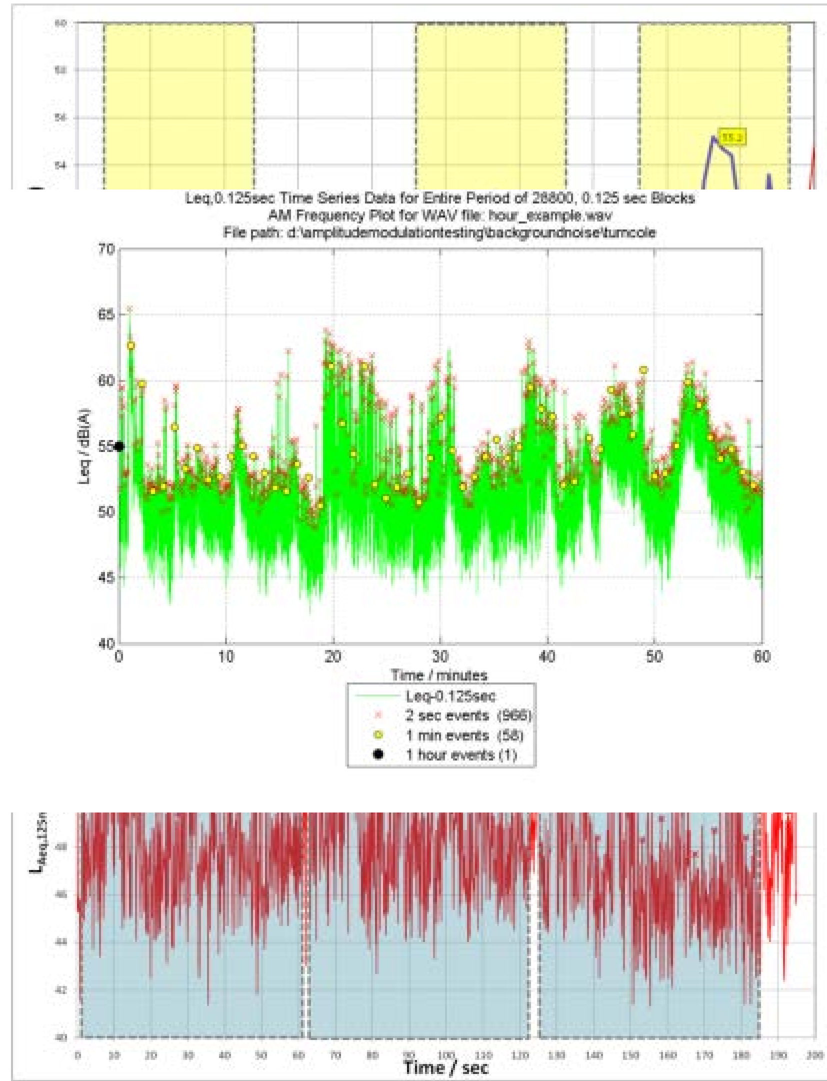
- noise shifts to lower frequencies
- the level of AM increases
- it is a ‘far-field’ feature
- unusual and still relatively rare
- often associated with night-time or stable atmospheric conditions
- why is this happening?

3b – Amplitude Modulation – A Possible Identification Methodology?

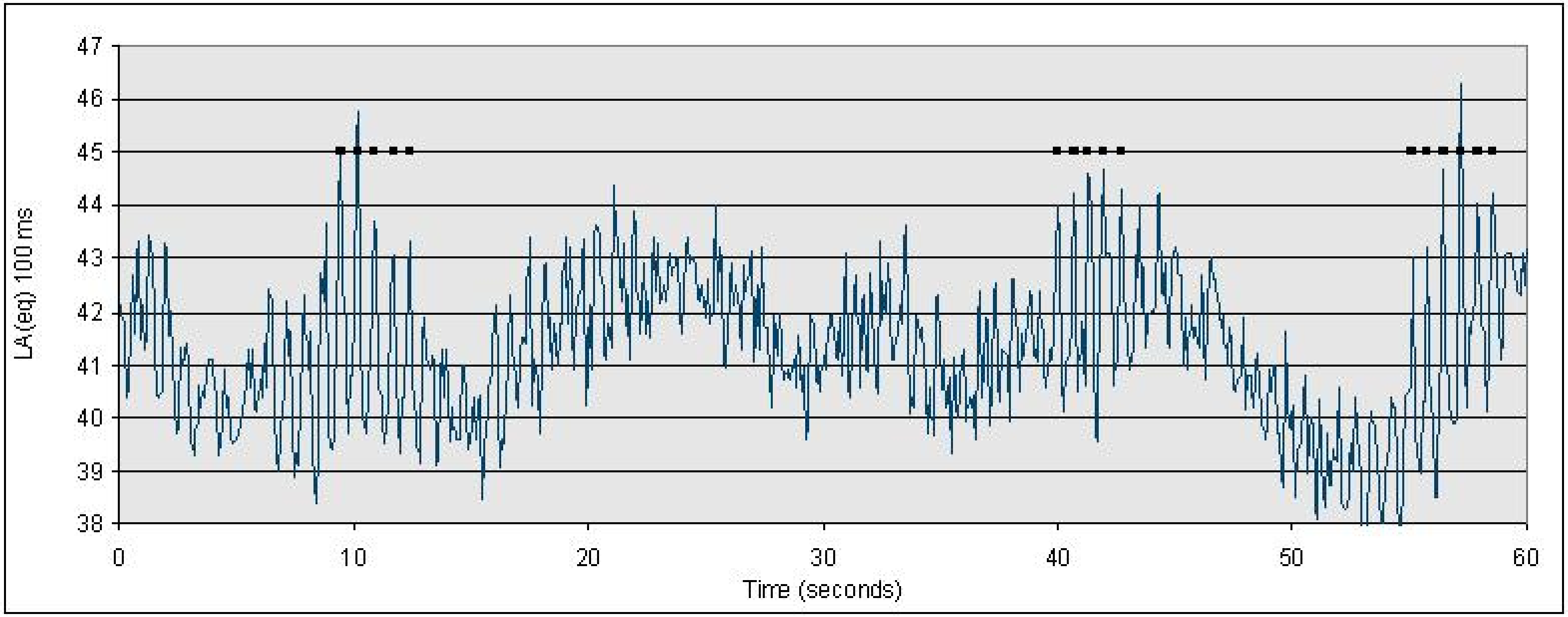
Key points of methodology:

- measure $L_{Aeq,125\ msec}$
  - a) need rise, and subsequent fall, of ≥ 3 dB within 2 sec period
  - b) a) must occur ≥ 5 times in 1 min provided $L_{Aeq,1\ min}$ is ≥ 28 dB(A)
  - c) b) must occur ≥ 6 times in 1 hour for AM to regarded as 'greater than expected'

- measure at affected residence:
  - a) ≤ 35 m from property
  - b) ≥ 3.5 m any reflective surface
  - c) ≥ 1.2 m of the ground.



- Analysis performed by Dr Lee Moroney & Dr John Constable of the Renewable Energy Foundation (REF)
- The Den Brook Amplitude Modulation Noise Condition - 1st November 2011
- http://www.ref.org.uk/publications/242-the-den-brook-amplitude-modulation-noise-condition



- Concluded that the methodology worked very well!

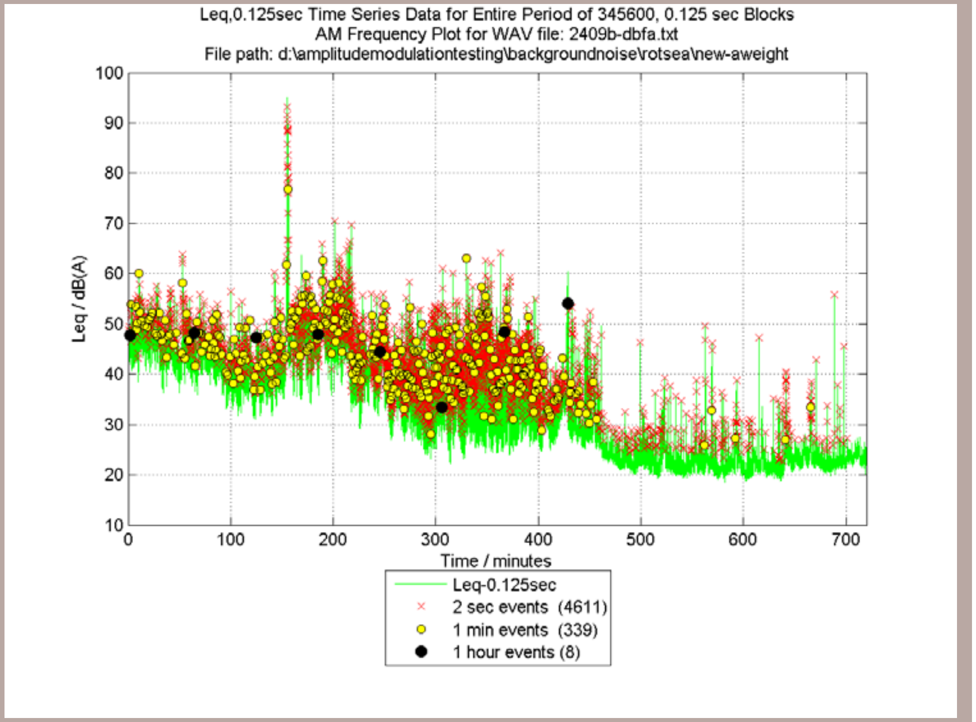
But:

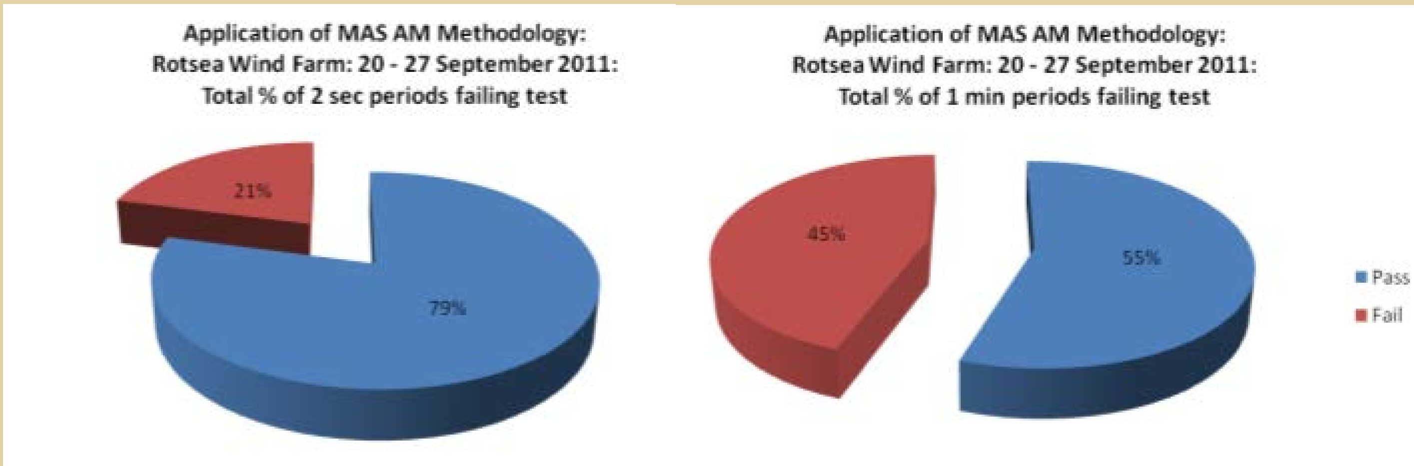
- work proceeded with data containing obvious AM
- method clearly is good indicator of presence of AM
- implies low rate of 'false negatives'
- not disputed!

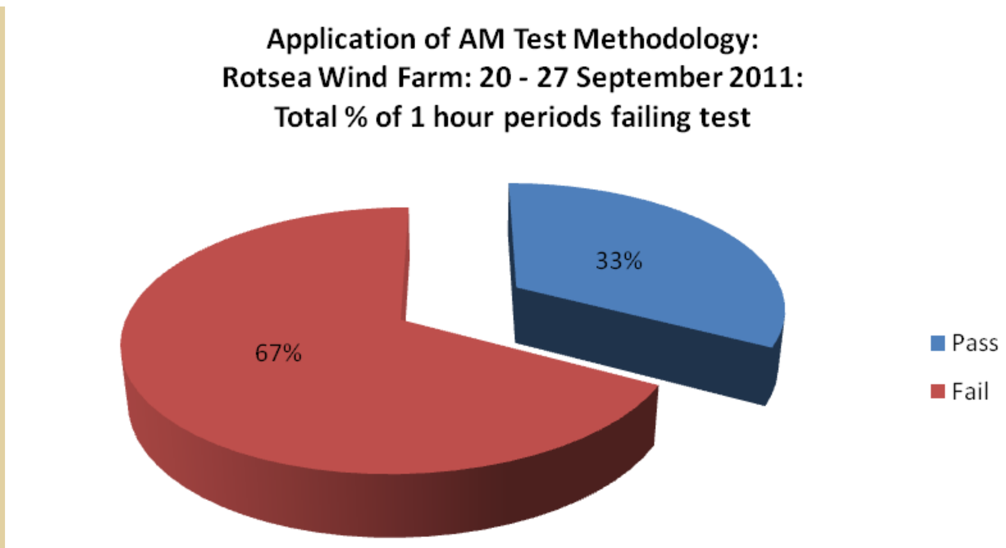
- what of 'false positives'?

- test methodology with real-world data and assess performance
- background noise is character-free source

1. Turncole, Essex
   - 19 – 27 Aug 2011
   - 185 hours
2. Rotsea, Humberside
   - 20 – 27 Sep 2011
   - 169 hours



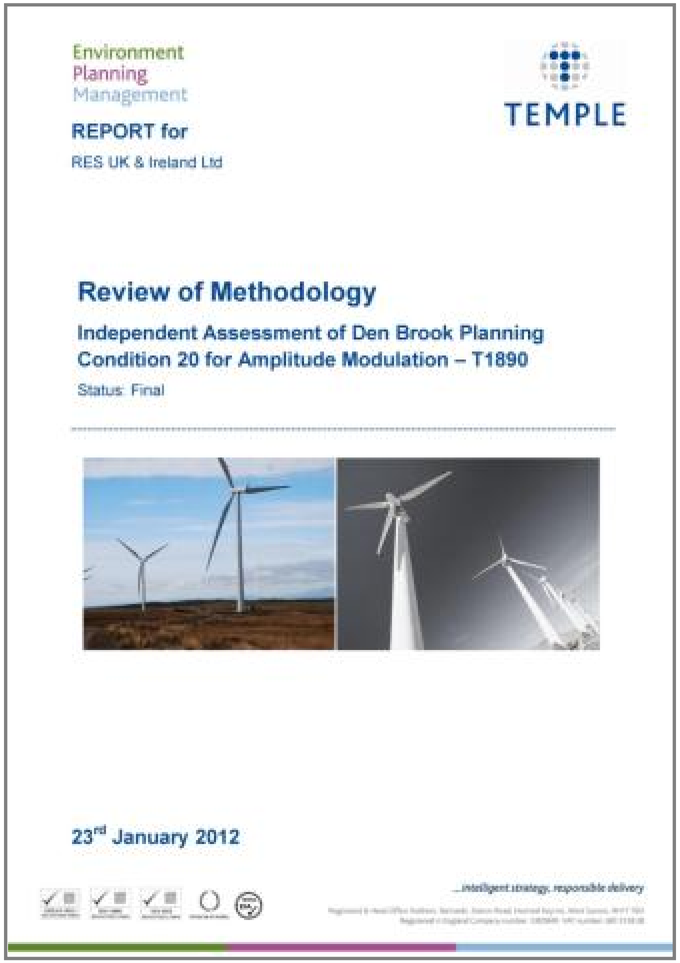

Application of MAS AM Methodology:
Rotsea Wind Farm: 20 - 27 September 2011:
Total % of 2 sec periods failing test
21%
79%
Application of MAS AM Methodology:
Rotsea Wind Farm: 20 - 27 September 2011:
Total % of 1 min periods failing test
45%
55%
Pass
Fail


Application of AM Test Methodology:
Rotsea Wind Farm: 20 - 27 September 2011:
Total % of 1 hour periods failing test
33%
67%
Pass
Fail

3b – Amplitude Modulation – A Possible Identification Methodology? Testing - 2

- not good indicator of presence of AM
- 70 - 80% rate of 'false positives'
- condition not specific to AM
- cannot be saved by filtering
- not fit for purpose!

- See Acoustics Bulletin article – Nov/Dec 2011 and errata in Jan/Feb 2012 Issue


Environment
Planning
Management

REPORT for
RES UK & Ireland Ltd

TEMPLE

Review of Methodology

Independent Assessment of Den Brook Planning Condition 20 for Amplitude Modulation – T1890

Status: Final

23rd January 2012

...intelligent strategy, responsible delivery

- implemented the methodology and tested on the Turncole and Rotsea audio data
  - 144 out of 184 hours of data at Turncole breached condition: **78% FPs**
  - 107 out of 167 hours of data at Rotsea breached the condition: **65% FPs**

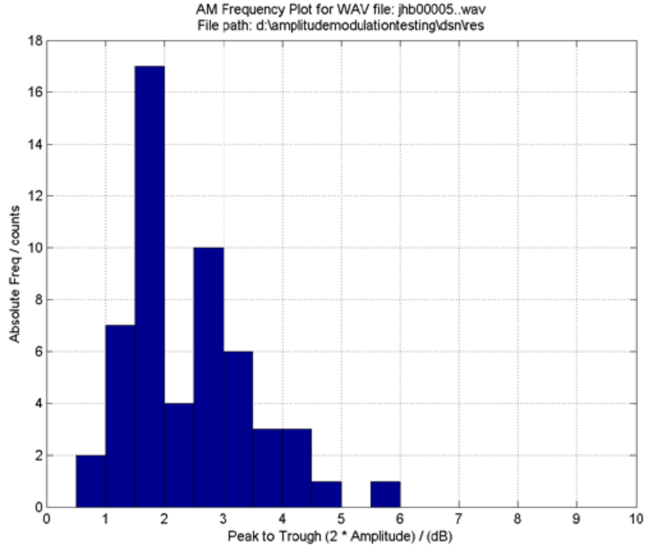
- also considered a second interpretation of Condition 20:
  - Rotsea results reduce from 65% to **38% FPs**
  - Turncole results reduce from 78% to **49% FPs**
  - **interpretation likely to have bearing on the rate of false negatives!**

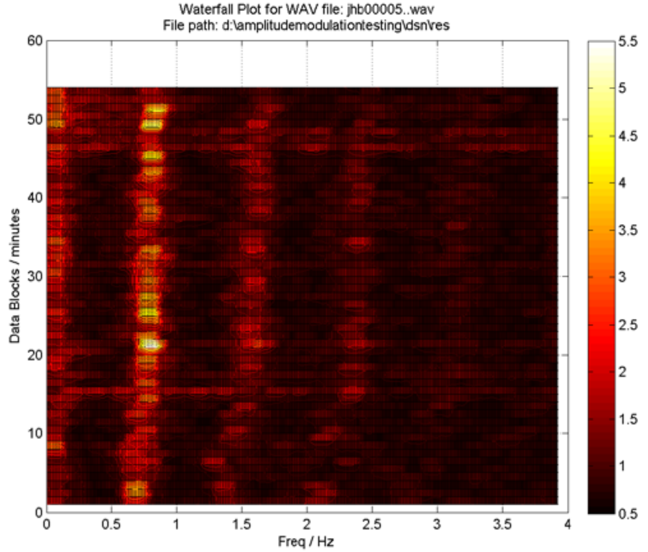
"A method of robustly assessing and proving beyond reasonable doubt whether unacceptable "excess or other AM" is occurring is ultimately desirable; but Condition 20 doesn't seem to meet this objective."

"There is a real risk that enforcement of the condition is likely to fail."

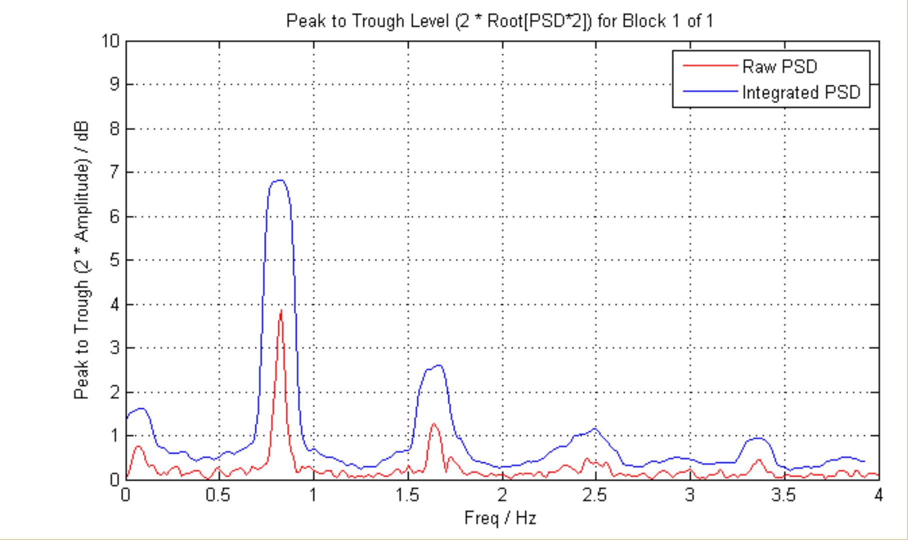
3b - Amplitude Modulation - RES Methodology

- developed own methodology
  - re-use elements of previous idea
  - use $L_{Aeq,125\ msec}$ data in 1 min blocks
  - frequency based analysis - PSDs
  - looks at modulation at BPF
  - *may give insight into AM waveform*?
- tested on huge array of near- and far-field data to assess levels of AM
  - only 2 % > 3 dB peak to trough
  - average of exceedances is 3.7 dB
- seeking to incorporate in IEC 61400-11 Edition 4?
- shortly to release into public domain

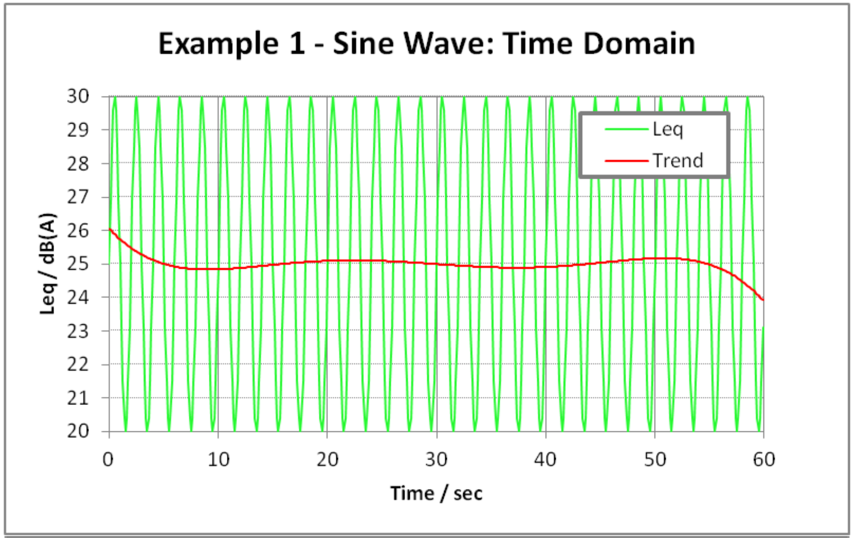


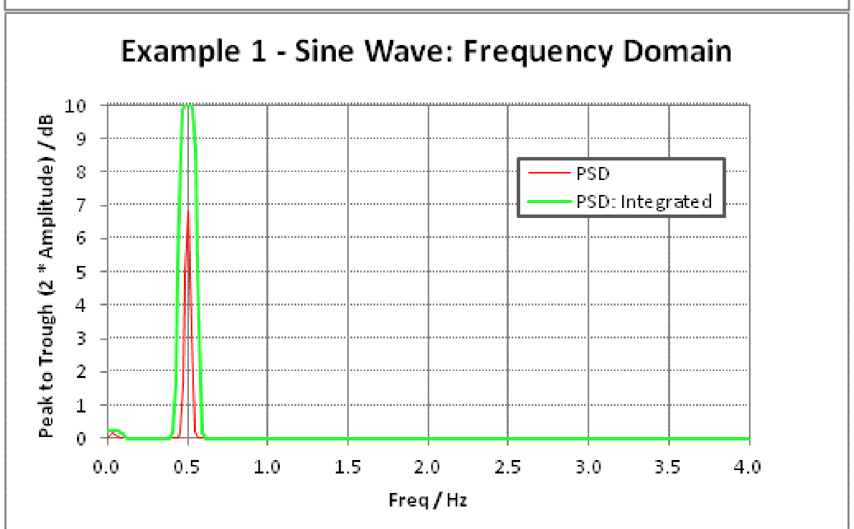


3b – Amplitude Modulation – RES Methodology



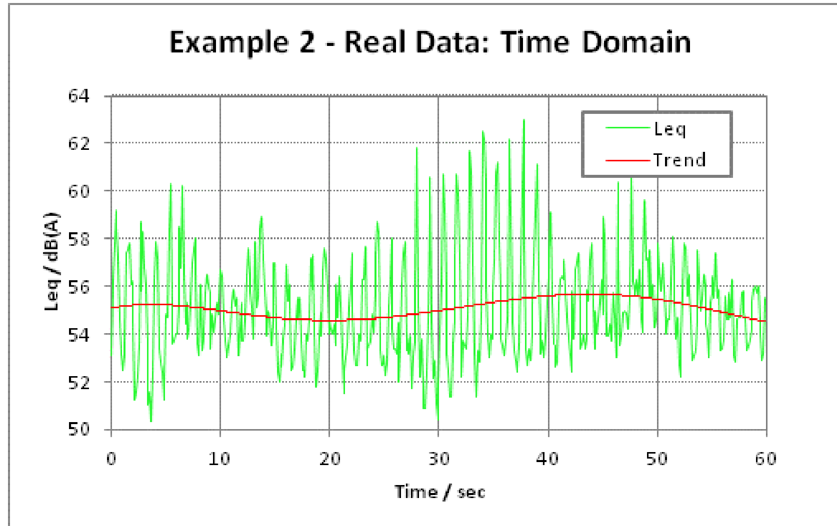
3b – Amplitude Modulation – RES Methodology – Example 1

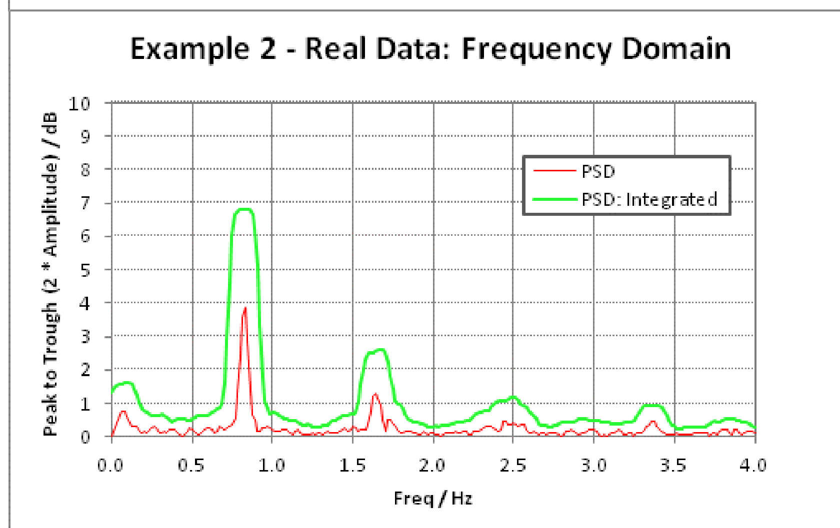




- in this example, the modulation frequency, f_c, is 0.5 Hz
- the frequency window over which the 'raw' power spectrum needs to be integrated is 0.9 - 1.1 f_c, equal to 0.45 - 0.55 Hz, i.e. 0.1 Hz
- as the frequency resolution is (1/64) Hz = 0.015625 Hz, this implies an integration window of 0.1/0.015625 frequency intervals, i.e. 6.4
- rounding this up to the next nearest odd integer, gives 7 frequency intervals
- the Green line on bottom figure has been generated by integrating the power spectrum using a moving average window of 7 frequency intervals, equivalent to ~ 0.1 Hz
- this integrated value is then unit converted, as before, to convert to decibels - giving the Green Line

- in this example, the modulation frequency, f_c, is 0.8125 Hz
- the frequency window over which the 'raw' power spectrum needs to be integrated is 0.9 - 1.1 f_c, equal to 0.73125 - 0.89375 Hz, i.e .0.1625 Hz
- as the frequency resolution is (1/64) Hz = 0.015625 Hz, this implies an integration window of 0.1625/0.015625 frequency intervals, i.e. 10.4
- rounding this up to the next nearest odd integer, gives 11 frequency intervals
- the Green line on bottom figure has been generated by integrating the power spectrum using a moving average window of 11 frequency intervals, equivalent to ~ 0.1 Hz
- this integrated value is then unit converted, as before, to convert to decibels - giving the Green Line



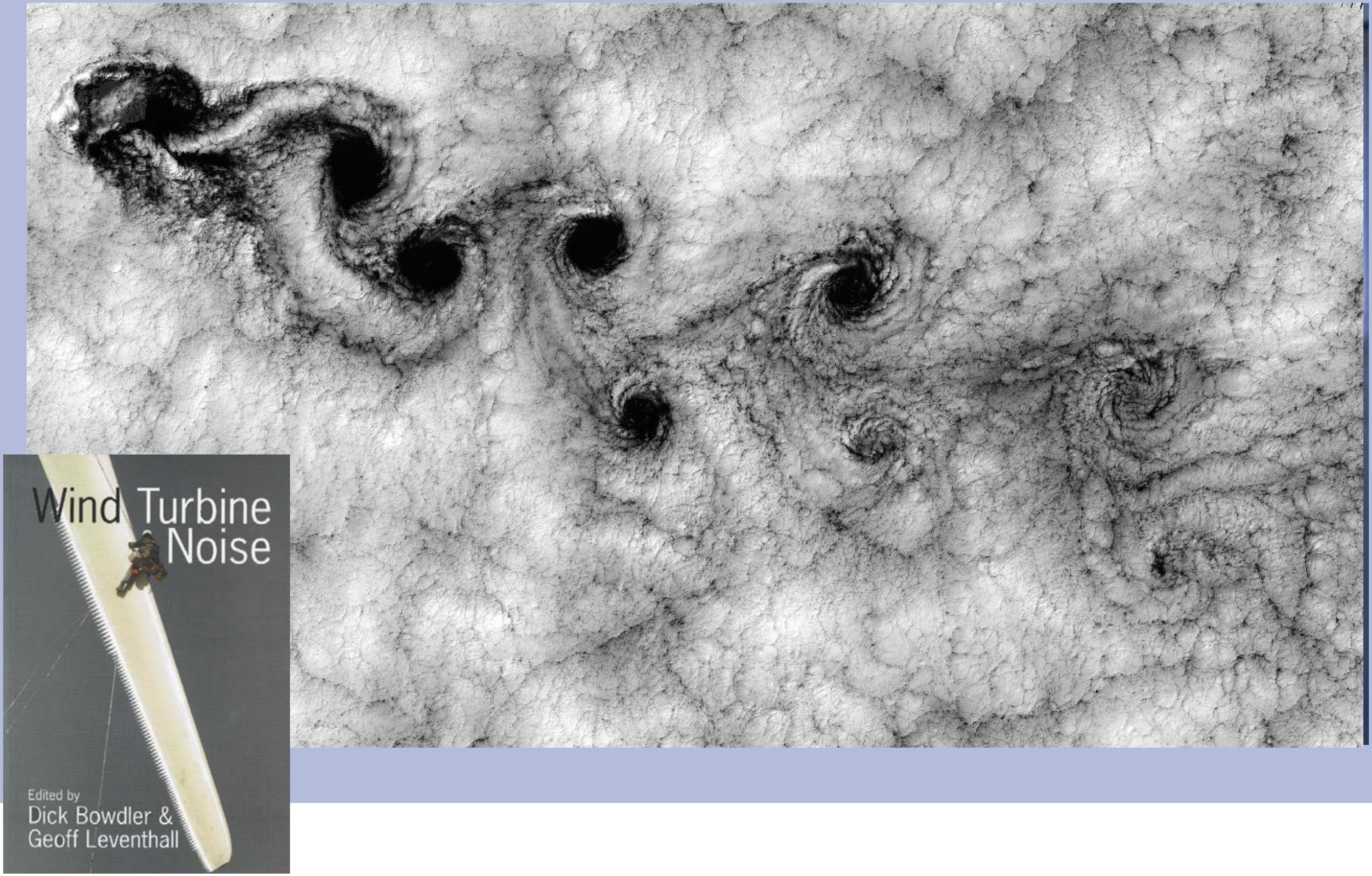


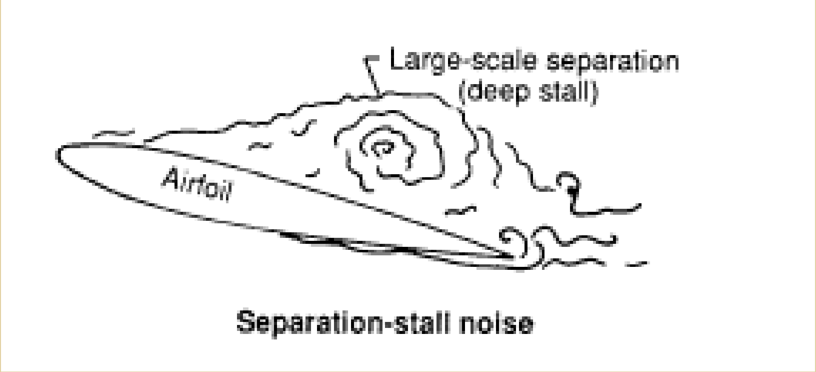
At least 4 possible theoretical explanations as to cause of OAM:

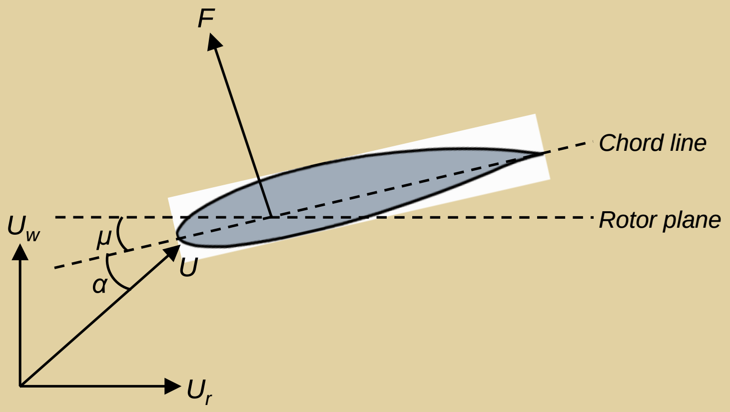
1. same explanation as for near-field AM, we just got something wrong!
2. turbulent eddy shedding - vortex streets & trailing edge serrations
3. blade tip stall due to high angles of attack
4. ‘flanging’ - possibly caused by stall-induced blade vibration
5. your idea?

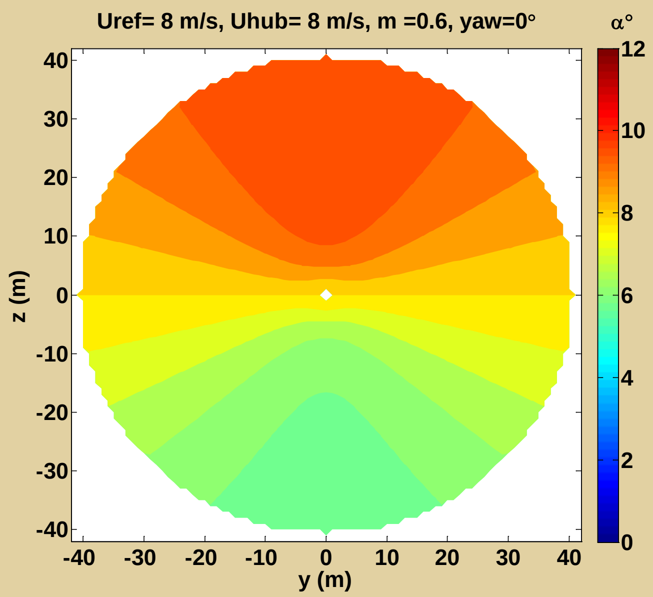
Still don’t have definitive proof of the cause, making mitigation difficult!

3c THEORY 2 – Turbulent Eddy Shedding







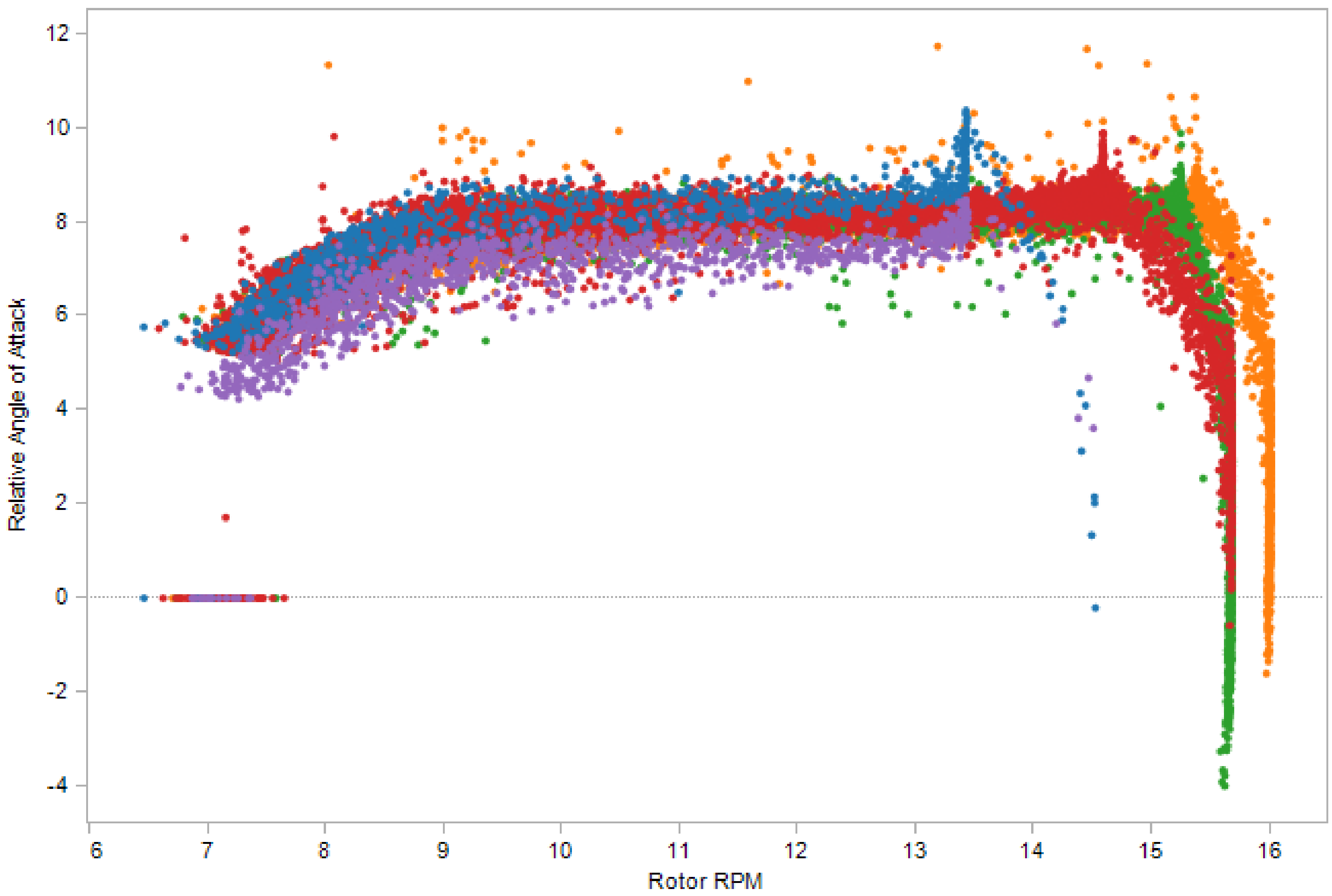


- in periods of high wind shear the wind speed increases rapidly with height
- pitch setting appropriate for hub height, but too low for blade tip when at 12 am (TDC)
- stall may occur around the tip of the blade at TDC
- sudden increase in noise (~10 dB) until flow re-attaches

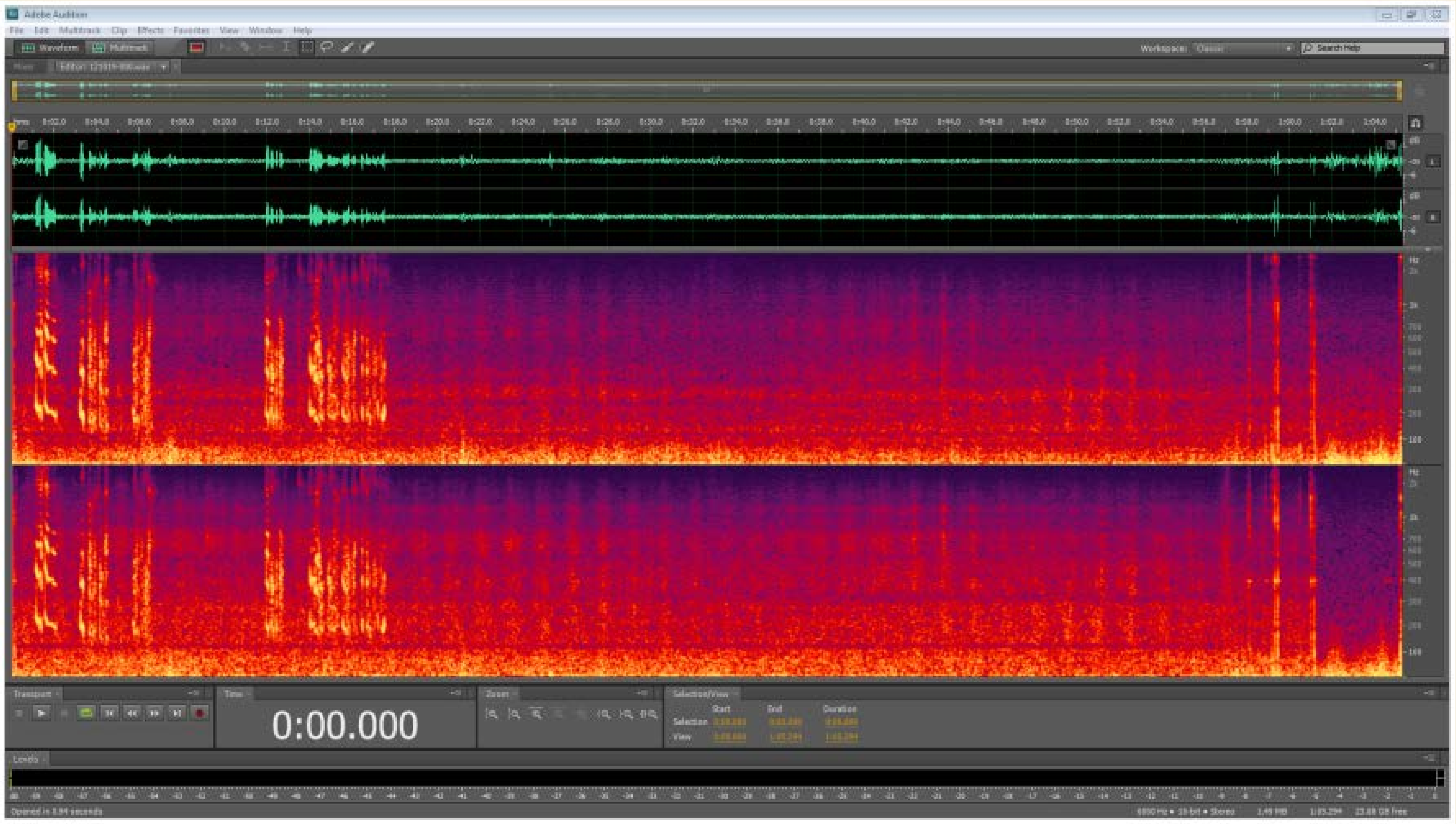
3c THEORY 3 - OAM Caused by Blade Stall in High Shear

Key Points:

- ‘Other’ AM occurs because of blade stall
- main driver is high wind shear
- effect more significant on large machines
- increased low frequency content
- explains high levels of OAM in the far-field


Relative Angle of Attack
Rotor RPM
12
10
8
6
4
2
0
-2
-4
6
7
8
9
10
11
12
13
14
15
16

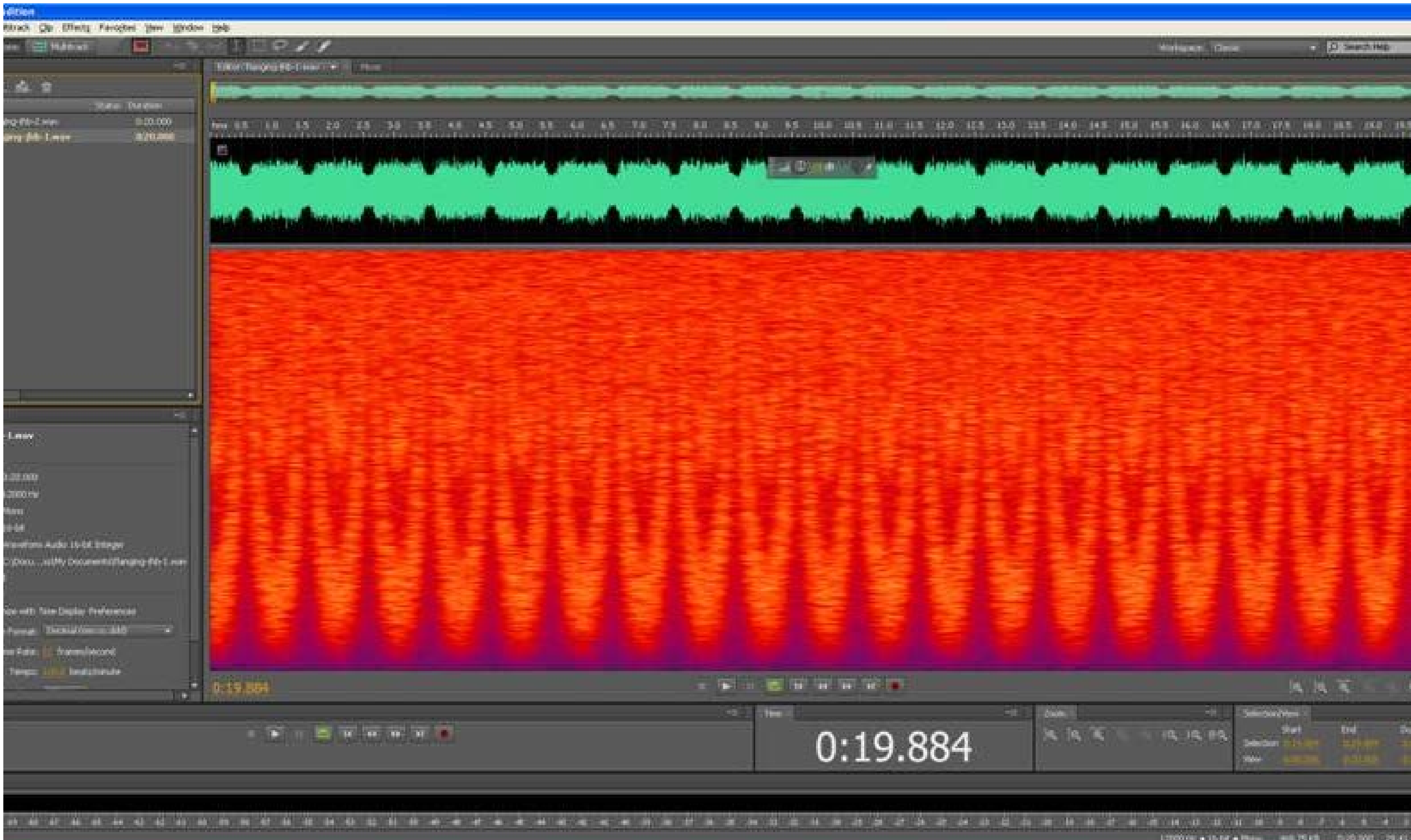
3c THEORY 3 Sidebar - The Effect on Icing



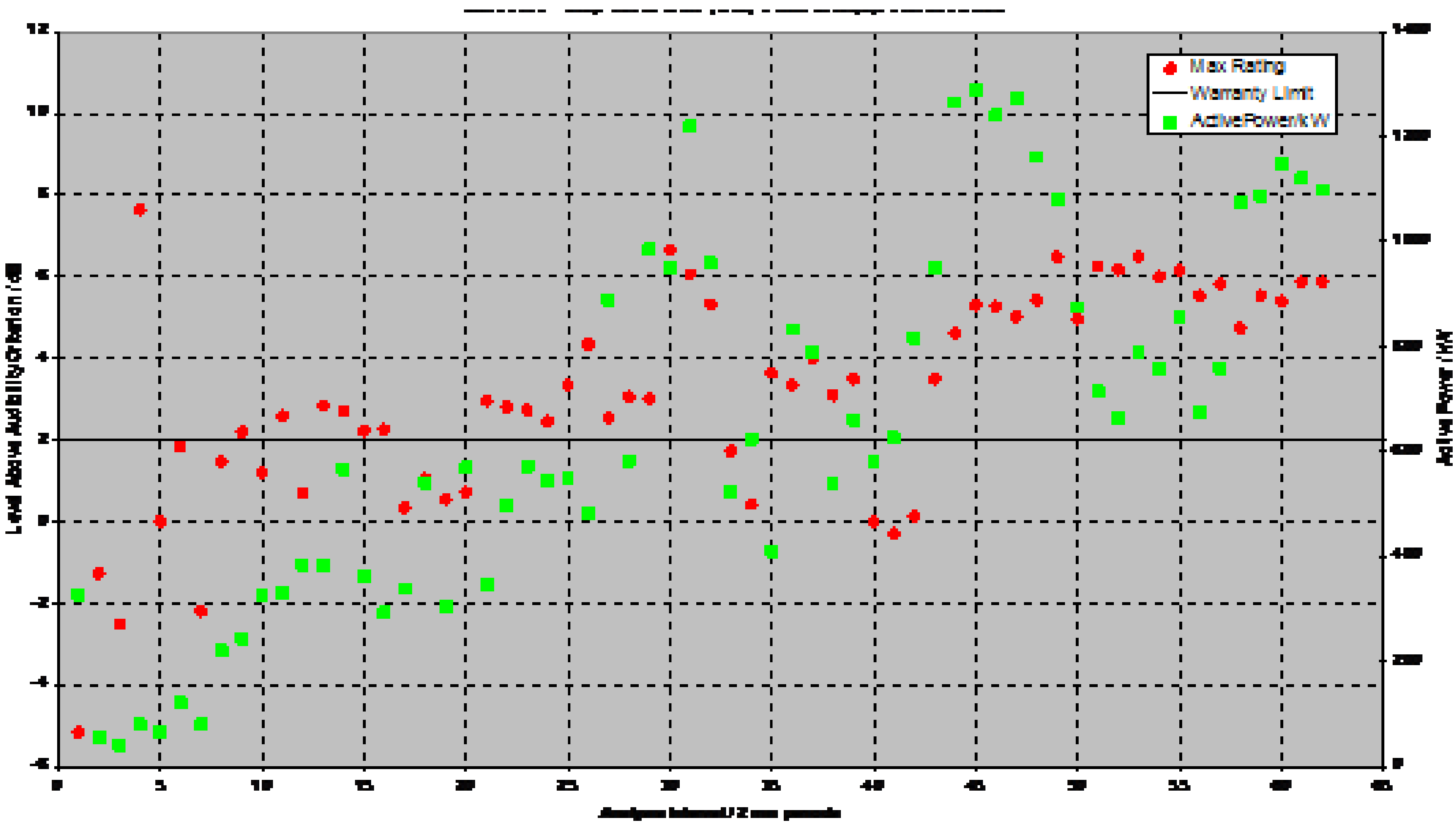
3c THEORY 3 - OAM Solutions / Mitigation & Comment

- if blade stall is the cause, then it's not just AM which is a problem, but also cyclic blade loads and power performance!
- alternative blade design and geometries?
- alternative pitch control strategies (collective)?
- 'cyclic' pitch control, e.g. Mervento, GE (tbc)?
- working closely with a number of manufacturers, e.g. Siemens, Vestas, Repower, GE etc

3c THEORY 4 – Vibration Induced Flanging



4 OTHER FAR-FIELD NOISE FEATURES



- the best protection against far field acoustic features is a well written Turbine Supply Agreements (TSAs) with the manufacturer
- contents may differ so that some developers (residents?) have more or less protection than others?
- may explain why the noise problems at some projects sometimes seem to go unresolved?
- should the industry push for a ‘universal’ TSA, or at least a minimal common TSA?
- could this then be shared with local authorities and residents?

res

power for good