Wind Turbine Amplitude Modulated Noise - AM

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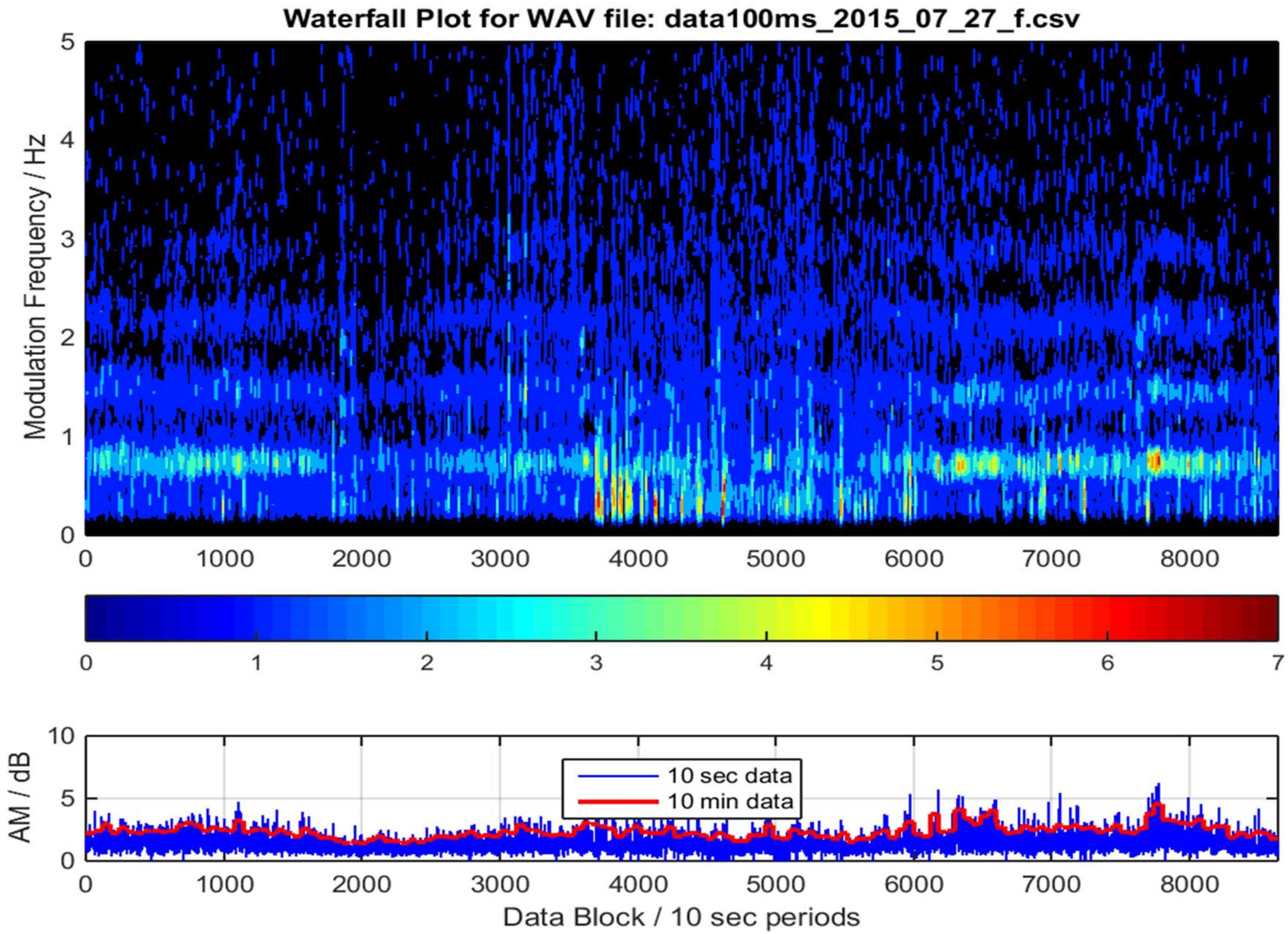
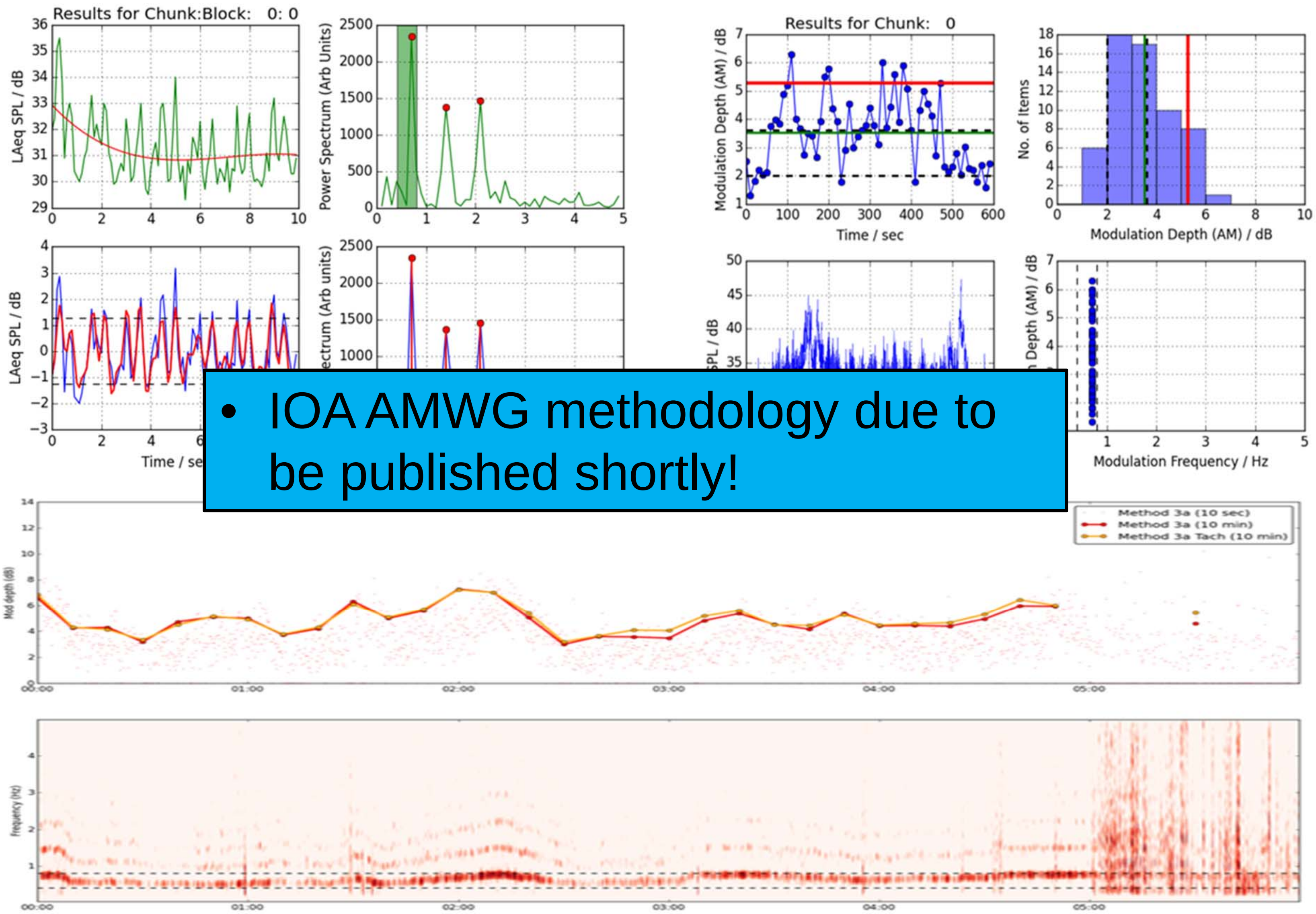
1 What is Amplitude Modulation (AM)?



2 Why is AM a Problem?

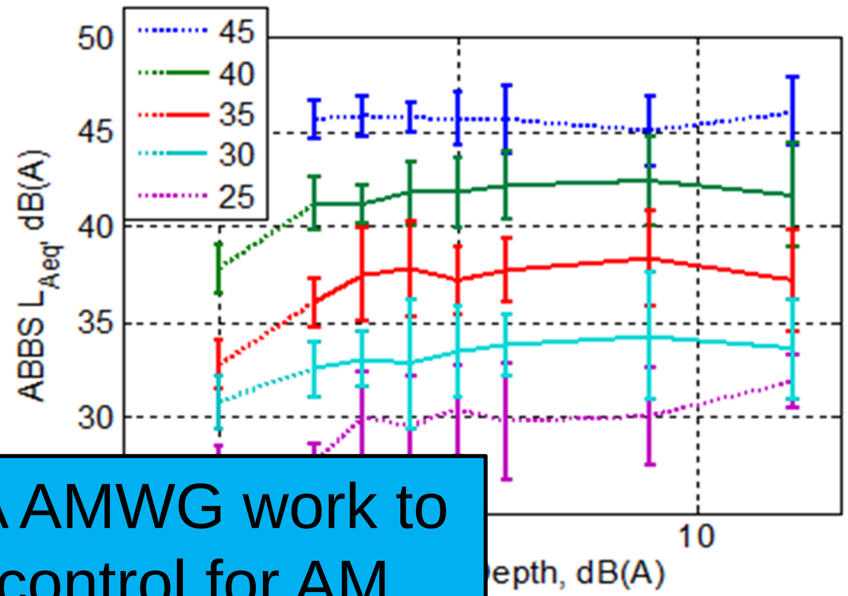


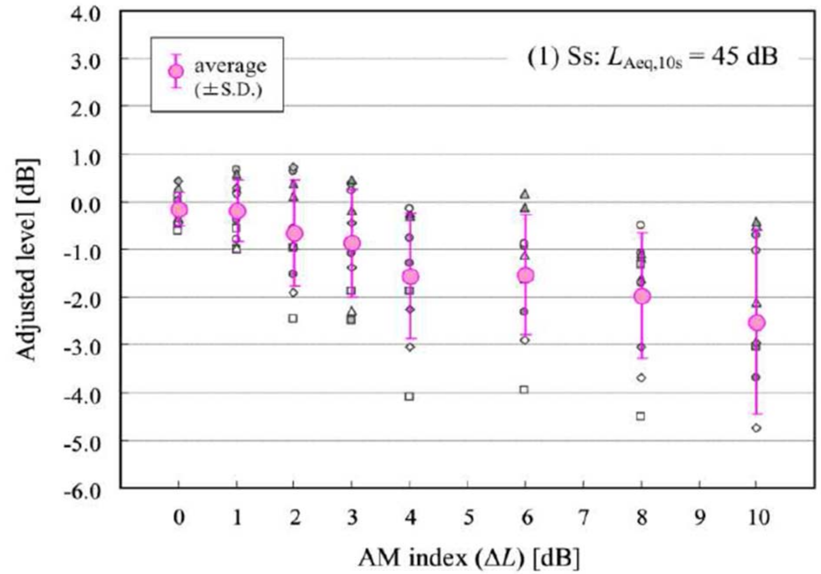
- IOA AMWG methodology due to be published shortly!

3.2 Dose – Response Relationship – DECC Study

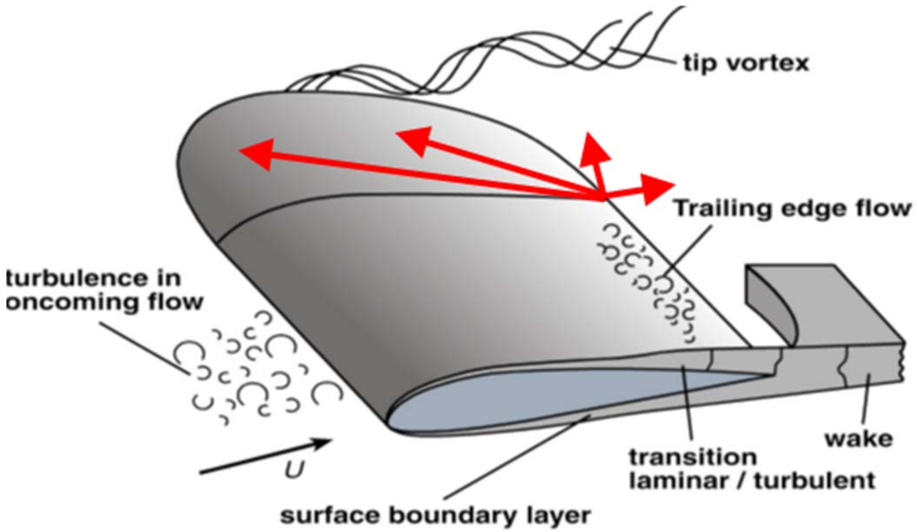
- having an agreed metric for AM only half the answer
- need to understand the psycho-acoustic response
- develop dose-response relationship
- agree suitable limit and/or acoustic pe
- matter of p
- IOA won't address – counter to their mission statement
- DECC currently commissioning research to address this
- Review entire area & bring in work from automotive and helicopter industries
- complete by early 2016

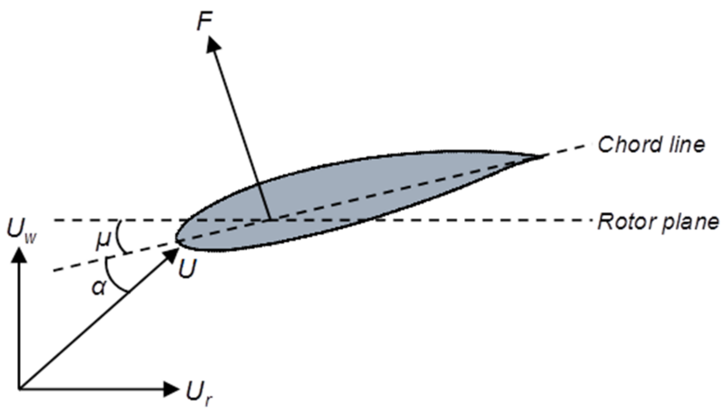
- Combine with IOA AMWG work to develop planning control for AM

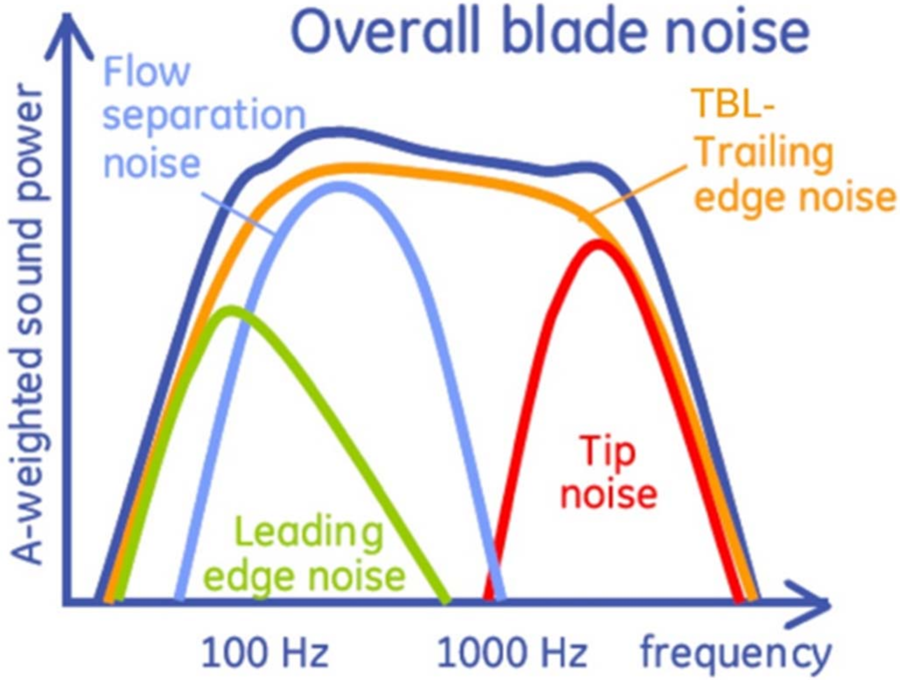




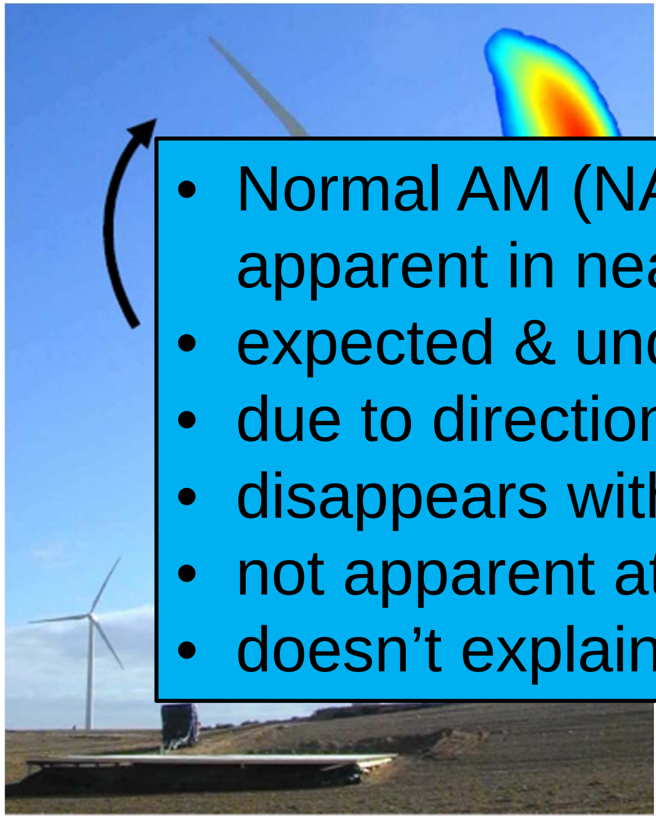
4.1 What Causes AM?

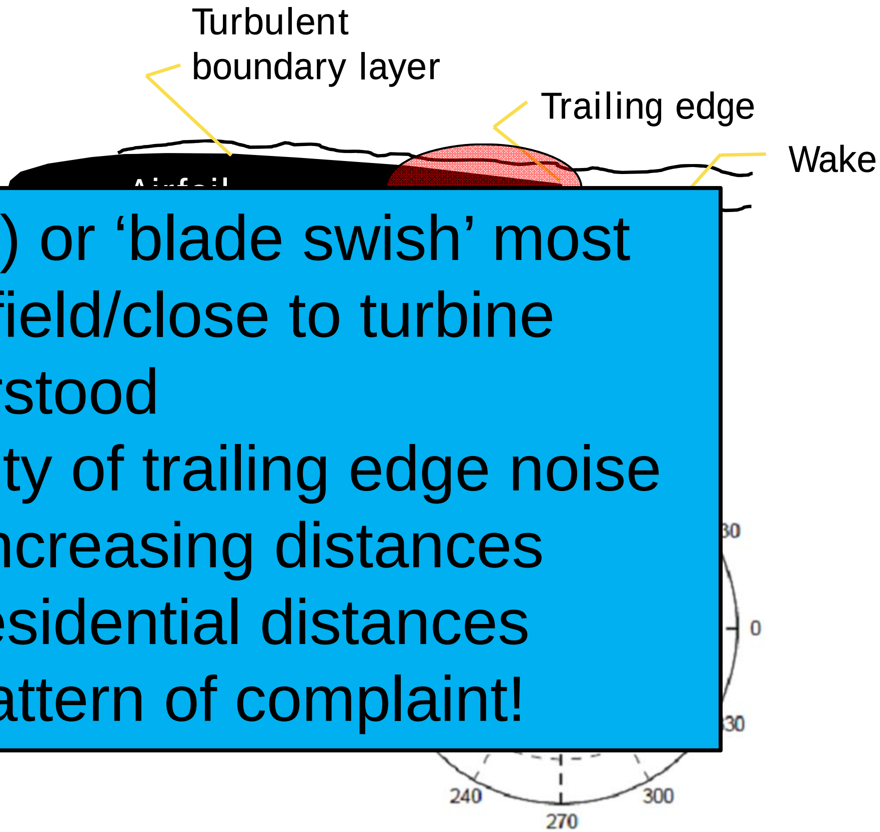






4.2 AM in the Near Field – ‘Normal’ AM

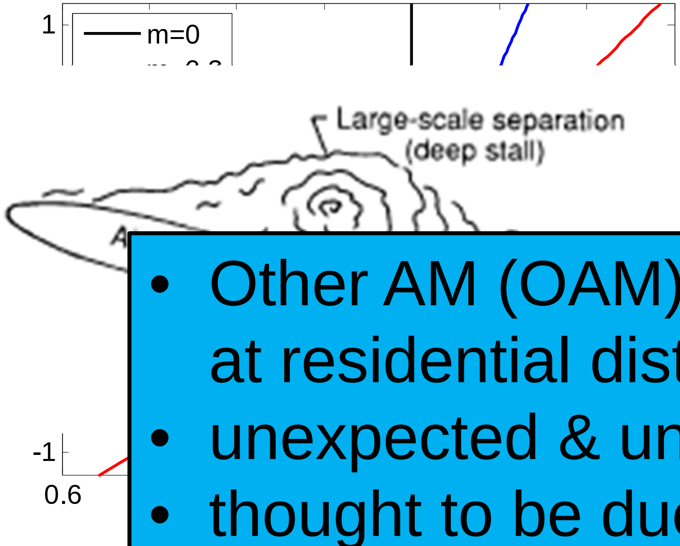


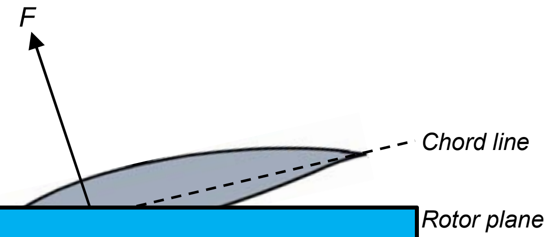


- Normal AM (NAM) or ‘blade swish’ most apparent in near field/close to turbine
- expected & understood
- due to directionality of trailing edge noise
- disappears with increasing distances
- not apparent at residential distances
- doesn’t explain pattern of complaint!

Stefan Oerlemans NLR

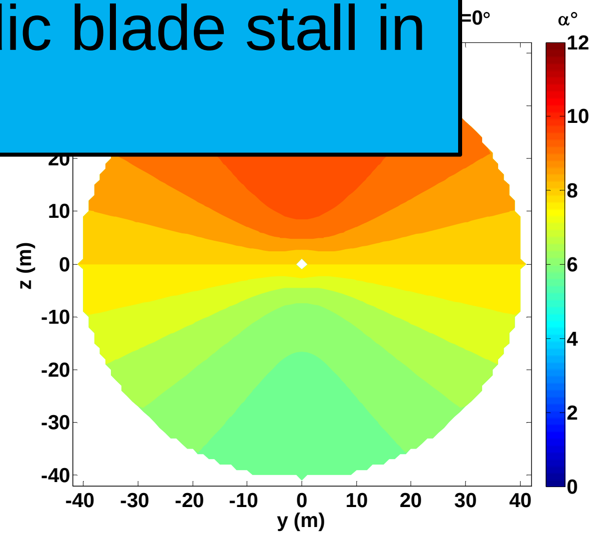
4.3 AM in the Far Field – ‘Other’ AM





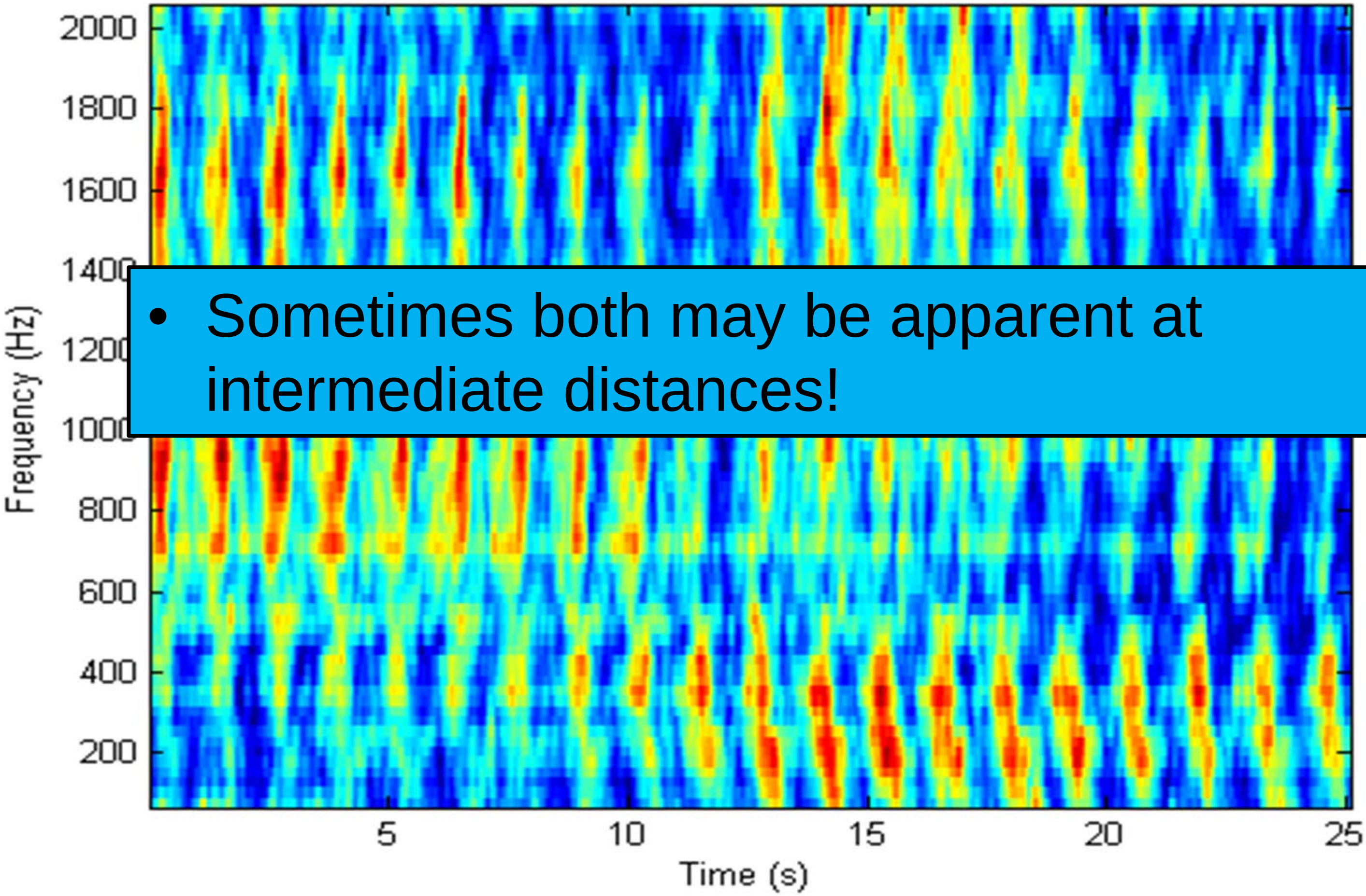
- Other AM (OAM) or ‘thump’ most apparent at residential distances
- unexpected & unwelcome
- thought to be due to periodic blade stall in high shear

- With hig
  speed U_w increases rapidly with height.
- Angle of incidence, a, is increased
- Stall may occur on the outer portions of the blade around TDC
- Effect more significant where large rotors on short towers



Blade angle of incidence over the rotor disc , shear factor m=0.6

Spectrograms



- Sometimes both may be apparent at intermediate distances!

4.5 Different Types of AM

Confusion

'Normal' AM

- commonly termed 'blade swish'
- part of normal WTN
- ~5dB modulation at source
- dominant crosswind effect
- decreases away from source
- dominated by mid frequencies (400Hz to 1000Hz) '*swish*'
- source mechanism understood

'Other' AM

- atypical, intermittent
- >5dB (>10dB) amplitude at times?
- audible/noticeable at large distances downwind to >1km?
- more impulsive '*thump*'
- additional lower frequency content (200 Hz to 500 Hz)? '*whooomp*'
- source mechanism?

4.6 Are we Sure About Causal Mechanism?

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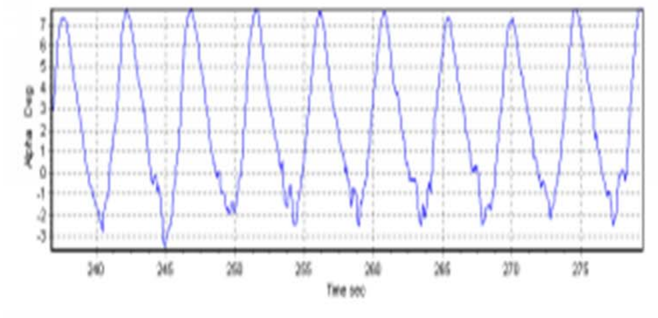
One pitot tube on the Siemens 3.6 MW turbine

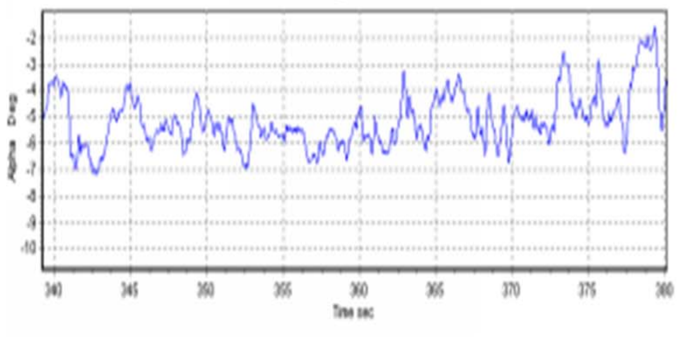
4 pitot tubes on the 80m, 2MW, NM80 turbine

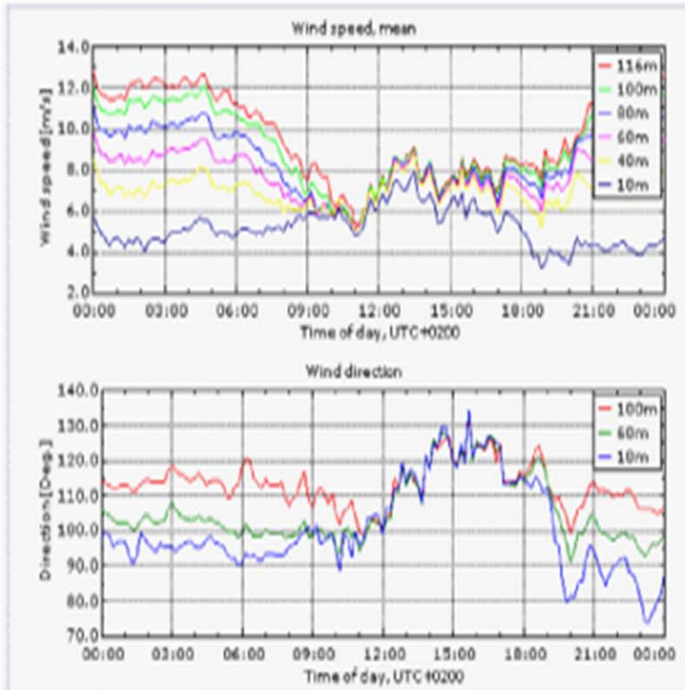
4.7 Risø DTU Report on OAM – Proof that OAM is a Source Effect?

night



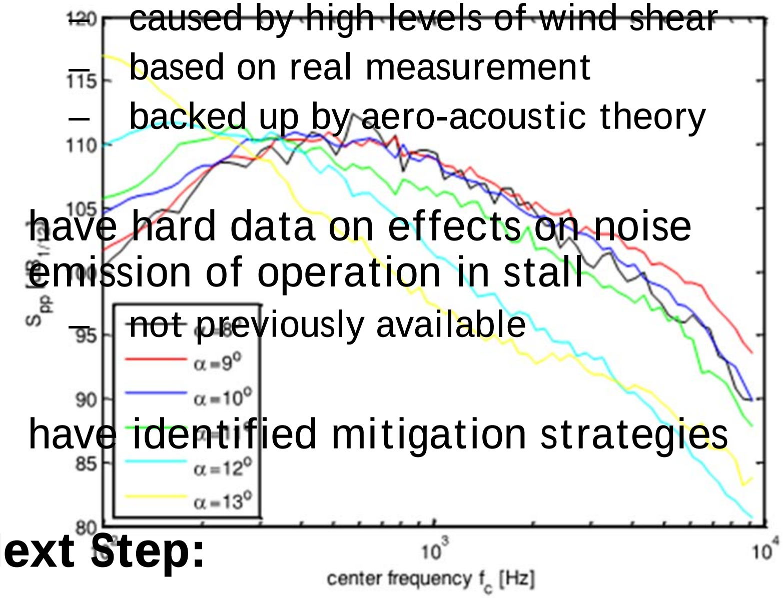
day





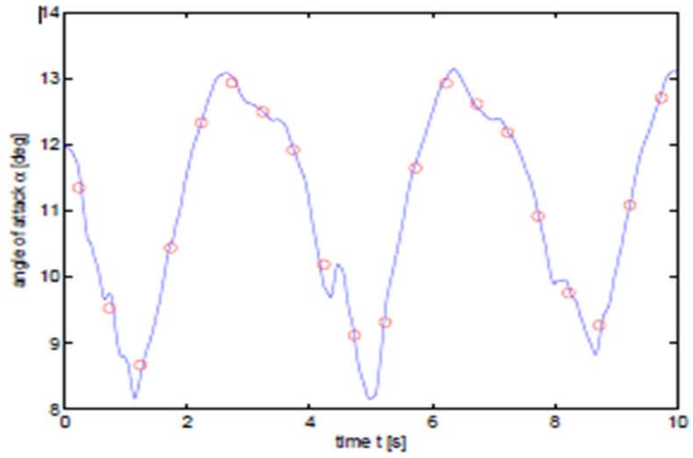
4.8 Risø DTU Report on OAM – Outcomes

- have definitive evidence for causal mechanism for OAM
  - high angle of attack induced stall
  - caused by high levels of wind shear
  - based on real measurement
  - backed up by aero-acoustic theory
- have hard data on effects on noise emission of operation in stall
  - not previously available
- have identified mitigation strategies

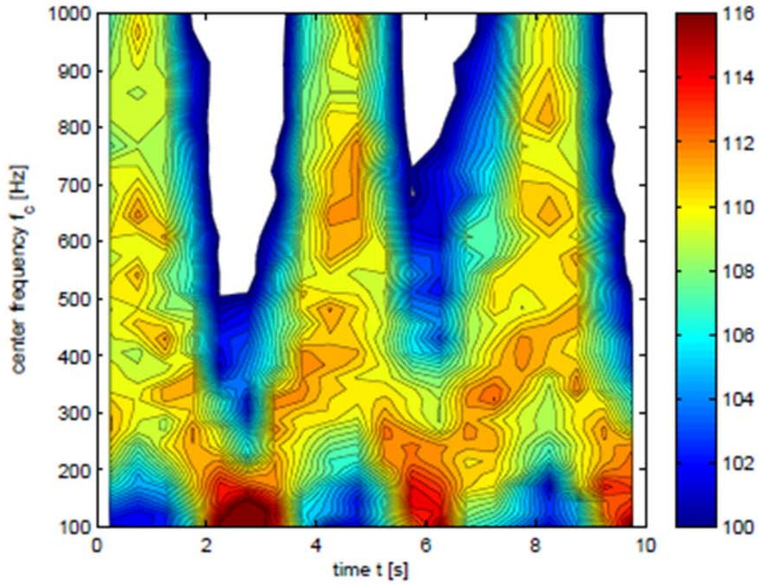


Next Step:

- Manufacturers Meeting @ Riso DTU
  - Occurred on 14 August 2014
  - Made case for mitigation/TSA
  - Senior level participation

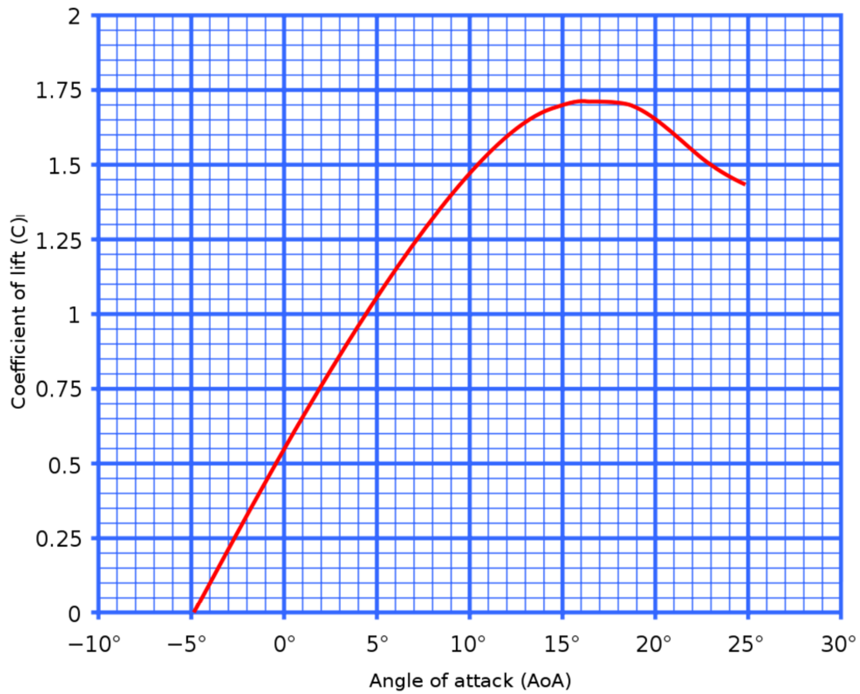


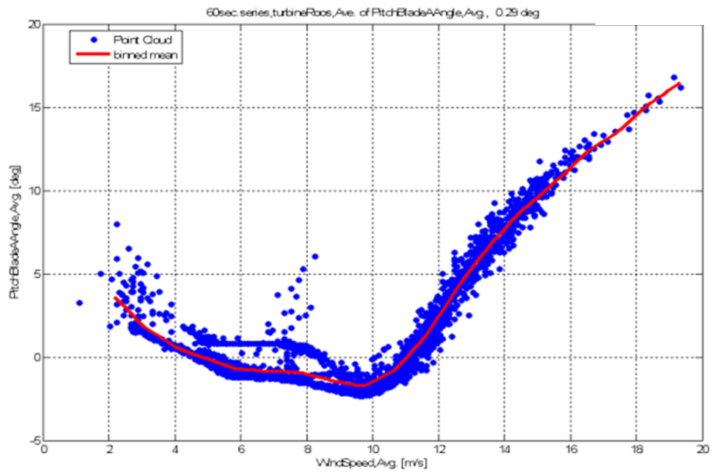
(a) time series



5 Can We Mitigate it?

- avoid (partial) blade stall
- avoid high angles of attack
- collective pitch control – de-optimisation?
- cyclic pitch control?
- blade geometry?
- mitigation likely only required in specific conditions
- also has effect on blade loads and power performance!





6 Relevance to FutureWind 2016?

- Real-world, practical problem facing the industry right now
- Causal mechanism largely understood
- Some (not great) mitigation options currently in operation
- Costing lost generation (~ 1 %) through curtailment / de-optimisation
- Causing difficulty /delays in planning process (not just in UK)
- Better technical solutions exists, involve better control

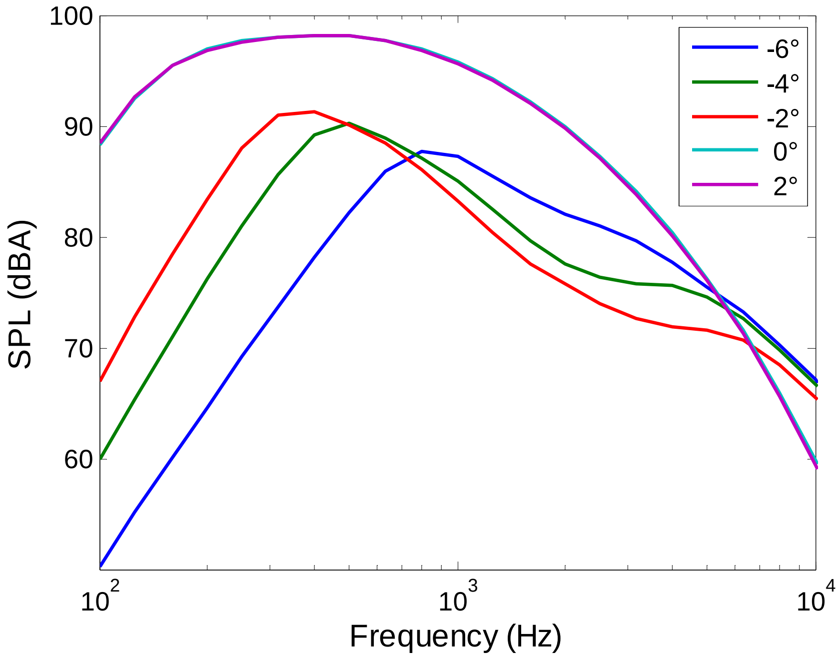
- **Opportunity for DTC @ University of Strathclyde to make contribution?**

7.1 Conclusions

- AM is periodic variation of sound from a wind turbine at the BPF
- AM can take at least two forms which appear to have fundamentally different source generation mechanisms
- NAM is an inherent feature of wind turbine noise, due to TBL-TE noise
- the principal cause of OAM identified is partial/ transient blade stall, caused by high angles of attack
- the different source mechanisms result in different radiation characteristics between NAM (‘normal’ blade swish) and OAM
- mitigation for OAM exists, but better options needed
- **opportunity for DTC @ University of Strathclyde?**

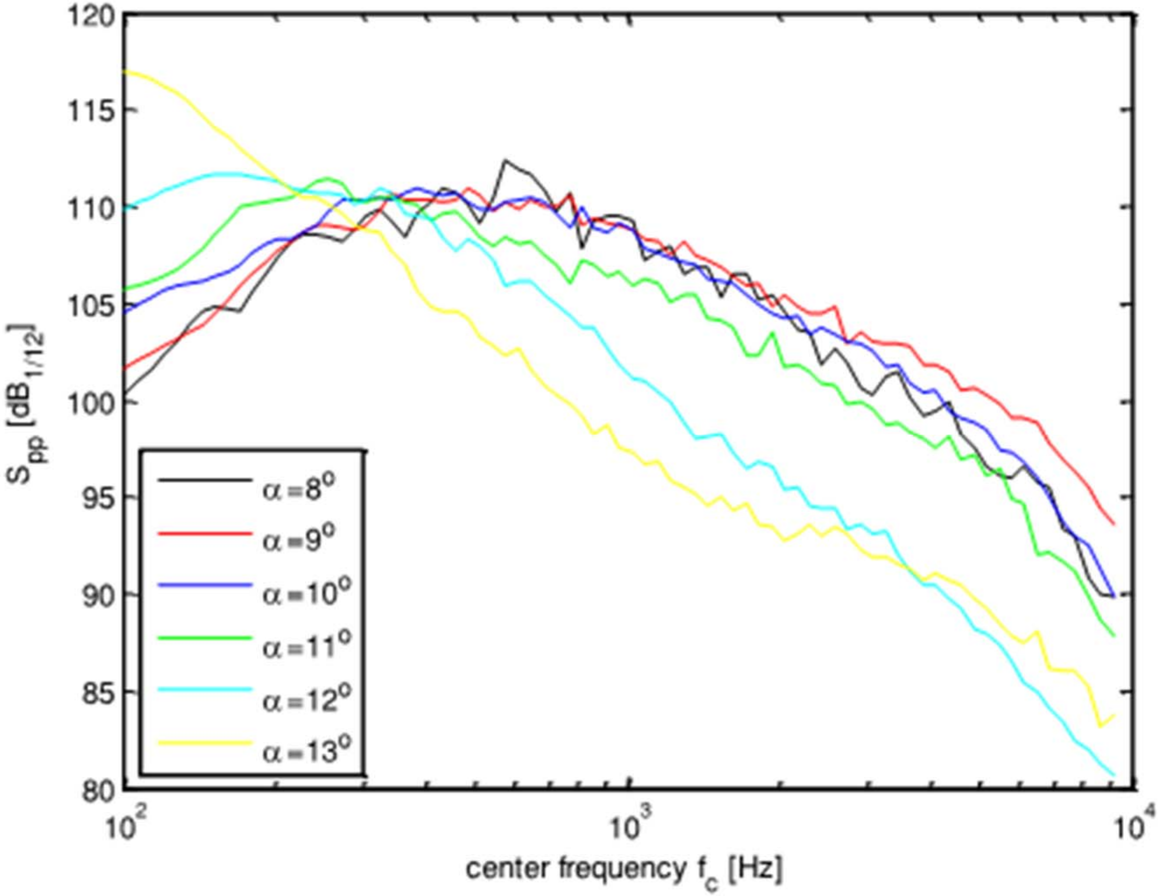
Any Questions?

- Stalled sections of blade produce wide band noise, with increased low frequency content
- Directivity of the noise and the distribution of AM is altered
- Thickened boundary layer pre-stall also produces lower frequencies
- Shear induced local stall is a plausible explanation for some aspects of AM
- Explains high levels of AM in the far-field

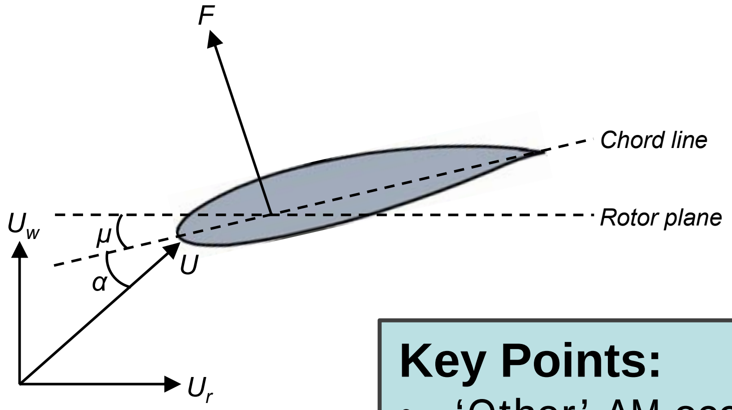


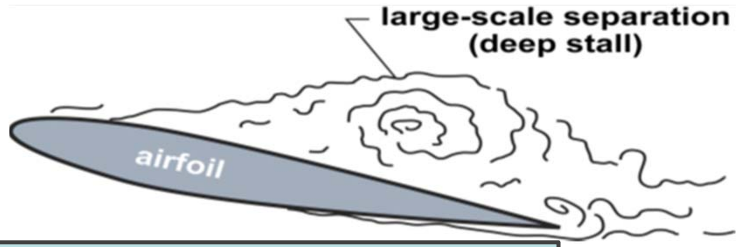
Blade element source spectrum as a function of angle of incidence
0°= stall angle

Surface pressure on suction side #2



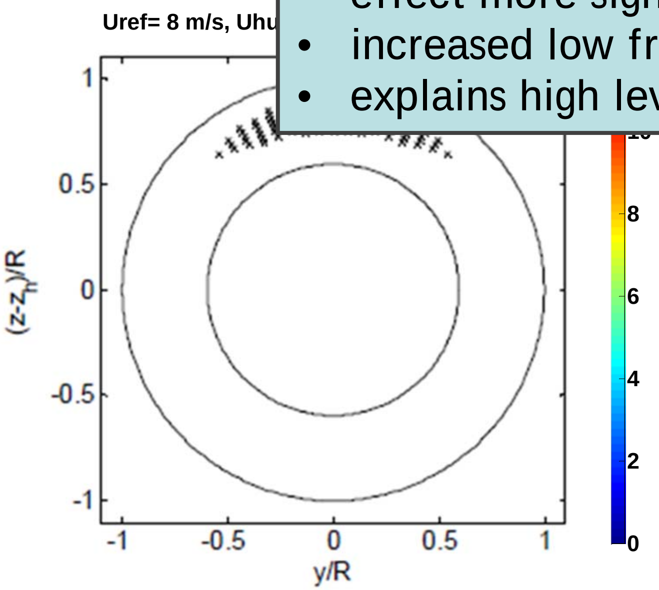
Transient Stall and ‘Other’ Amplitude Modulation





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



ear the wind
ith 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