Technology Collaboration Programme
by IEA

IEA Wind Task 54:
Ice, noise and impact on acceptance

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Motivation

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- Turbine noise a big driver on public opinion of wind power
- Generally, attitudes have been ”out of sight of mind”
- More and more wind is being constructed closer to people
- Noise issues become increasingly relevant also in cold climate

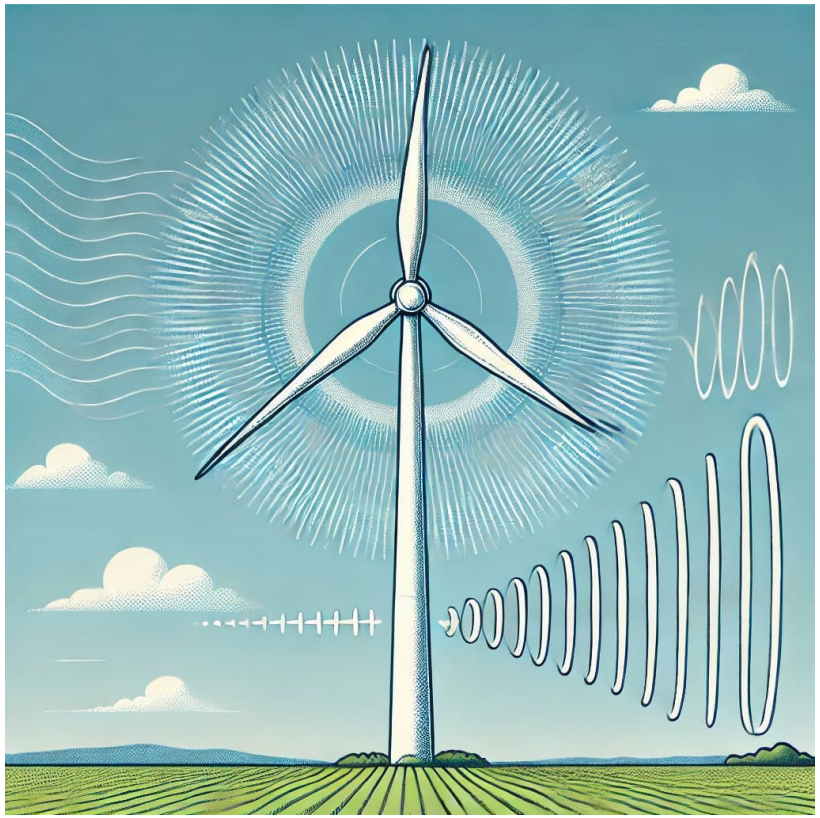

Image created by Copilot AI

Motivation

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- Map the current state of the art
- Publications from the last 5 years
- Focusing on icing specifically
- Many are focusing on blade damage detection using similar methods
  - Sensitivity
  - Changes due to icing can be more dramatic

Airfoil self-noise mechanisms

- Noise created by wind turbine blade
  - Interaction between inflow and blade
    - Tip
    - Trailing edge
  - Turbulence
  - Wake
  - Boundary layer separation

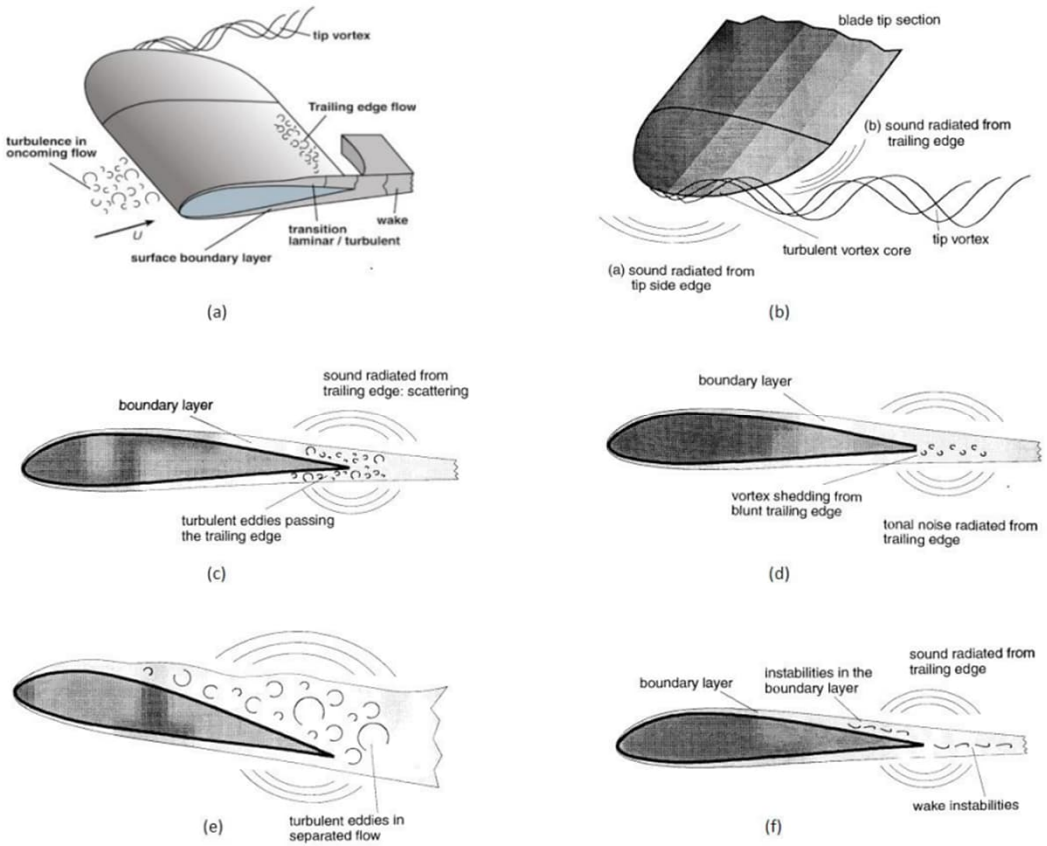

Fig. 4. (a). Flow over the outer section of a wind turbine blade; (b - f) Airfoil self-noise mechanisms [7]

Icing

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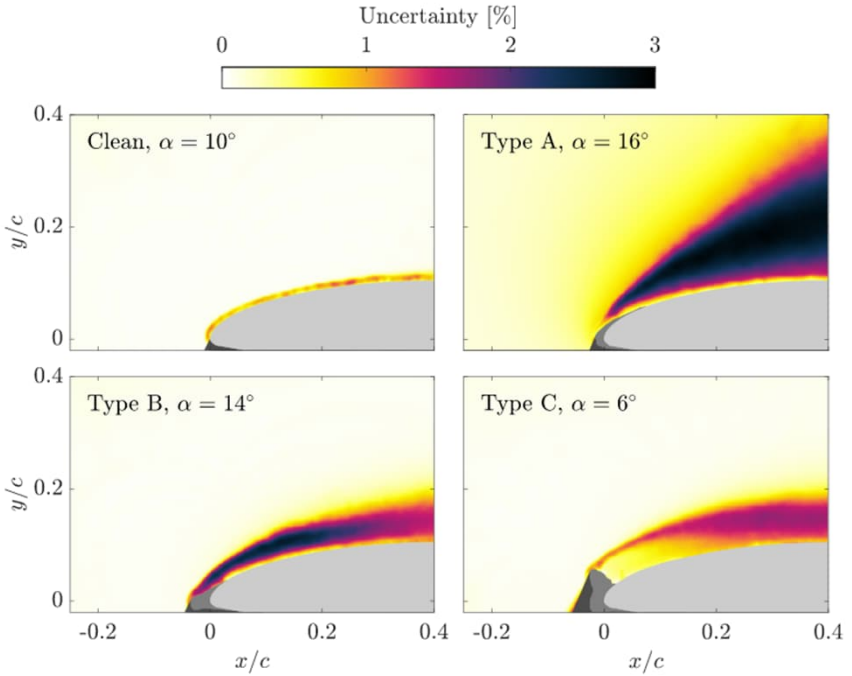
- Blade icing can increase the aerodynamic noise
- Changes in surface roughness, shape of airfoil
  →Flow separation, more turbulence
  →Increased noise levels
- Commercial products exist
  - Use noise monitoring for ice detection



[1]

M. K. Vinnes and R. J. Hearst, "Aerodynamics of an airfoil with leading-edge icing," *Wind Energy*, vol. 24, no. 8, pp. 795–811, 2021, doi: 10.1002/we.2603.

Noise effects

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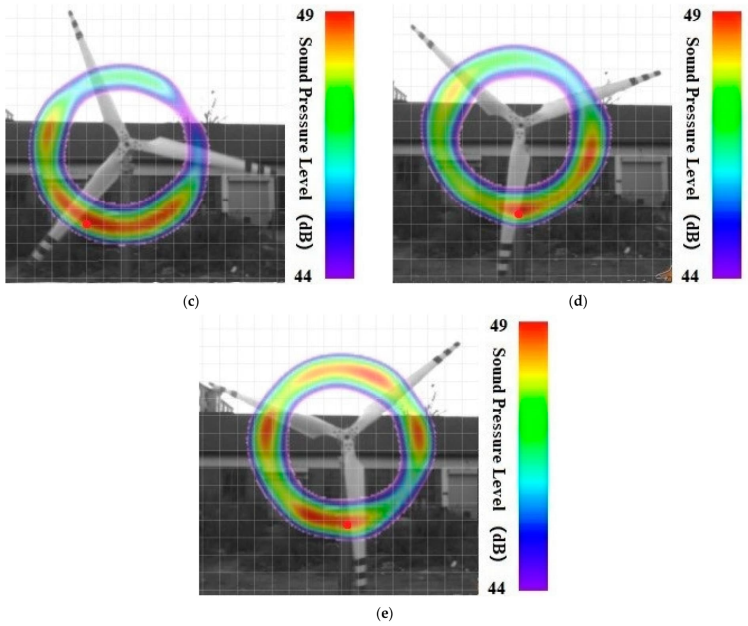
- Measurable increase in sound levels
- Relatively early in icing events
- Increase in trailing edge noise
- Icing causes changes in the boundary layer around the airfoil
- Source of noise towards the tip of the blade
  - Higher speed
  - More likely to have ice

[1],[7],[4]



Sun, B., Cui, H., Li, Z., Fan, T., Li, Y., Luo, L., & Zhang, Y. (2022). Experimental Study on the Noise Evolution of a Horizontal Axis Icing Wind Turbine Based on a Small Microphone Array. *Sustainability*, *14*(22), 15217. https://doi.org/10.3390/su142215217

Prevailing factors

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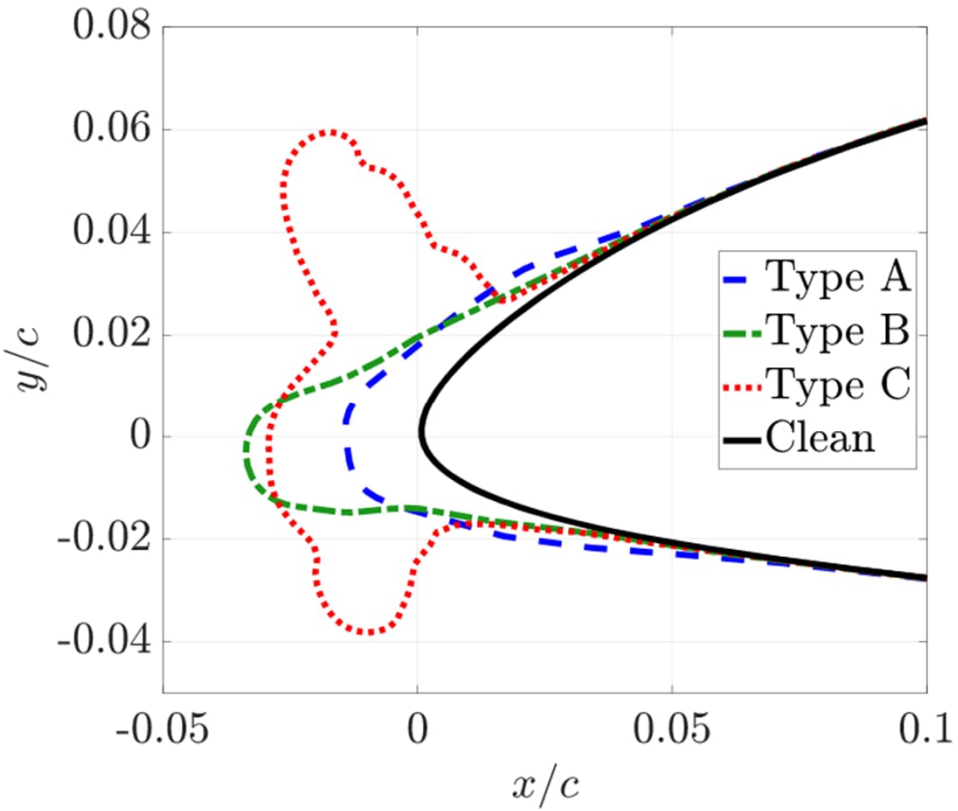
- Ice shape on the blade a dominant factor
  - More ice →larger deformation of the airfoil → higher noise levels
- Icing conditions have less of an impact
  - LWC
  - Droplet size
  - Etc.

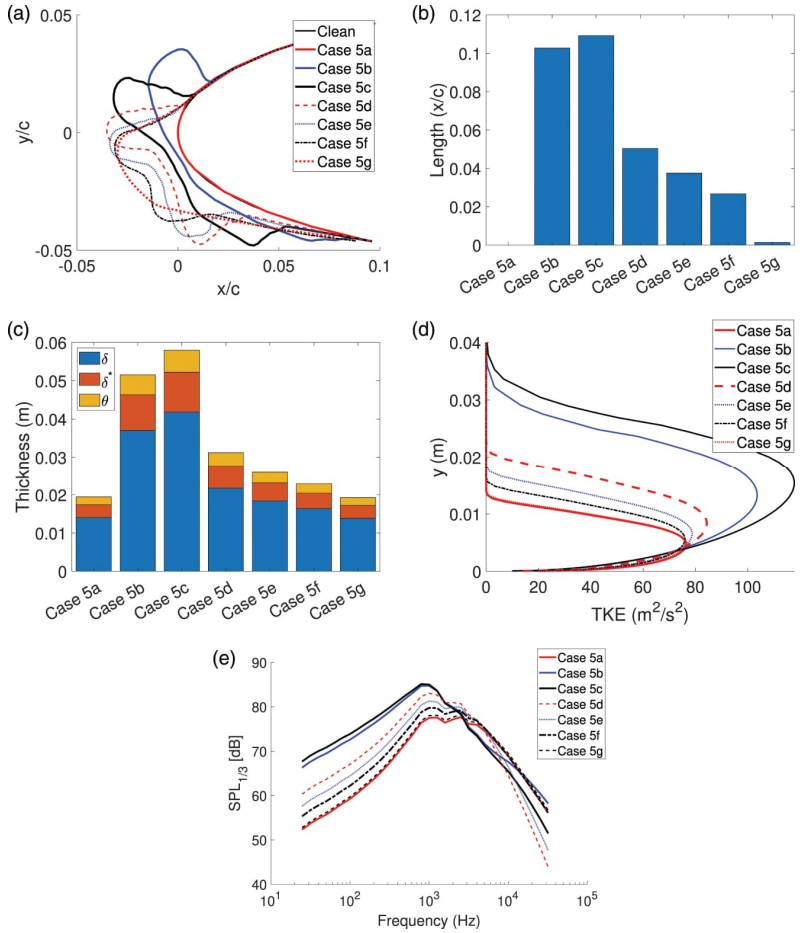


[1],[2],[4],[7]

Vinnes MK, Hearst RJ. Aerodynamics of an airfoil with leading-edge icing. *Wind Energy*. 2021; 24: 795–811. https://doi.org/10.1002/we.2603

Noise effects

- Increase more significant at lower frequencies
- Changes larger at larger ice mass
- Ice thickness matters
- Changes similar otherwise, magnitude differs



[1]

H. Gill and S. Lee, “Effect of 2D ice accretion on turbulent boundary layer and trailing-edge noise,” *International Journal of Aeroacoustics*, vol. 21, no. 3–4, pp. 260–285, Jun. 2022, doi: 10.1177/1475472X221099497.

[1],2,[11],[14]

Social consequences

- Increase in noise levels can increase opposition of individual projects
- Changes in noise characteristics can make turbine noise more annoying
- Icing can make these effects more intense

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WF Noise Level Class	Noise Level L_{den} dB(A)
Very low	0–40
Low	41–70
Medium	71–100
High	101–140
Very high	>140

The day–evening–night noise level (Lden) is a European standard to express the noise levels from machines throughout an entire day

Przysucha, B.; Pawlik, P.; St ˛epie ´n, B.; Surowiec, A. Impact of the noise indicators components correlation Ld, Le, Ln on the uncertainty of the long-term day–evening–night noise indicator Lden. Measurement 2021, 179, 109399. [CrossRef]

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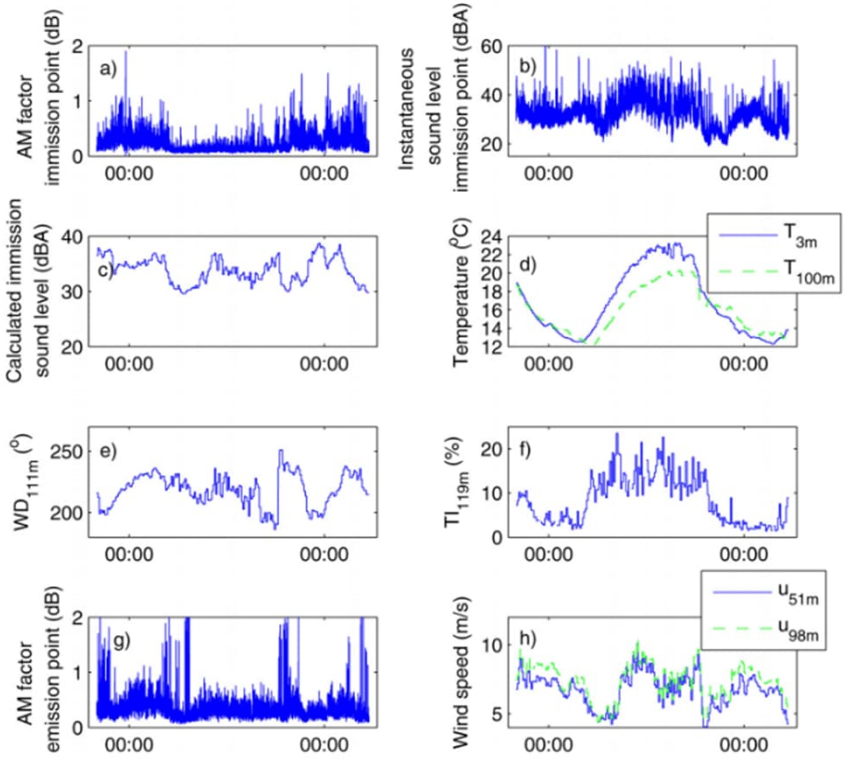
Social consequences

- Amplitude modulation of noise can increase the annoyance of wind turbine noise
- Field experiments in Sweden have found AM to be more common in winter
- Also more likely at night, due to more common stable atmospheric conditions
- Correlates with temperature inversion
- Has an impact on perception of wind power

[13][14]



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C. Larsson and O. Öhlund, "Amplitude modulation of sound from wind turbines under various meteorological conditions," *The Journal of the Acoustical Society of America*, vol. 135, no. 1, pp. 67–73, Jan. 2014, doi: 10.1121/1.4836135.

Siting and noise

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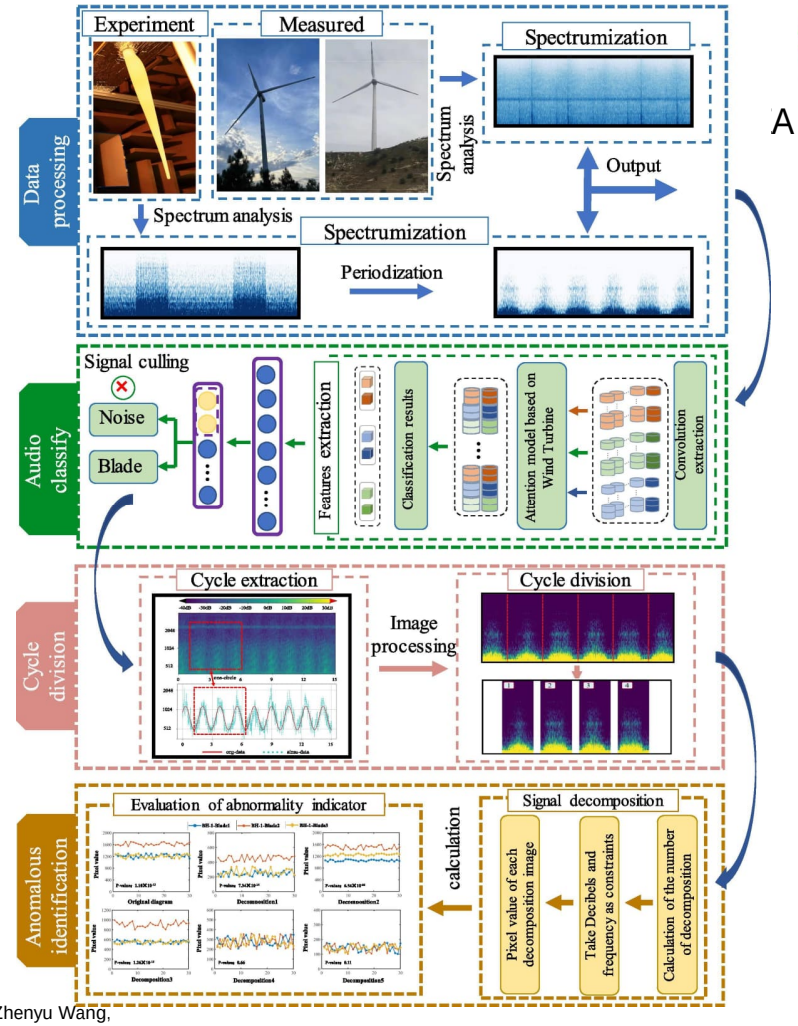
- Need to define an audible distance
- Complaints, protests
- Acceptance important for future depolyments
- Winter conditions impact sound travel
  - Snow on the ground
  - Atmospheric conditions during winter
  - Increase of noise levels during icing events

Image created by Copilot AI

Developments

- Improvements in machine learning methods and increased availability of these tools resulted in applications into this field as well
  - Large amounts of structured data
- Anomaly detection
- General blade damage models, can be used for ice detection as well



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Anomaly identification of wind turbine blades based on Mel-Spectrogram Difference feature of aerodynamic noise,
Measurement,
Volume 240,
2025,
115428,
ISSN 0263-2241,
https://doi.org/10.1016/j.measurement.2024.115428.

Conclusions

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- Icing increases noise levels
- More ice -> larger increase
- Trailing edge noise mainly
- Higher wintertime noise levels can lead to wind turbines being audible from a longer distance
- Amplitude modulation
  - Annoyance
- Acceptance issues related to icing.

References

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