MOTION AND MOBILITY

Avoiding wind turbine tonalities

A structured, system based approach

Frederik Vanhollebeke
Wind Power Technology

Avoiding wind turbine tonalities
Agenda

1. Wind turbine sound sources
2. Wind turbine mechanical sound
    1. Historical way of thinking
    2. Versus experimental measurements
3. Avoiding wind turbine tonalities: ALARM research project

Wind turbine sound
Aeroacoustic sound

Generated by aero-elastic interaction between the air, the rotating blades and the tower and nacelle.

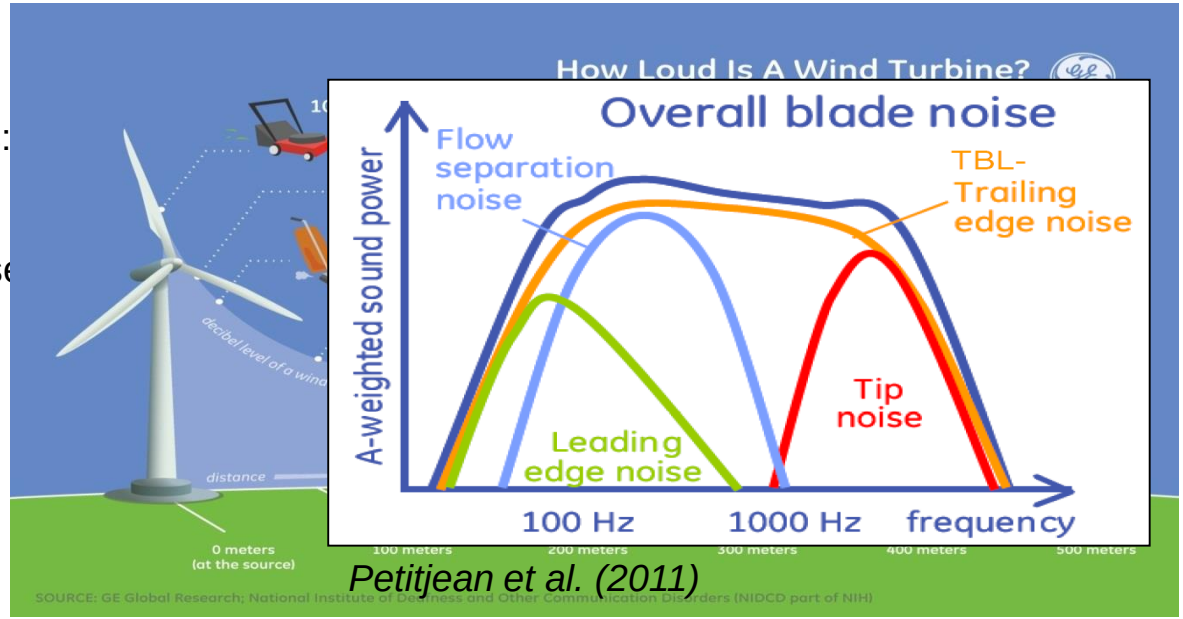
Determines overall level

Radiates directly
to the surroundings

Broadband of nature

Several noise mechanisms such as:

- Flow separation noise
- Turbulent layer trailing edge noise
- Leading edge noise
- Tip noise



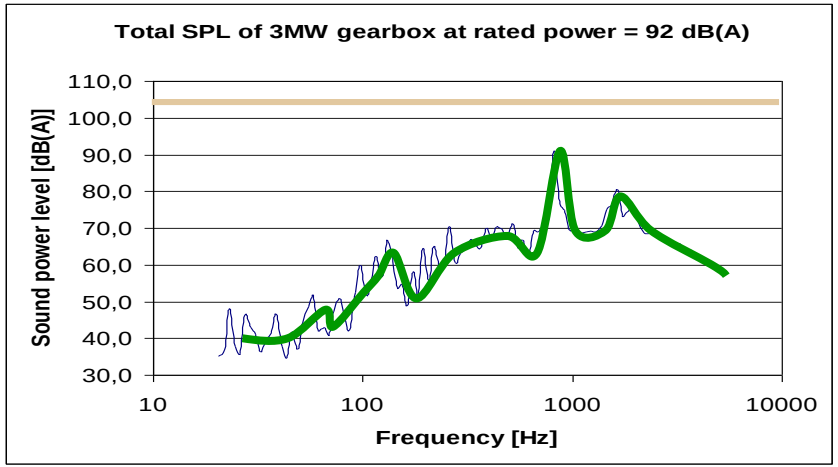
Petitjean et al. (2011)

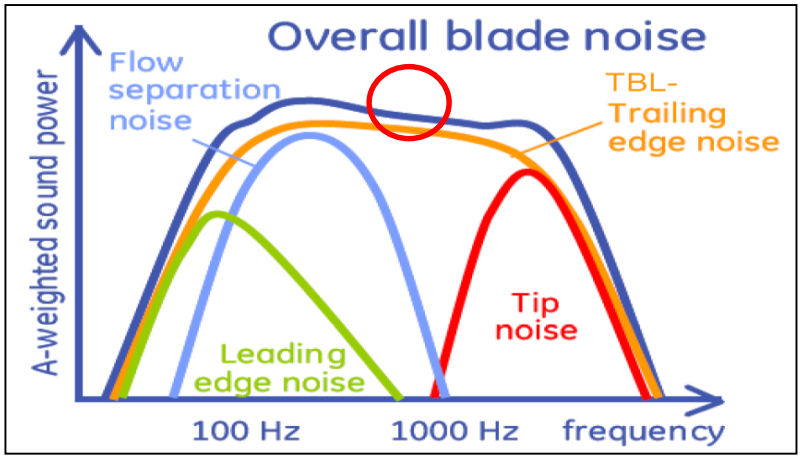
Wind turbine sound
Mechanical sound

Originates from mechanical components such as gearbox, generator, fans, …

=> Mechanical tonalities occur at both wind turbines with gearbox or direct driven wind turbines

Tonal of nature and only audible when above aerodynamic sound



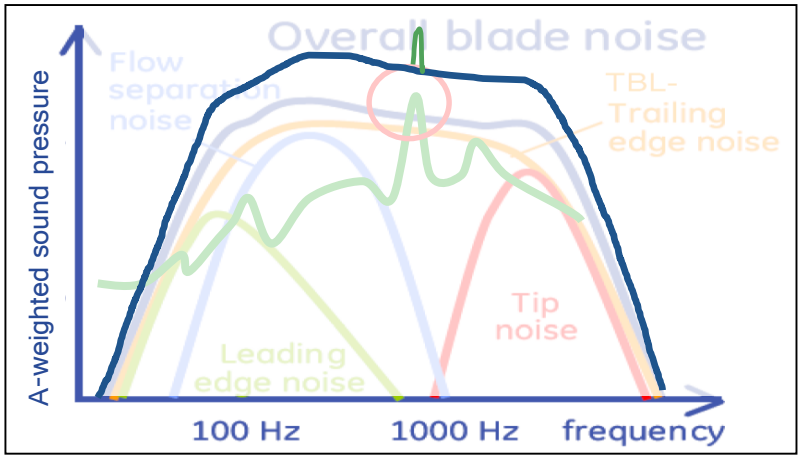


Petitjean et al. (2011)

Wind turbine sound
Mechanical sound - Challenges

Challenges

- Wind turbines are installed closer to urbanised areas => increase in sound pressure

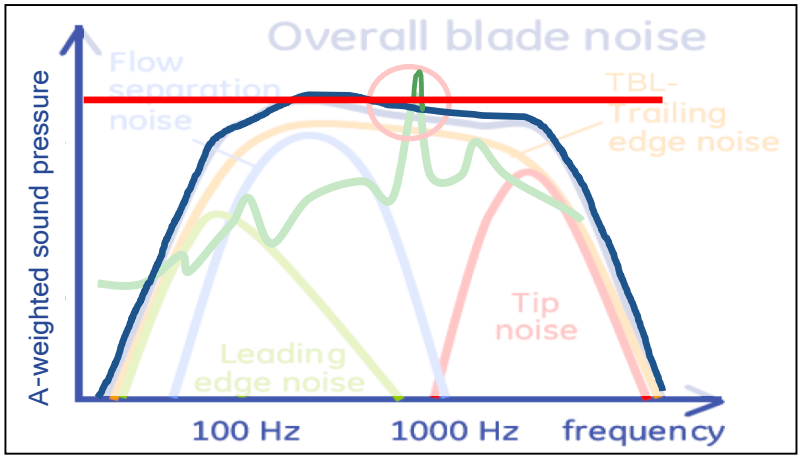


Petitjean et al. (2011)

Wind turbine sound
Mechanical sound - Challenges

Challenges

- Wind turbines are installed closer to urbanised areas => increase in sound pressure
- More stringent limits on total sound and tonal levels

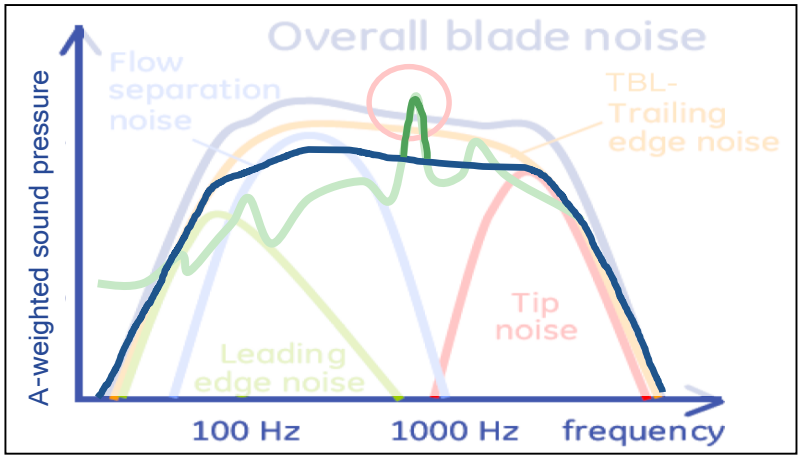


Petitjean et al. (2011)

Wind turbine sound
Mechanical sound - Challenges

Challenges

- Wind turbines are installed closer to urbanised areas => increase in sound pressure
- More stringent limits on total sound and tonal levels
- Optimised blade design

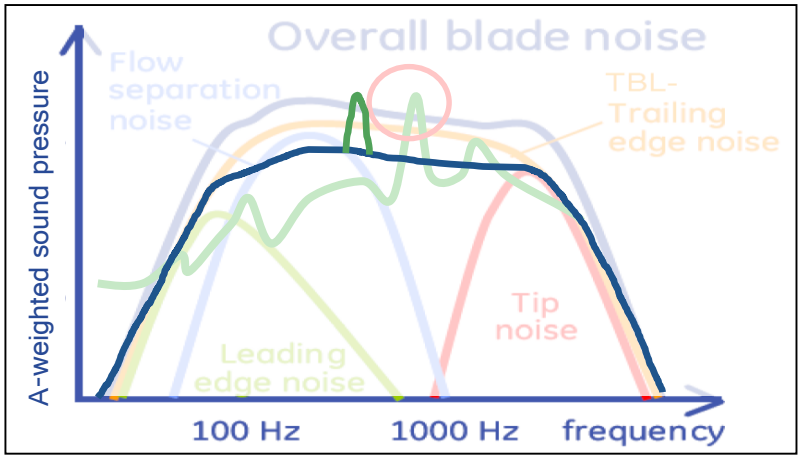


Petitjean et al. (2011)

Wind turbine sound
Mechanical sound - Challenges

Challenges

- Wind turbines are installed closer to urbanised areas => increase in sound pressure
- More stringent limits on total sound and tonal levels
- Optimised blade design
- Low sound operating modes

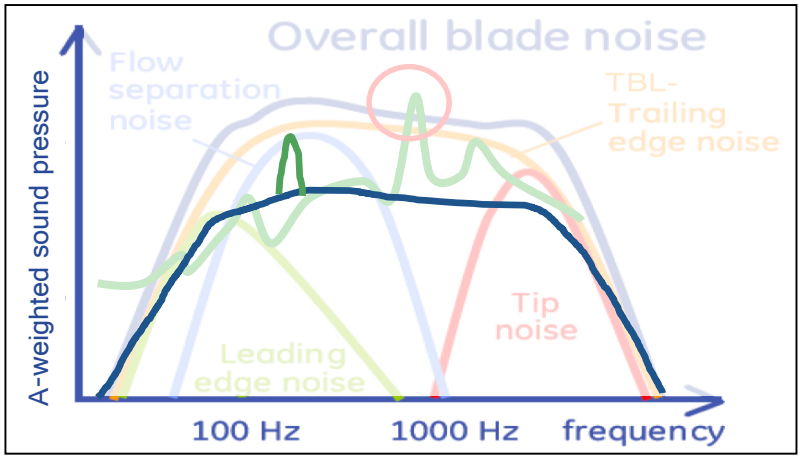


Petitjean et al. (2011)

Wind turbine sound
Mechanical sound - Challenges

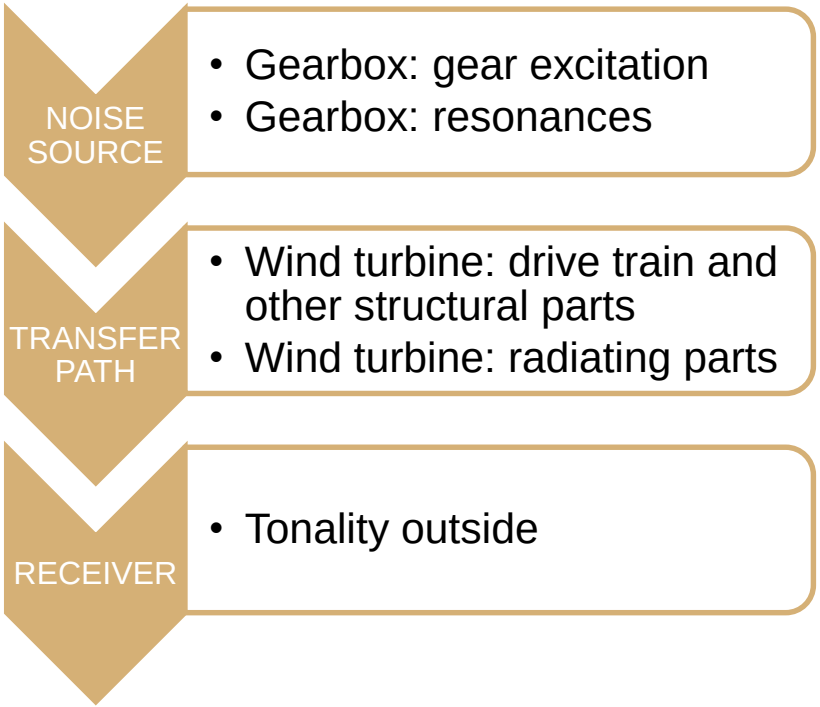
Challenges

- Wind turbines are installed closer to urbanised areas => increase in sound pressure
- More stringent limits on total sound and tonal levels
- Optimised blade design
- Low sound operating modes
- Tonal sound evaluation at very low wind speeds



Petitjean et al. (2011)

Wind turbine mechanical sound



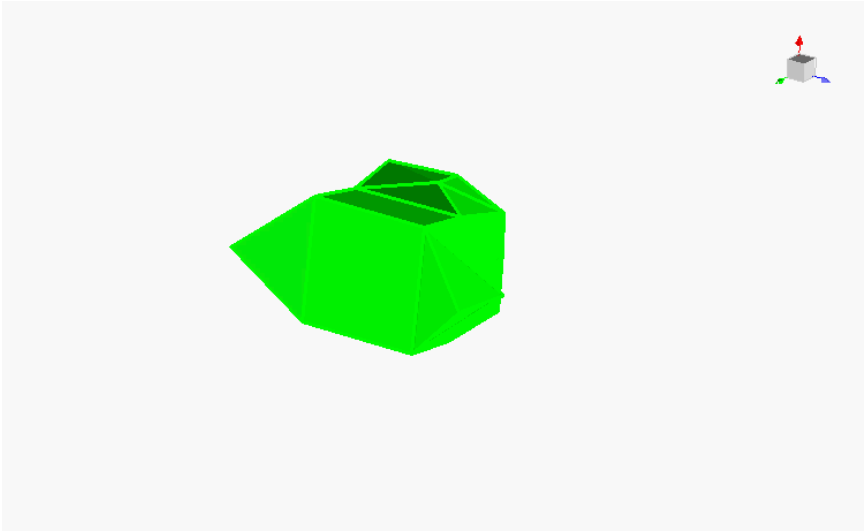
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



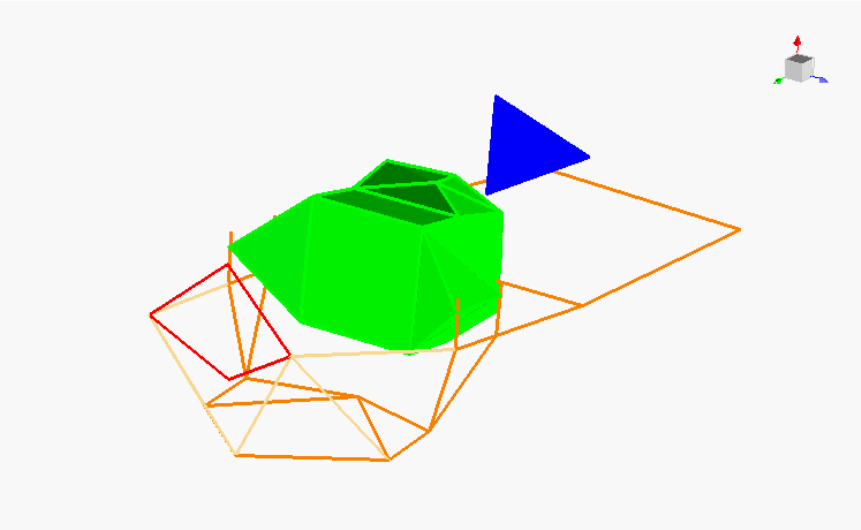
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



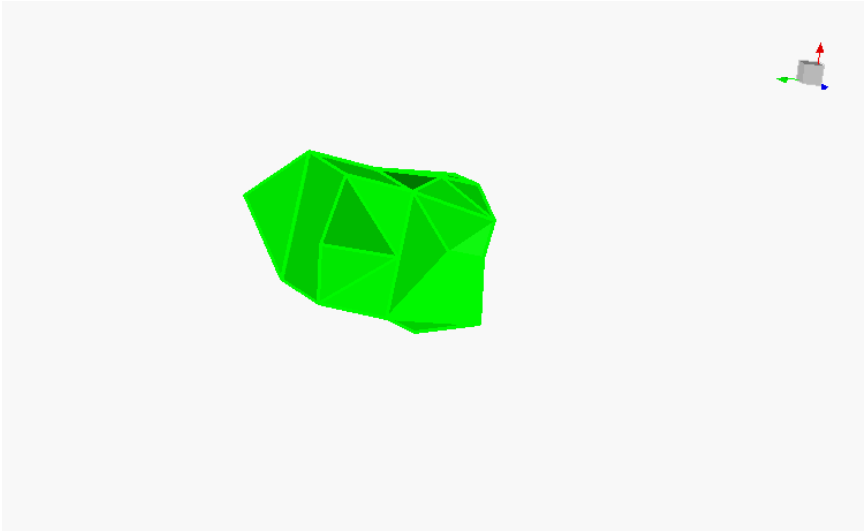
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



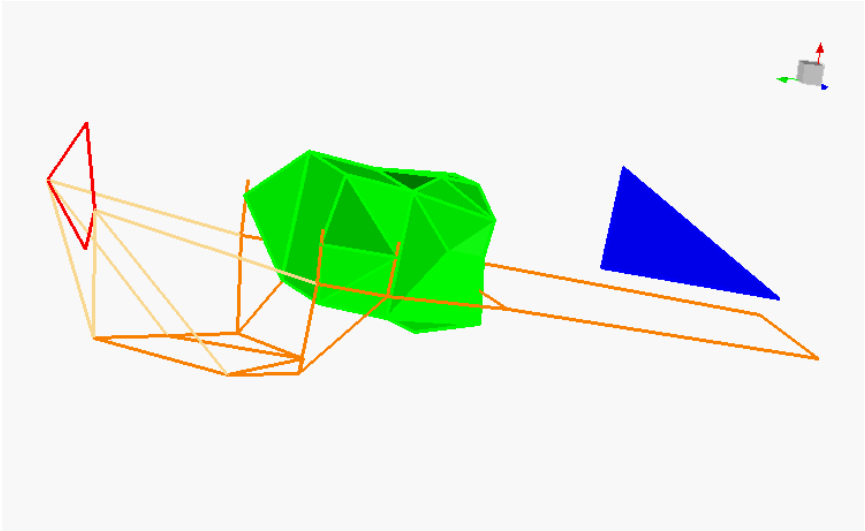
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



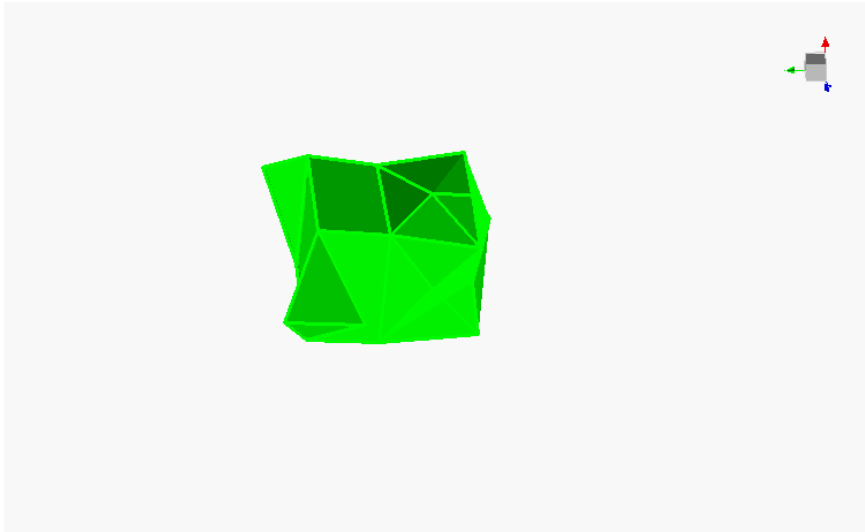
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



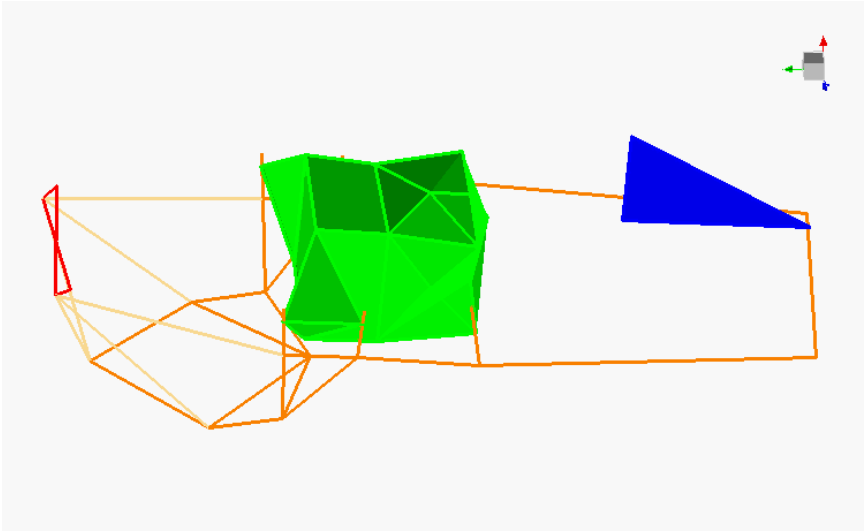
Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

NOISE SOURCE
- Gearbox: gear excitation
- Gearbox: resonances

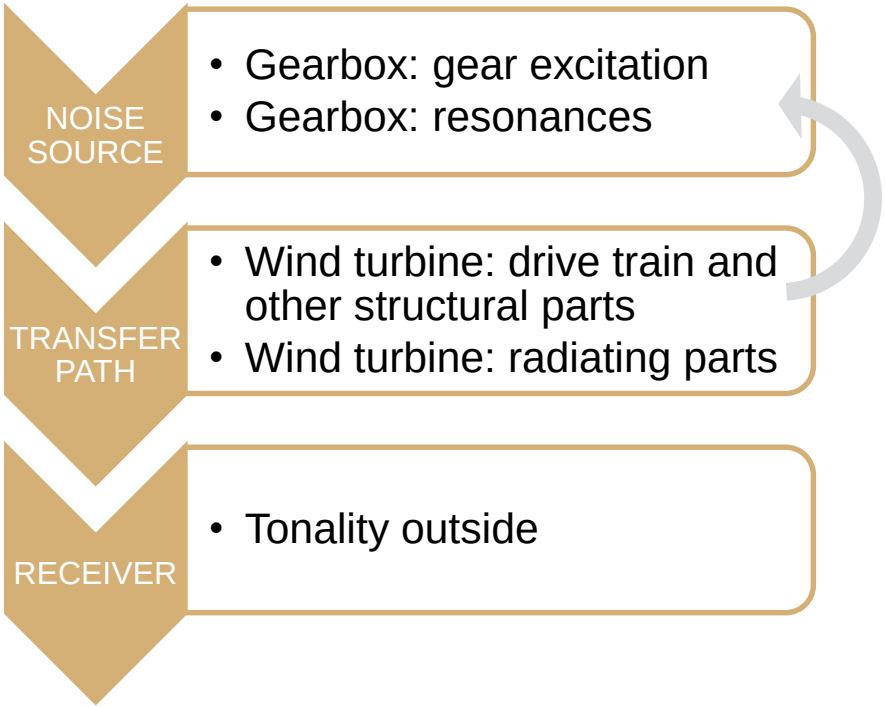
TRANSFER PATH
- Wind turbine: drive train and other structural parts
- Wind turbine: radiating parts

RECEIVER
- Tonality outside



Wind turbine mechanical sound

Historical way of thinking versus Experimental validation

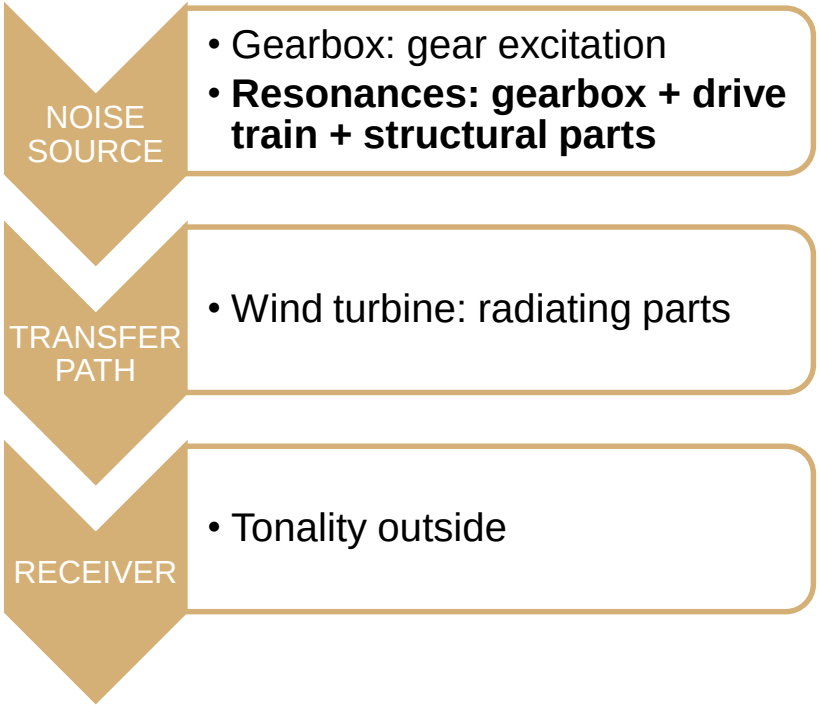


Experimental measurements show:

- Significant coupling between dynamic behaviour of both gearbox and wind turbine structure

Wind turbine mechanical sound

Historical way of thinking versus Experimental validation



Experimental measurements show:

- Significant coupling between dynamic behaviour of both gearbox and wind turbine structure

Resonances are influenced by

- **Gearbox design**
- **Wind turbine design**

&

Resonances should be tackled by following a system based approach - a component approach alone will not be successful

Avoiding wind turbine tonalities

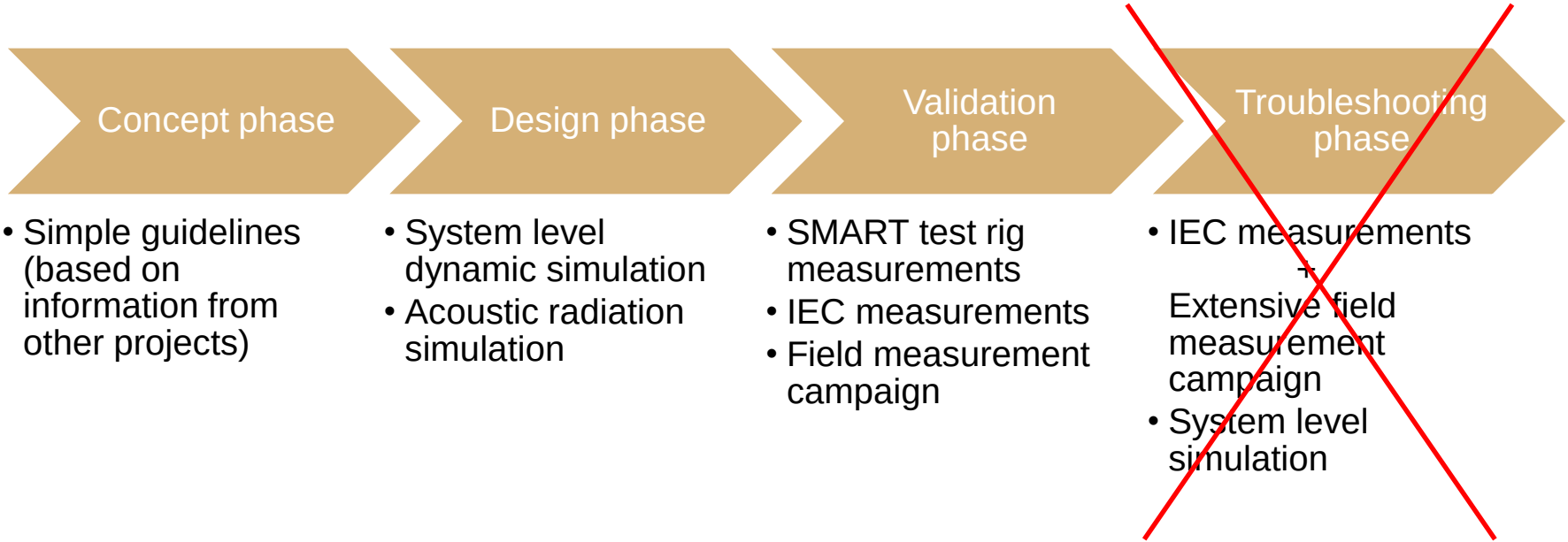
- Simple guidelines (based on information from other projects)

- System level dynamic simulation
- Acoustic radiation simulation

- SMART test rig measurements
- IEC measurements
- Field measurement campaign

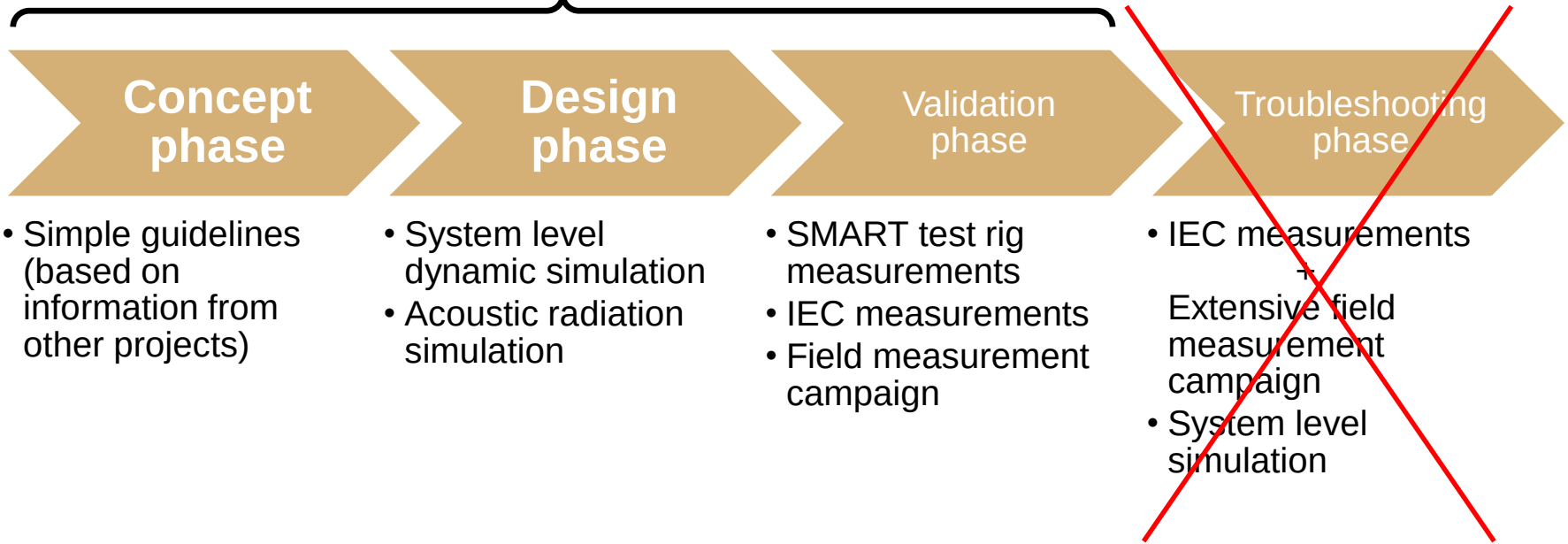
- IEC measurements
  +
  Extensive field measurement campaign
- System level simulation

Avoiding wind turbine tonalities



Avoiding wind turbine tonalities

ALARM research project



Avoiding wind turbine tonalities
ALARM

Gear excitation

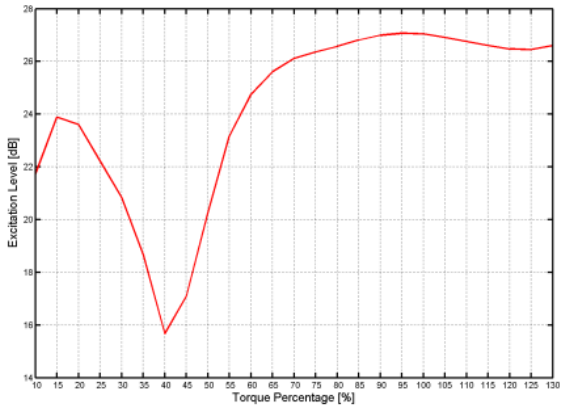
System dynamics

Sound radiation

Wind turbine mechanical sound

Virtual prototyping

- Advanced gear excitation calculations
- Development of gear excitation models



Experimental

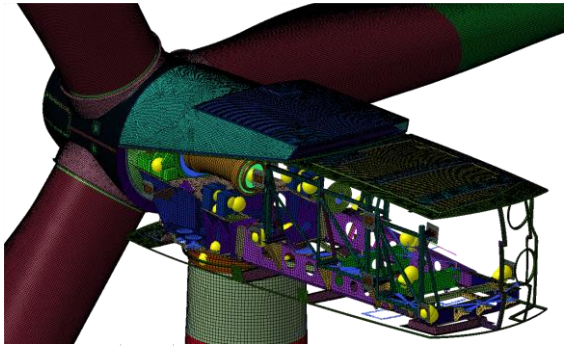
- Experimental validation of gear excitation

Avoiding wind turbine tonalities
ALARM

- Gear excitation
- System dynamics
- Sound radiation
- Wind turbine mechanical sound

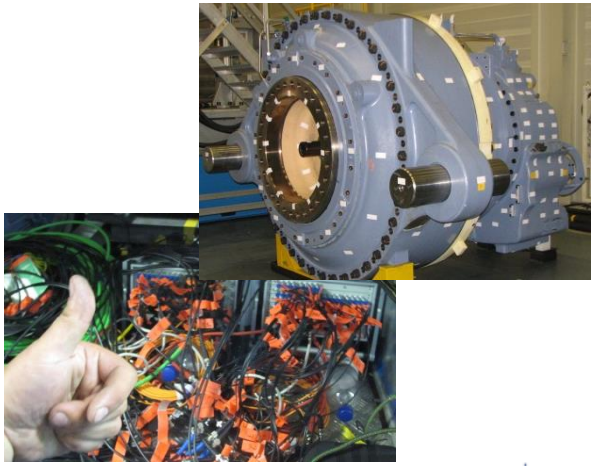
Virtual prototyping

- Advanced multibody and finite element modelling of the complete wind turbine



Experimental

- In depth experimental validation of the gearbox (eigenmodes)
- Experimental validation of the wind turbine (eigenmodes, transfer paths, vibration levels)



SENVION wind energy solutions

Novicos

LMS ENGINEERING INNOVATION

ESM

KATHOLIEKE UNIVERSITEIT LEUVEN

KT mfk

Avoiding wind turbine tonalities
ALARM

Gear excitation

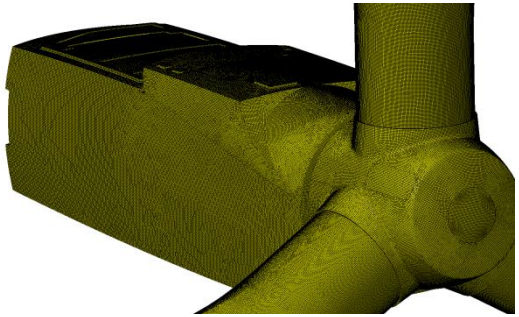
System dynamics

Sound radiation

Wind turbine mechanical sound

Virtual prototyping

- Advanced coupled acoustic model of the complete wind turbine



Experimental

- Experimental validation of the wind turbine
  - Noise inside nacelle
  - Noise outside (IEC locations)
  - Noise radiation (HUGE acoustic camera)

Avoiding wind turbine tonalities
ALARM

Concept phase | Design phase | Validation phase | Troubleshooting phase

IEC measurements remain conclusive

Lessons learnt from ALARM:

- Optimal sensor set to investigate turbine dynamic behaviour (during wind turbine validation)
- Innovative analysis techniques to investigate wind turbine sound

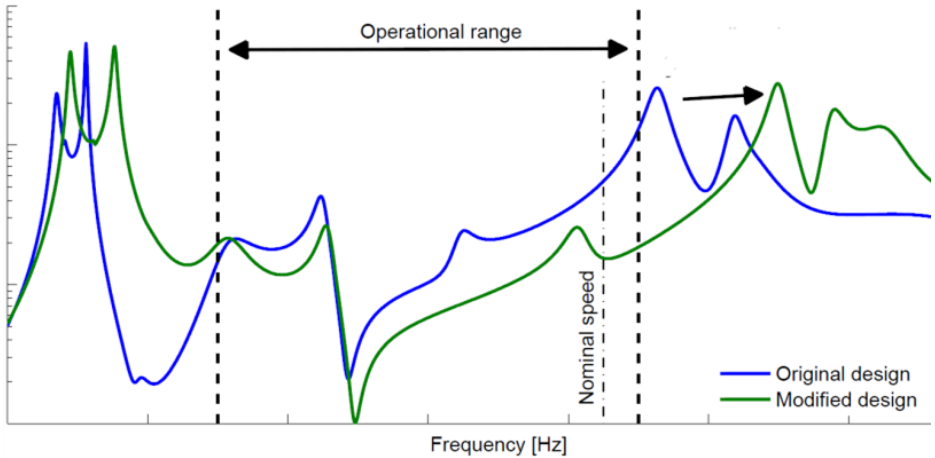
Avoiding wind turbine tonalities
ALARM

Concept phase | **Design phase** | Validation phase | Troubleshooting phase

Transition from blind design towards model based design

Lessons learnt from ALARM:

- Wind turbine dynamic model is capable of predicting relevant dynamic phenomena
- Accuracy of the wind turbine dynamic model
- Insight in relevant dynamic behaviour



Avoiding wind turbine tonalities
ALARM

Concept phase | Design phase | Validation phase | Troubleshooting phase

Transition from blind concept phase towards a concept phase in which generic insights from previous measurements / models are used.

Lessons learnt from ALARM:

- There exist noise sensitive frequency ranges in any wind turbine that should be avoided in the concept phase!

Wind turbine mechanical sound
ALARM

Conclusions

- Dynamics are determined by a coupled system behaviour
- A system based approach is key to understand the dynamic phenomena causing wind turbine tonalities
- Alarm has shown that wind turbine tonal behaviour can already be assessed during both concept & design phase!
- Open cooperation between wind turbine, gearbox and bushing OEM necessary to systematically avoid tonal wind turbine sound

Thank you for your attention