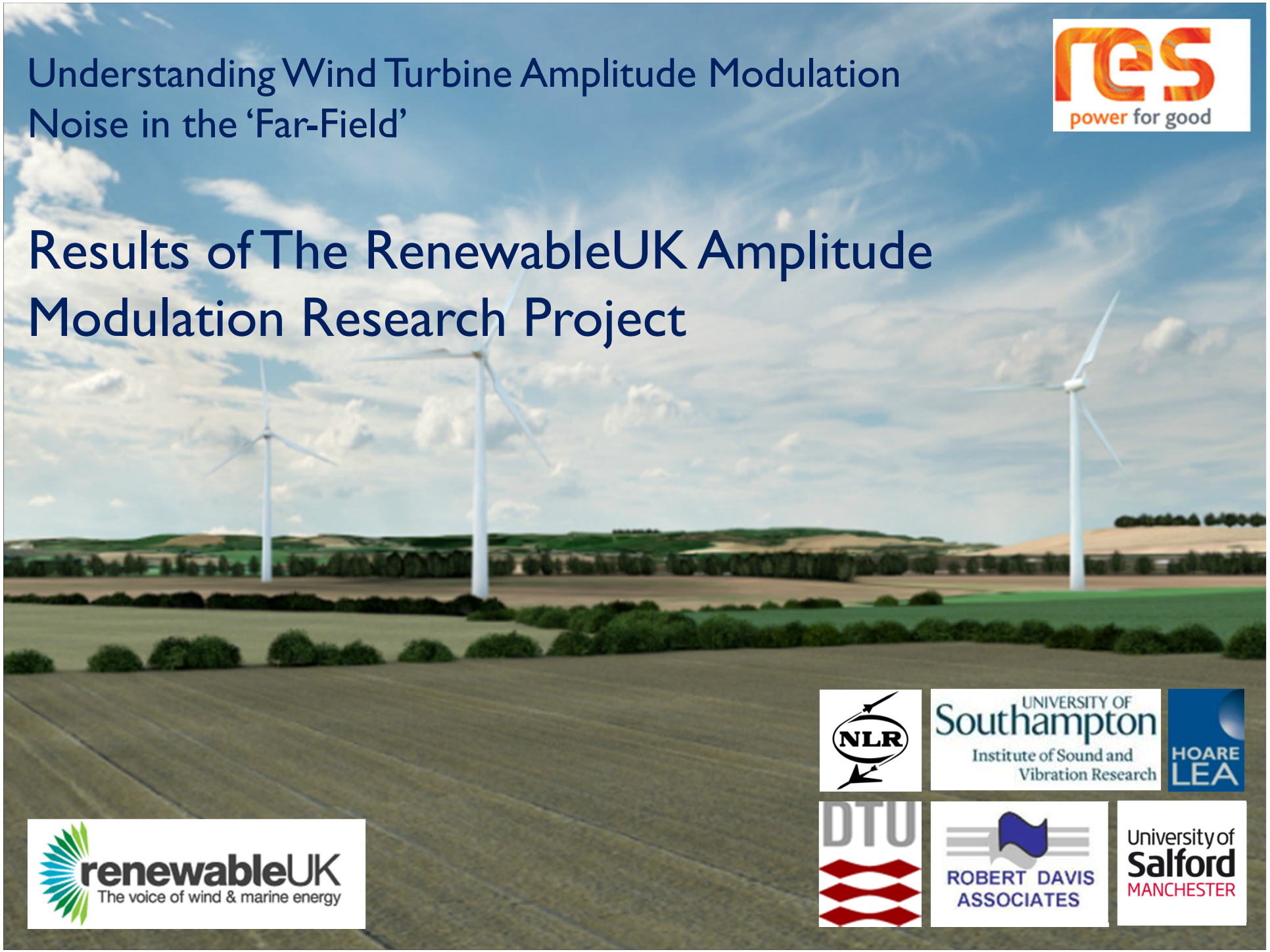
Understanding Wind Turbine Amplitude Modulation Noise in the 'Far-Field'

Results of The RenewableUK Amplitude Modulation Research Project



res power for good

renewableUK The voice of wind & marine energy

NLR

UNIVERSITY OF Southampton Institute of Sound and Vibration Research

HOARE LEA

DTU

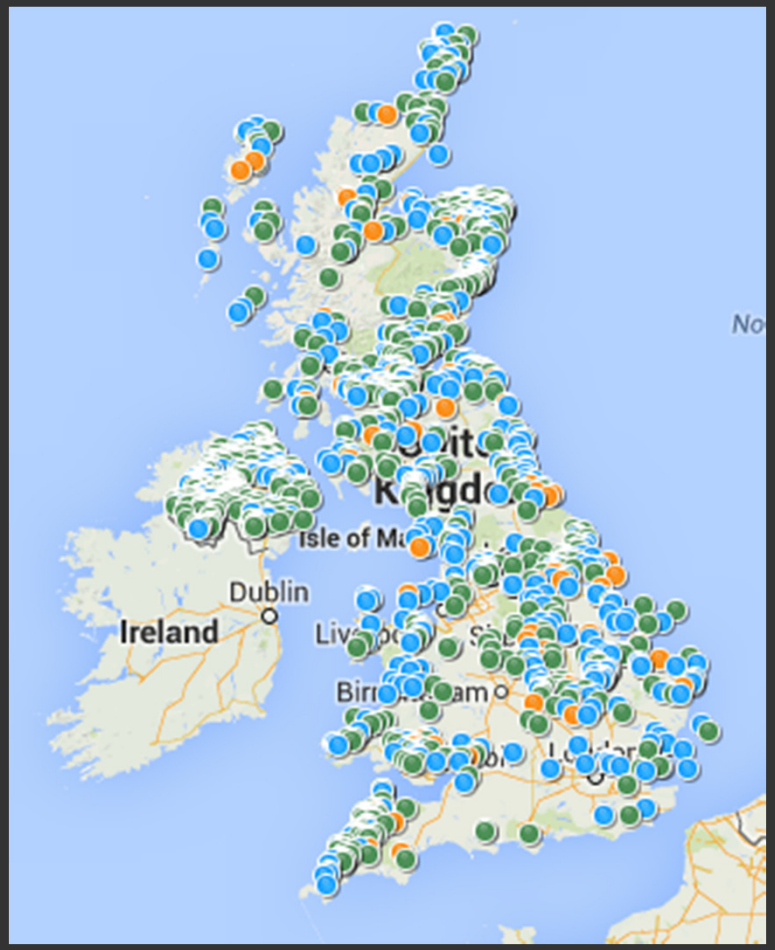
ROBERT DAVIS ASSOCIATES

University of Salford MANCHESTER

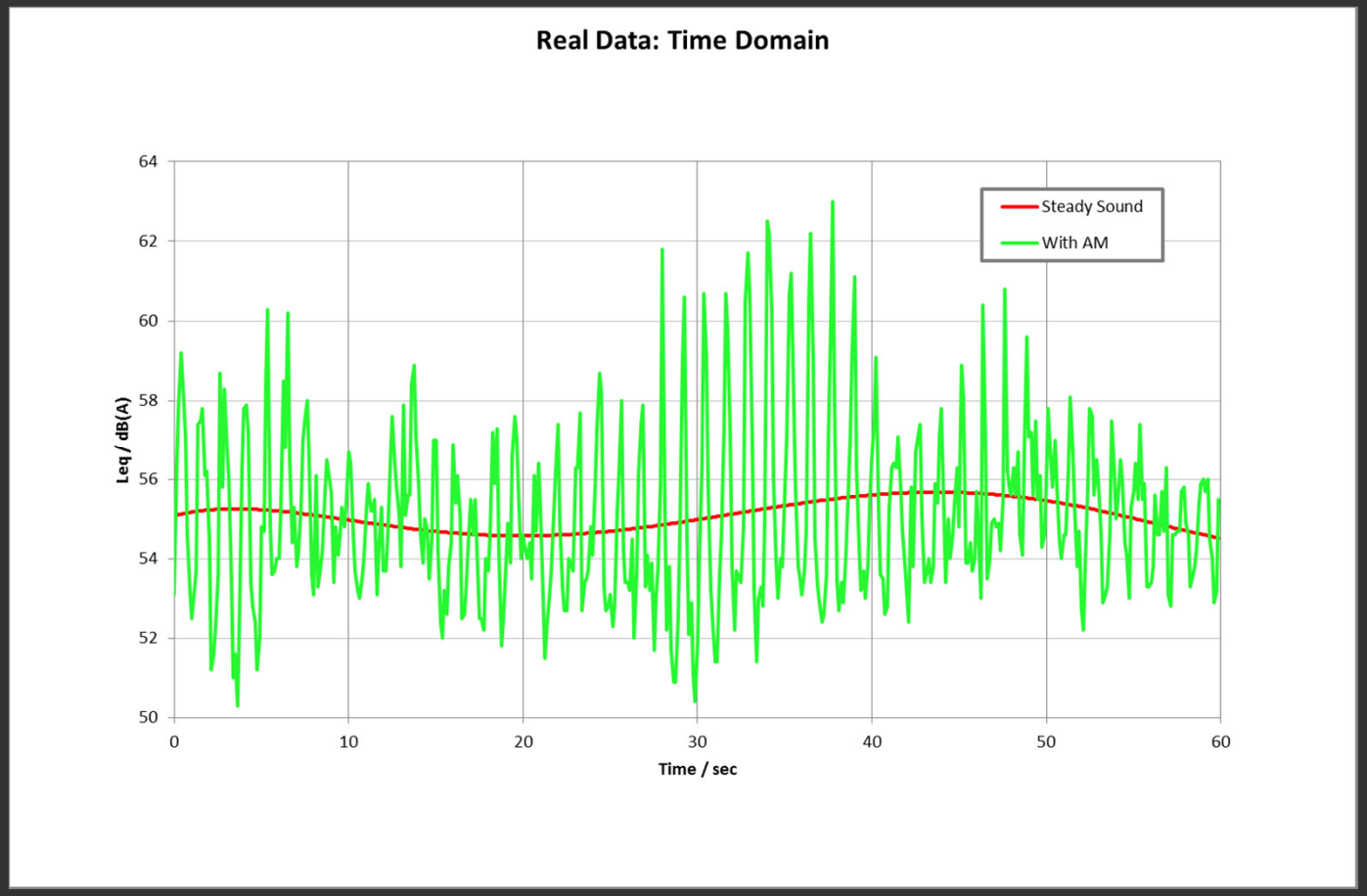
RELEVANCY TO AQPER SYMPOSIUM
ENERGY 2.0 - a changing world

- already huge success, particularly for wind
- greater 'push-back' from residents
- increased focus on planning process & community engagement
- address noise concerns

- Amplitude Modulation!

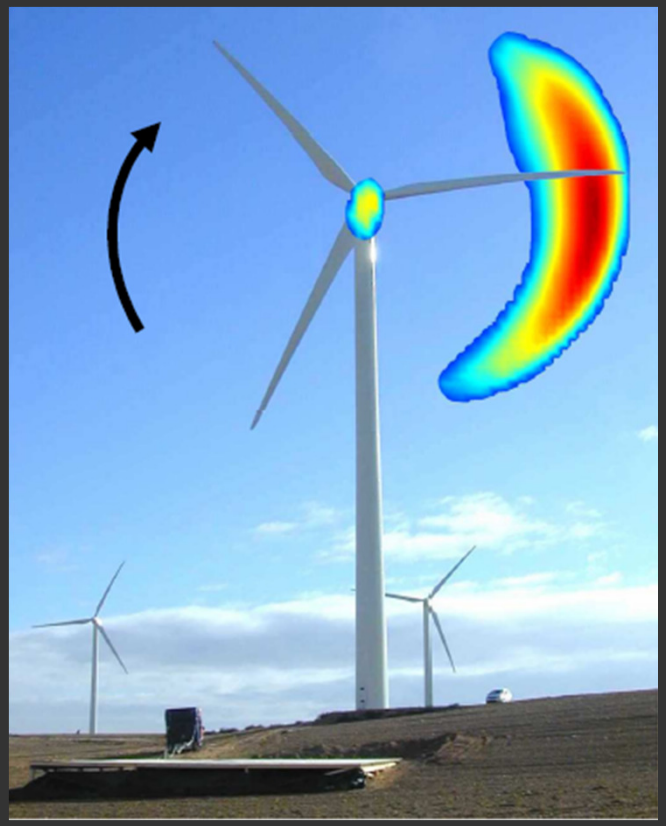


SO WHAT IS 'AMPLITUDE MODULATION' (AM)?

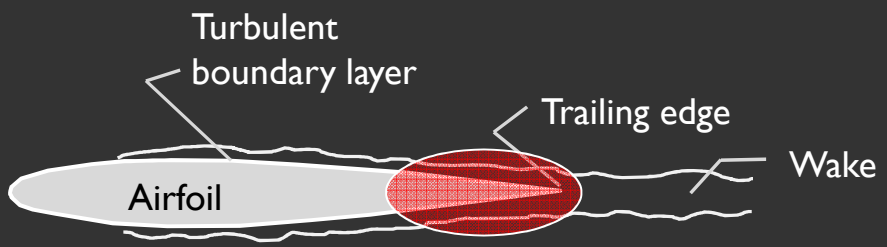


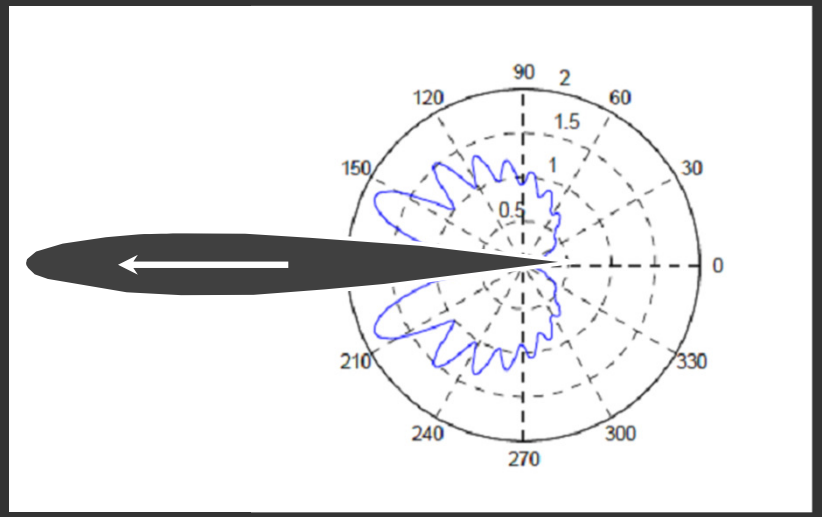
'Amplitude Modulation', also known as 'blade swish', is simply modulation of the sound pressure level at a wind turbine's blade passing frequency

NEAR-FIELD AM – BLADE SWISH: MECHANISM

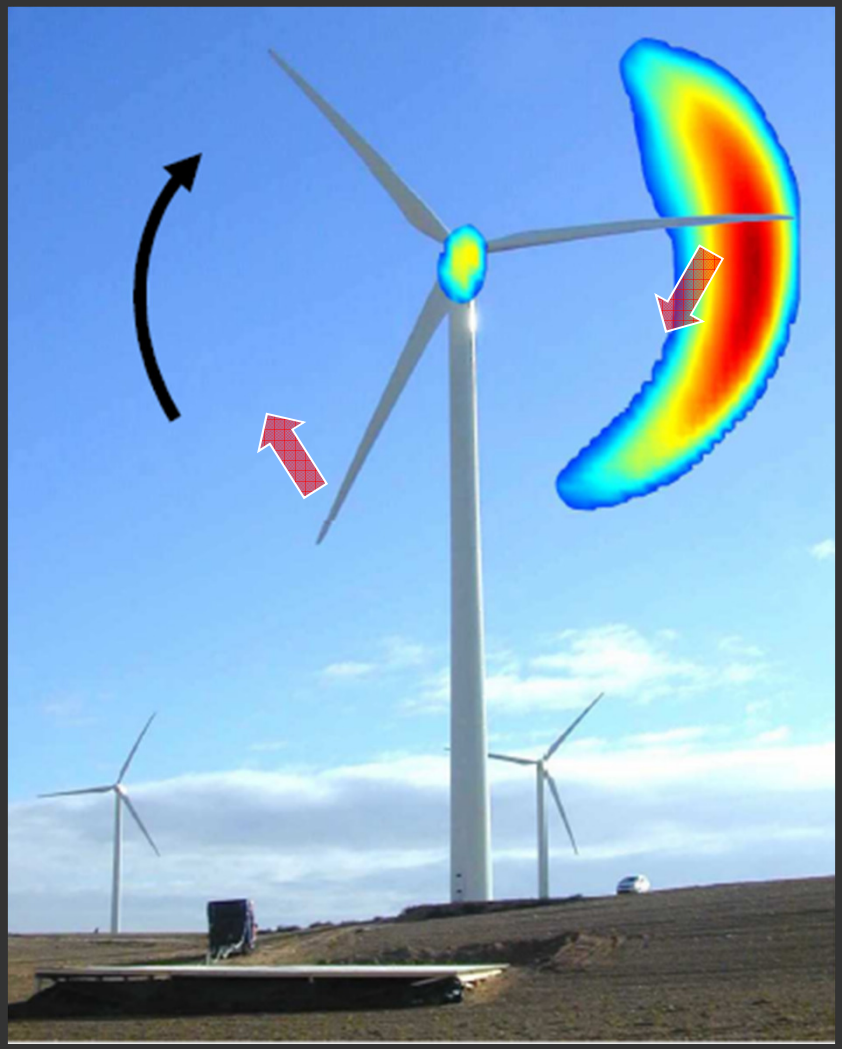


Stefan Oerlemans NLR





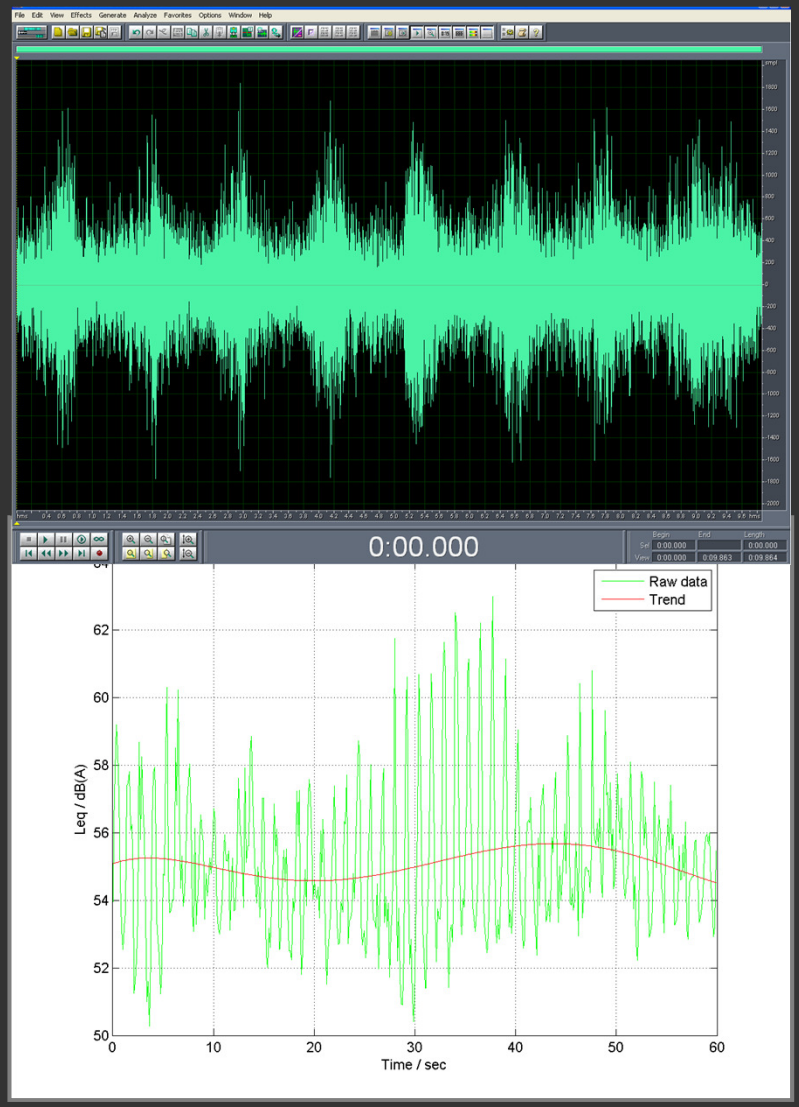
NEAR-FIELD AM – BLADE SWISH: PERCEPTION



‘Other’ Amplitude Modulation (OAM) - 2007

- at some sites AM is apparent at residential distances (‘far field’)
- observed levels of 5 – 10 dB!
- despite rarity, complaints vociferous - genuine nuisance?
- damaging to reputation of the wind industry
- erodes public support
- reduces chances of planning success

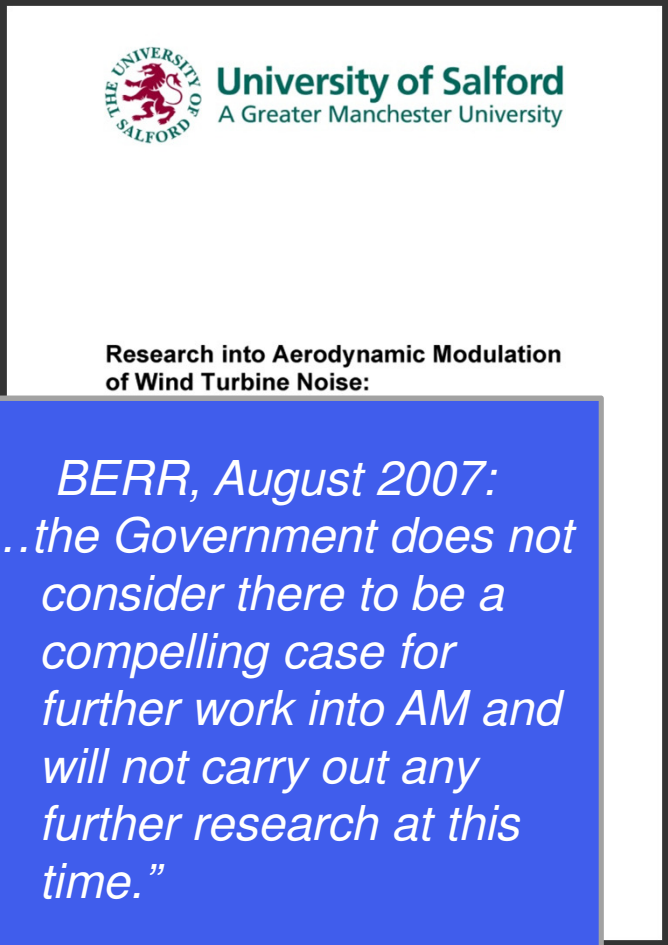
- **‘other’ amplitude modulation - OAM**



HOW WIDESPREAD IS THE 'AM' PROBLEM? - 2007

Key findings:

- 27 of 133 have had noise complaints at some point
- 239 complaints in total, with 152 from single site
- 81 complainants in total
- only 1 wind farm designated 'statutory nuisance'
- AM a factor at 4 sites
- complaints subsided at 3 of these due to remedial action
- occurs 7 – 15 % of time
- very low incidence



BERR, August 2007:
"…the Government does not consider there to be a compelling case for further work into AM and will not carry out any further research at this time."

AN ALTERNATIVE VIEW – 2014

MAS
ENVIRONMENTAL

Environmental Health Consultancy
01223 441671 / 510430

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NOISE & ACOUSTICS

TRAINING & WORKSHOPS

OTHER SERVICES

MAS Environmental have over 8 years of experience in dealing with wind farm noise

WIND FARMS & THE LISTENING ROOM EXPERIENCE

Wind Farms Introduction

Wind Farm Planning Applications

Operational Wind Farms / Turbines

Known sites with complaints

Deeping St Nicholas

North Pickenham

Red Tile

Swaffham, Norfolk

Find out more

Wind Farm Courses

Operational Wind Farms / Turbines

As part of our ongoing research and interest in noise generated by wind turbines and wind farms we would be very interested to hear from anyone experiencing unusual or intrusive noise from wind developments.

Known Wind Farm sites causing or known to have caused complaints

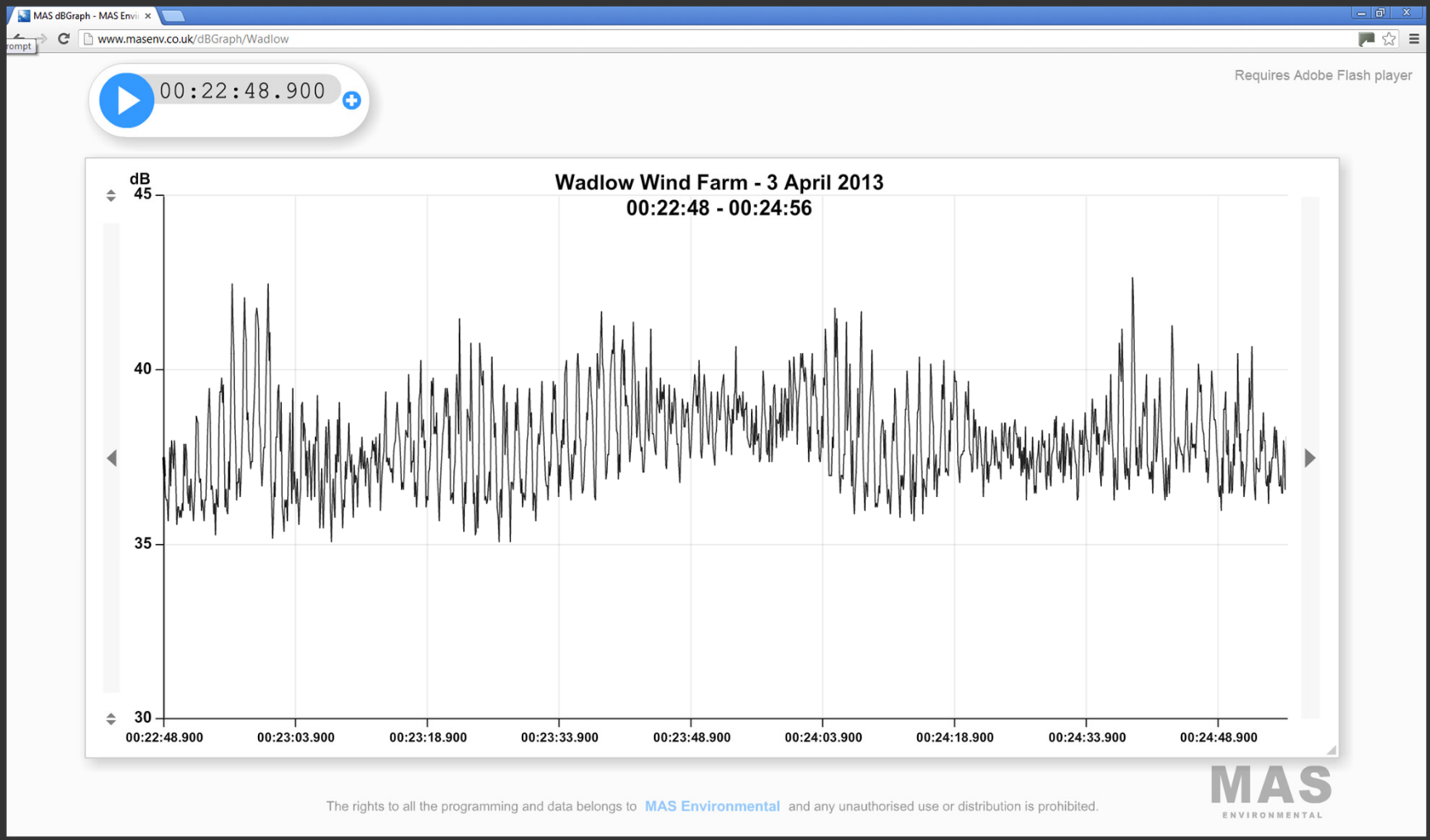
We have compiled a list of over 30 wind farms across the UK that we are aware of as generating Amplitude Modulation (AM). See below

At MAS Environmental we have currently measured unreasonable wind farm noise or been asked to investigate complaints of noise from wind farms at 13 developments including Bicker Fen, Blaen Bowi, Coldham, Darracott, Delabole, Fullabrook, Deeping St Nicholas, North Pickenham, Red Tile and Swaffham. The occurrence of AM is often noted by the industry as rare; the table below contains only wind farms generating AM of which MAS are aware due to written evidence. We understand there are many other cases. As can be seen from the table below, the occurrence of AM is not specific to turbine make, model, size, rated power or number of turbines.

AN ALTERNATIVE VIEW – 2014

Wind Farm	Location	MW per turbine	No. of turbines	Hub Height (m)	Reference
Aggregate Ind Newquay	Cornwall	0.5MW	1	59	Audio examined
Alltwalis	Carmarthenshire	2.3MW	10	65	Statement from complainant - clear case
Askham	Cumbria	660kW	7	40	Salford - clear case added
Site B	Banff and Buchan	ANON			Confirmed AM by resident - anonymous at moment
Bears Down	Cornwall	600kW	16	30	Salford - clear case added
Bicker Fen	Lincolnshire	2MW	13	59	Statement from complainant - clear case
Black Law, Forth	South Lanarkshire	2.3MW	42	82	Reported by others
Blaen Bowi	Carmarthenshire	1.3MW	3	46	Salford - clear case but not added
Carland Cross	Cornwall	400kw	15	30	In ETSU-R-97 and Salford - now repowering
Cairnmore	Aberdeenshire	850kW	3	55	Information on complaints is second hand
Causeymire	Highland	2.3MW	21	60	In Salford but not added by Salford
Coal Clough	Lancashire	400kw	24	30	In ETSU-R-97 missed in Salford
Cold Northcott	Cornwall	300kw	22	25	In ETSU-R-97 - in Salford but not added by them
Coldham	Cambridgeshire	1.75MW	8	60	Statements from complainant matches AM
Conisholme	East Midlands	800kW	20	65	Evidence from others
Cotton Farm	East Anglia	2MW	8	80	MAS have measured EAM
Cruach Mhor	Argyll & Bute	850kw	35	45	Salford - but not added

AN ALTERNATIVE VIEW – 2014



A further definition 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

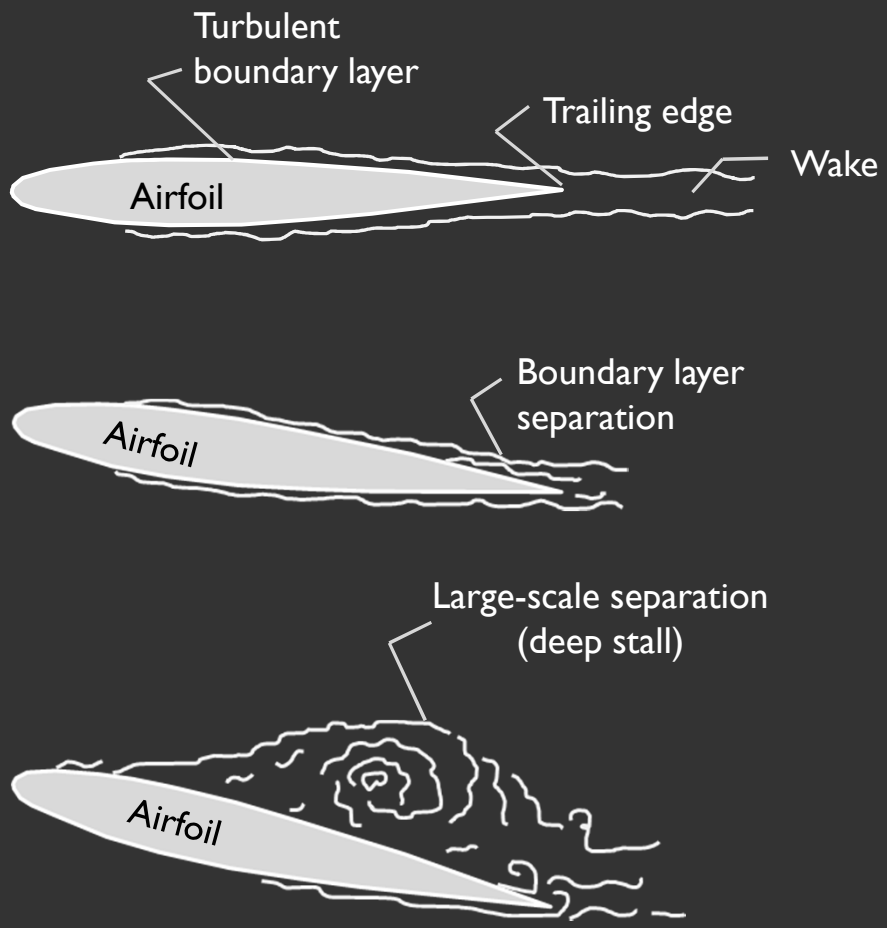
‘Other’ AM

- 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?

RENEWABLEUK AM PROJECT: 2011 - 2013

WP	Description	LEAD
A1	Source generation effects modeling	NLR
A2	Fundamental Research into Possible Causes of Amplitude Modulation	ISVR
B1	Development of an Objective Measure for Quantifying AM	ISVR
B2	Development of an AM Dose-Response Relationship	ARC
C	Collation and Analysis of Existing Acoustic Recordings	HLA
D	Measurement and Analysis of New Acoustic Recordings	HLA
E	Wider Dissemination of Results	ALL
F	Collation of Work Package Reports and Final Reporting	HLA
G	Blade surface measurements	DTU (RISO)

Possible origin of OAM (Oerlemans)



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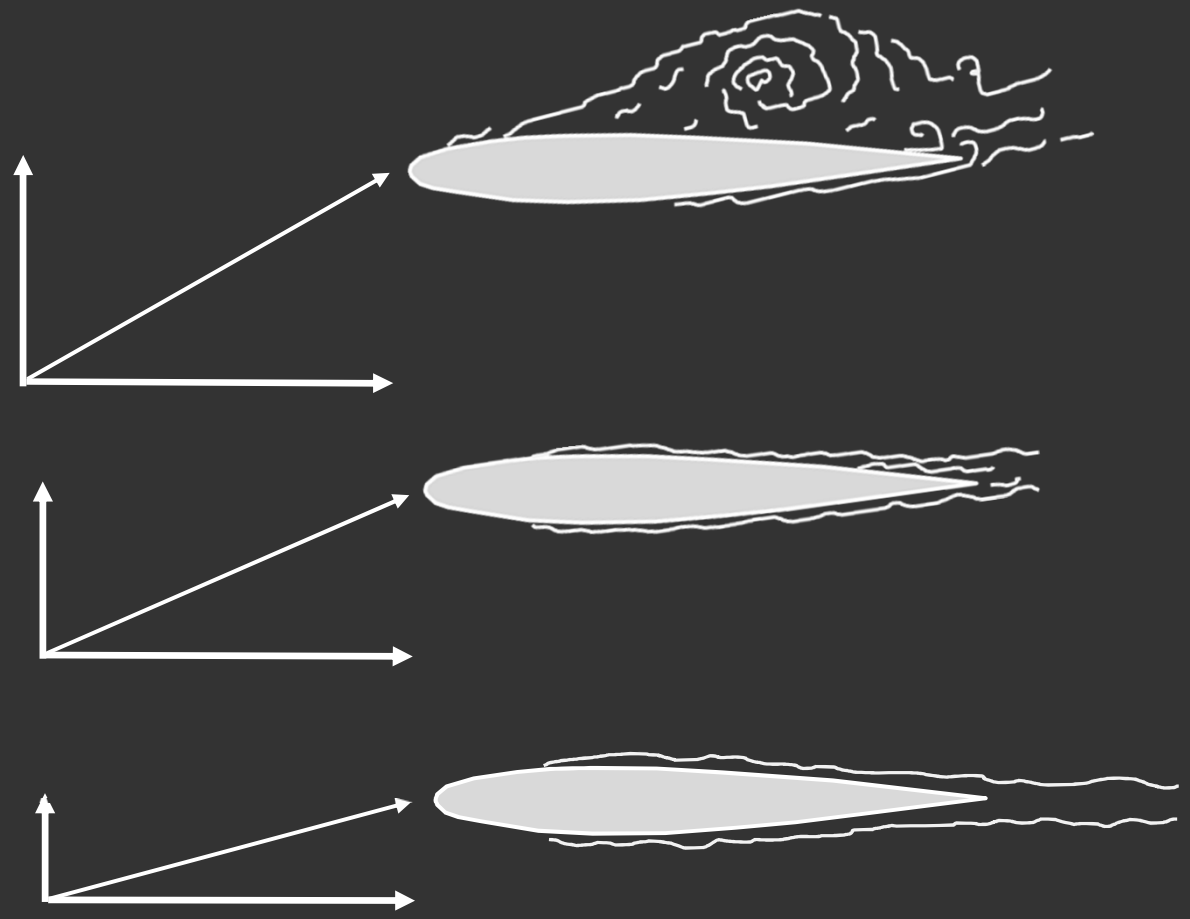
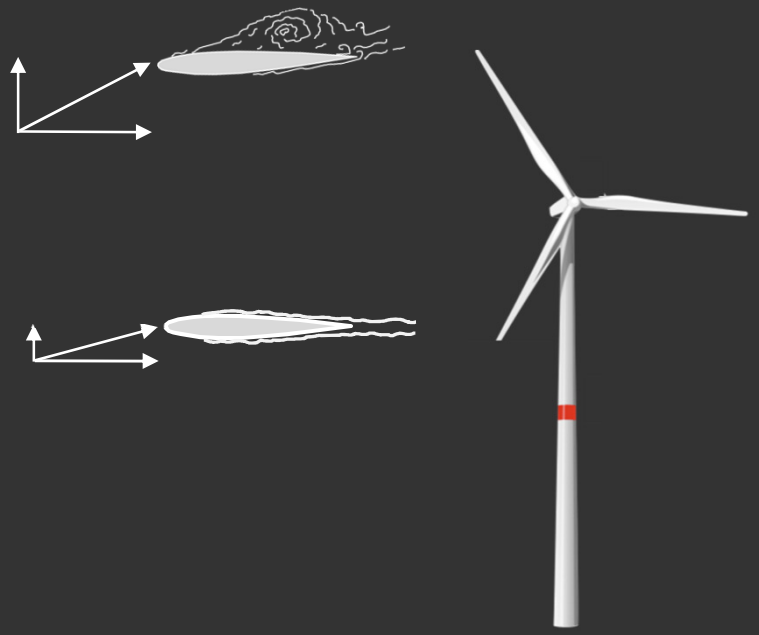
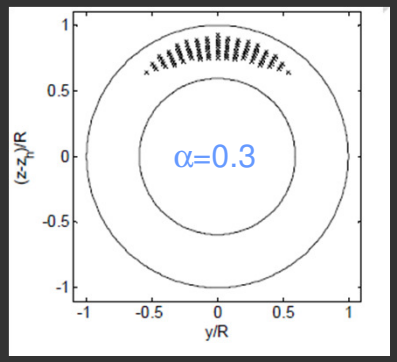


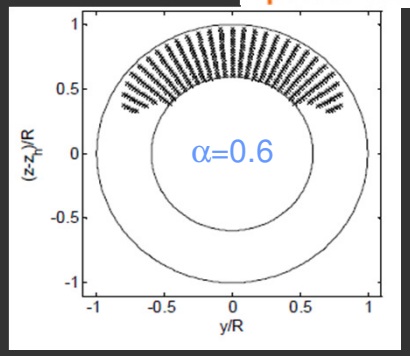
fixed pitch and rpm, different inflow wind speeds

(speed vectors shown for clarity of representation only)

Possible origin of OAM (Oerlemans)







- variable inflow conditions across the rotor could lead to localised stall on some portions of the blade,
- medium/high wind shear conditions can lead to such inflow conditions, as can other factors …

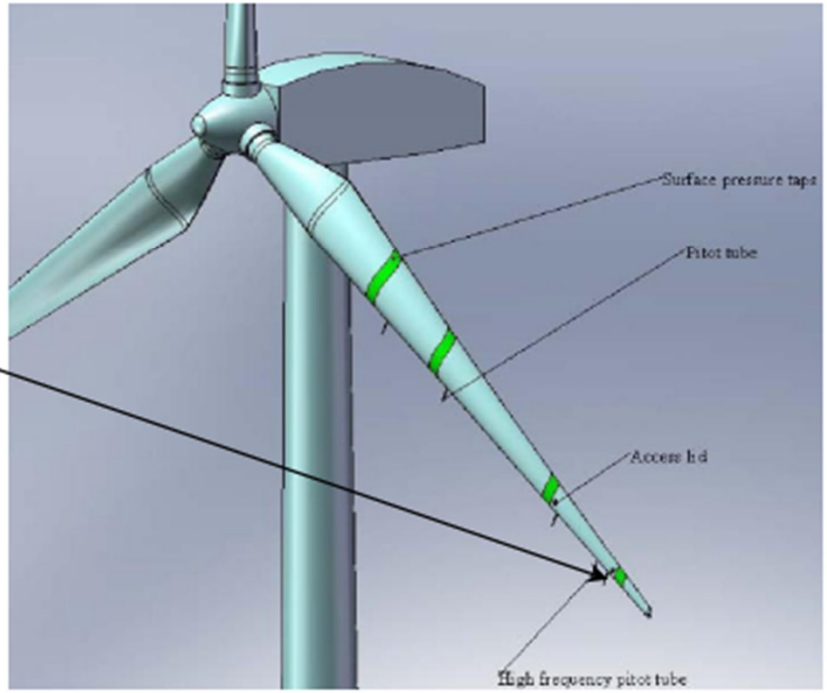
  yaw wake topography inflow turbulence

- occurrence will also be dependent on blade design and control logic

DTU studies – DAN-AERO MW

Measurement of SP on a full scale rotor blade, 80m diameter rotor, 2MW - - DAN-AERO MW project

- surface pressure and inflow measured at 4 radial stations
- **the outboard station also instrumented with around 60 microphones for high frequency surface pressure measurements**
- high frequency measurements of the inflow
- measurements from June to September 2009

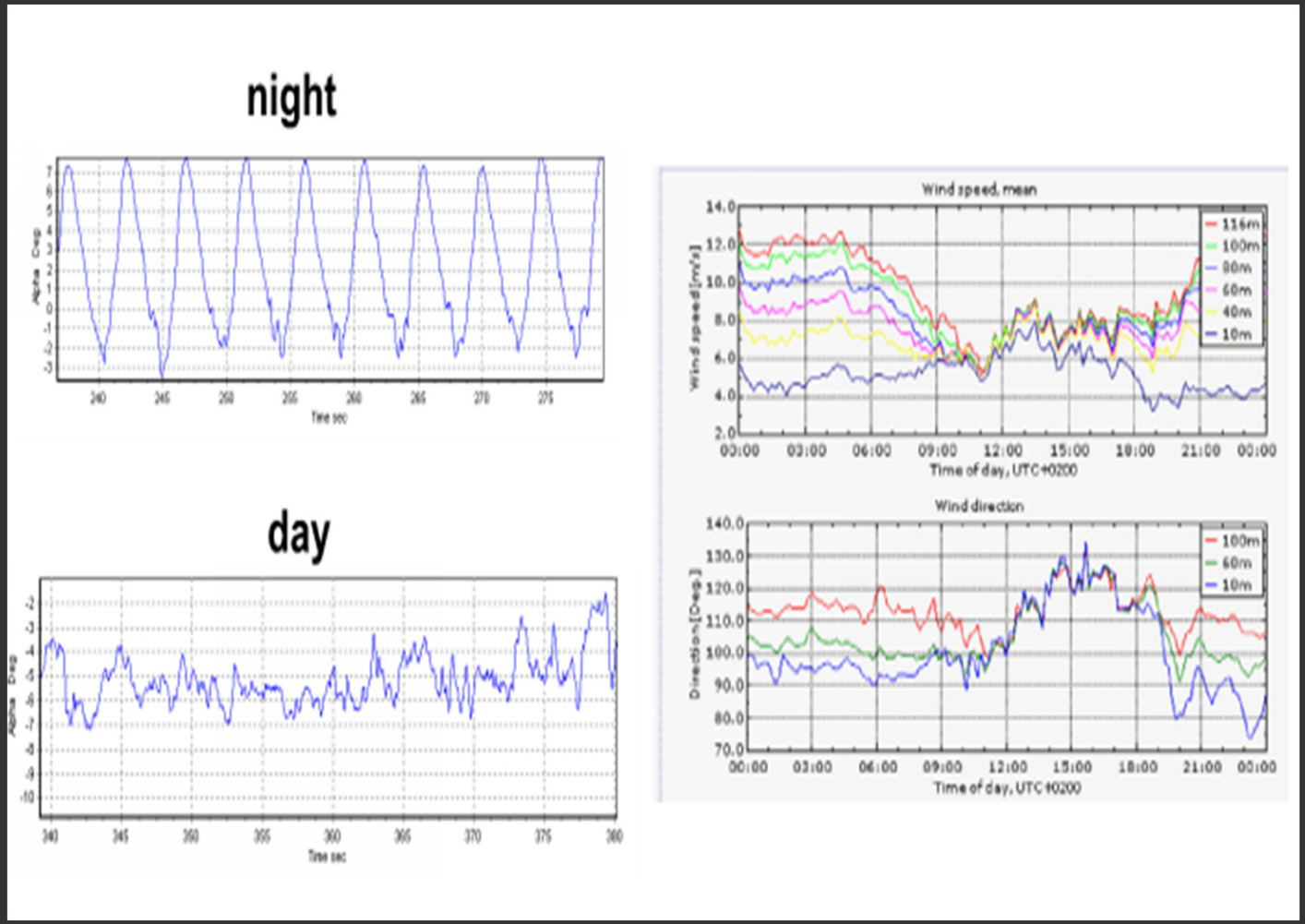


DTU studies – DAN-AERO MW

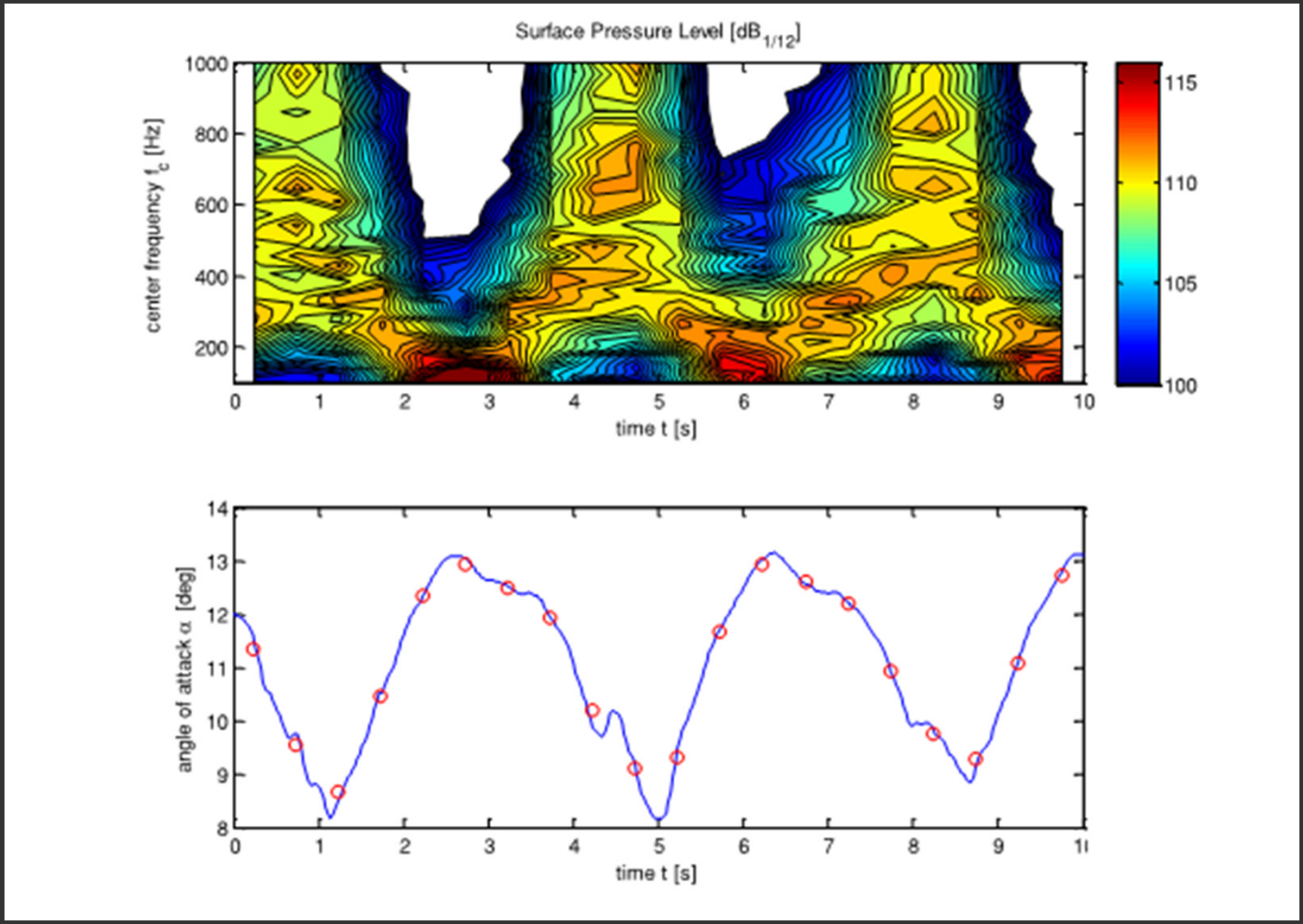
One pitot tube on the Siemens 3.6 MW turbine

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

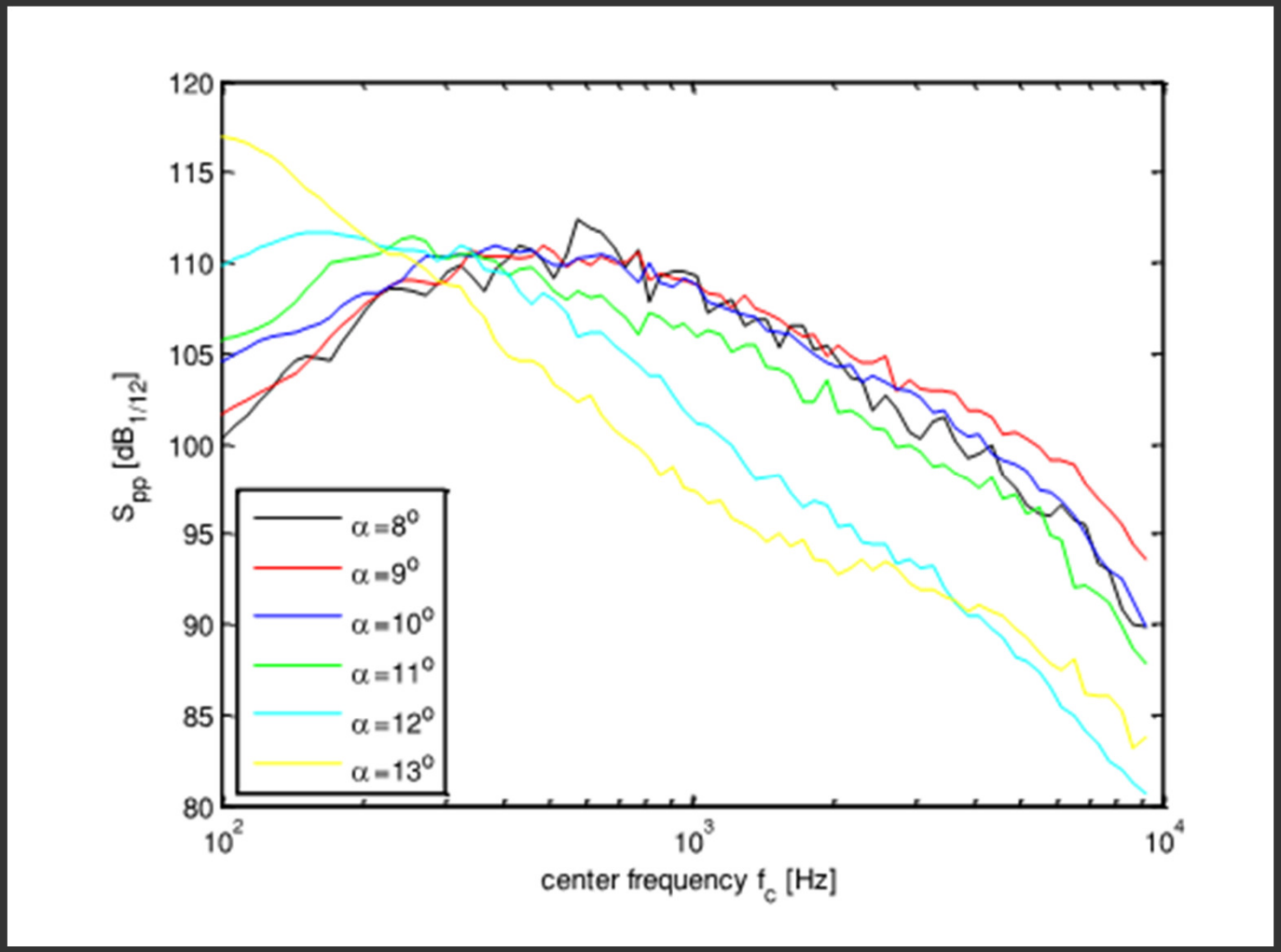
Proof that OAM is a source effect?



Surface pressure on suction side #1

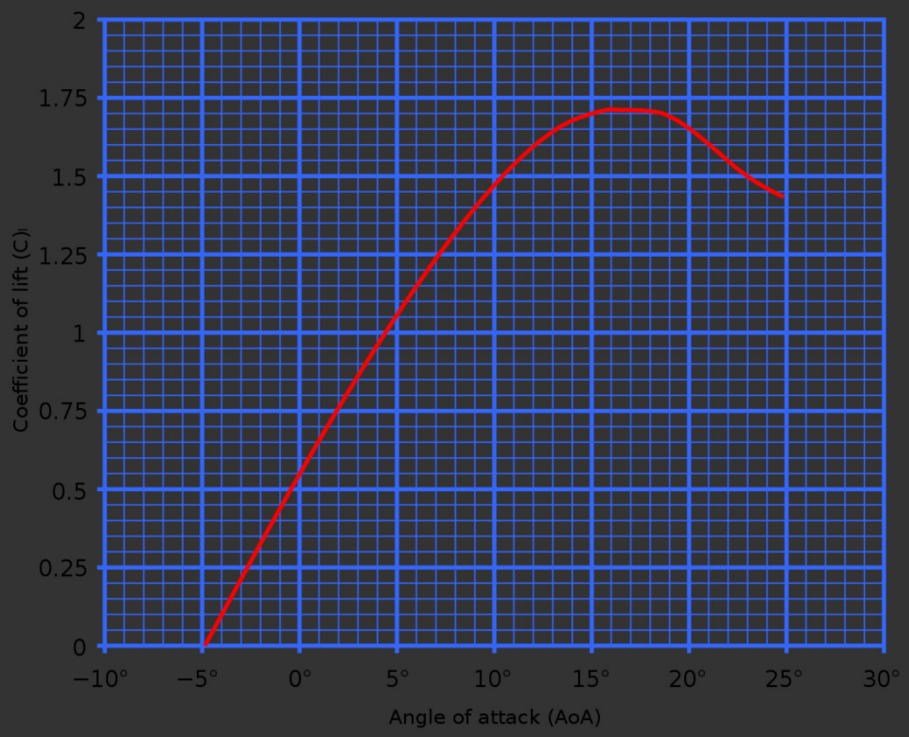


Surface pressure on suction side #2



Possible Mitigation for OAM

- 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!



Objective quantification of AM - #1

Any successful metric must:

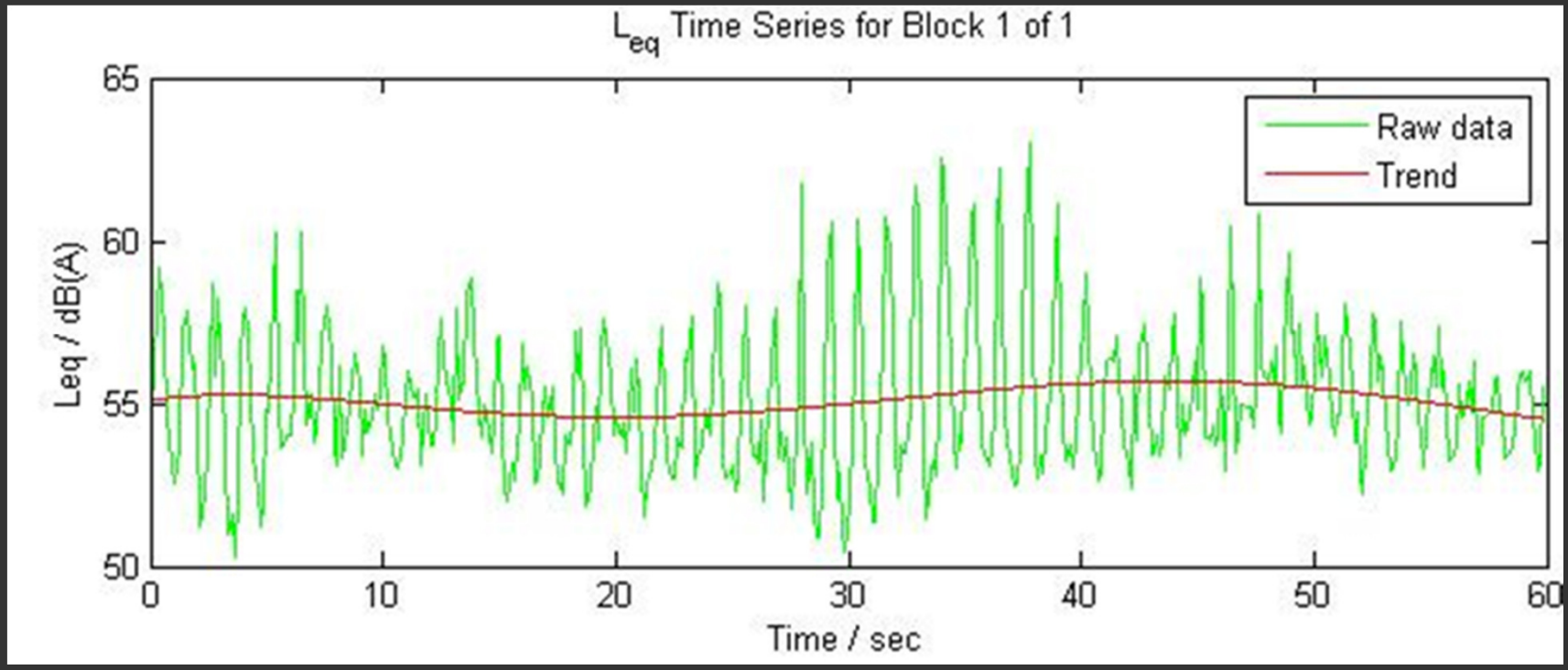
- be objective
- be repeatable
- be robust (avoid false positives and false negatives)
- relate to subjective response
- work on real & simulated AM data
- allow automated application

The method adopted here is based on frequency domain analysis of the LAeq levels within a 10 sec time window

- variation of existing techniques used in sonar and condition monitoring
- relies on the periodicity of AM data at the BPF

Objective quantification of AM - #2

A metric has been identified to quantify the level of AM (NAM or OAM) at BPF present in a sample of acoustic data



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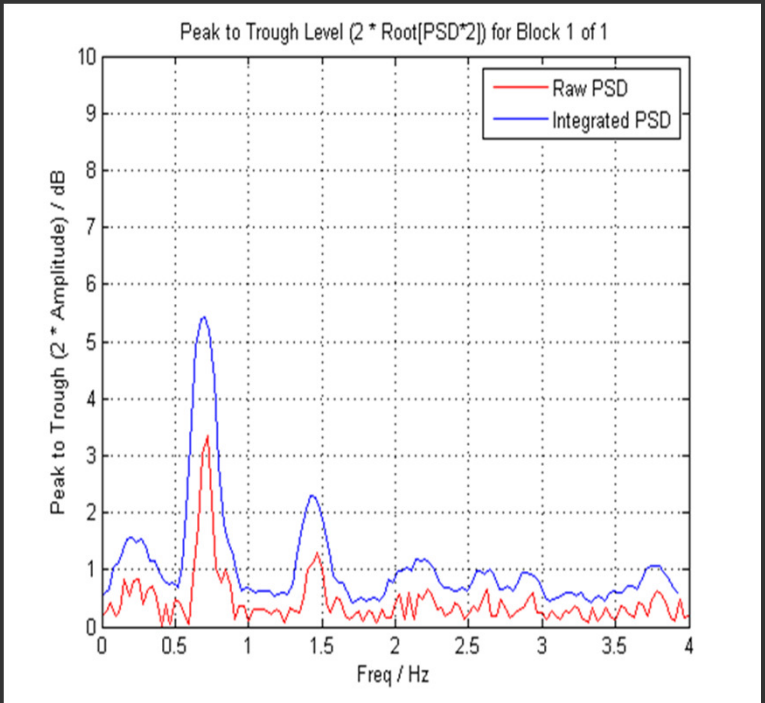

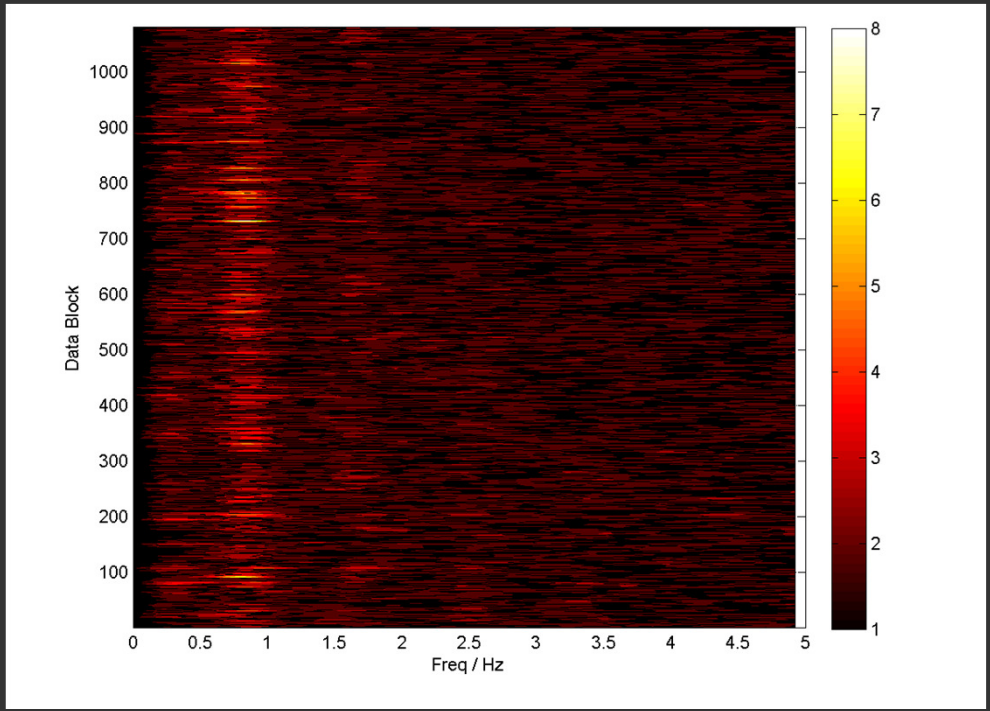

Sample analysis over a 3 hour period

Objective quantification of AM - #2

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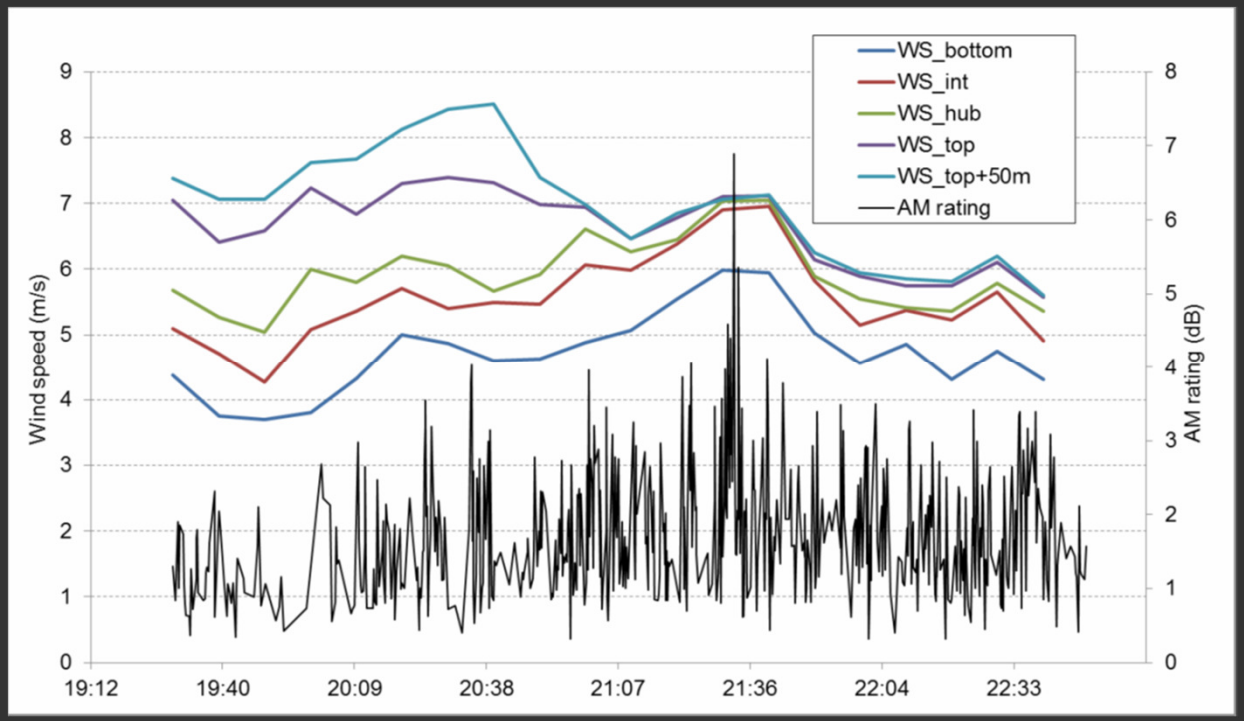
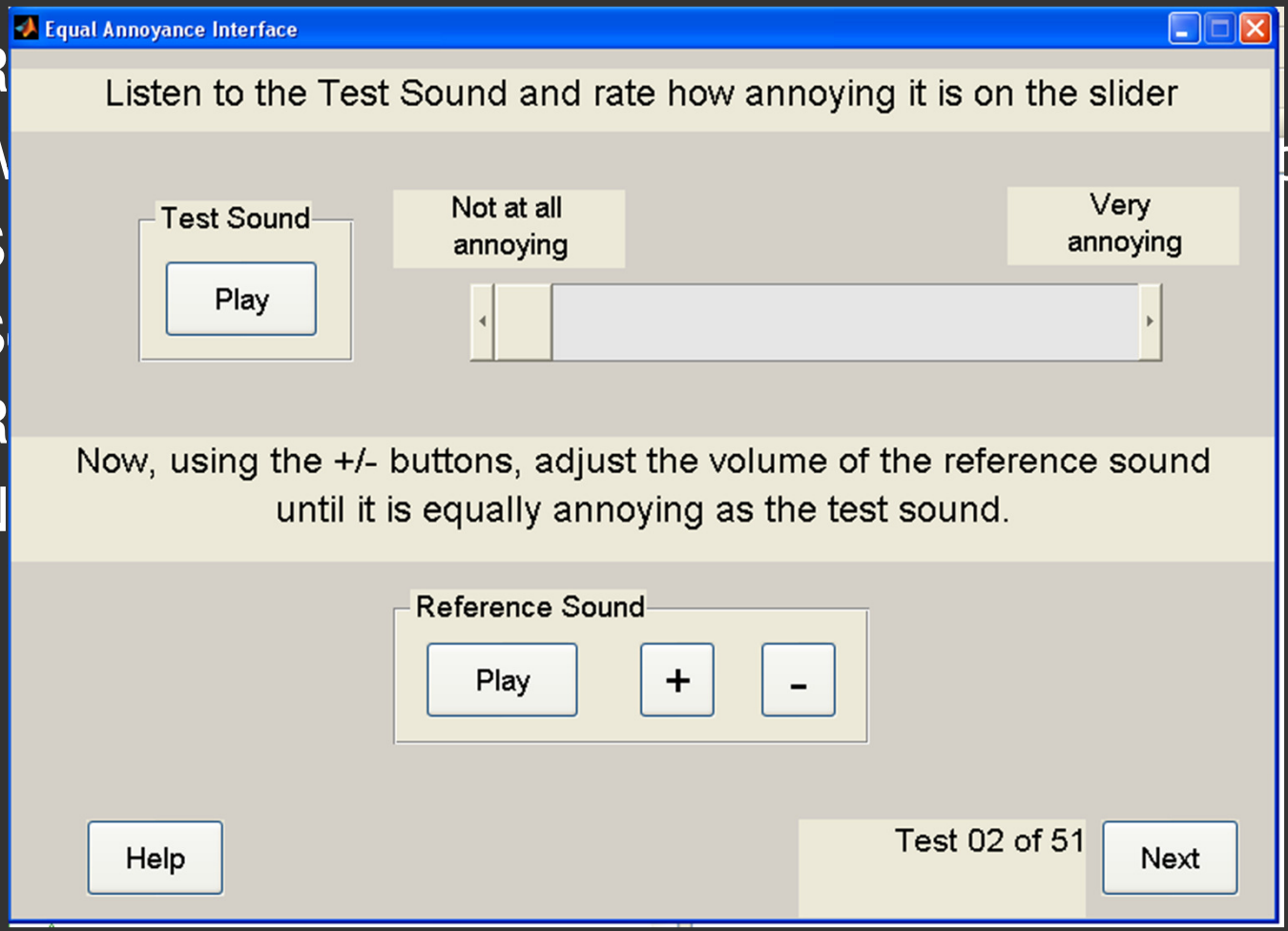


Listening tests on AM

- Reports in the published literature …..
- WTN more annoying than other environmental noise
- Speculation in literature
- Sound characteristics to blame?
- Response by industry and government
- Need for dose-response relation

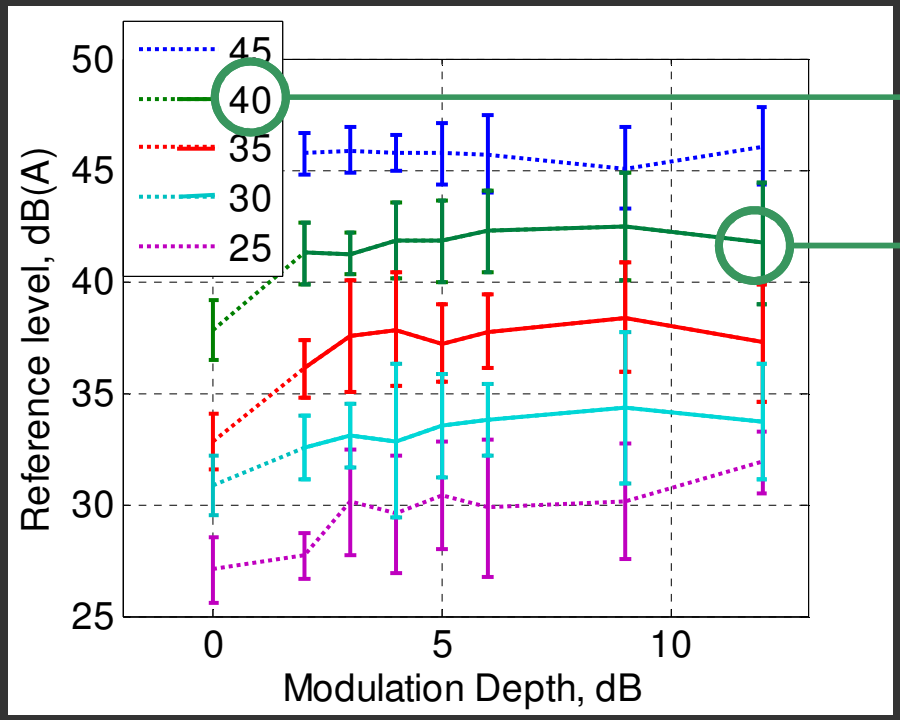
Listening tests on AM

- R
- W
- S
- S
- R
- N



bise

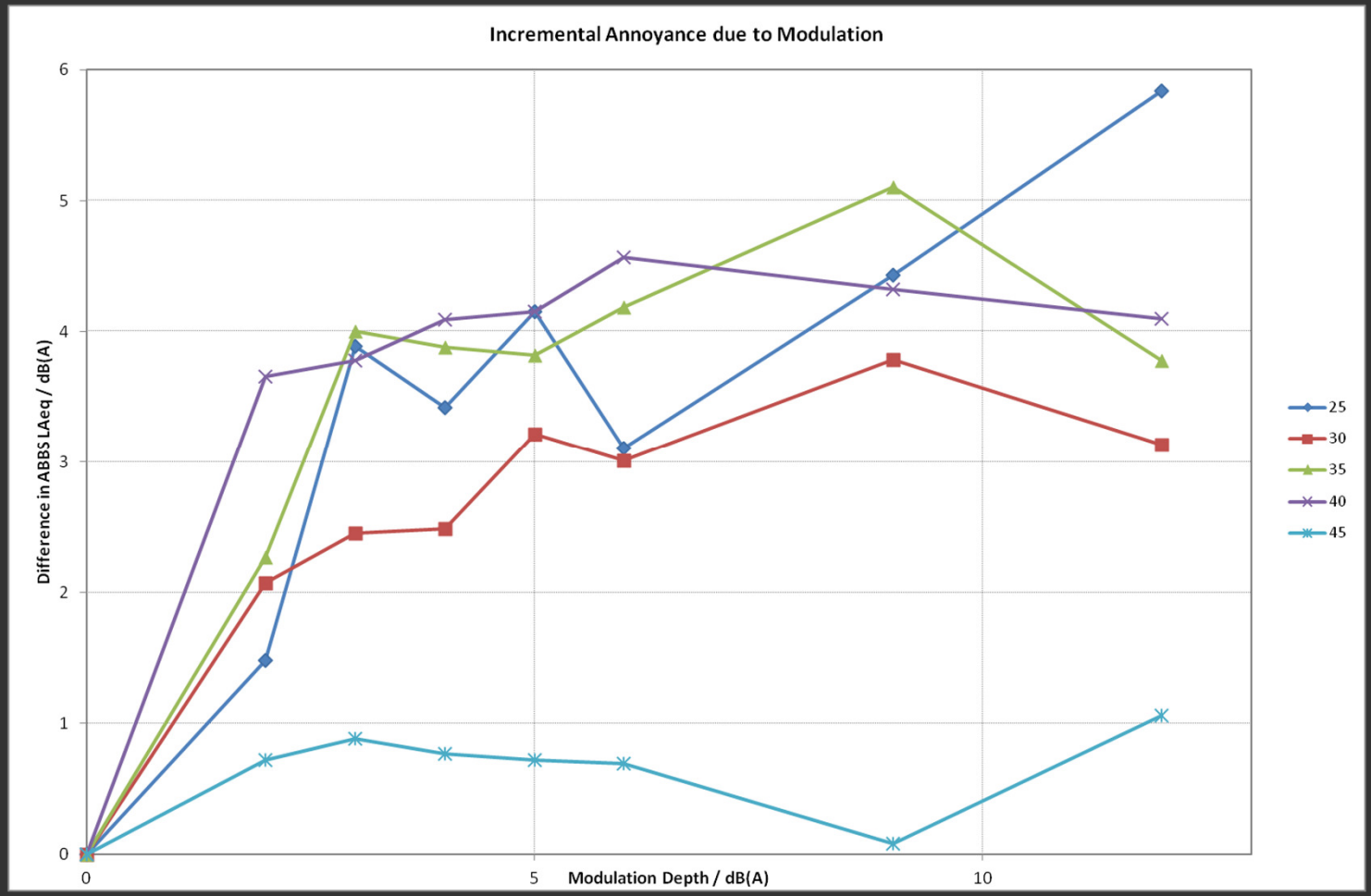
Normalising adaptive rating levels



41.8 – 40 = 1.8

reference – test = normalised

Dose – Response Relationship & Penalty Scheme



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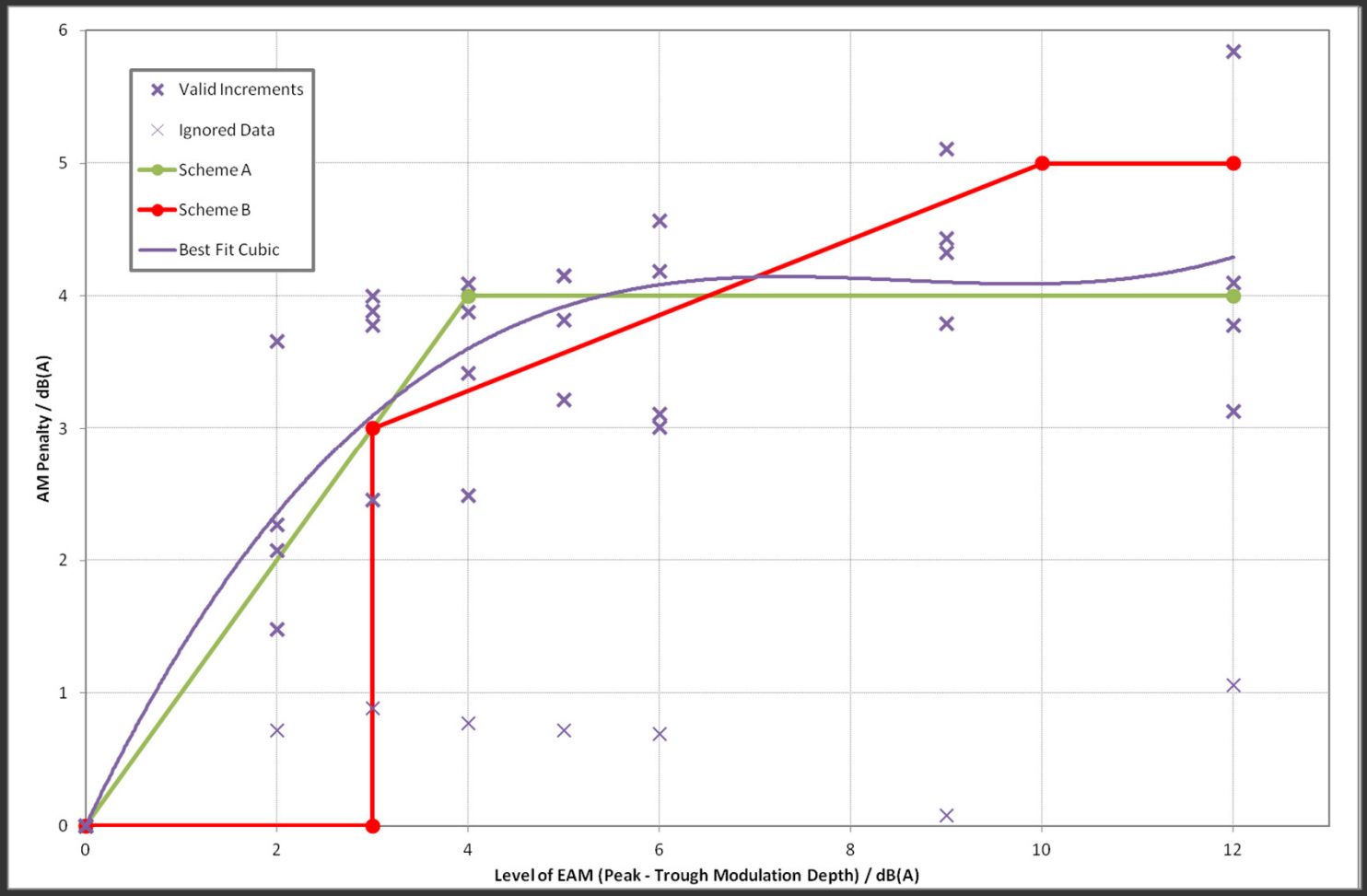

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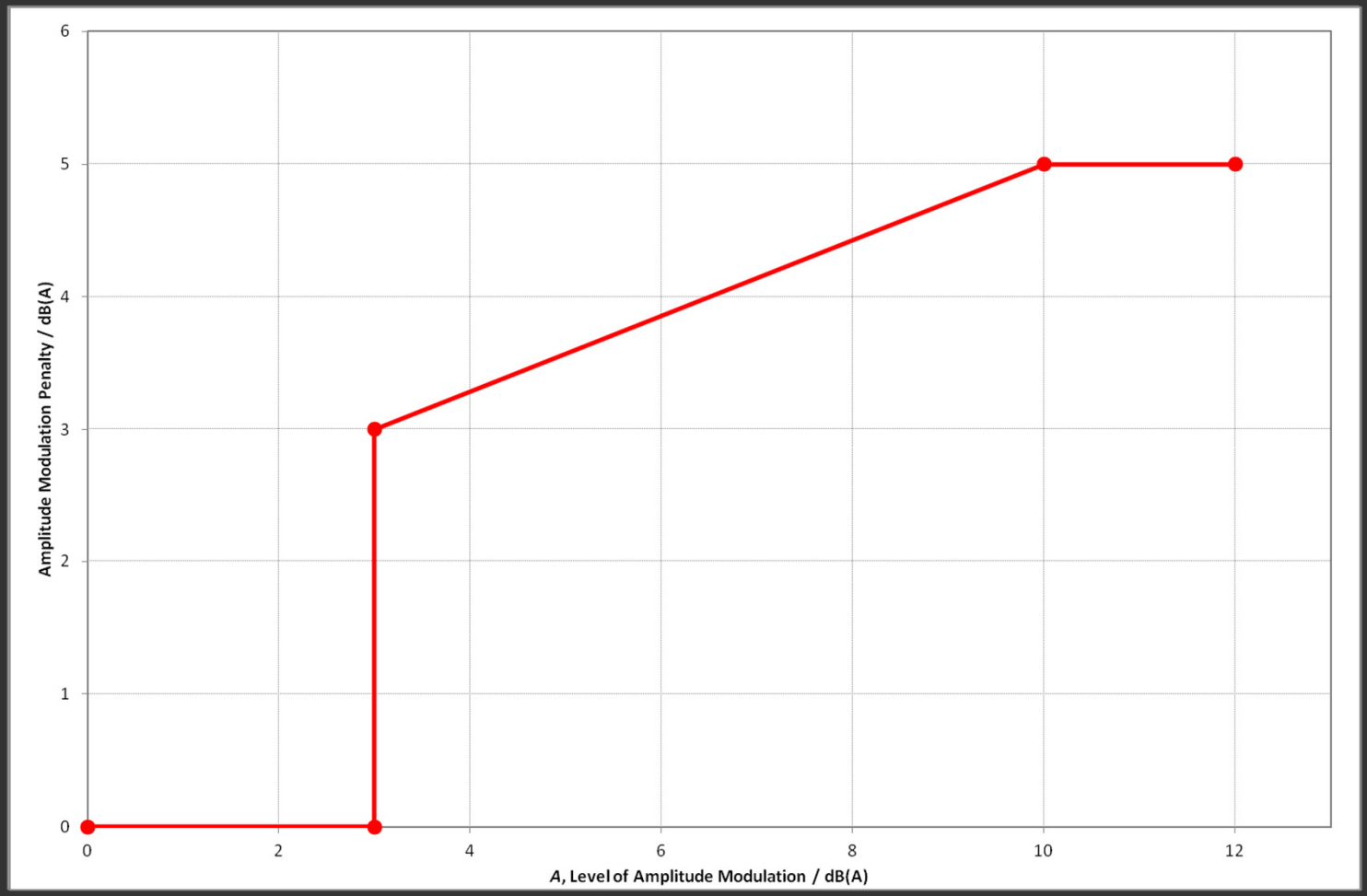
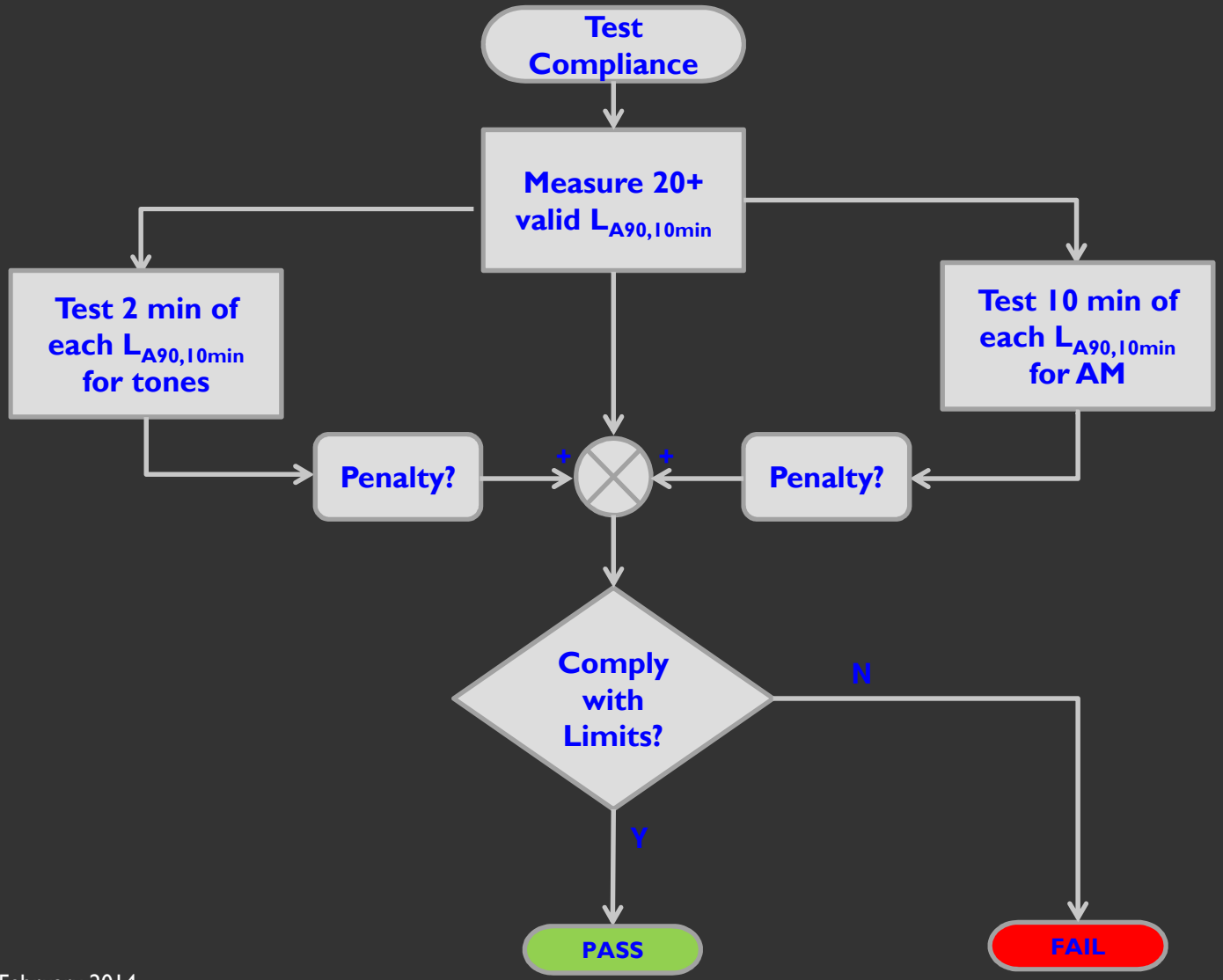
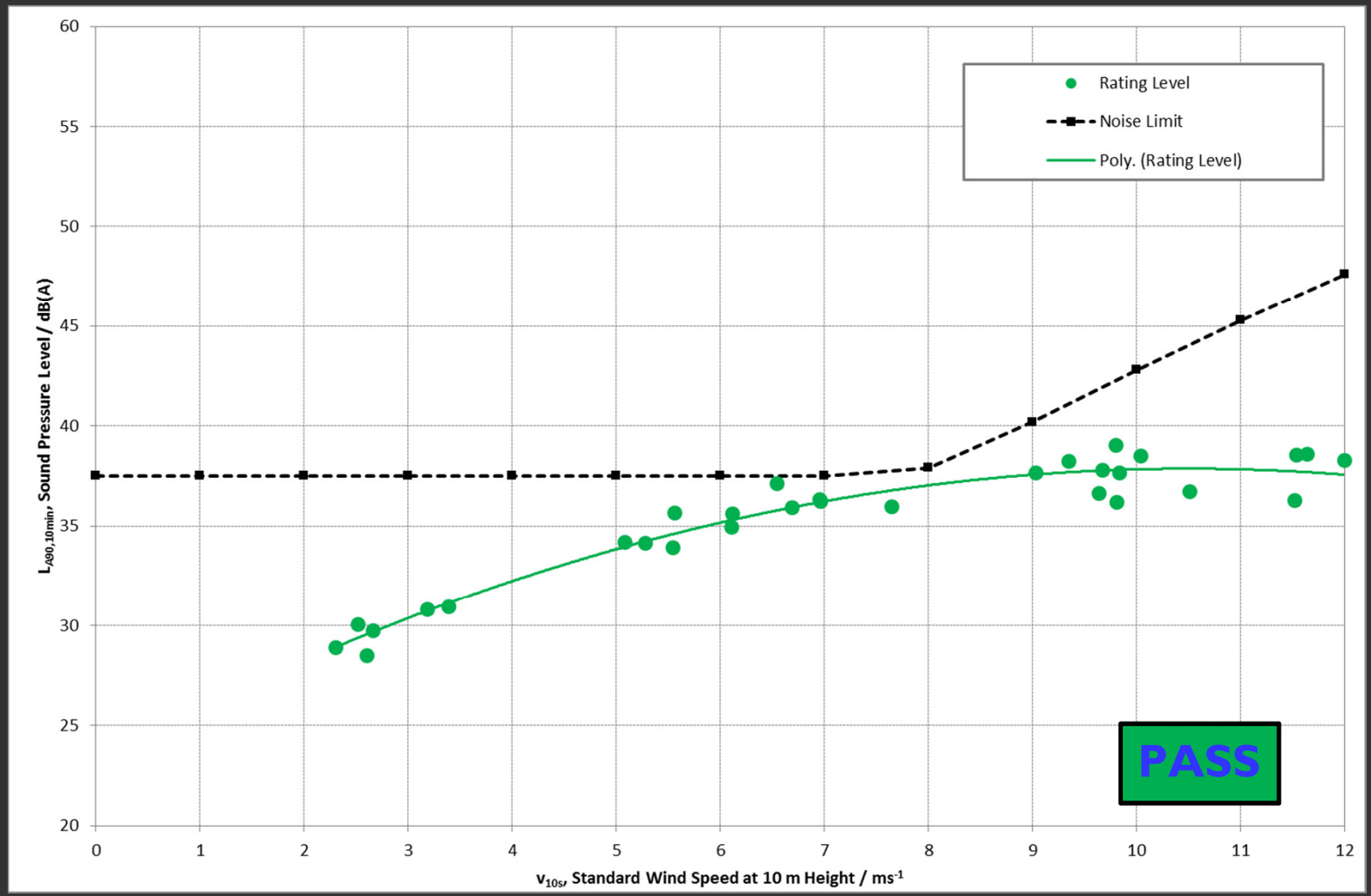


Possible AM Planning Control - Flowchart



Possible AM Planning Control – Real-World



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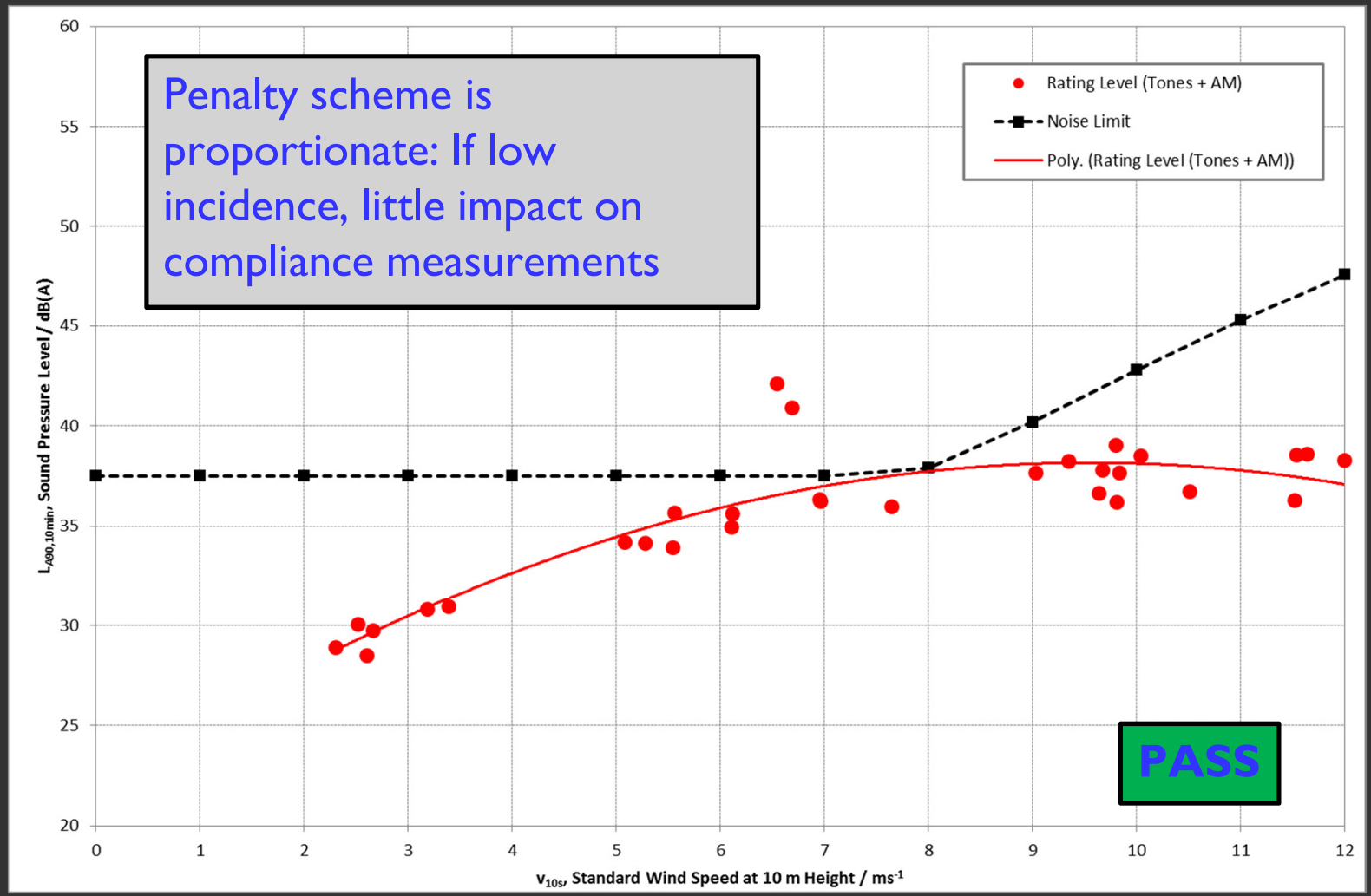

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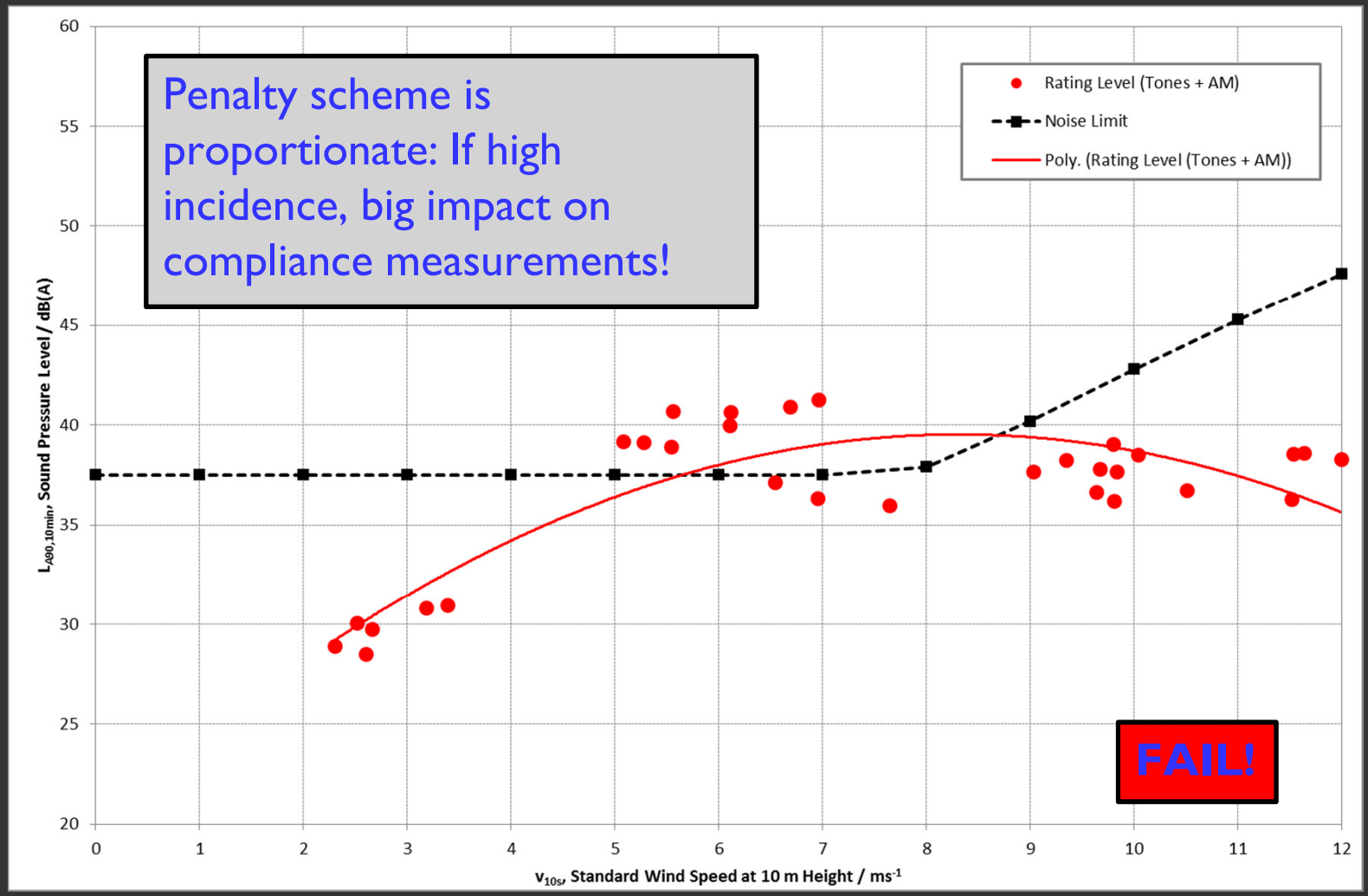

CONCLUSIONS:

- need more focus on community engagement and the planning process if we are to continue to be successful
- 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 & OAM
- the principal cause of OAM identified is partial/ transient blade stall, caused by high angles of attack
- combine robust objective quantification methods for AM with dose-response relationship combined to create planning control for AM
- need warranty protection & meaningful mitigation for OAM - requires leadership from manufacturers