Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Low-Noise Technologies for Wind Turbine Blades

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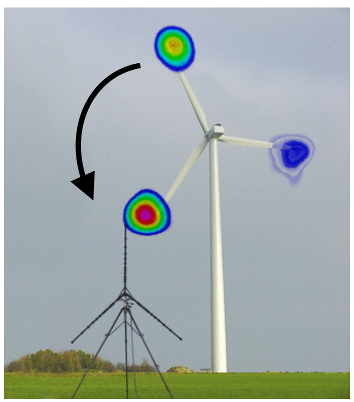
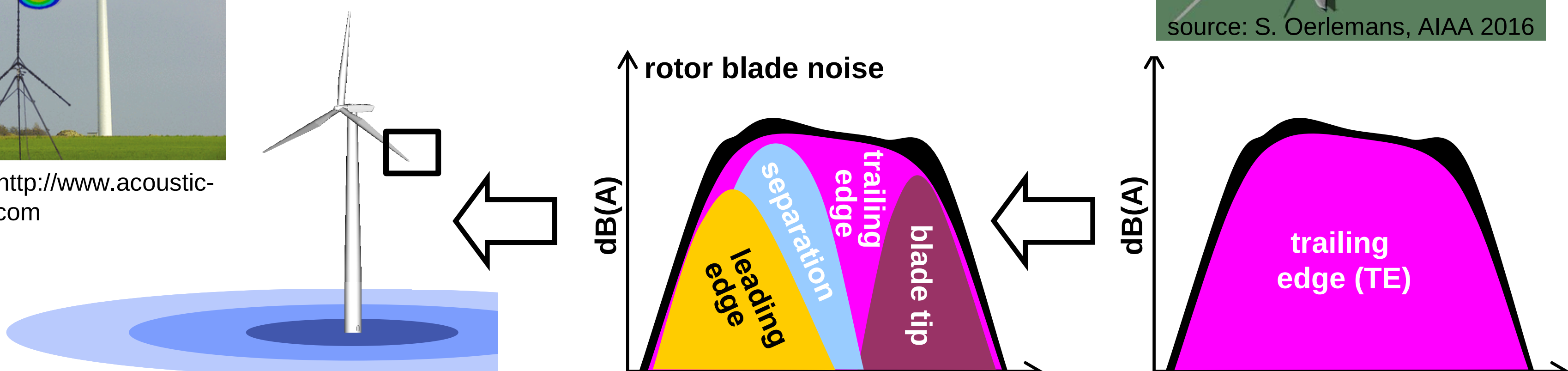
Background

- Modern large turbines typically involve sufficient treatment of machinery noise, so that mainly flow-induced noise by the blades contributes to the total noise emission.
- Trailing-edge noise (TEN) in the outer 20–25% of rotor radius is the dominant contributor to total wind turbine noise.
- Knowledge from aerospace-related TEN studies & applications can be directly transferred due to same noise generation (& reduction) mechanisms.



Source: http://www.acoustic-camera.com

source: S. Oerlemans, AIAA 2016



source: R. Drobietz, GE Wind Energy

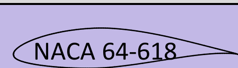
Research aim in BELARWEA

Blattspitzen für Effiziente und Lärmarme Rotoren von Windenergieanlagen

- Development and validation of improved methods for the design of both efficient and low-noise wind turbine rotors, i.e. high-fidelity 2D/3D CFD- & CAA- methods for
    - 2D profile design
    - 3D winglet design
- Demonstration of minimum 3-dB noise reduction for given rotor performance through 3D redesign of outer 20% of rotor radius (phase 1: in AWB & DNW-NWB wind tunnels)
- Adaptation of passive noise reduction technologies from aerospace applications

‘DESIGNBOX‘ (struct. & aero. constraints) @ scaled NREL-5MW reference rotor

2D-profile design:



XFOIL → polars (forces + moments)

2D CAA → noise driving parameters ‘acoustic profile catalogue‘

→ **variant 1: rotor blade with new profile @ outer 20% R**

3D-blade design:

Lifting line method + CFD

3D CAA → aeroacoustic analysis

→ **variant 2: rotor blade with winglet @ outer 4% R (→ reduction of R)**

→ **TE add-ons to reference / variant 1 / variant 2**

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TODAY'S PRESENTATION

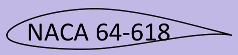
Research aim in BELARWEA

Blattspitzen für Effiziente und Lärmarme Rotoren von Windenergieanlagen

- Development and validation of improved methods for the design of both efficient and low-noise wind turbine rotors, here: high-fidelity 2D CFD- & CAA- methods for
    - 2D profile design

- Demonstration of minimum 3-dB noise reduction for given reference performance in AWB wind tunnel
- Adaptation of passive noise reduction technologies from aerospace applications

2D-profile design:



2D CAA

→ **aeroacoustic assessment of new profile design RoH-W-18%c37**

→ **TE add-ons to reference / new profile**

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Scope

- **Part 1: Experimental approach**
  → Limitations of current TEN data sets (TEN benchmarks)

- **Part 2: 2D Numerical approach**

- **Part 3: Results**
  → Results for design conditions vs. wind tunnel conditions
  → Comparison of numerical with experimental data
  → Noise reduction potential of porous TE extensions

Part 1: Experimental approach

TEN measurements

Experience from ongoing TEN benchmark activities (AIAA BANC* workshops)

- TEN is a very low intensity noise source, i.e. focusing measurement technos. or specific source correlation technologies are necessary!

- High-quality measurements are challenging, in particular, if efficient noise reduction devices are applied!
  - Single free-field microphone measurements will contain all existent facility-inherent extraneous noise sources & TEN is generally masked
  - Side-plate / model junction noise sets low frequency limit (≥ 1–1.25 kHz in the current study) → TEN maximum often located at these low frequencies!

- TEN benchmark data are limited (and still reflect a large +/- 3 dB scatter band among test facilities!) because data rely on individual calibrations & source assumptions…

- Combined numerical/experimental approaches are necessary (common rationale behind BANC activity) → reconstruction of the low-frequency range

***BANC: Benchmark Problems for Airframe Noise Computations**

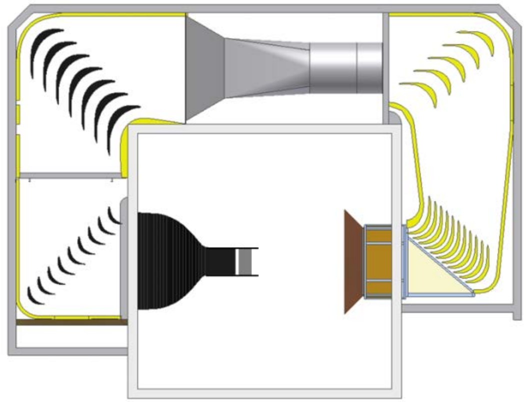
Category 1: TEN 2012: BANC-II-1 2014: BANC-III-1 2016: BANC-IV-1 …

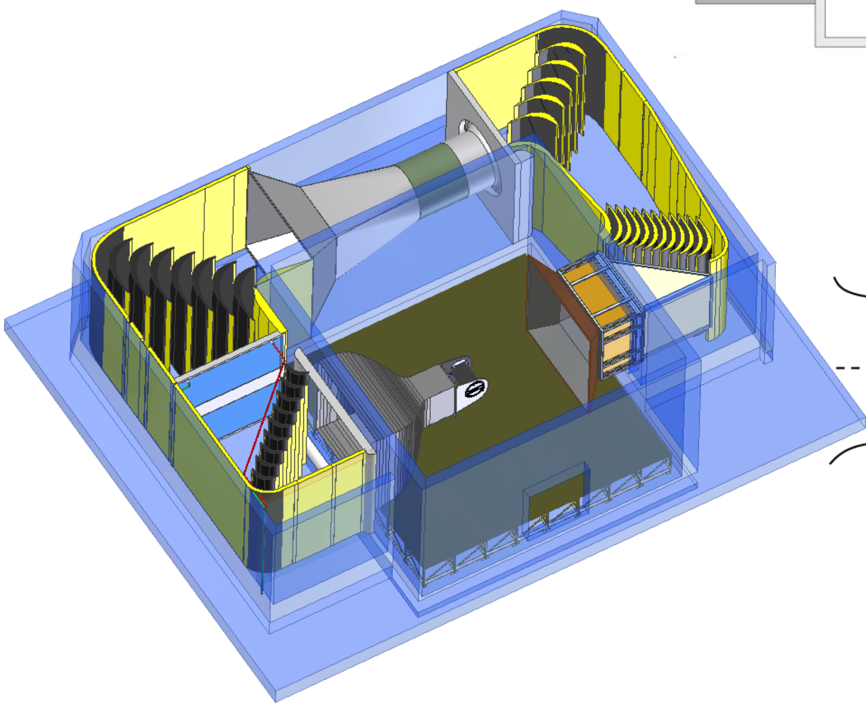
AIAA-2013-2123 AIAA-2015-2847

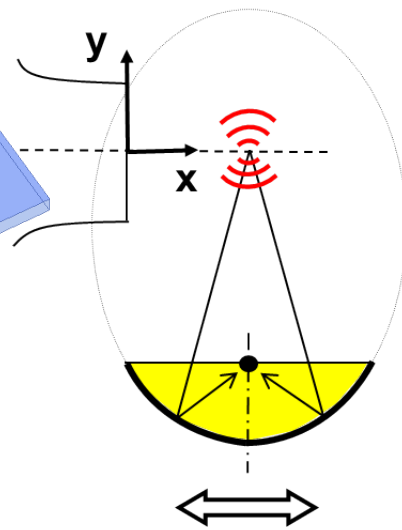
TEN measurements

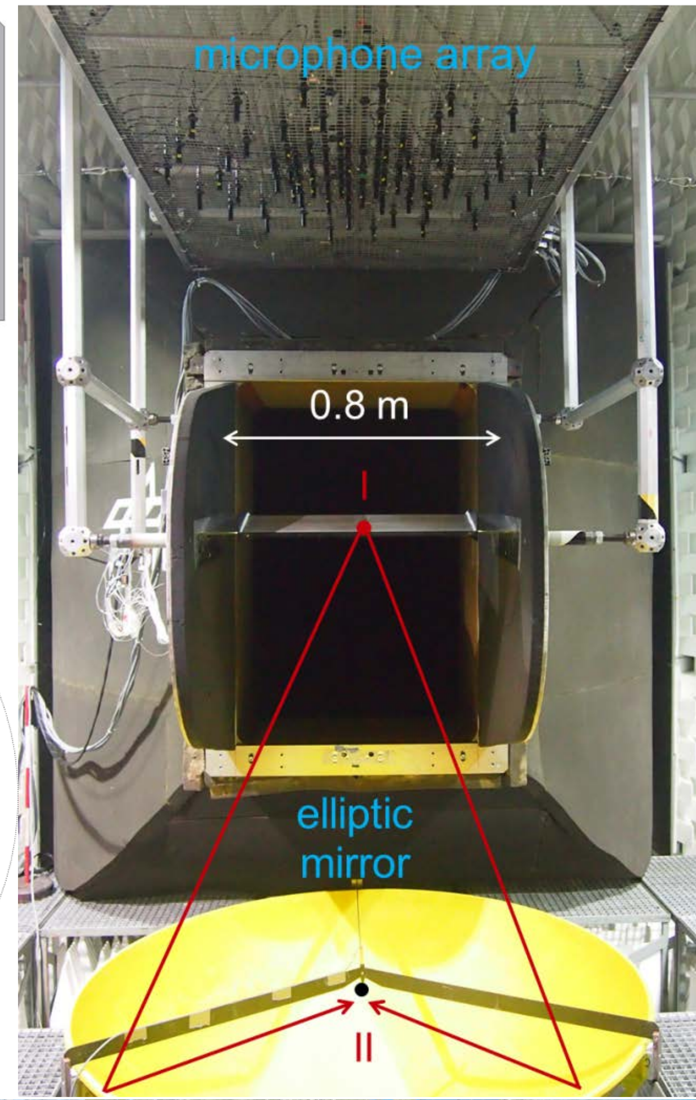
DLR‘s Acoustic Wind Tunnel Braunschweig (AWB)

- AWB operational data:
  - nozzle: 0.8 m by 1.2 m
  - max. speed: 65 m/s
  - Tu < 0.3 % @ 60 m/s









TEN measurements

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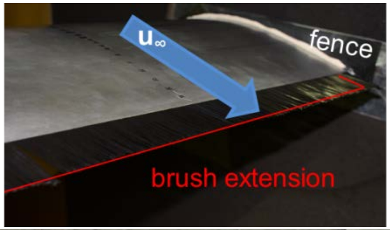
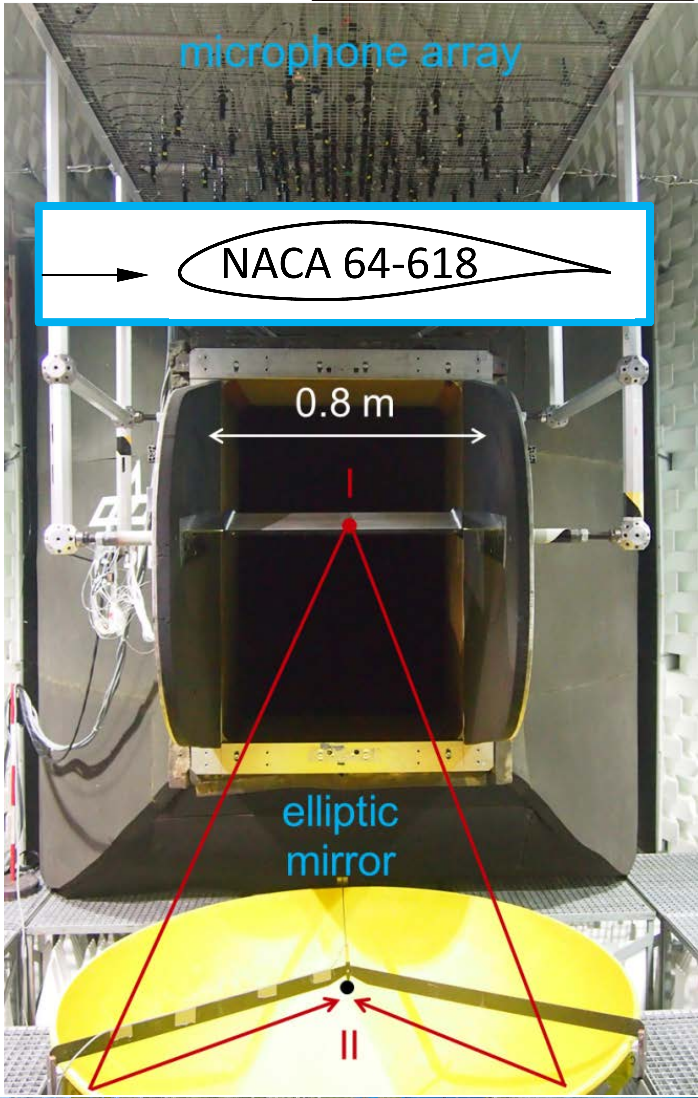
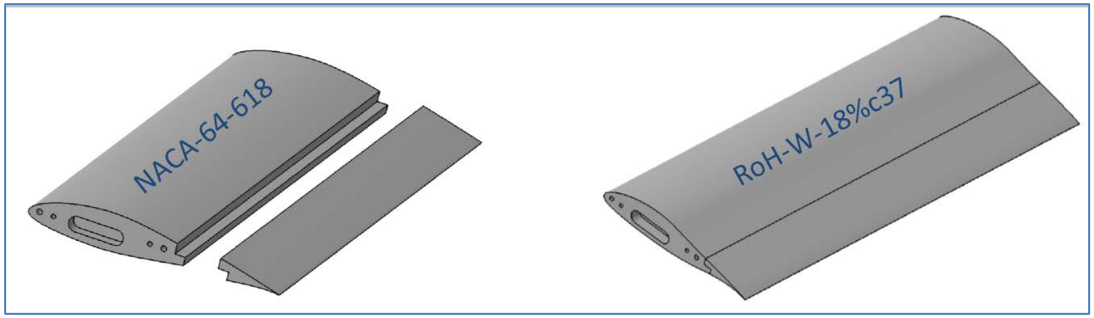
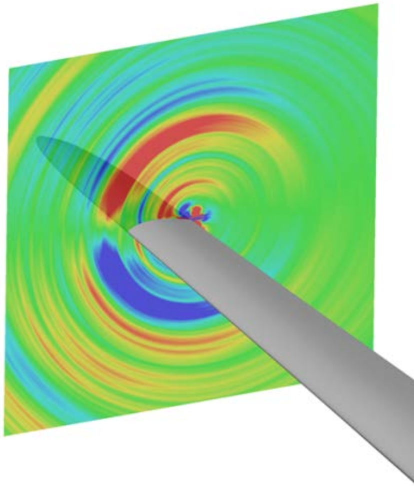


- AWB operational data:
  - nozzle: 0.8 m by 1.2 m
  - max. speed: 65 m/s
  - Tu < 0.3 % @ 60 m/s

- 2 WT blade airfoils:
  - NACA64-618 vs. RoH-W-18%c37 (new low-noise design)
  - profile chord length l_c = 0.3 m (0.8 m span)
  - @ ‘clean’ and ‘tripped’ TBL conditions
  - @ varying a-o-a
  - @ varying WT speeds u_∞ = 40/50/60 m/s (Re_{max} = 1.2 Mio.)



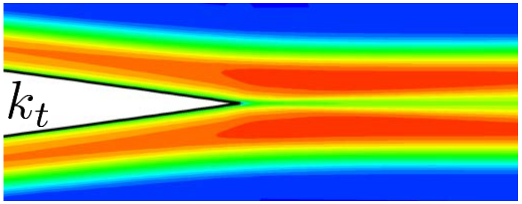


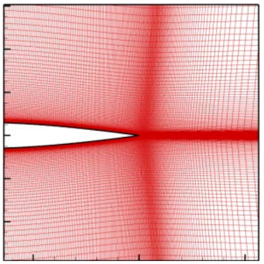


Part 2: Numerical approach

Numerical approach

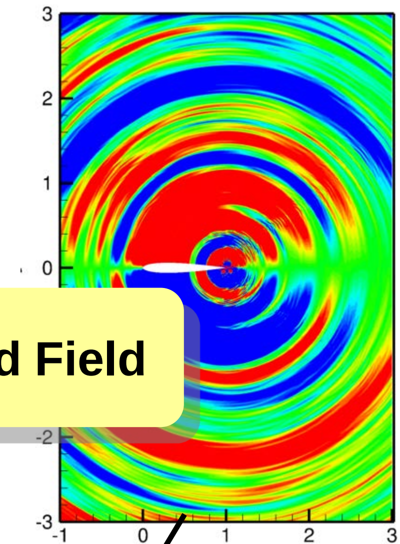
DLR‘s CAA-Code PIANO with stochastic source model FRPM*





mean flow; here:
DLR code TAU
with SST
$\vec{u}_0, \rho_0, p_0$

CFD RANS → **CAA APE** → p' → **Sound Field**

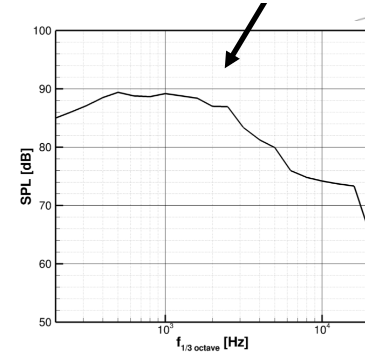


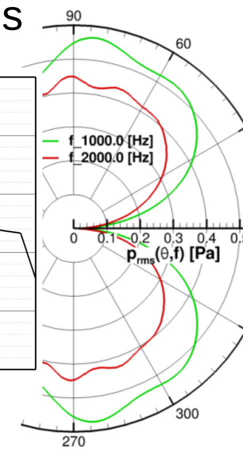
turbulence
k_t, ω

source
$\vec{L}'$

4D-Stochastic Sound Sources FRPM*

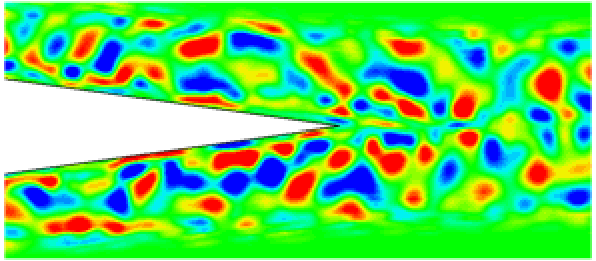
Spectral analysis





vortex sound sources

$$\vec{L}' = -\vec{\omega}_0 \times \vec{u}^t - \vec{\omega}^t \times \vec{u}_0$$

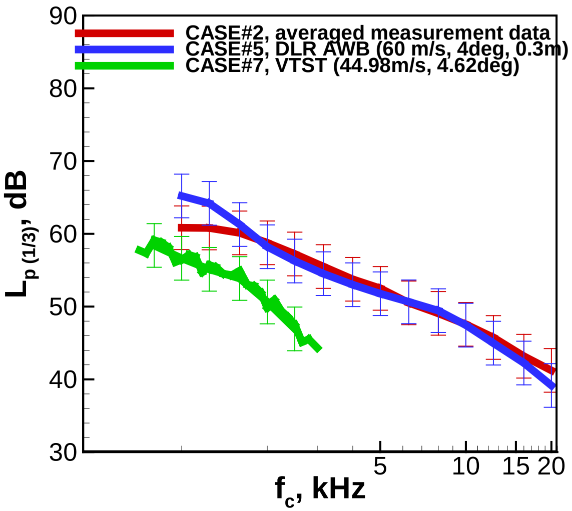


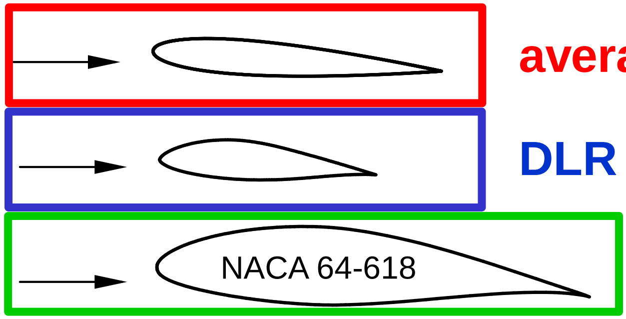
*Ewert, Comp. & Fluids (Vol. 37)

AIAA-2009-3269 AIAA-2014-3298

Example benchmark results

- Overview on selected comparison measurement data from BANC-IV





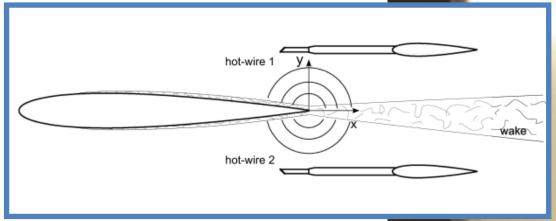
average IAG/DLR – CPV/mirror

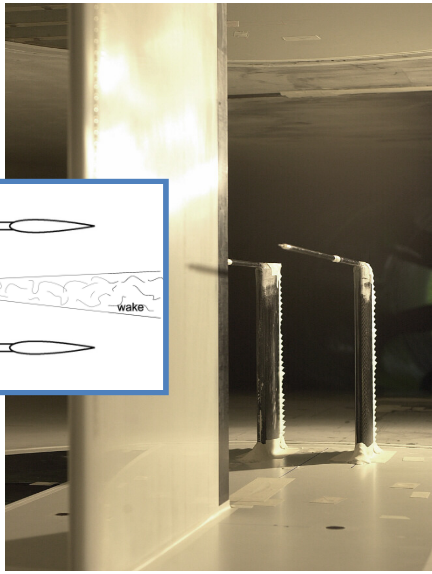
DLR - mirror

DTU/VTST + Kevlar - array

array @ VTST

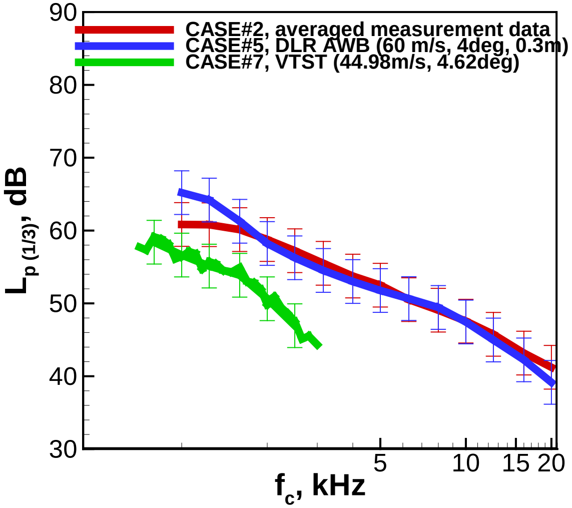
CPV @ IAG LWT

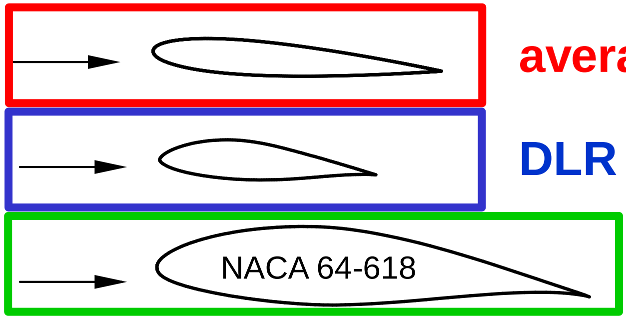




Example benchmark results

- Results are promising & indicate the applicability of PIANO/FRPM for low-noise design purposes!



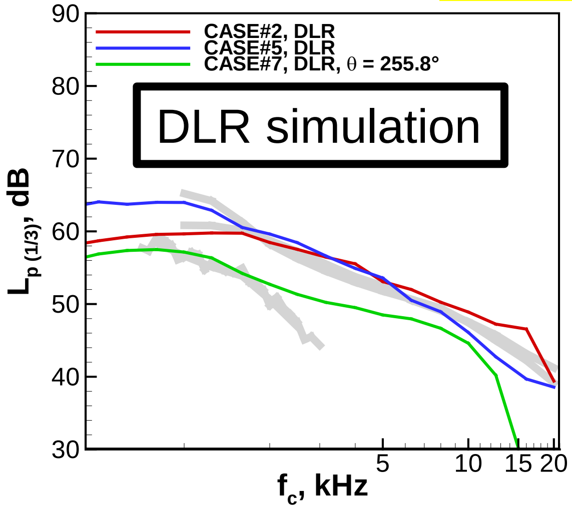


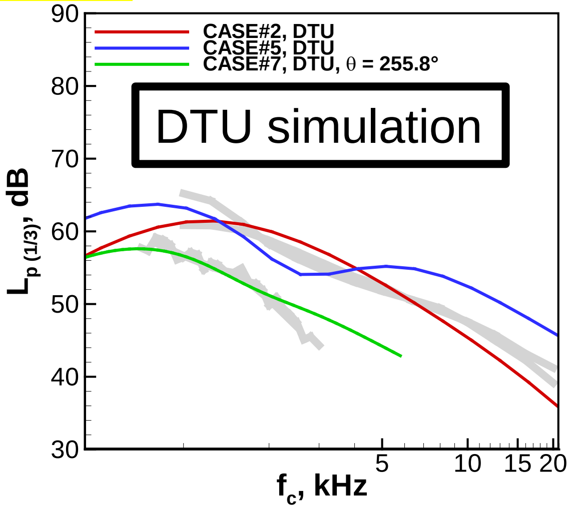
average IAG/DLR – CPV/mirror

DLR - mirror

DTU/VTST + Kevlar - array

BANC-IV-1

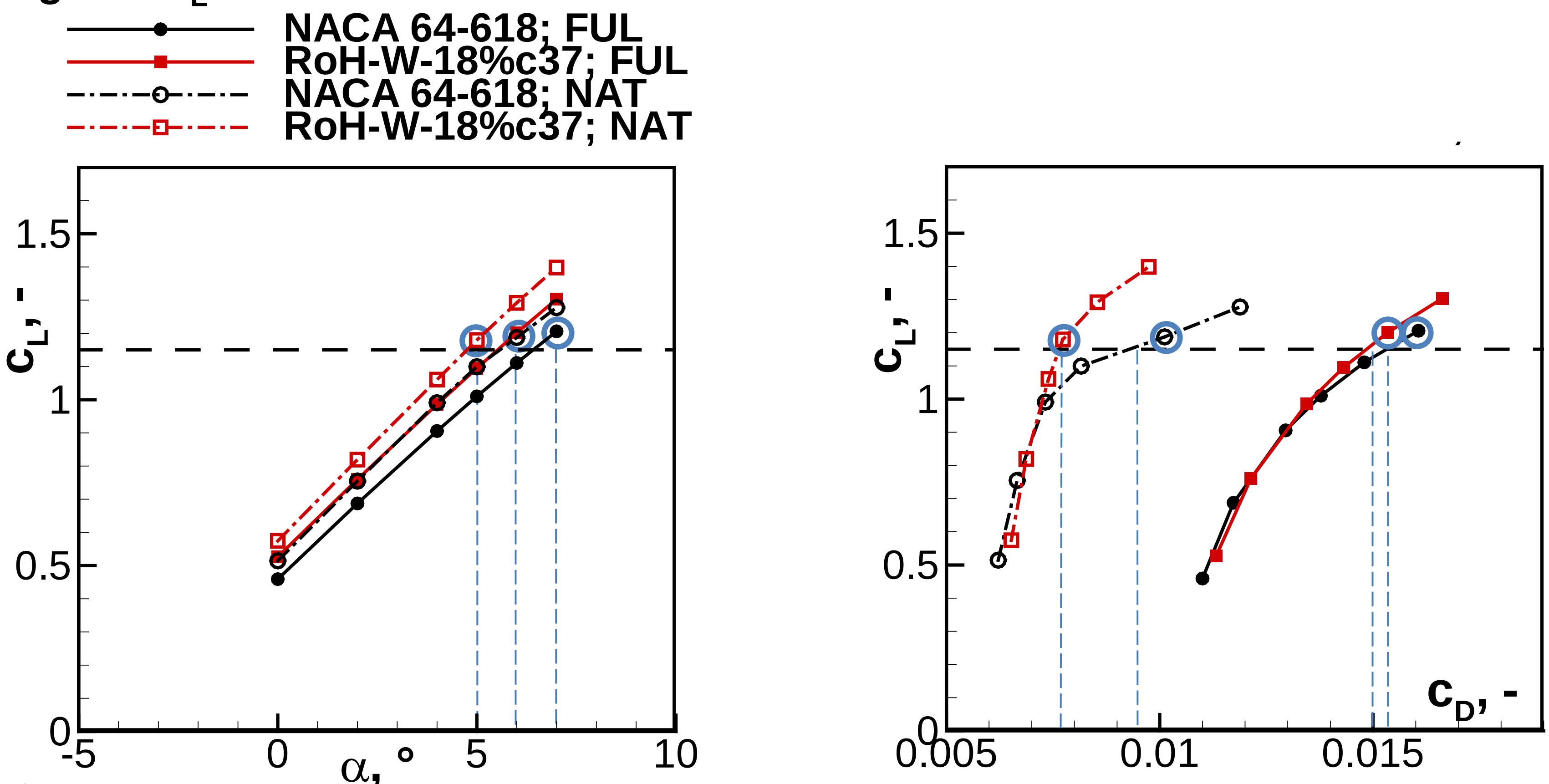




Part 3: Results

Numerical results for design conditions

- Re = **3 Mio**.
- M = **0.2**
- u_∞ = **68 m/s**
- l_c = **0.65 m**
- **targeted c_L = 1.15**



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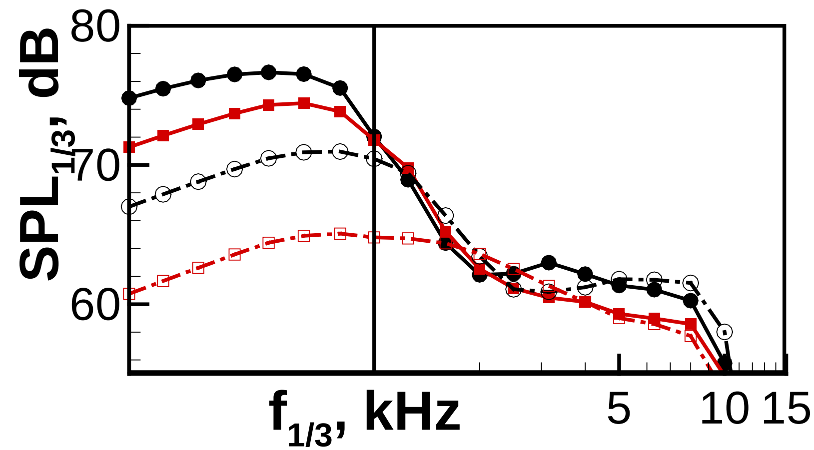

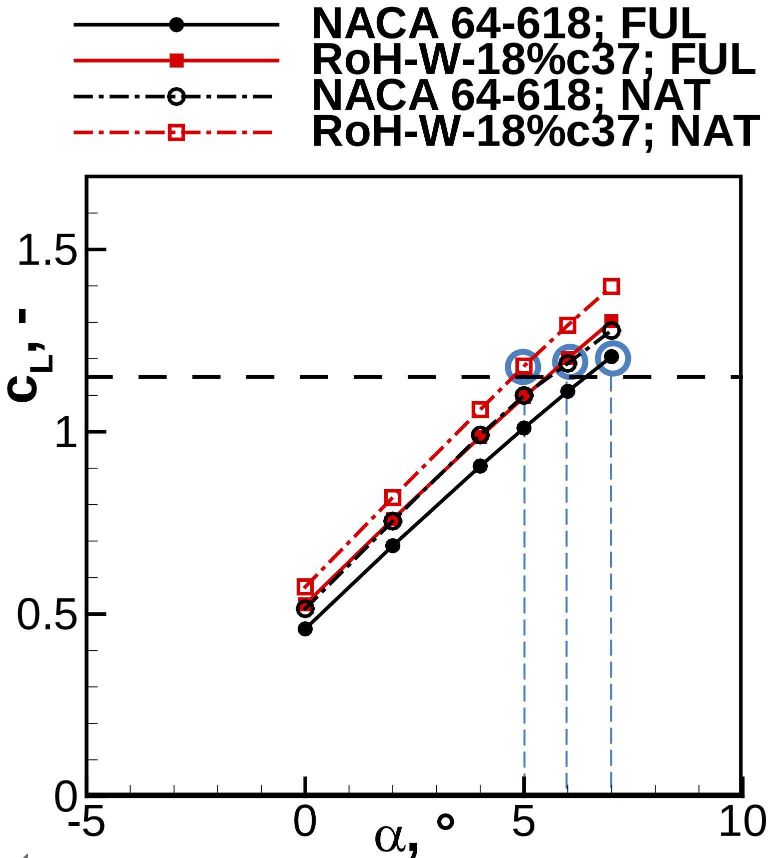

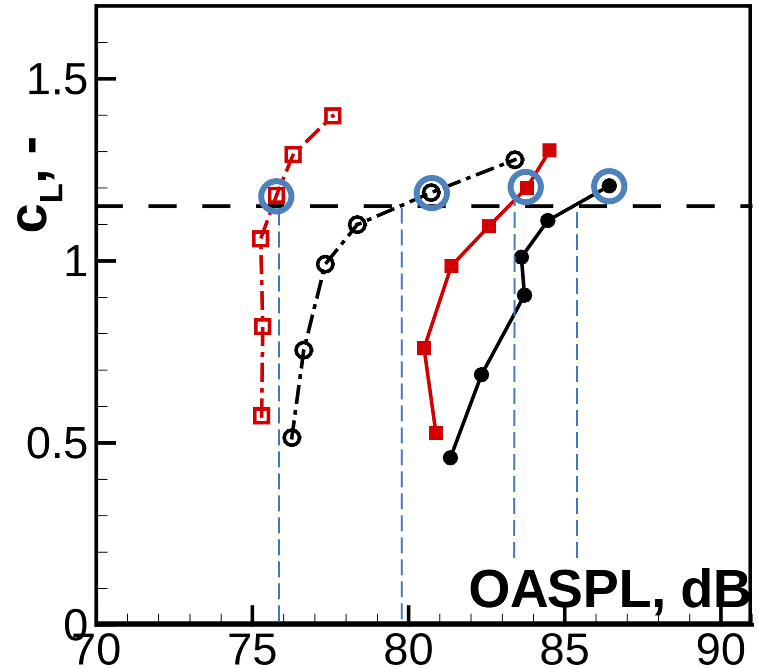

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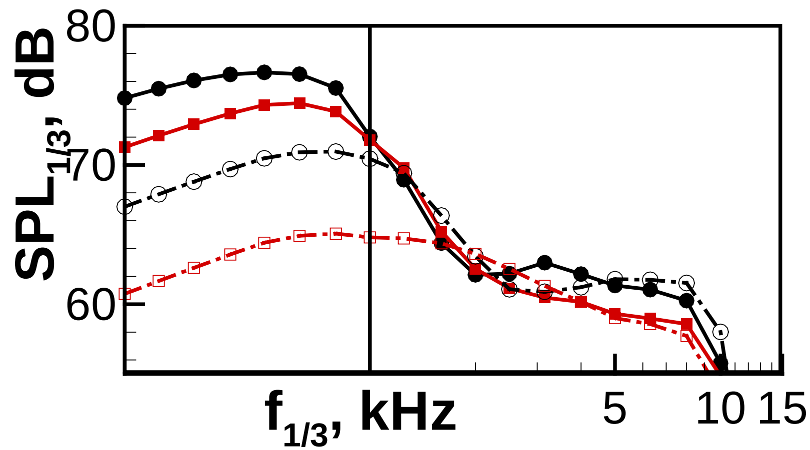
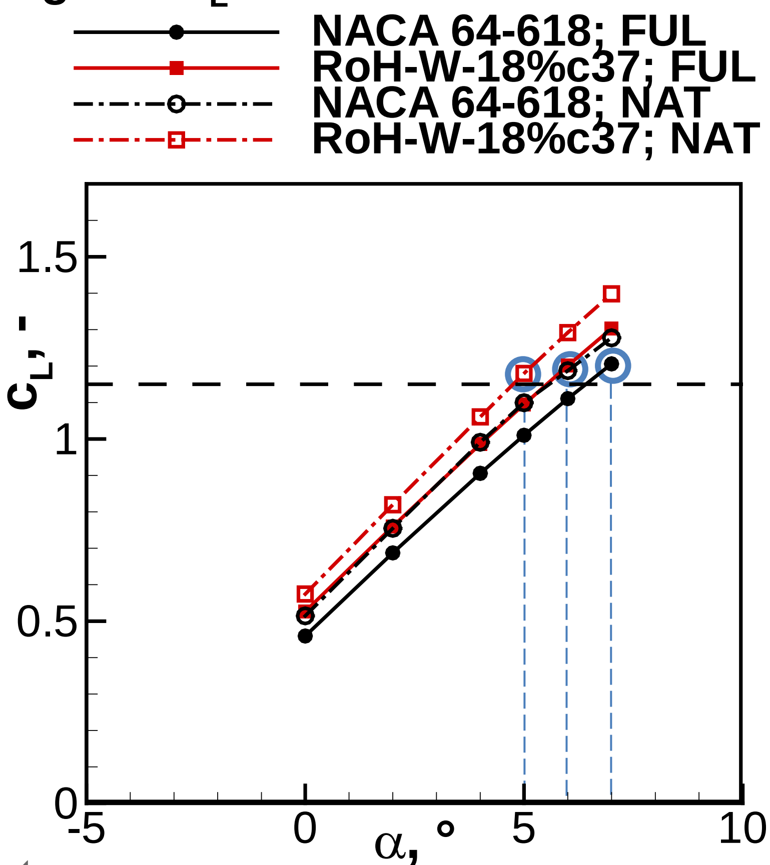
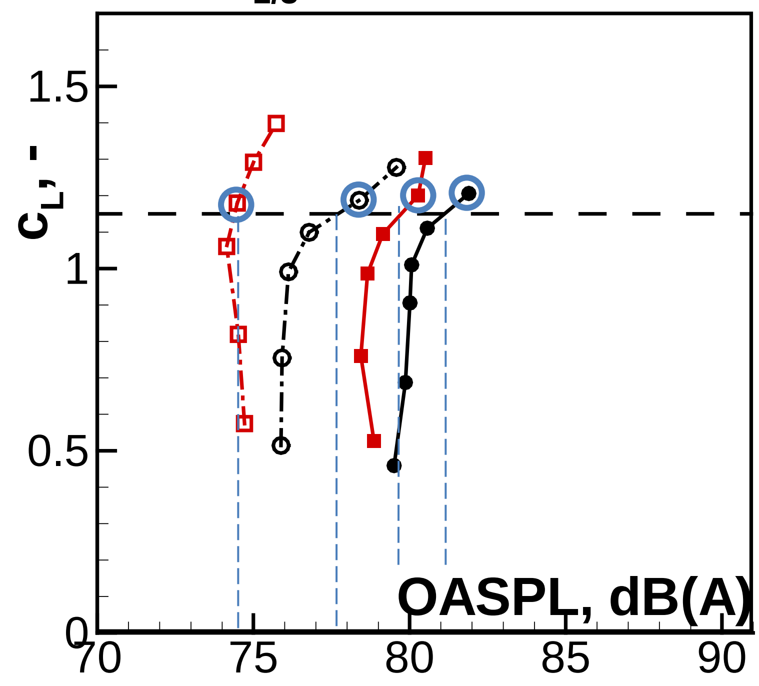
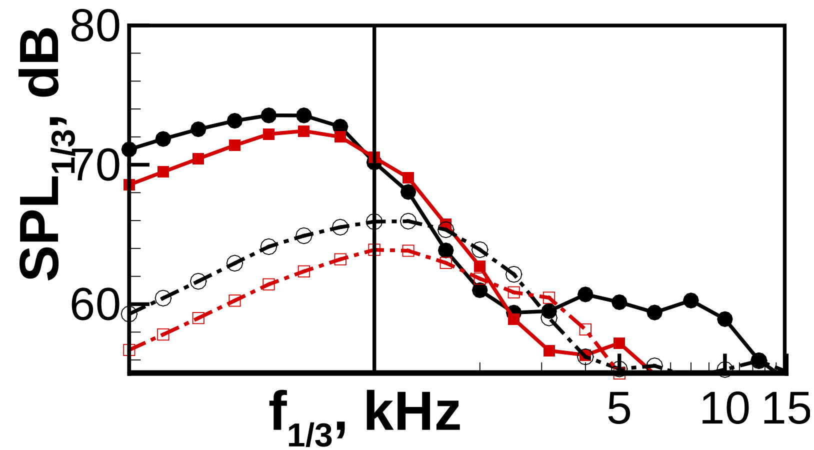




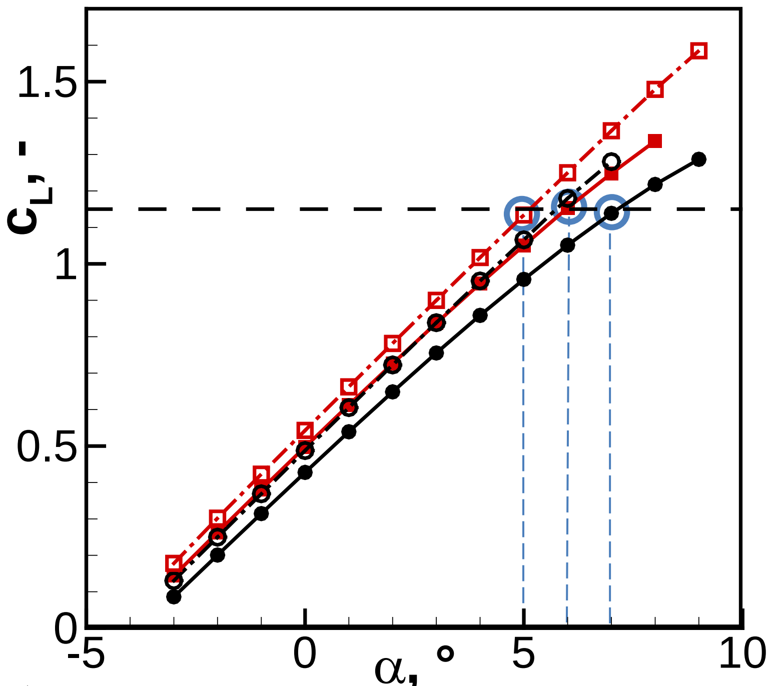


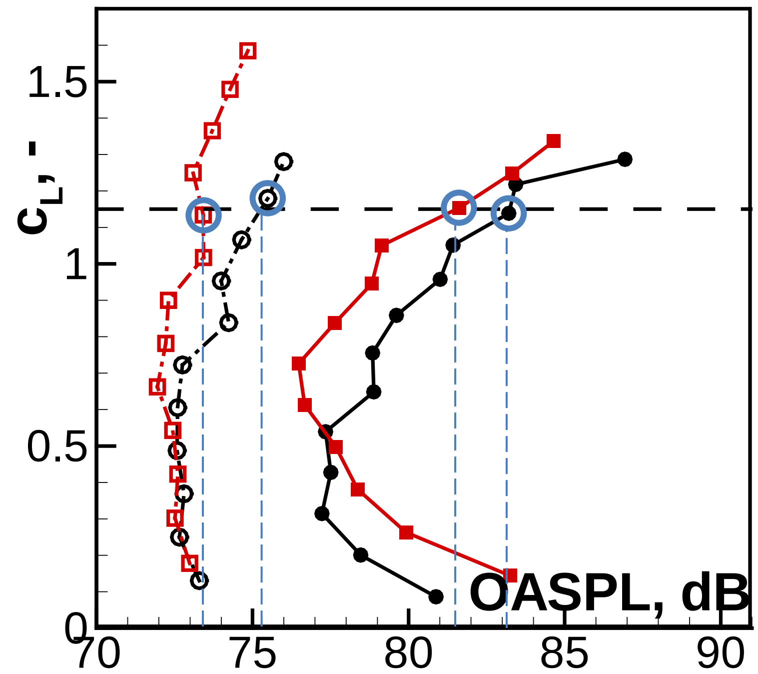
Numerical results for AWB conditions

- Re = **1.23 Mio.**
- M = **0.176**
- u_∞ = **60 m/s**
- l_c = **0.3 m**
- **targeted c_L = 1.15**



NACA 64-618; FUL
RoH-W-18%c37; FUL
NACA 64-618; NAT
RoH-W-18%c37; NAT

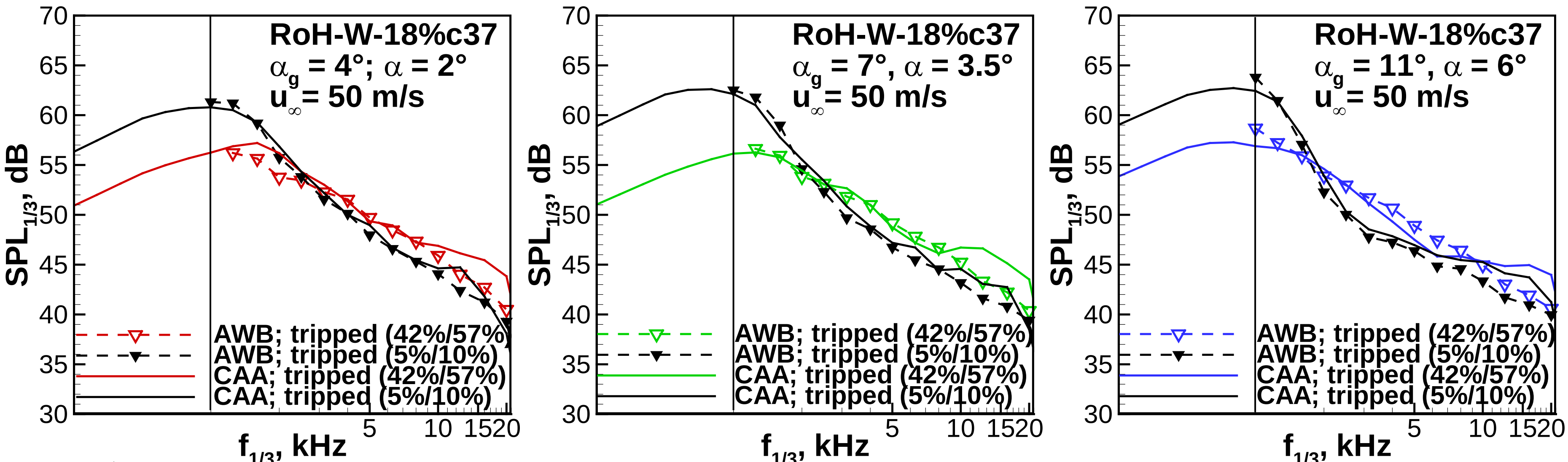




Comparison of numerical with experimental data

- Almost perfect predictions for new design RoH-W-18%c37
- 'CLEAN' (42%/57%) vs. 'TRIPPED' (5%/10%):
  - Significant effect of laminar TBL extent on noise!

- But…



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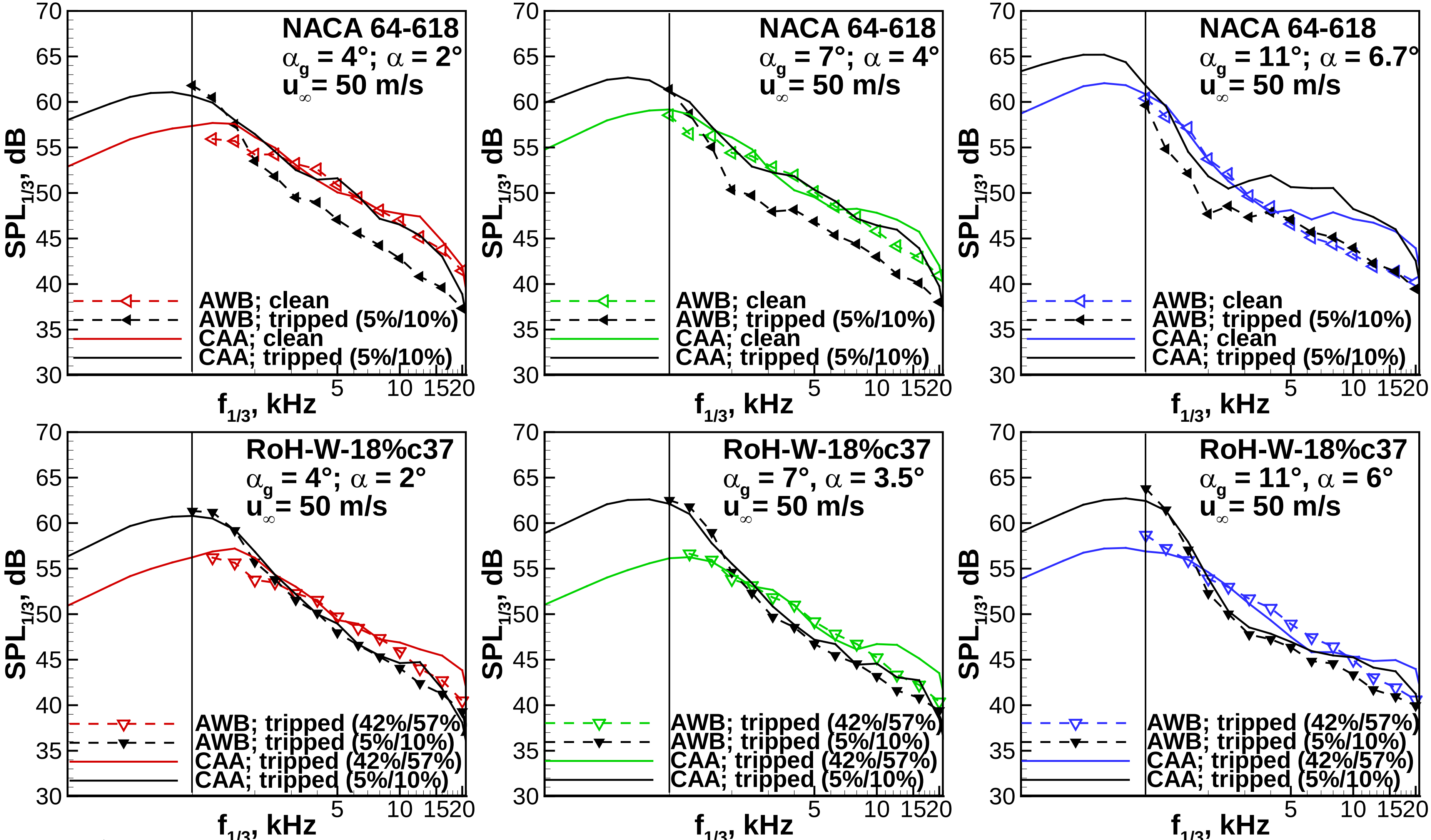

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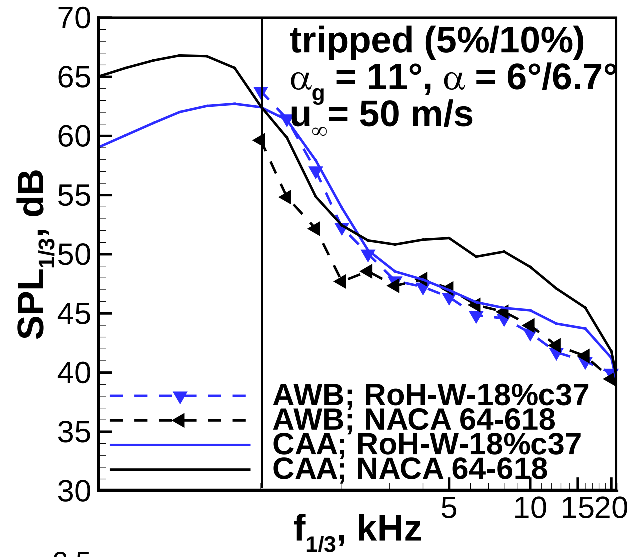
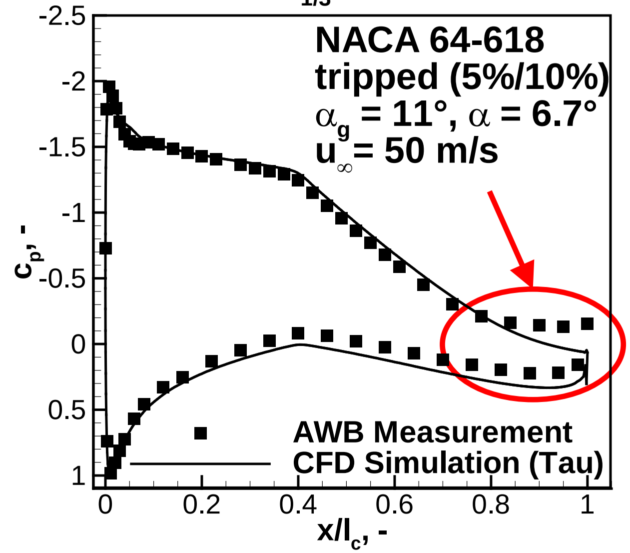
Comparison of numerical with experimental data

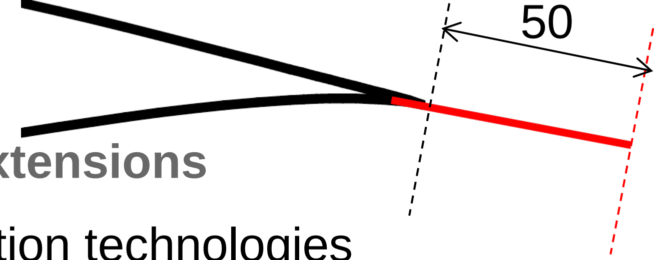
- …poor prediction quality for 'TRIPPED' NACA 64-618 reference profile leads to wrong TEN deltas between the two airfoils!
- Design conditions cannot be reproduced in open-jet AWB experiment due to early TE separation (which is not predicted)





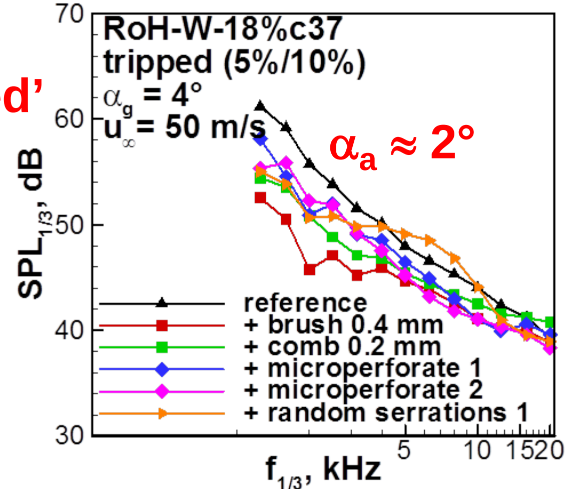
Experimental results for TE add-ons

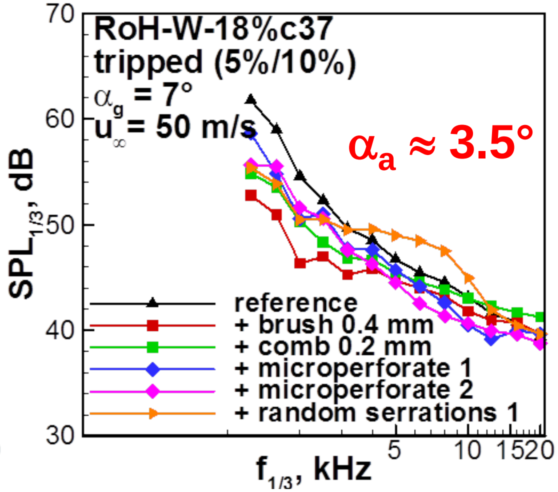
Additional noise reduction potential of selected TE extensions

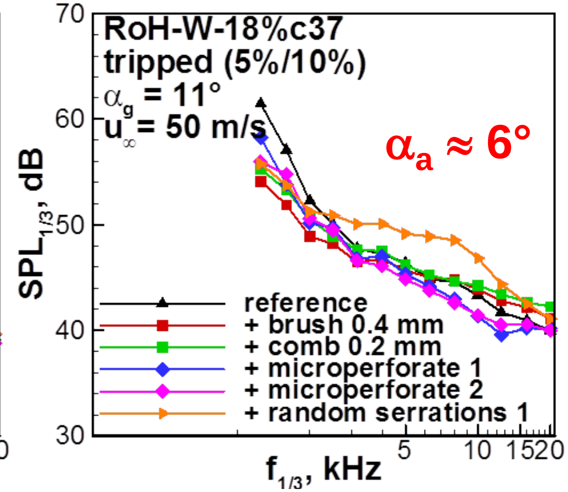


- principle noise reduction effect for selected TEN reduction technologies confirmed, here shown for low-noise RoH-W-18%c37 airfoil

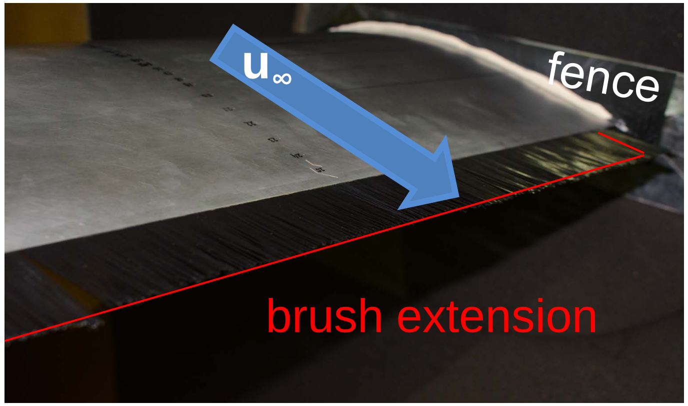
'tripped'







'clean'

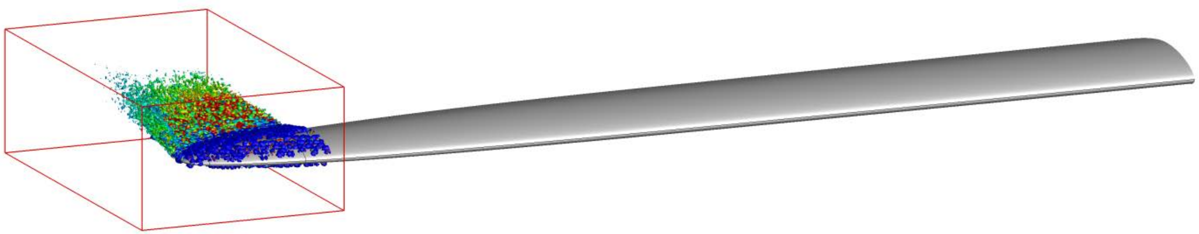


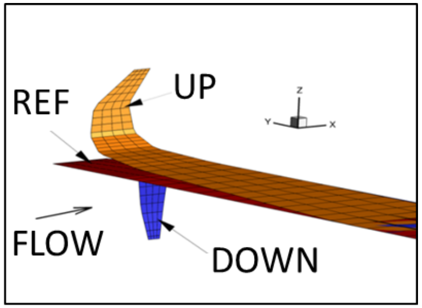
Summary & conclusions

- Results from a numerical & experimental aeroacoustic assessment of 2D wind turbine blade sections were presented
  - 2–4 dB (OASPL) noise benefit RoH-W-18%c37 re. NACA 64-618 (predicted for design conditions)
  - Up to 8 dB noise benefit, if a maximum laminar extent of the TBL can be realized
  - Additional 4–6 dB reduction of TEN peak levels realizable through flow-permeable TE extensions (note that the lift either remains unchanged or increases for the tested flap extensions)
- Overall, very promising results obtained w.r.t. the next steps within BELARWEA; open questions are related to the ‘TRIPPED’ NACA 64-618 reference profile

Future activity in BELARWEA

- 3D winglet design & 3D CFD/CAA simulations





- Test of 3D blade sections (outer 20% R) in DNW-NWB to validate 3D approach; model instrumentation with Kulites & measurements in open vs. closed test section environment will provide additional clarification of the observed discrepancies between simulations and measurements for the ‘TRIPPED’ NACA 64-618

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- This work has been conducted within the project BELARWEA (ref. 0325726) funded by the German Federal Ministry for Economic Affairs and Energy (BMWi).

Gefördert durch:

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aufgrund eines Beschlusses des Deutschen Bundestages

BELARWEA

Thank you for your attention!

michaela.herr@dlr.de

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