CHARACTERIZING AIRFLOW TURBULENCE IN THE ACOUSTIC WIND TUNNEL BRAUNSCHWEIG (AWB) USING TURBULENCE GRIDS

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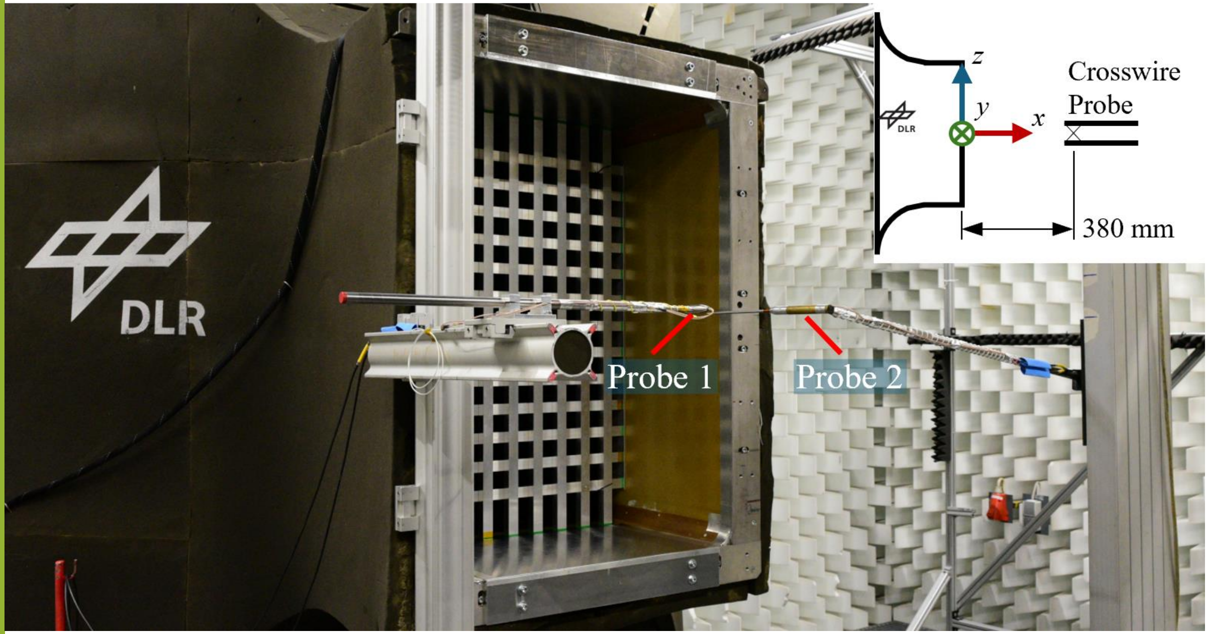
- Experimental Setup
- Numerical Setup
- Results
- Conclusions

Introduction

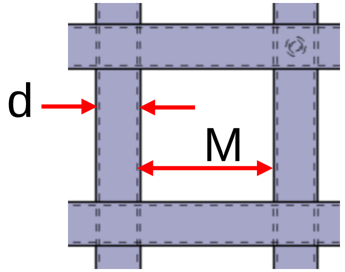
- Wind turbines immersed in atmospheric turbulence with eddies on a scale larger than the leading edge radius of the blade profile leads to excess noise radiated from the leading-edge.
- Wind tunnels are configured to have minimal inflow turbulence, hence unsuitable for leading-edge noise study.
- A turbulence grid generator is a well-known device to produce homogeneous and isotropic turbulence.
- In this study, the Acoustic Wind Tunnel Braunschweig is equipped with turbulence grid generators to produce large scale turbulence for the purpose of leading-edge noise research.
- Isotropy is not a constraint as anisotropy can be present in the atmosphere.

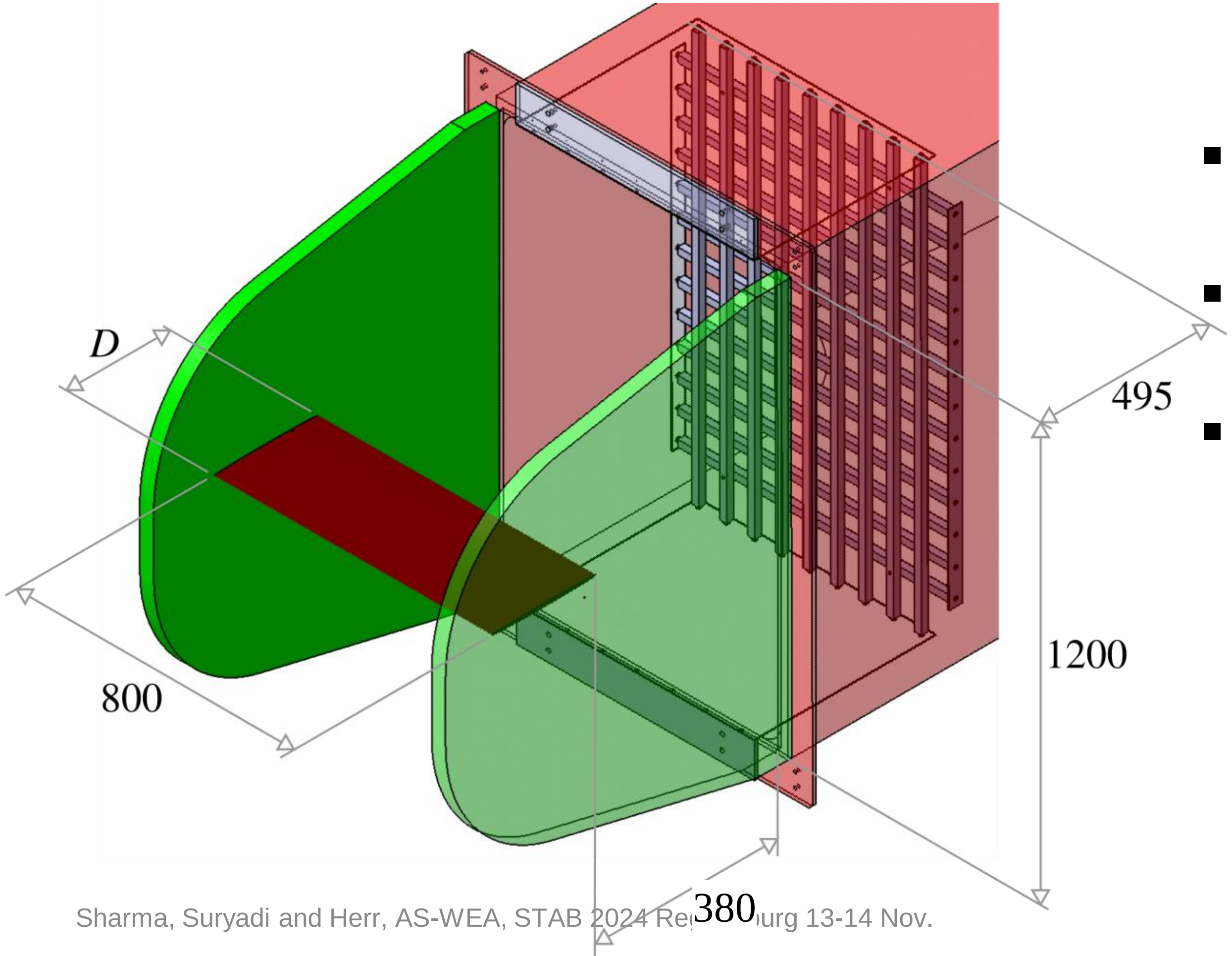
Experimental Setup



- Acoustic Wind Tunnel Braunschweig,
  - Max wind speed= 65 m/s
  - 0.3% turbulence intensity
  - Anechoic at f> 200 Hz
- HWA: 2 X-wire probes
  - Probe 1: stationary
  - Probe 2: traversing in *x, y, z*
- Probes are placed at x= 380 mm (<10 mm from the leading edges of NACA 0012 and NACA 66-006)
- SR= 50 kHz, T=10s
- Discussion today is focused on flow measurements.

Turbulence Grid



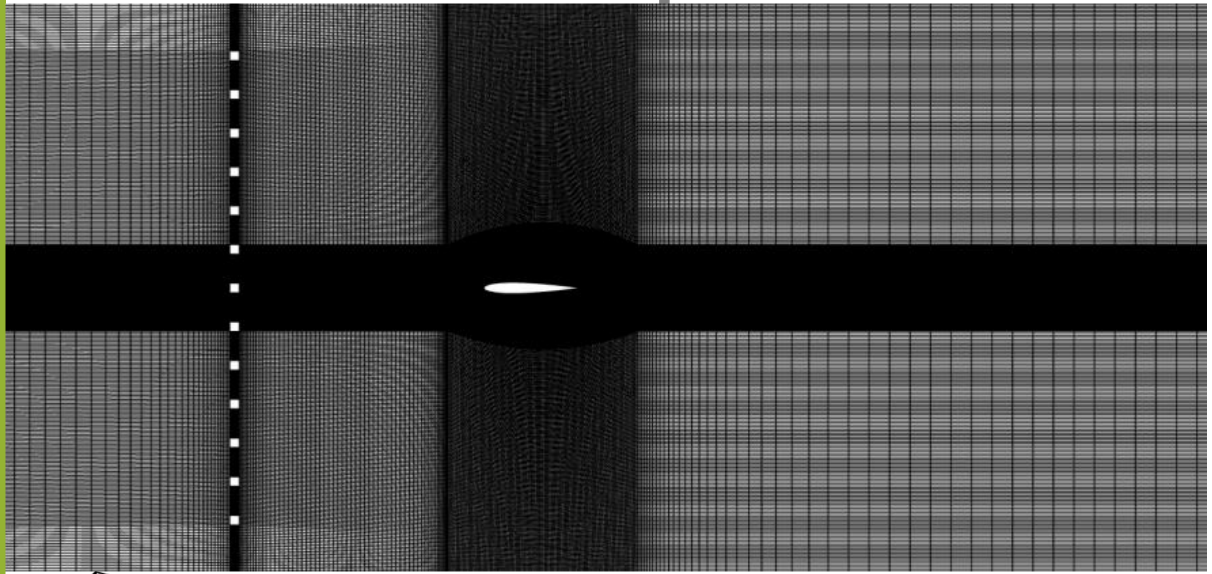


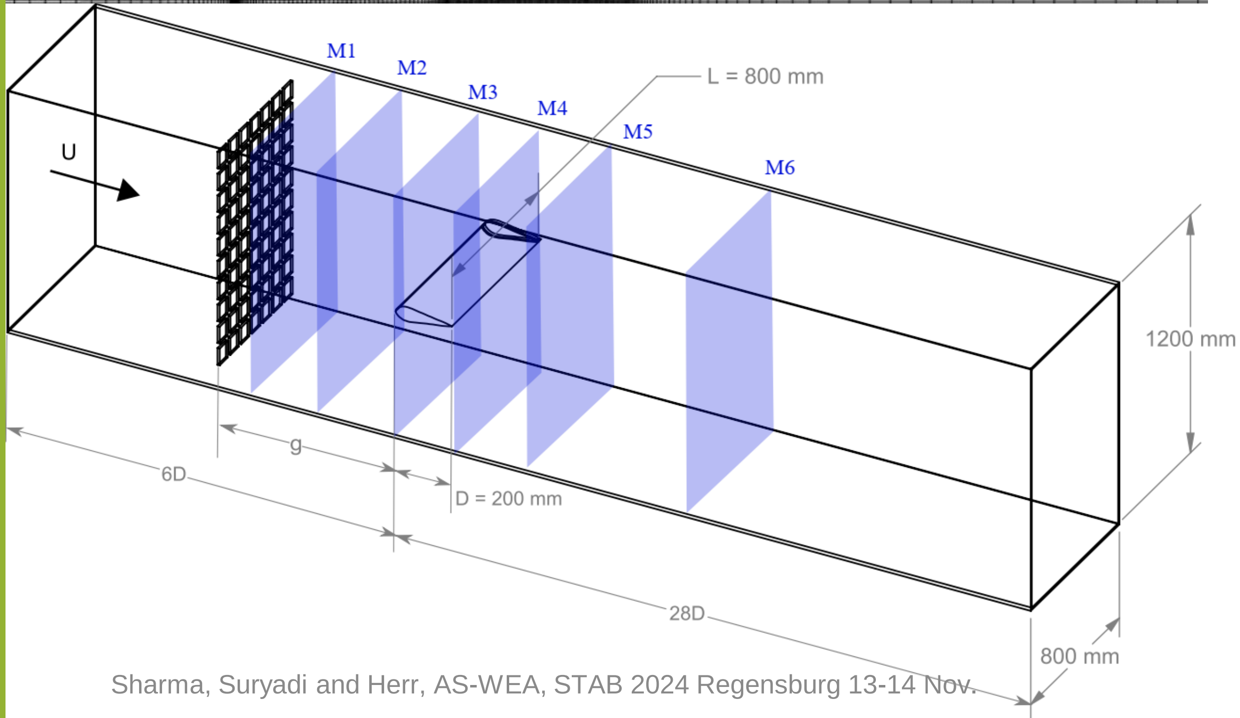
- Grid is placed 495 mm inside the nozzle held by 2 plates top and bottom of the nozzle fastened to the outside frame of the nozzle
- Vertical and horizontal square-profiled aluminium pipes: *d* x *d* mm, spaced by *M*
- 4 fastening points between the vertical and horizontal bars
- Side panels connects horizontal bars with each other
- Blockage ratio >33% reduces maximum velocity below 40 m/s

Grid	Blockage Ratio, %	$\max(U_\infty)$, m/s
20×20_M60	39.3	30
20×20_M140	22.7	40
30×30_M50	55.3	20
30×30_M130	33.0	40
40×40_M120	42.5	25

Anisotropic Isotropic

Numerical Setup

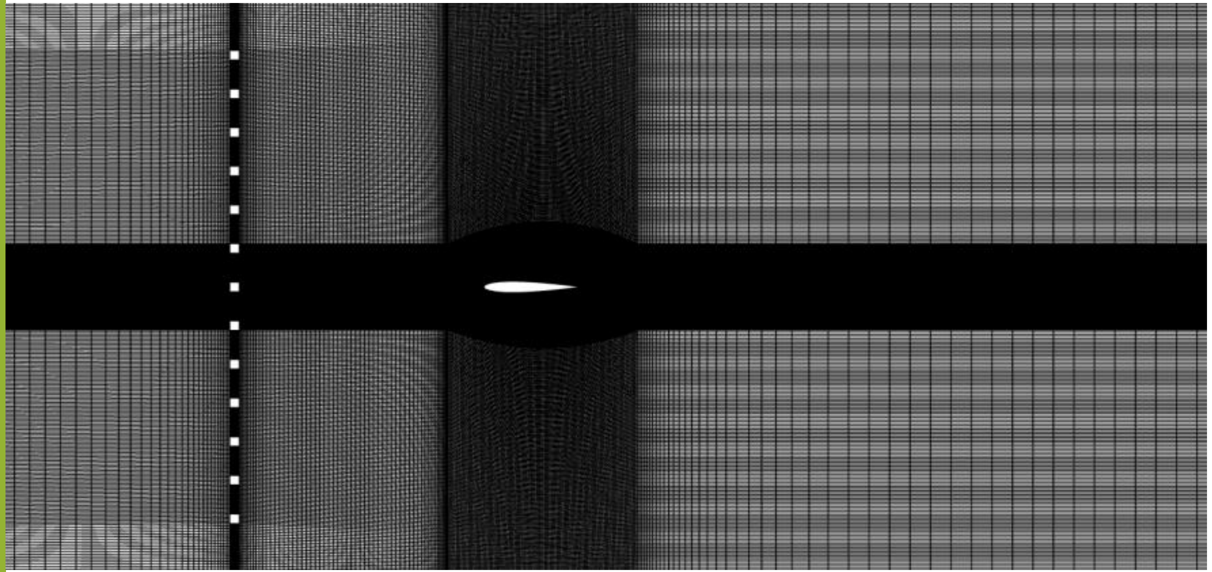


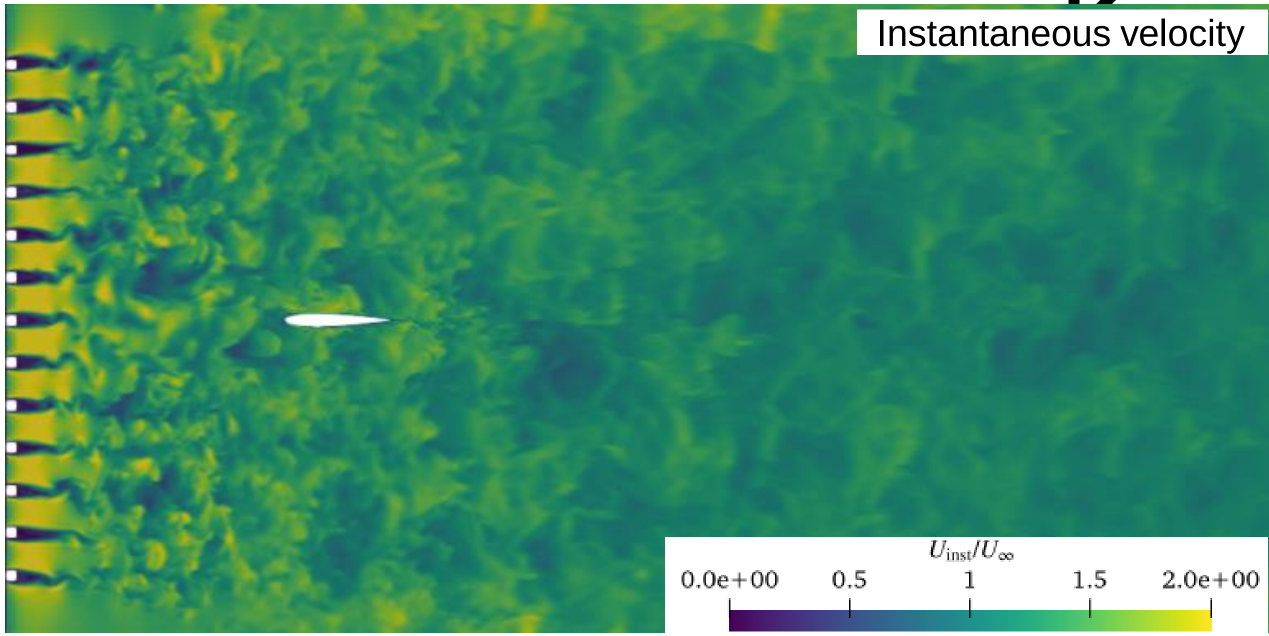


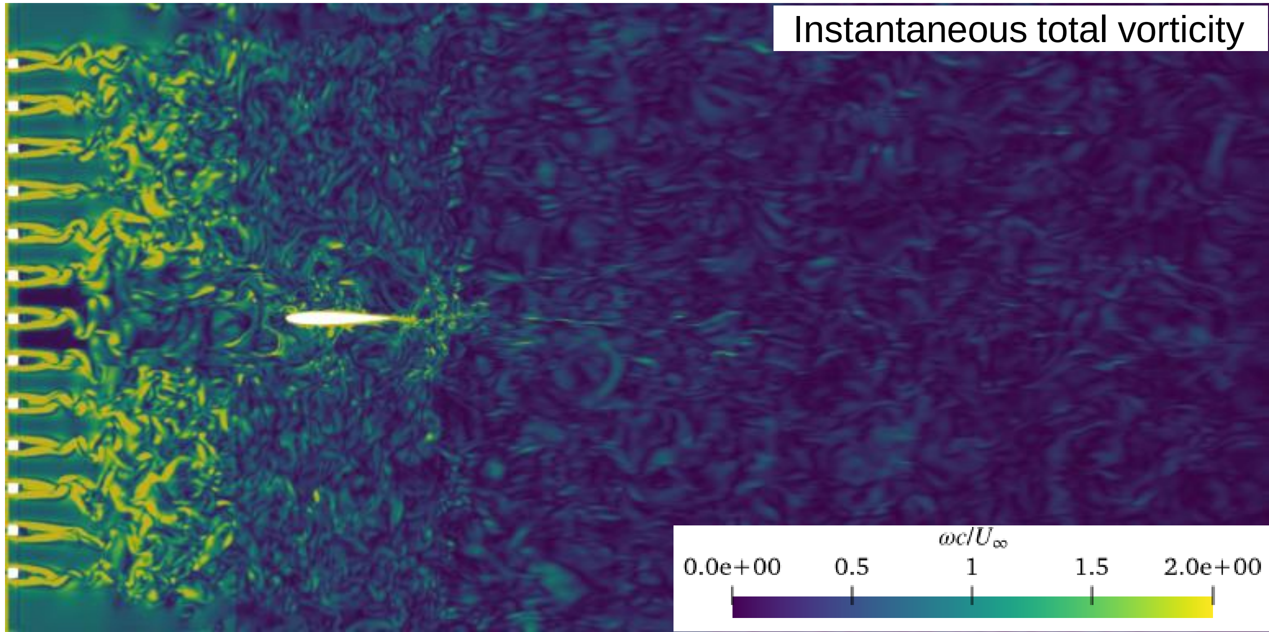
- LES implemented in OpenFoam
- Smagorinsky SGS
- Upper, lower boundary: symmetry planes
- Sides: periodic boundary conditions
- Airfoil and grid: no-slip walls
- Mesh refinement near airfoil, y+<1
- 20.6 Million cells
- Nozzle is not defined in the simulation

Results

Numerical



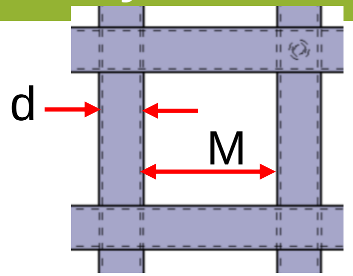




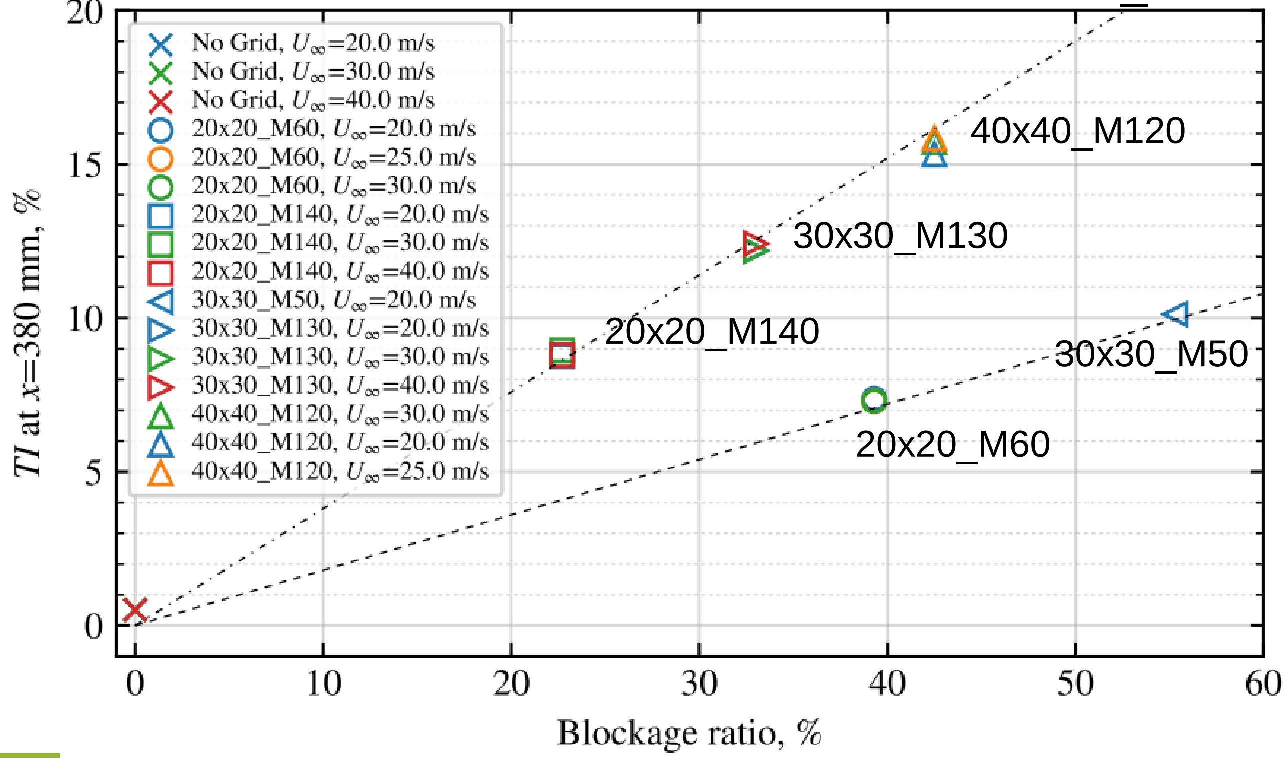
Results

Blockage Ratio vs Turbulent intensity

$$TI = \frac{\sqrt{\overline{u'u'}}}{\sqrt{U^2 + V^2 + W^2}} \times 100\%.$$



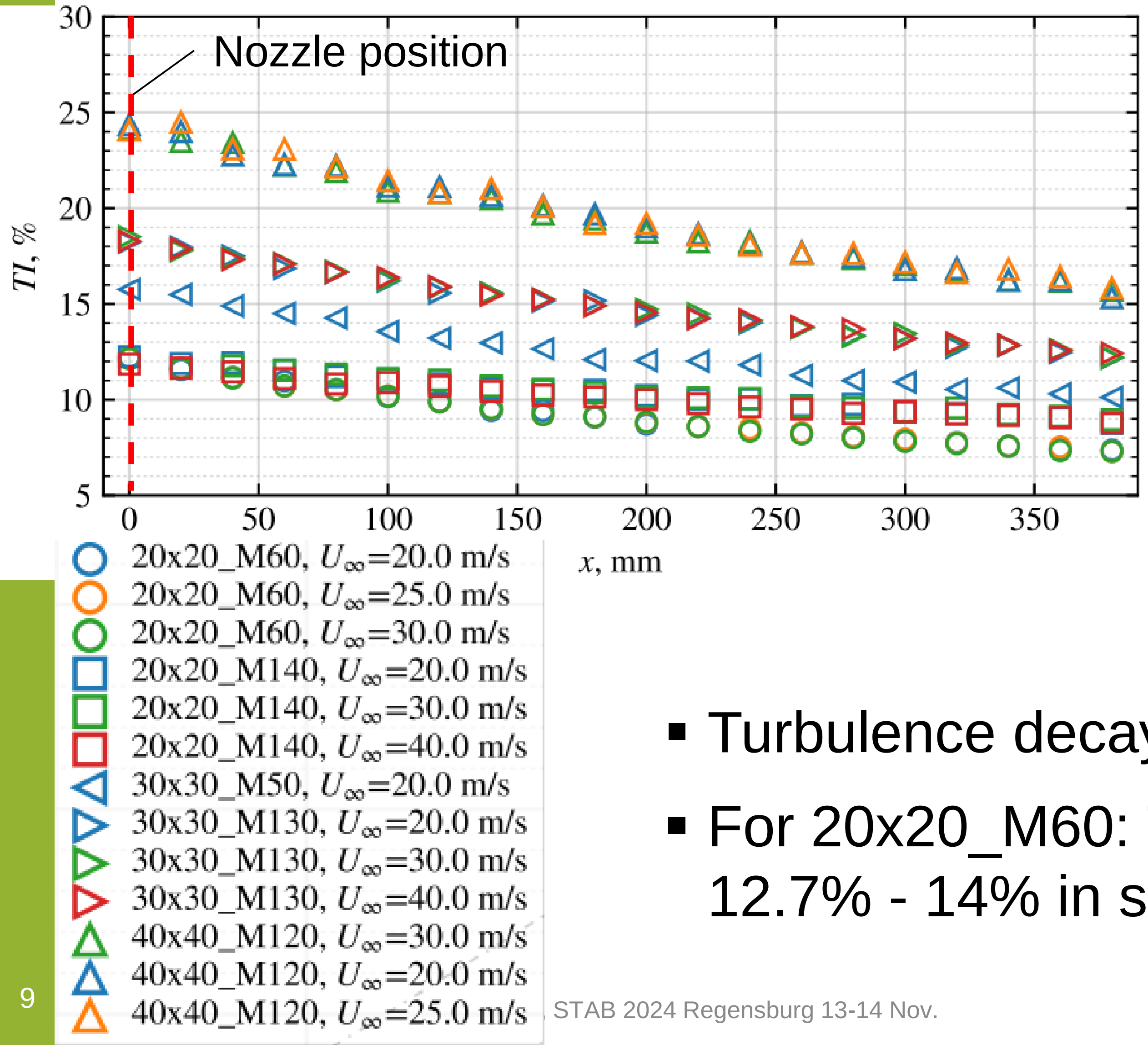
Grid: *d*x*d*_M*M*

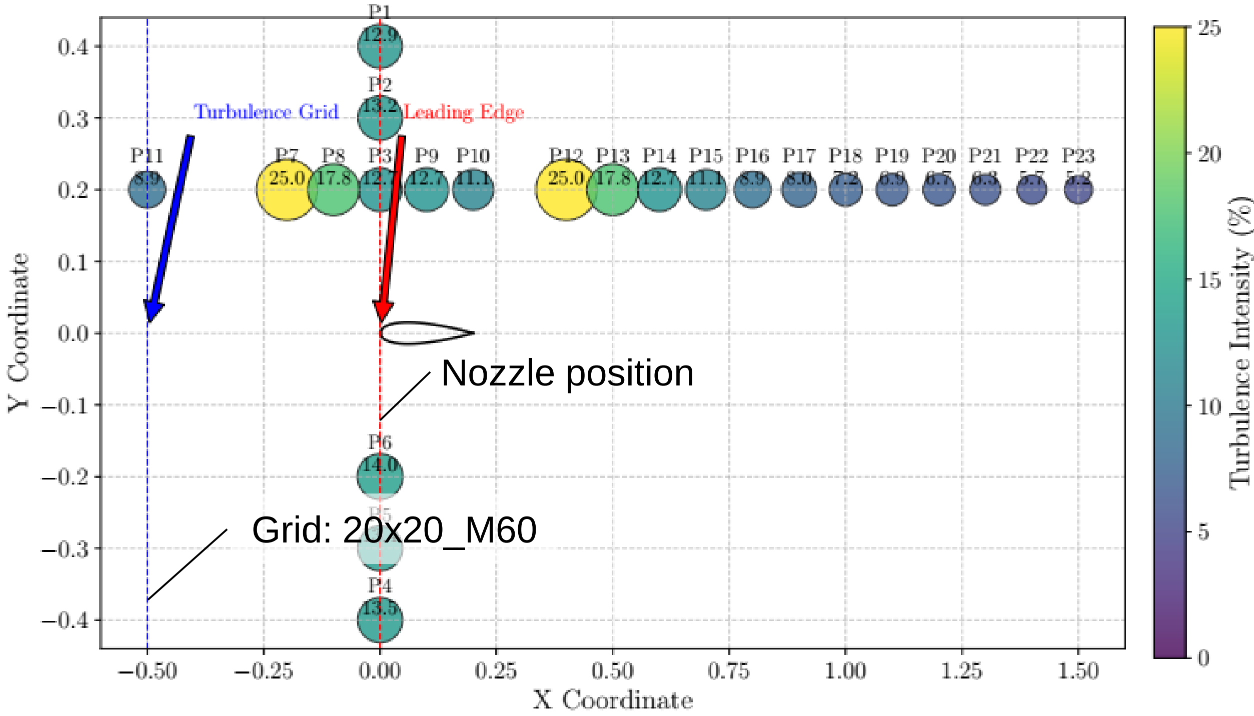


- Measured 875 mm downstream of grid
- Increased grid spacing reduces the blockage ratio but slightly increases the turbulence intensity
  - For d=20 mm, M60 → M140.
  - For d=30 mm, M50 → M130
- For approximately equal spacings, Turbulence intensifies with *d*

Results

Turbulent Intensity





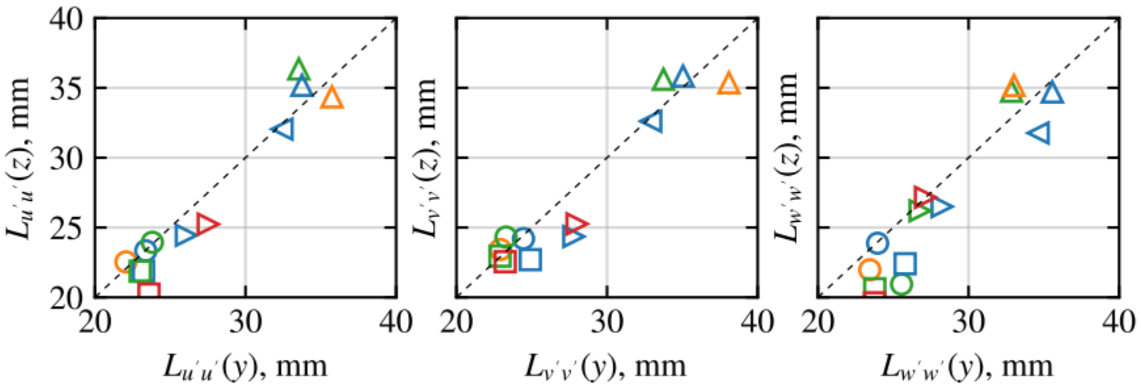
- Turbulence decay with *x*
- For 20x20_M60: Turbulence intensity at nozzle, *x*=0 mm, 12.7% - 14% in simulation, 12.5% in measurements.

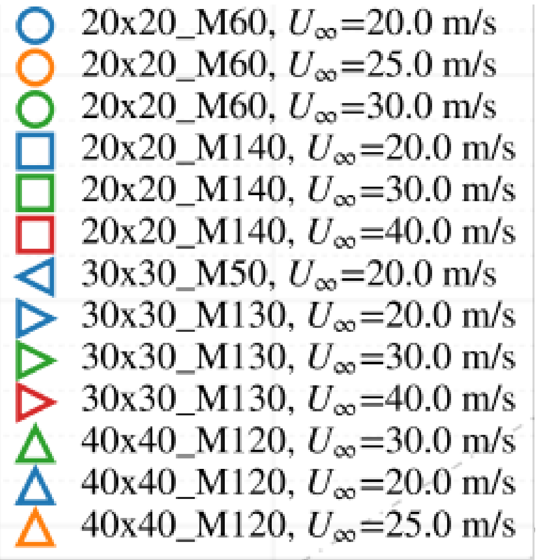
Results

Isotropy

$$L_{u'_i u'_i}(x_j) = \int_0^\infty R_{u'_i u'_i}(r)\,\mathrm{d}r,$$

u’: stream vel., v’: vertical vel., w’: span vel.





- Integral length scales in span (*y*) and vertical (*z*) directions.
- $L_{u'u'}$ and $L_{v'v'}$:
  - M60 and M50 produce equal length scales in both direction.
  - Larger spaced grids are more spread.
- $L_{w'w'}$:
  - No agreement with the diagonal line
  - Turbulence grid produces an approximate of isotropic turbulence [1]
- Alteration of the bar spacings to better approximate isotropy or induce more anisotropy

[1] Comte-Bellot and Corssin, 1966, The use of contraction to Improve the Isotropy of Grid-Generated Turbulence JFM 25(4): 657-682

Conclusions

- The effects of turbulence grid in an open-jet wind tunnel was evaluated experimentally and numerically.
- Grid configuration varies the resulting inflow turbulence
  - Equal bar sizes with larger spacings (~2x) reduces the blockage ratio but increases turbulence intensity.
  - Increasing the bar size increases the blockage ratio and turbulence intensity
- The present study allows for the optimization of grid designs for wind energy applications.

<u>Perspectives:</u>

- Numerical simulation of the empty tunnel
- Analysis of leading-edge noise measurements
- Simulation of leading-edge noise
- Characterize the turbulence from WiValdi Research Wind Park at Krummendeich

Impressum

Thema: Characterizing Airflow Turbulence in the Acoustic Wind Tunnel Braunschweig (AWB) using Turbulence Grids

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Integral Length Scale

$$L_{u'_i u'_i}(x_j) = \int_0^\infty R_{u'_i u'_i}(r)\,\mathrm{d}r,$$

$$\begin{aligned} R_{u'_i u'_i}(r) &= \langle u'_i(x,t)u'_i(x+r,t+\tau_m)\rangle \\ R_{u'_i u'_i}(\tau_m) &= \max\left(R_{u'_i u'_i}(\tau)\right) \\ R_{u'_i u'_i}(\tau) &= \langle u'_i(x,t)u'_i(x+r,t+\tau)\rangle \end{aligned}$$

- ○ 20x20_M60
- ◁ 30x30_M50
- □ 20x20_M140
- ▷ 30x30_M130
- △ 40x40_M120