Trailing Edge Noise of Wind Turbine Blades - TENwinds

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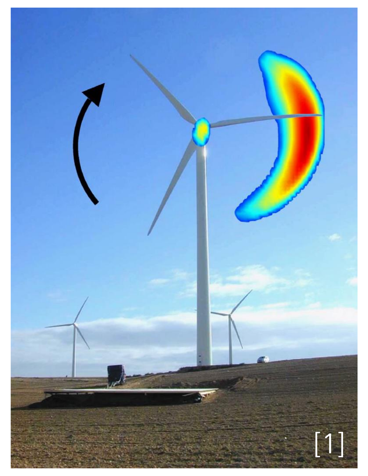
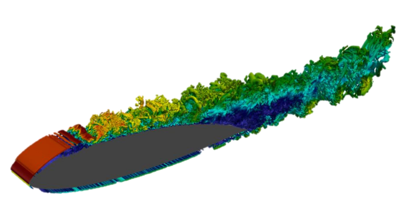
Motivation



TEN is a significant contributor to noise emissions

→ Study & understand flow-induced TEN mechanisms



- $Re_c \sim O(10^6)$ & elements ~ $Re_c^{\ 3}$ (DNS)
- Computational costs
  - Scale with Re_c
  - Dependent on resolved scales

Efficient simulation of **trailing-edge noise** with as **little modelling** as possible utilizing the **Lattice-Boltzmann Method (LBM)**.

Status

Preliminary results from:

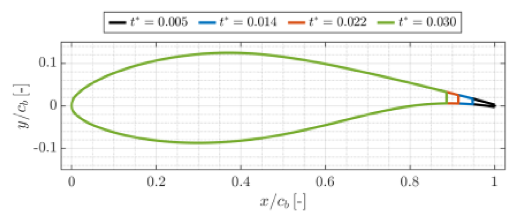
- Wind tunnel experiments
- Very large eddy simulations (VLES)
- Validation of VLES with wind tunnel experiments with:
  - Static pressure distribution
  - Far-field noise
  - Unsteady surface pressure

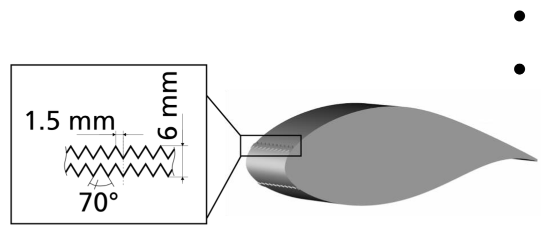
Optimization of LBM solver Musubi

- Improved scaling by using non-blocking collectives
- Tuning on HAWK

→ Determine setup & operational parameters

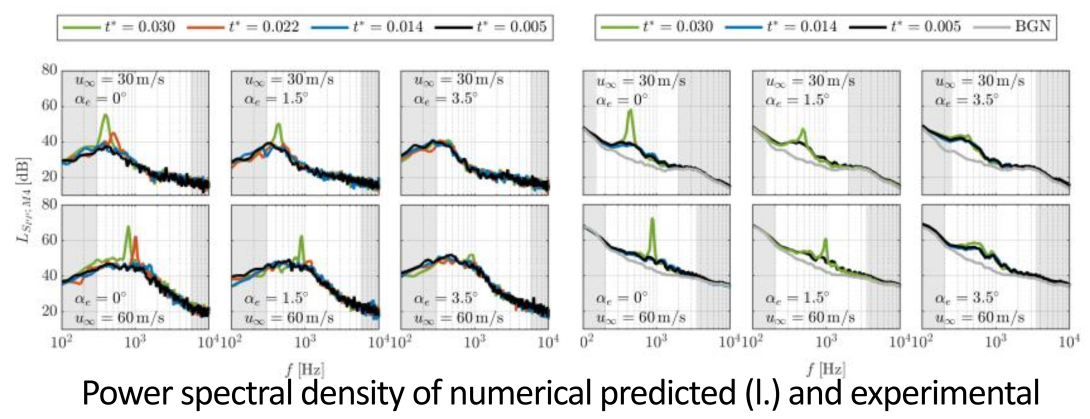
Airfoil and parameters





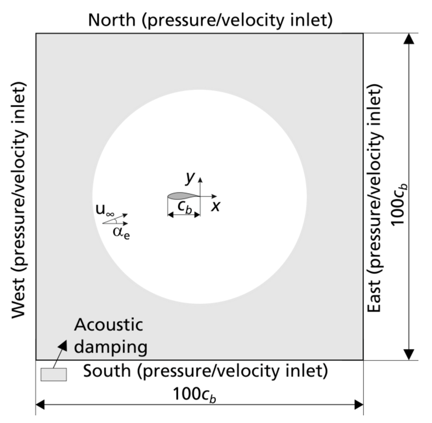
- Cambered airfoil DU93W210
- Truncation of airfoil
  → Different degrees of bluntness t^*
- From moderate to high Re_c
- Fully turbulent boundary layer

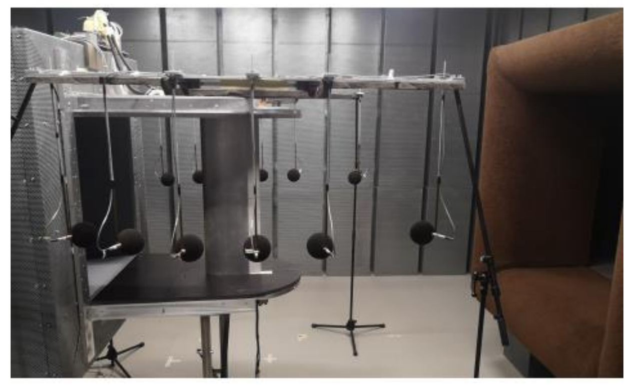
Acoustic results



Power spectral density of numerical predicted (l.) and experimental measured (r.) far-field noise captured at microphone position M4: Effect on degree of bluntness t^*, Re_c, and angle of attack a_e.

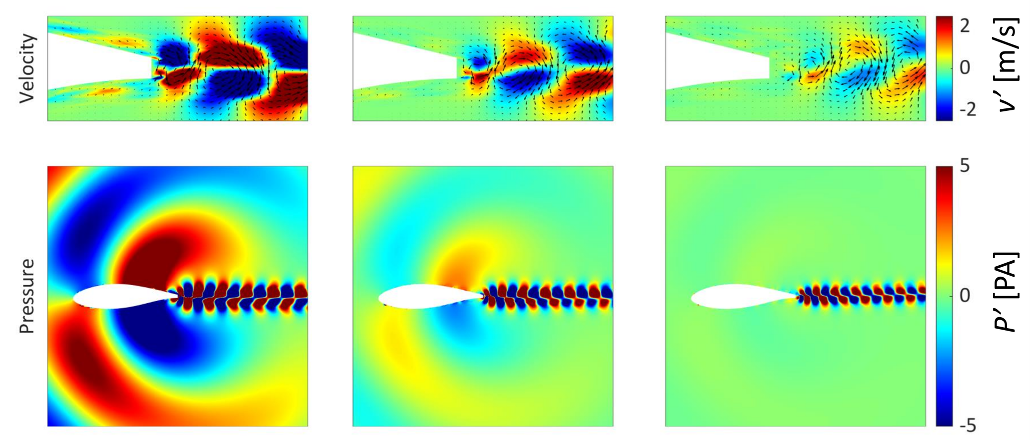
Numerical and experimental setup





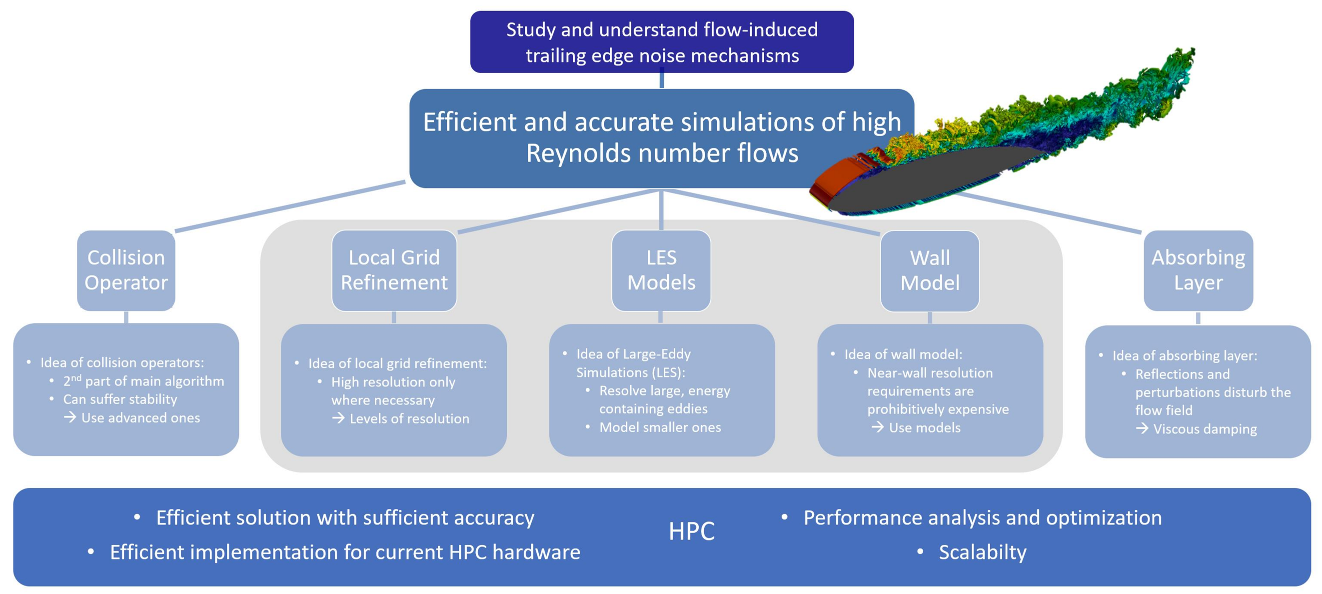
Numerical setup for lattice-Boltzmann simulation (l.) and experimental setup in the aeroacoustic wind tunnel at the University of Siegen (r.)

Transient flow field results

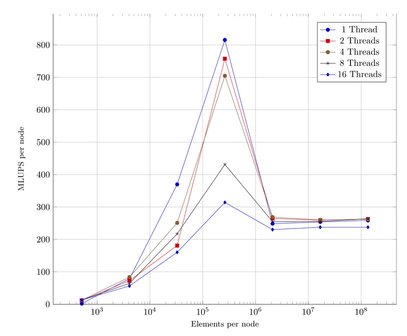


Reconstructed velocity and pressure field at peak frequency for t^*=0.03, u_∞=60 m/s and angles of attack a_e=0°, 1.5°, and 3.5° (from left to right)

Efficient and economical computational modeling



Performance measurements

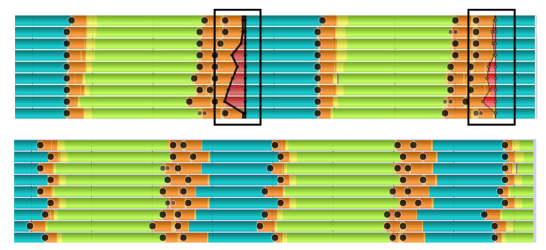


Performance map on a single node for different number of threads utilizing all 128 cores.

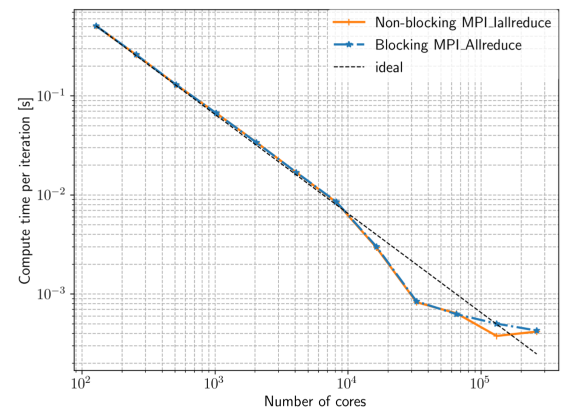
Operational parameters

- 8 *OpenMP* threads per process
- 512 nodes
- Roughly 2 million elements per node
- Non-blocking reduction in health checks
- Interval length 5

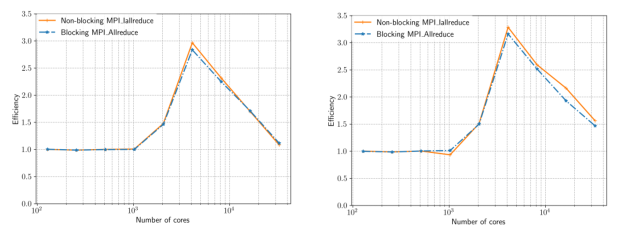
New feature: non-blocking collectives for health checks



Comparison of traces for blocking (top) & non-blocking (bottom, delayed) health check. Computations are green & blue, communication brown, Allreduce red.



Compute time per iteration of *Musubi* on *Hawk* using 1 to 2, 048 nodes. Strong scaling measurement for 134, 217, 728 elements with non-blocking (orange) and blocking (blue) reduction. A dashed black line indicates ideal scaling.



Efficiency of *Musubi* on *Hawk* using 1 to 256 nodes for different check intervals: 1 (left) and 5 (right). Strong scaling measurement for 16, 777, 216 elements with non-blocking (orange) and blocking health check (blue).

Acknowledgement and publications

[1] Oerlemans, S., Sijtsma, P., Mendez Lopez, B. (2007) . Location and Quantification of Noise Sources on a Wind Turbine. Journal of Sound and Vibration.

[2] Spinelli, G. G., Horstmann, T., Masilamani, K., Soni, M. M., Klimach, H., Stück, A., & Roller, S. (2023). HPC performance study of different collision models using the Lattice Boltzmann solver Musubi. Computers&Fluids **255**(105833).

[3] Bald, A., Stahl, K., Foysi, H., & Roller, S. (2023). Attenuation of low-frequency pressure fluctuations within the test section of an aeroacoustic wind tunnel using Helmholtz resonators. Fortschritte der Akustik. DAGA 2023.

[4] Spinelli, G. G., Gericke, J., Masilamani, K. and Klimach, H. (under review) Key ingredients for wall-modeled LES with the Lattice Boltzmann Method: systematic comparison of collision schemes, SGS models, and wall functions on simulation accuracy and efficiency for turbulent channel flow. Discrete and Continuous Dynamical Systems Series S.

[5] Gericke, J., Klimach, H., Ebrahimi Pour, N., Roller, S. (2023). Using MPIs Non-Blocking Allreduce for Health Checks in Dynamic Simulations. Parallel and Distributed Computing, Applications and Technologies. PDCAT 2023. Lecture Notes in Computer Science

[6] Hasert, M., Masilamani, K., Zimny, S. et al.: Complex fluid simulations with the parallel treebased Lattice Boltzmann solver Musubi. Journal of Computational Science 5(5), 784-–794 (2014)

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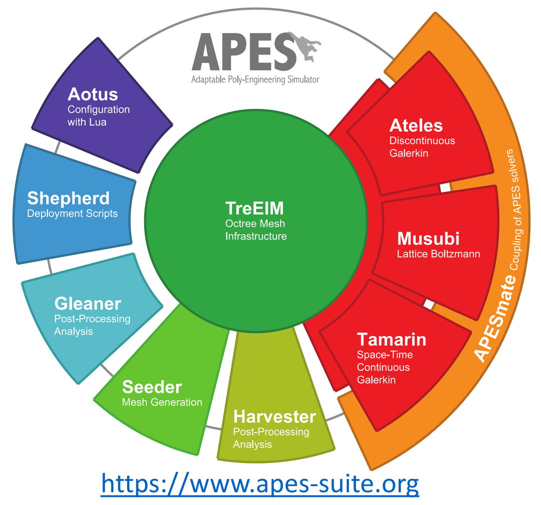
Software

APES – **A**daptable **P**oly-**E**ngineering **S**imulator – is a massively parallel CFD framework providing pre- and post-processing tools. APES relies on a common octree-based library and follows a modulare approach with dedicated tools for different purposes like the Lattice-Boltzmann solver Musubi.

Preliminary simulations with:

SIMULIA PowerFLOW™, version 2020 R1



https://www.apes-suite.org

Next Steps

High-fidelity runs utilizing Musubi with:

- Vreman LES model
- Musker wall model
- MRT & Cumulant collision scheme
- Refinement of the mesh
  → ~ 1 billion elements
- Domain extension in spanwise direction

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