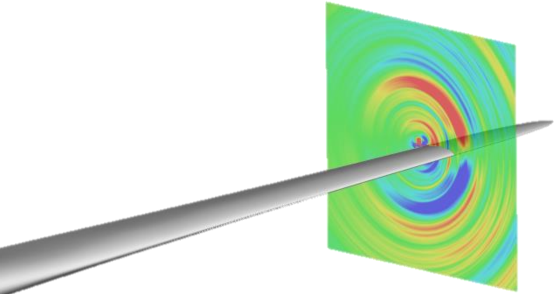

Aeroacoustic Evaluation of Low-Noise Wind Turbine Blade Tips

M. Herr, C.-H. Rohardt, B. Faßmann, J. Pereira-Gomes*, C. Appel

German Aerospace Center (DLR)
Institute of Aerodynamics and Flow Technology

*German-Dutch Wind Tunnels (DNW-NWB)

ICA 2019, Aachen
9 September 2019

DLR

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Overview – project BELARWEA
blade tips for efficient and low-noise wind-turbine rotors

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Research aim:

- Development and validation of improved (non-empirical!) methods to support the design of both efficient and low-noise wind turbine rotors, i.e. high-fidelity 2D/3D CFD/CAA-methods applicable to evaluate
  - 2D profile designs
  - 3D tip shapes / winglet designs
  - any other arbitrary 3D geometry variants…

  → future publications
- Demonstration of a minimum 3-dB noise reduction***** for a given aero performance through
  - a new 2D profile contour &
  - noise reduction add-ons, i.e. adaptation of passive noise reduction technologies from aerospace applications (brushes, porous materials, slotted TEs)
- Experimental proof in static wind tunnel tests at
  - 2D blade sections in the AWB &
  - 3D blade tip models in the DNW-NWB
- Provision of high quality validation data w. and w./o. winglets

***Reference:** outer 20% of rotor radius of generic NREL 5-MW turbine with NACA 64-618 profiles

Overview – project BELARWEA
blade tips for efficient and low-noise wind-turbine rotors

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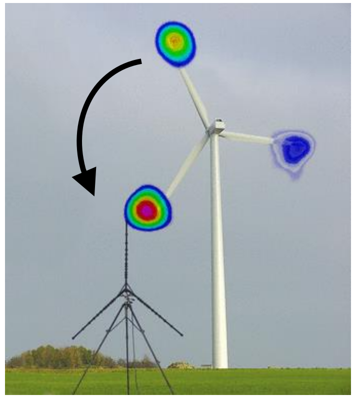
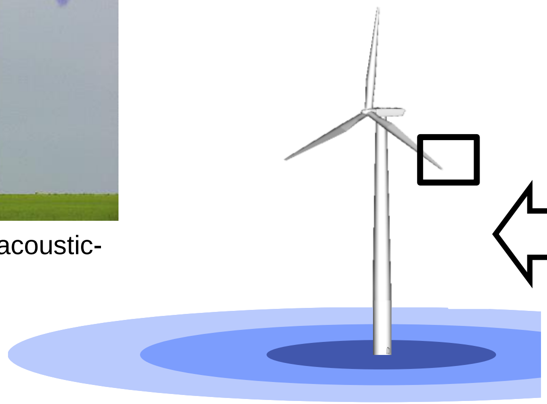
Background:

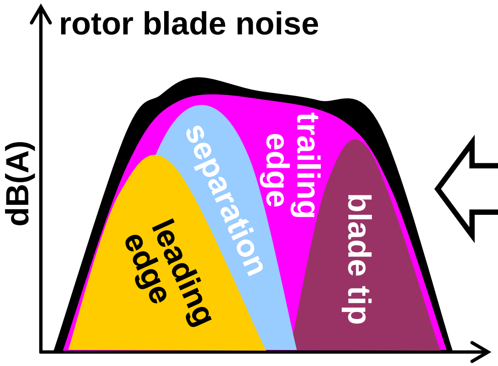
- Modern large turbines typically involve sufficient treatment of machinery noise, so that mainly flow-induced noise by the blades contributes to the total noise emission.
- Trailing-edge noise (TEN) in the outer 20–25% of rotor radius is the dominant contributor to total wind turbine noise.
- Knowledge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

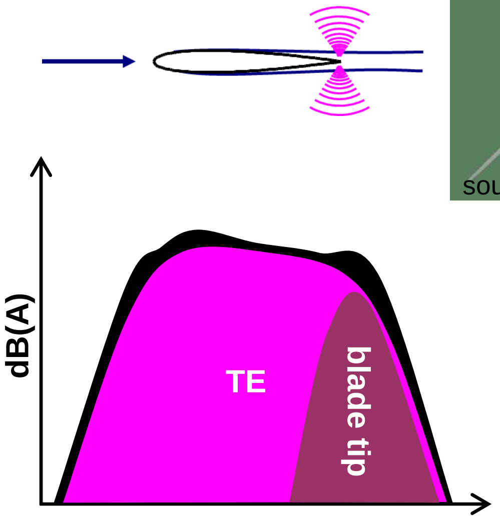


source: http://www.acoustic-camera.com



source: R. Drobietz, GE Wind Energy





source: S. Oerlemans, AIAA 2016

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PART A: 2D profile assessment

@ 2D blade sections
@ 3D tip models

Applicability of hybrid CFD/CAA method to assist design?

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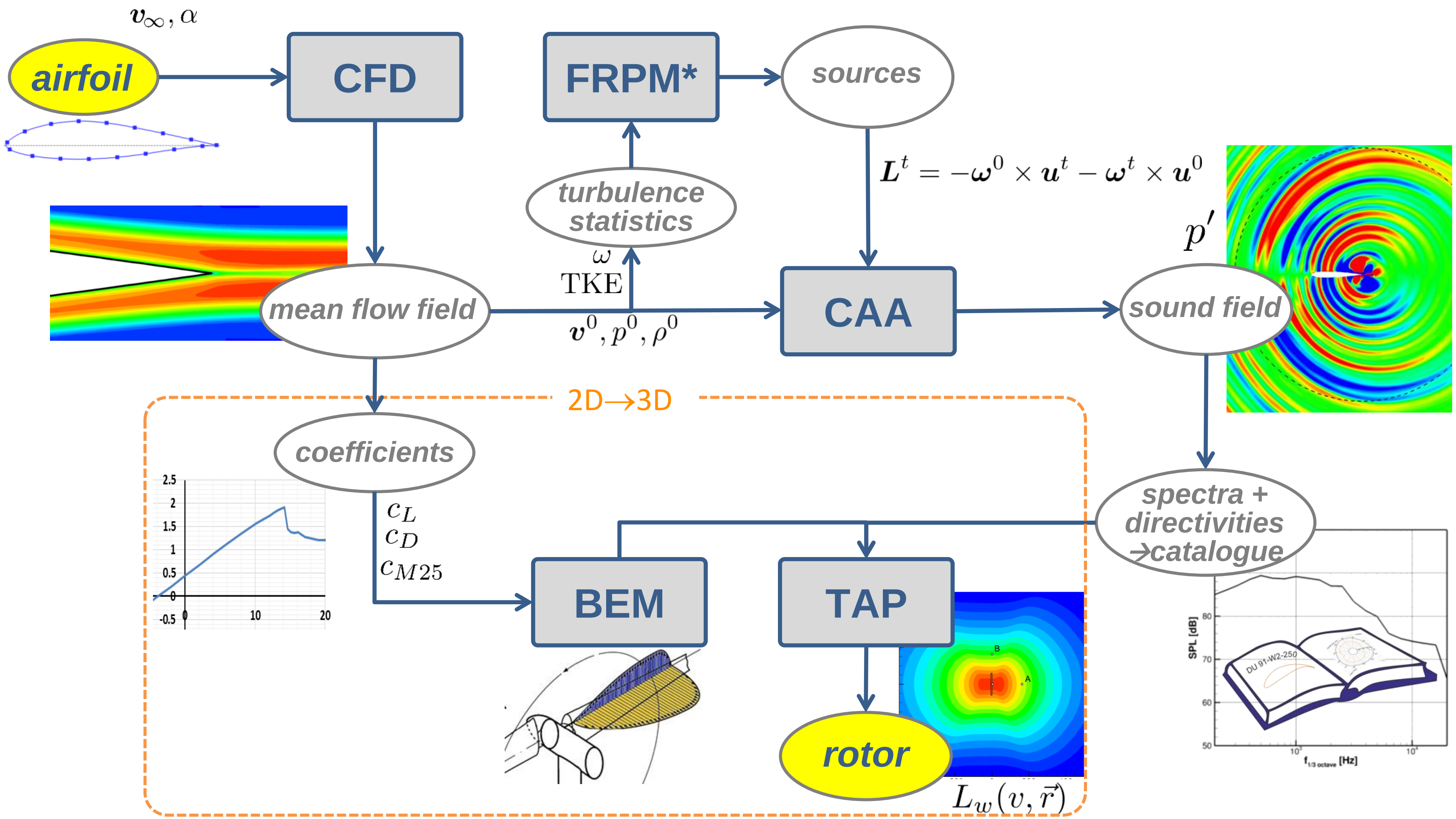
Numerical approach
2D-based non-empirical hybrid CFD/CAA TEN prediction method



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

Numerical approach
2D-based non-empirical hybrid CFD/CAA TEN prediction method

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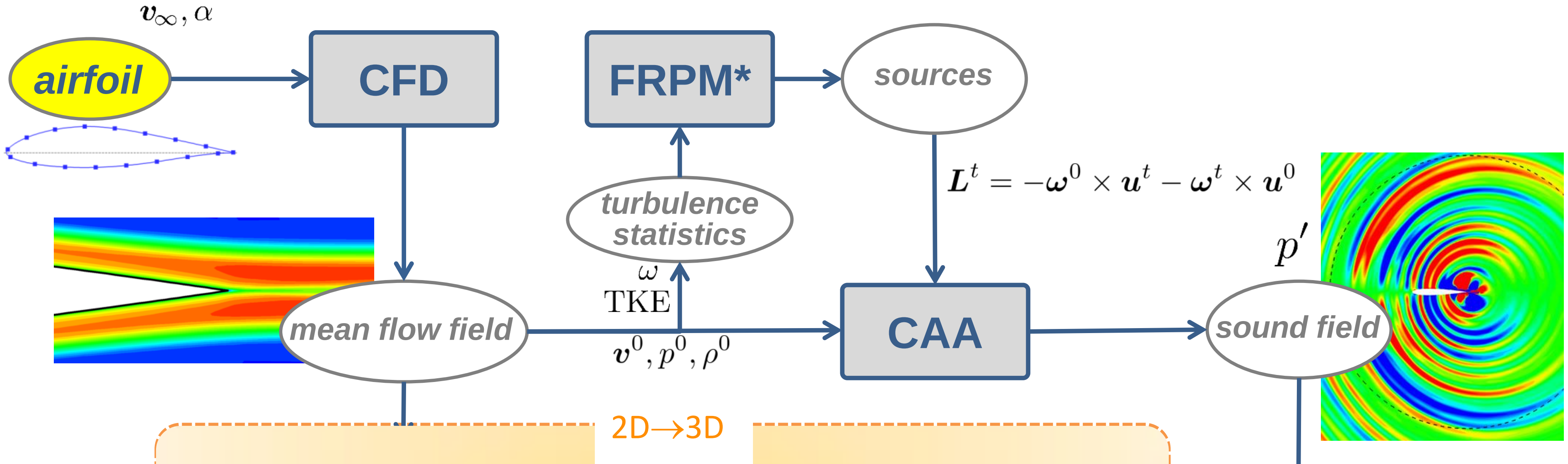
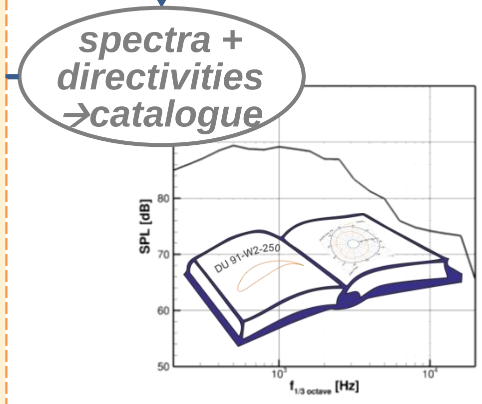


2D→3D



Validation of overall turbine noise prediction
will be subject to IEA WIND TCP Task 39
(Low-Noise Wind Turbine Technologies)
“WIND TURBINE NOISE CODE BENCHMARK”

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

1st validation step: 2D blade sections in multiple facilities

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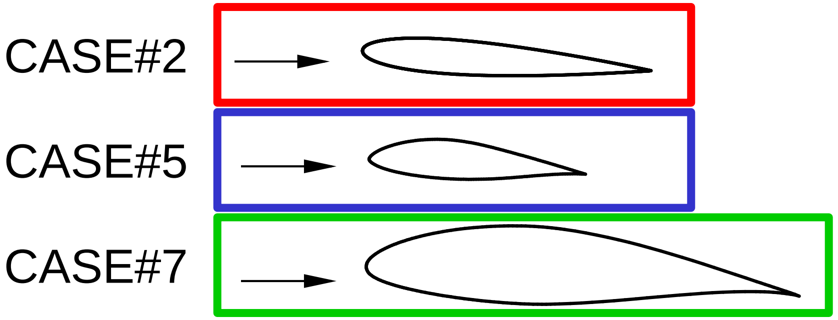
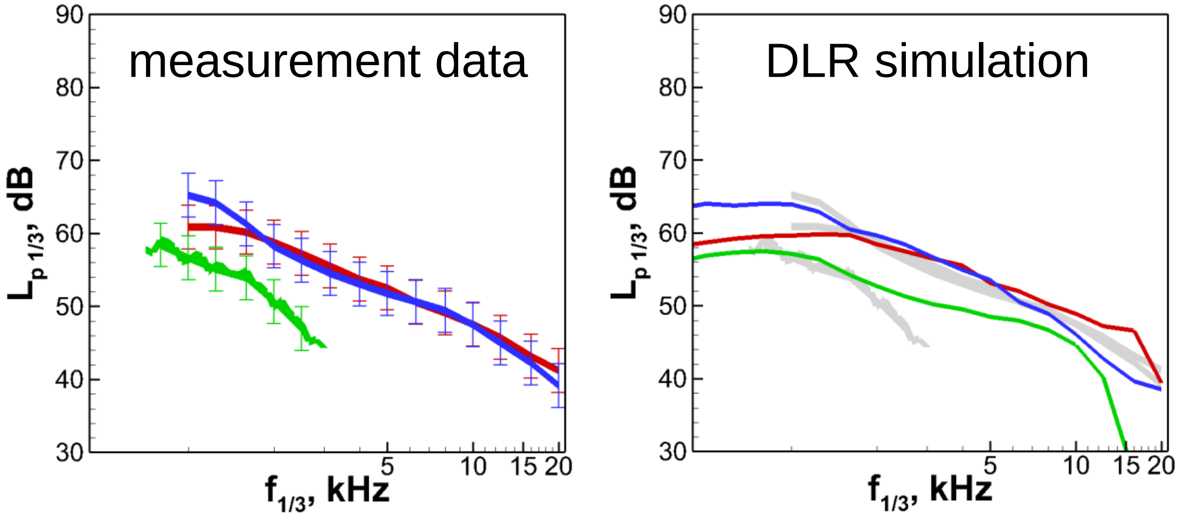
5th AIAA/CEAS Benchmark Workshop of Airframe Noise Computations (BANC V, 2018)
Category 1: Trailing-Edge Noise





→ Strong motivation to apply DLR approach for low-noise profile design, i.e. inserting an acoustic assessment step within iterative design loops

→ New profile contour RoH-W-18%c37 vs. NACA 64-618 reference contour

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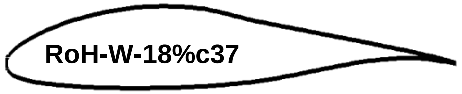
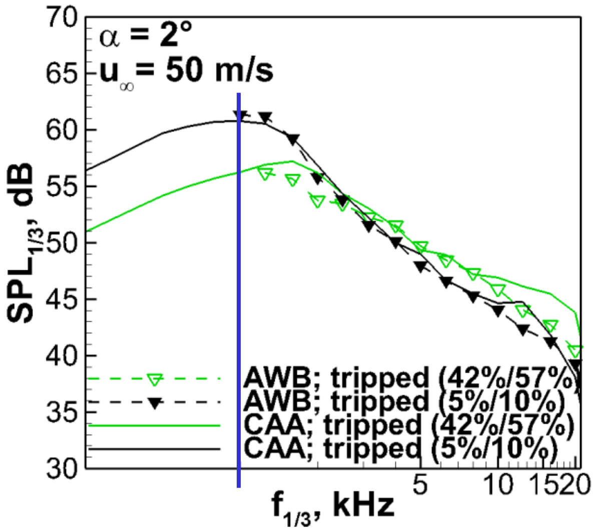
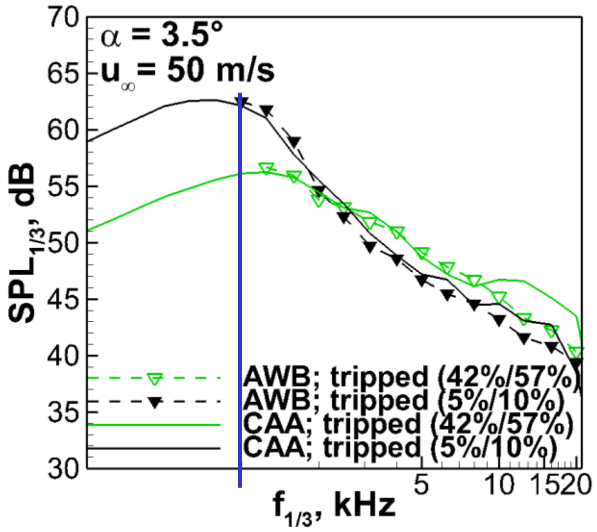
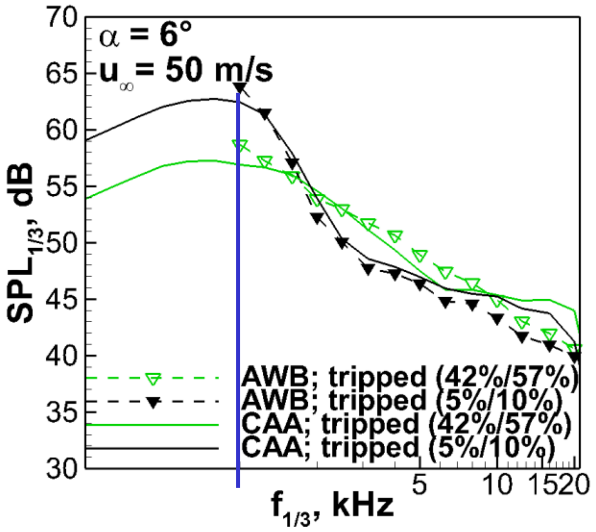
2nd evaluation step: 2D blade sections in AWB spectral shape & parametric dependences new profile contour

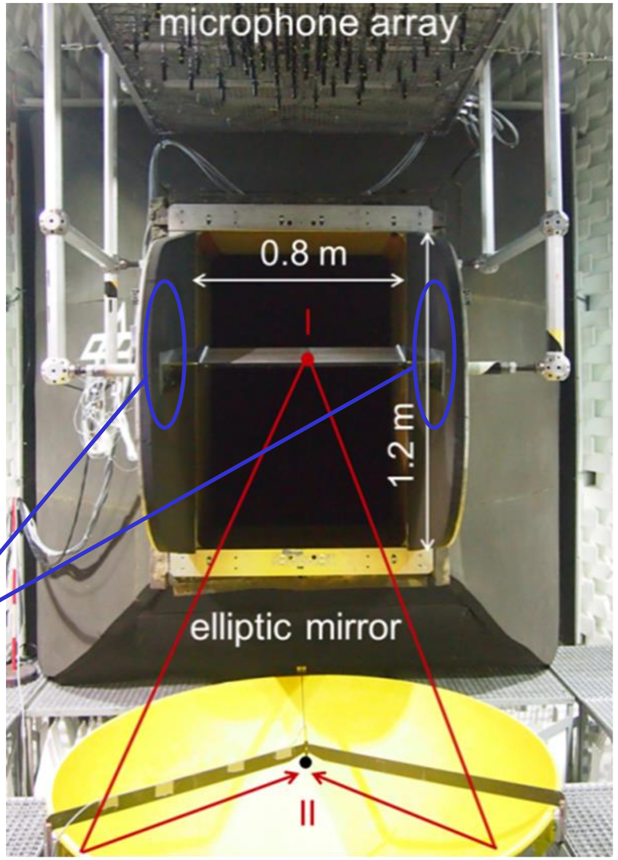
AWB measurements vs. ‚blind‘ predictions RoH-W-18%c37 with varying tripping position











→ but: predicted noise reduction vs. NACA 64-618 reference could not be evaluated because TEN maximum for NACA 64-618 is located below the **low-frequency limit of the measurement!**

→ move over to DNW-NWB

3rd evaluation step:
3D blade tips in low-speed wind-tunnel DNW-NWB

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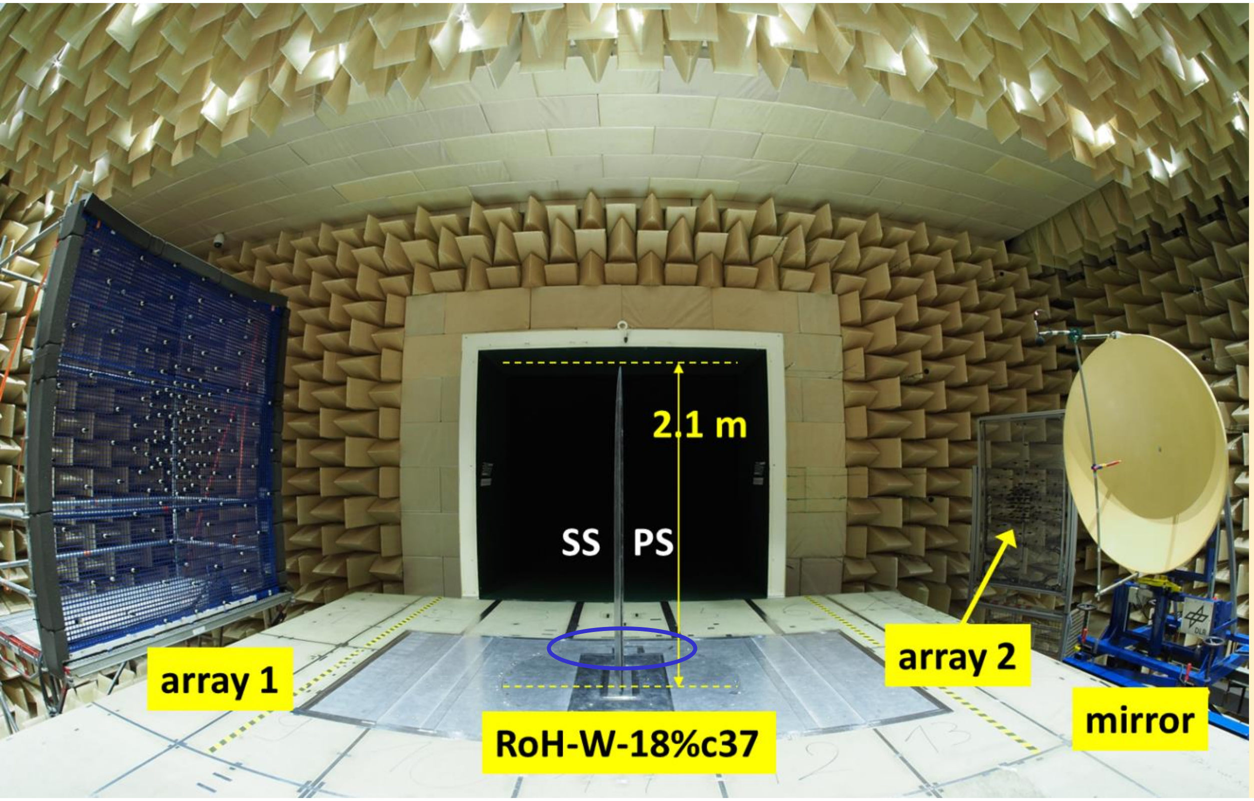
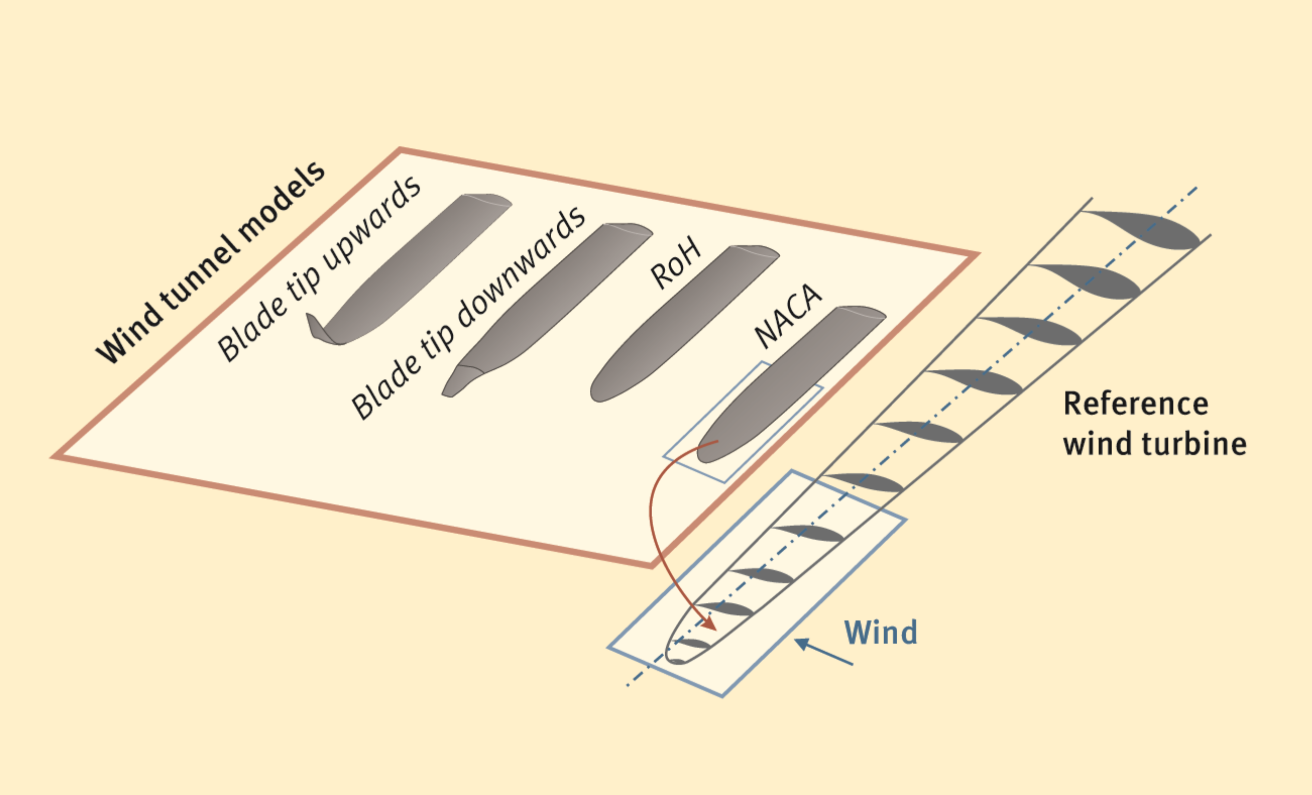
Test setup





- Provision of full 3D validation data for configs. w. and w./o. winglets (1:6 model scale)
- Detailed aerodynamic assessment in ¾-open & closed test sections (open jet section: 3.25 m x 2.8 m x 6 m)

3rd evaluation step:
3D blade tips in low-speed wind-tunnel DNW-NWB

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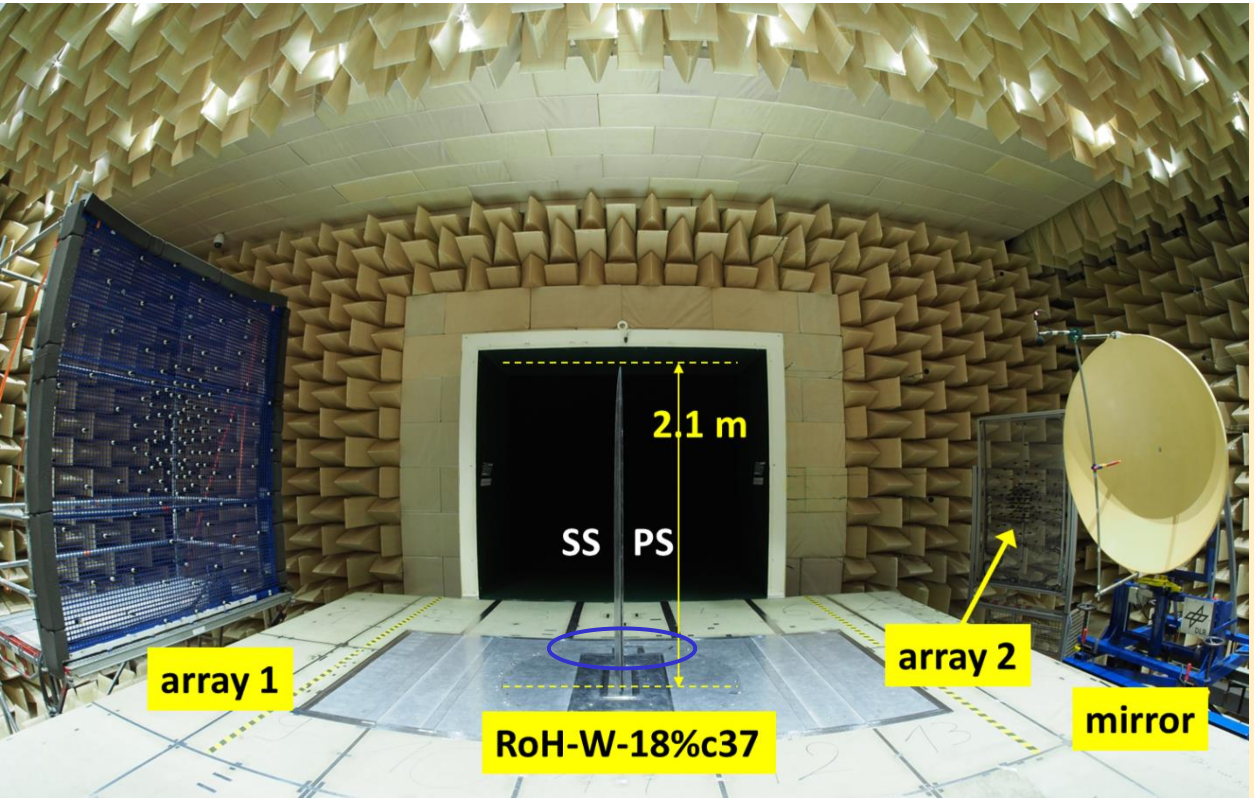
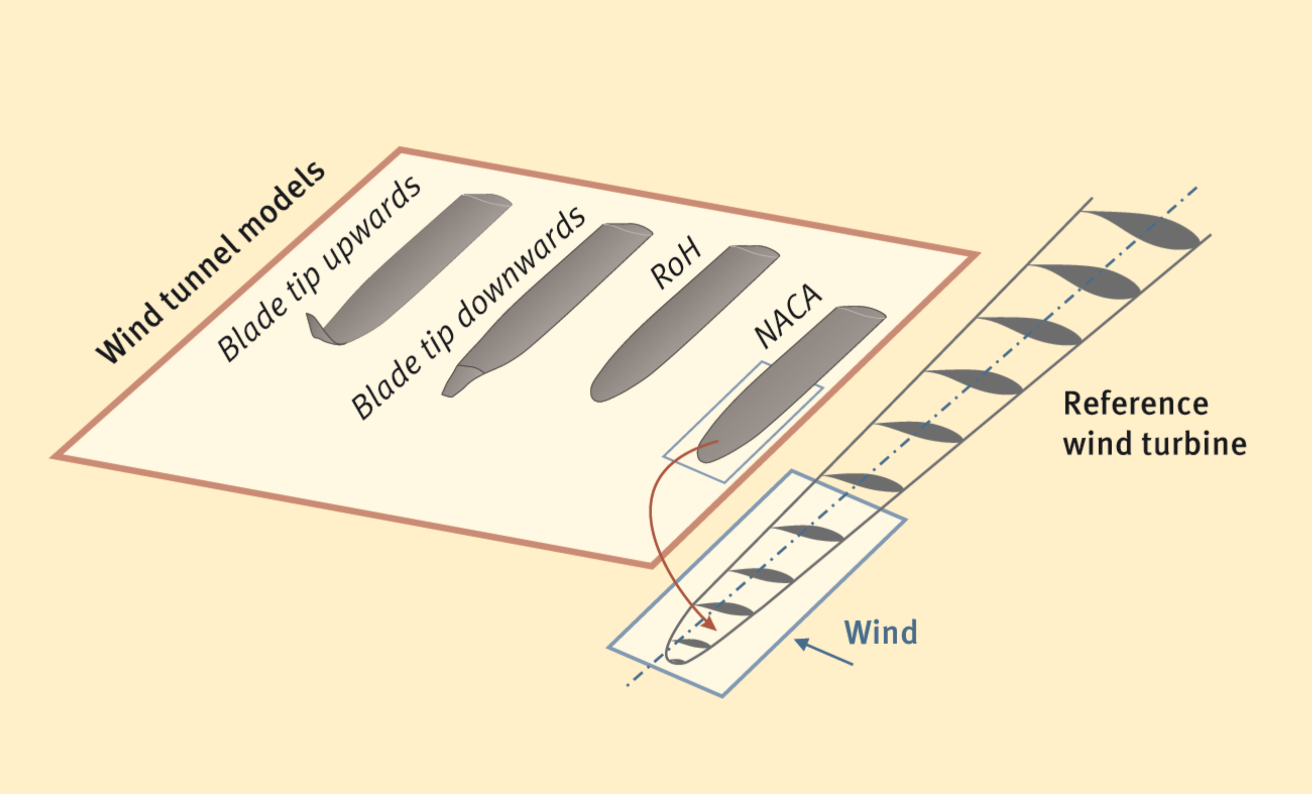
Today‘s focus: 3D validation data for configs. w./o. winglets; evaluation of new profile contour

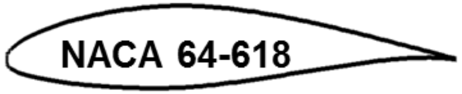




- Provision of full 3D validation data for configs. w. and w./o. winglets (1:6 model scale)
- Detailed aerodynamic assessment in ¾-open & closed test sections (open jet section: 3.25 m x 2.8 m x 6 m)

What to expect according to 2D CFD/CAA predictions?

vs.



reference at NWB-conditions

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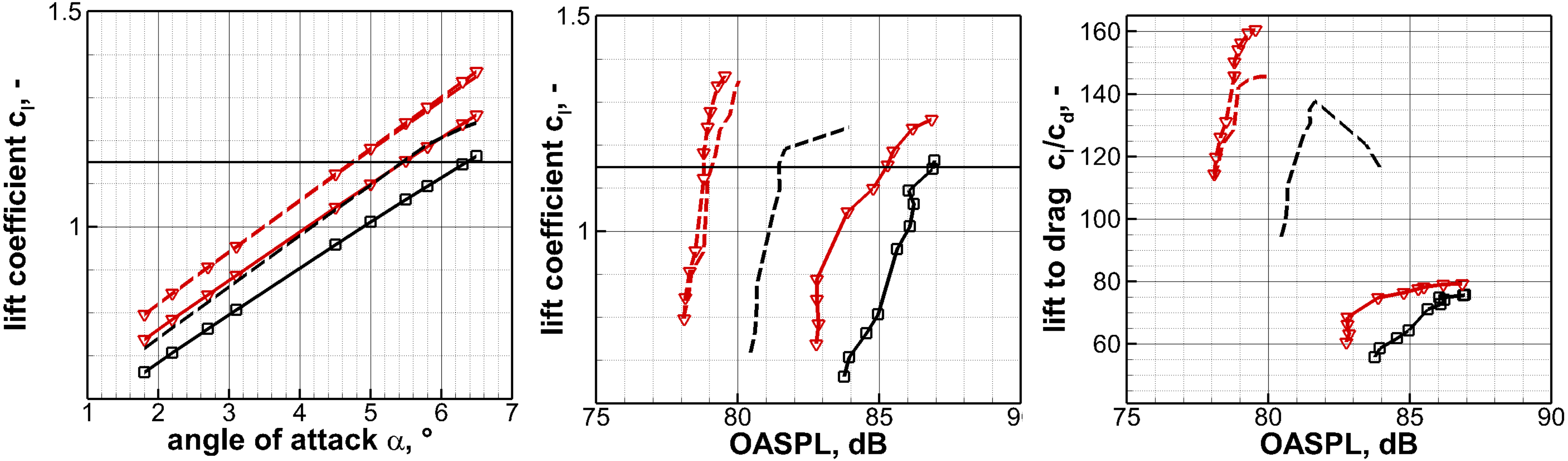
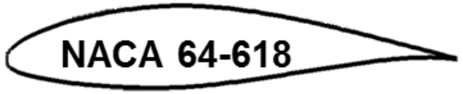
u_∞= 80 m/s

solid lines with symbols: FUL = tripping (SS/PS) @ 5%/10%
dashed lines with symbols: NATFIX = tripping (SS/PS) @ 42%/60%
dashed lines: NAT = untripped airfoils



→ Expectation for WTT: 2–2.5 dB reduction in terms of OASPL

3rd evaluation step
3D evaluation of RoH-W-18%c37 wing tip in NWB



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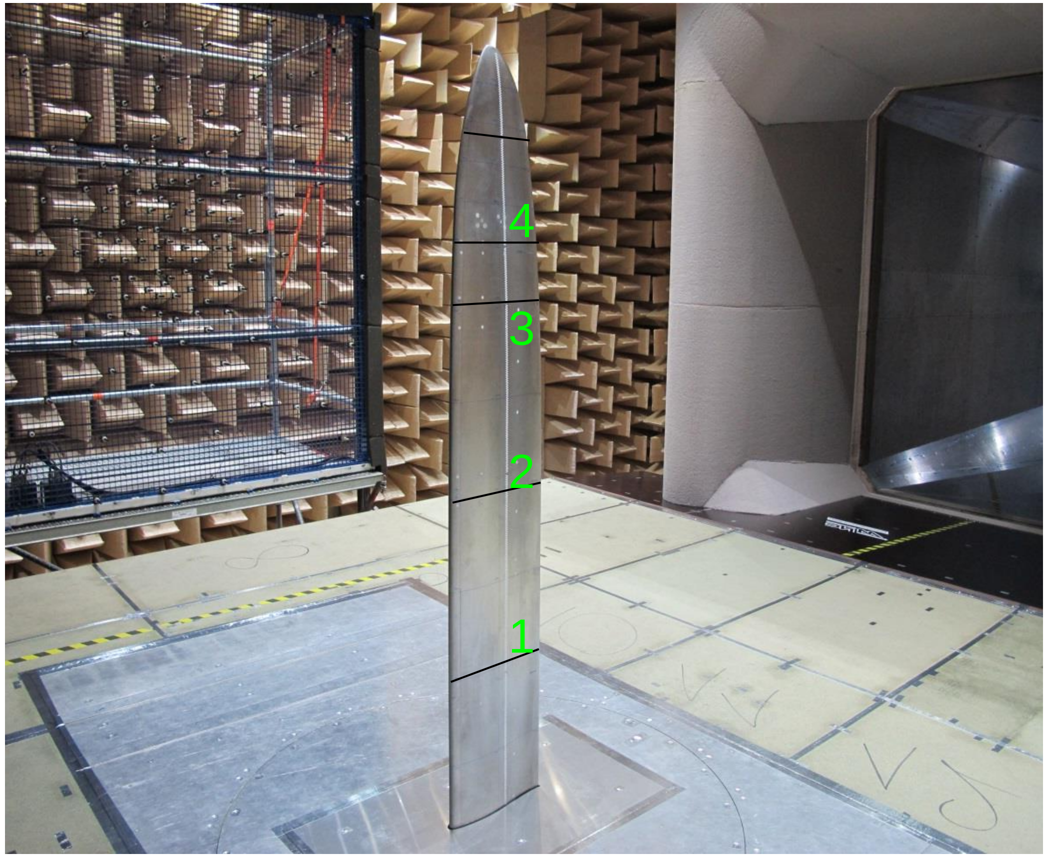
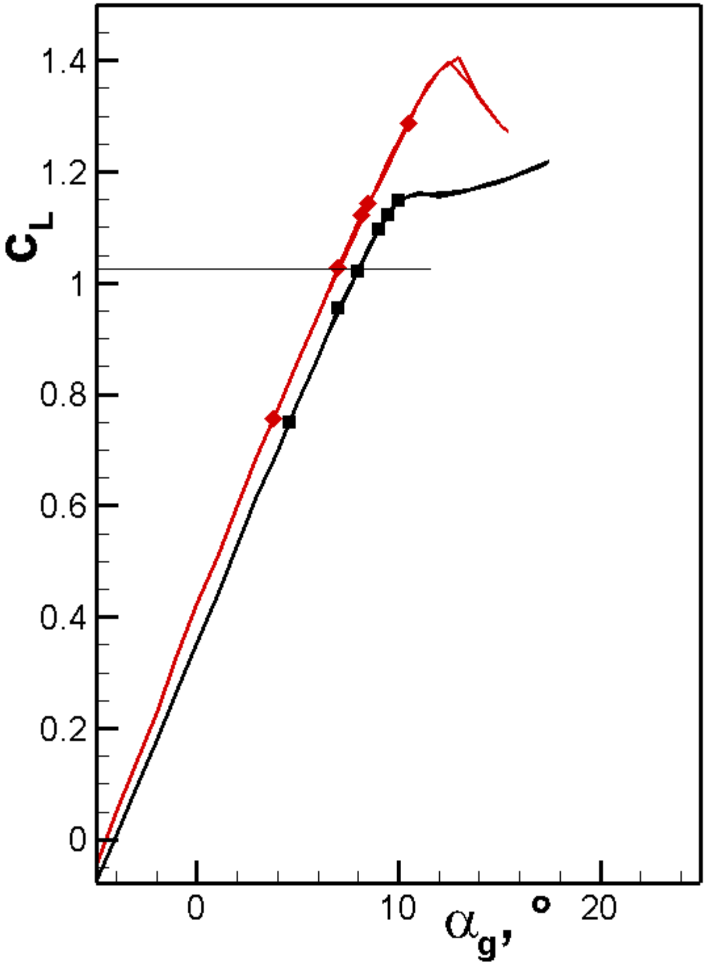
u_∞ = 80 m/s

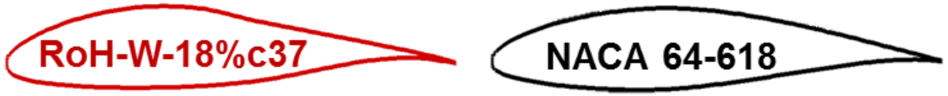
NAT = untripped airfoils



Force balance:
c_L = 1.02…1.03



3rd evaluation step
3D evaluation of RoH-W-18%c37 wing tip in NWB



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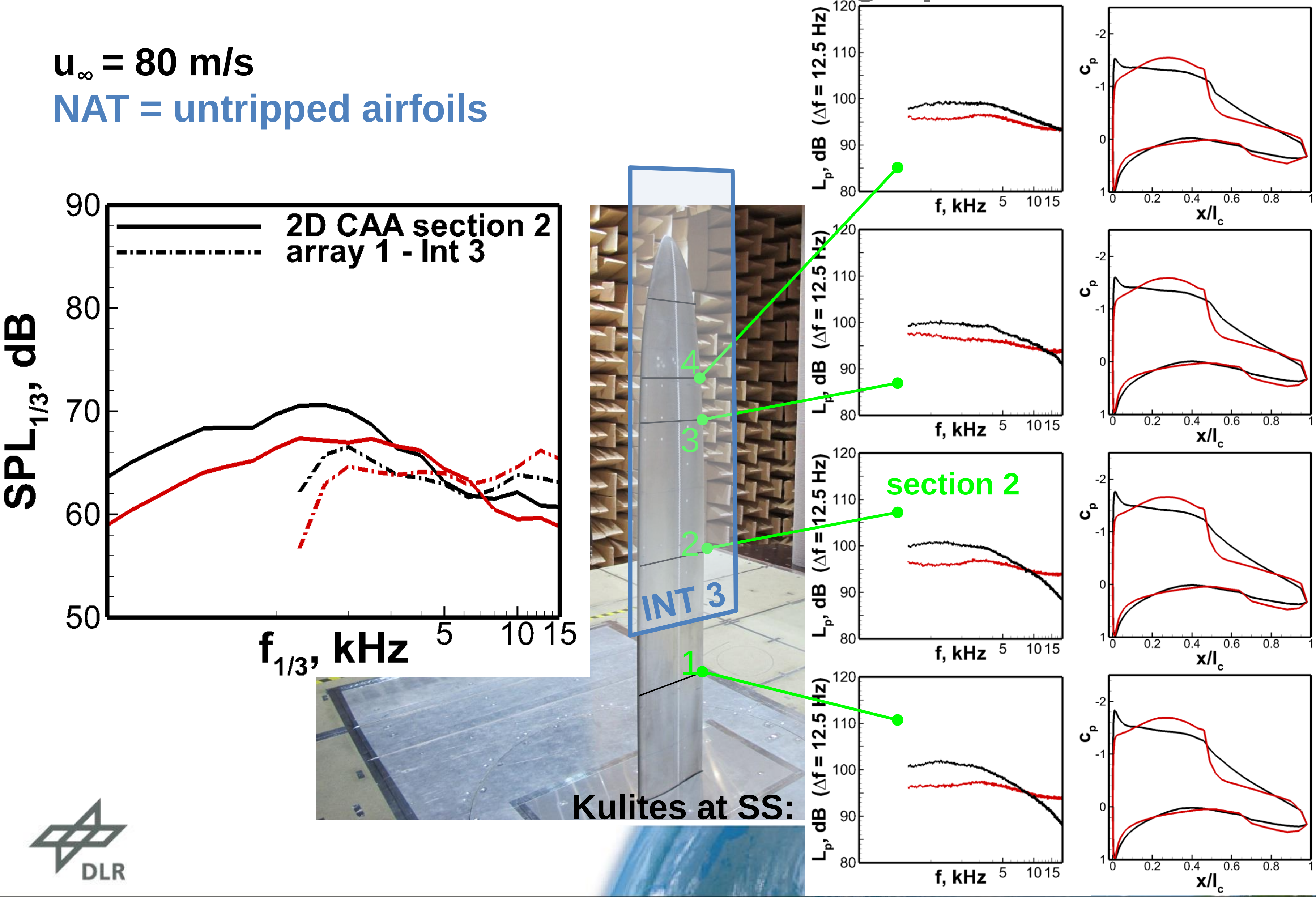
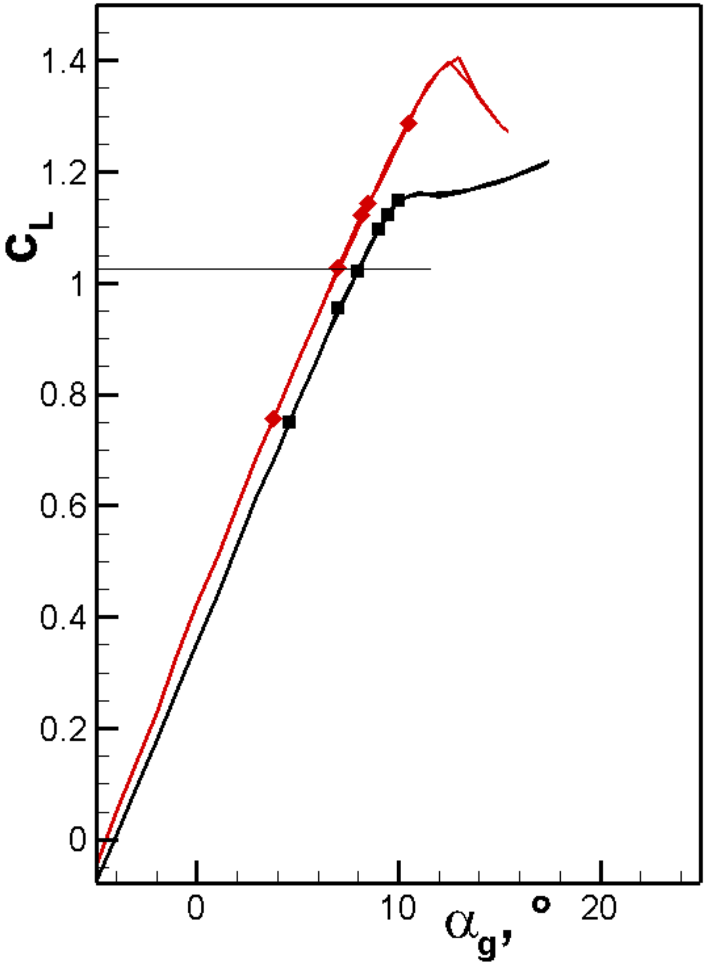
u_∞ = 80 m/s

NAT = untripped airfoils

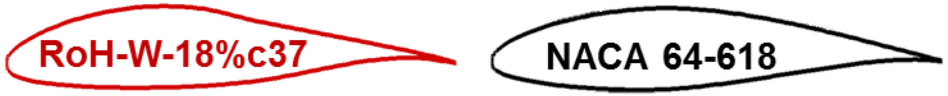


Force balance:

c_L = 1.02…1.03



3rd evaluation step
3D evaluation of RoH-W-18%c37 wing tip in NWB



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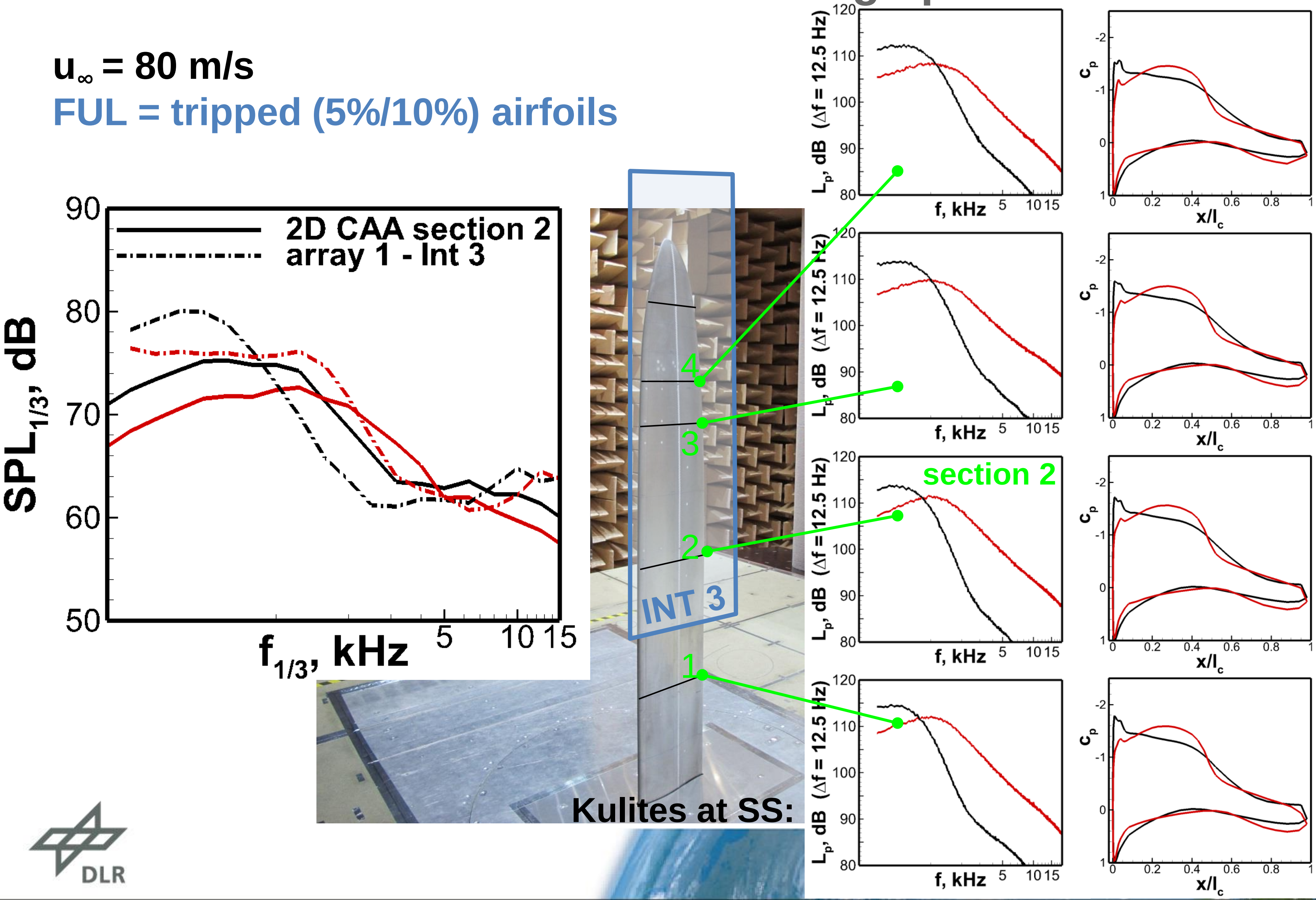
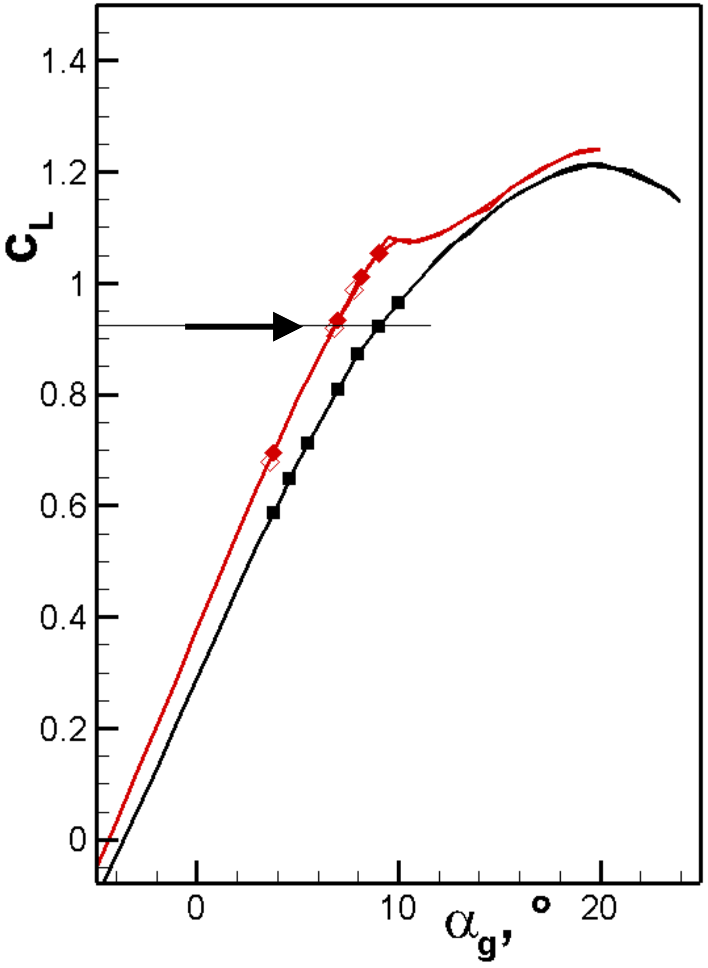
u_∞ = 80 m/s

FUL = tripped (5%/10%) airfoils



Force balance:
c_L = 0.92…0.93



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PART A: 2D profile assessment
PART B: Assessment of TE add-ons

PART B: Assessment of TE add-ons

@ 2D blade sections
@ 3D tip models

Are noise reduction effects maintained?

Assessment of TE add-ons @ 2D blade sections

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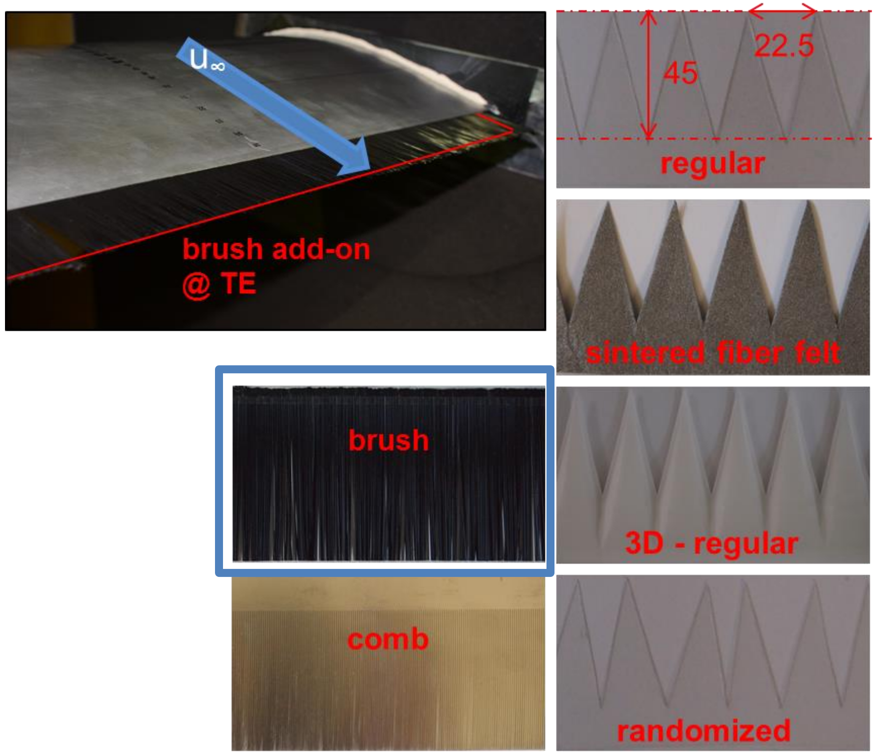
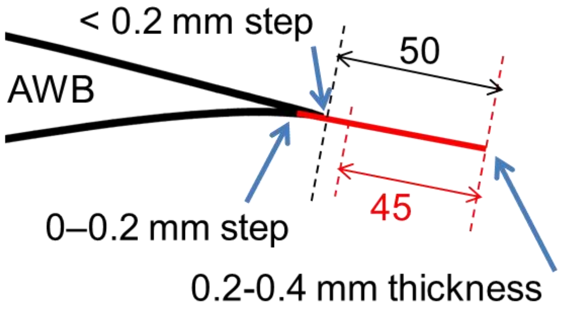
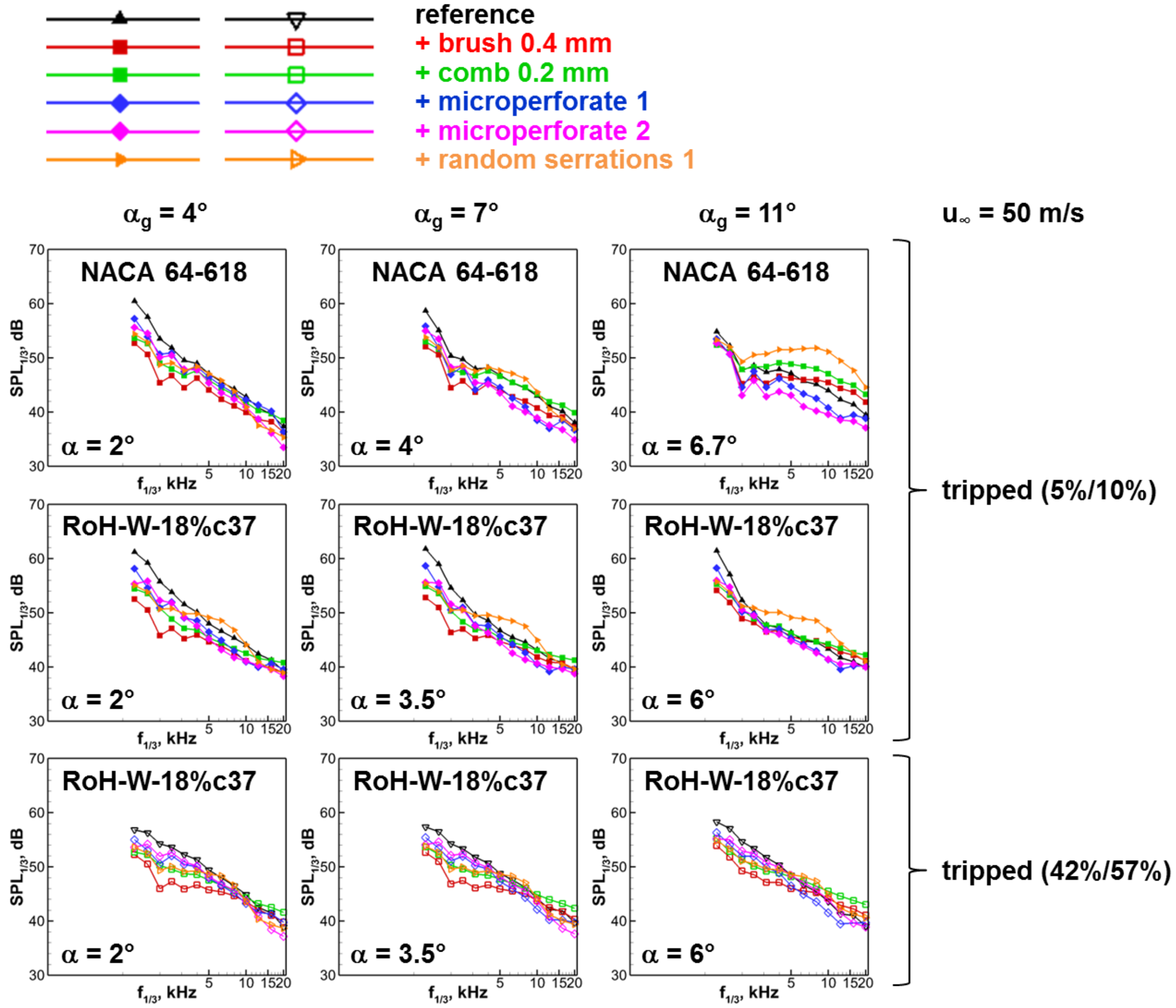
AWB: preselection of best add-on solution to be tested at the wing tip config. in DNW-NWB







Assessment of TE add-ons @ 3D tip models

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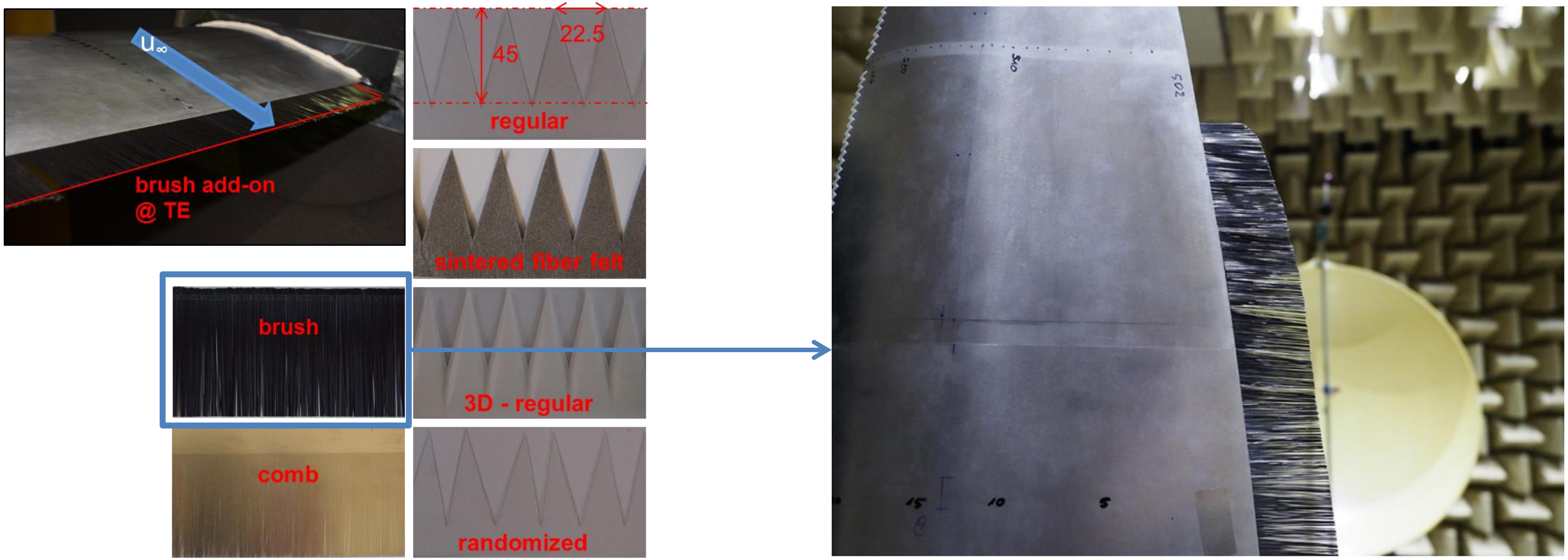
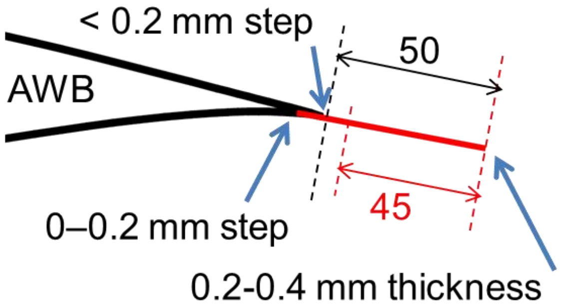
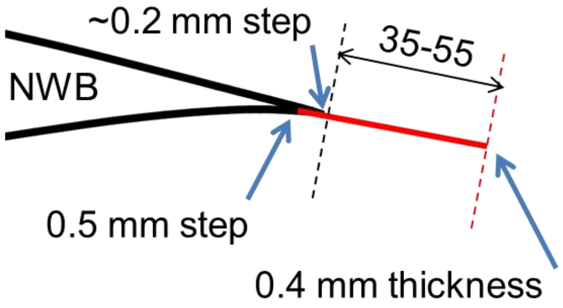
AWB: preselection of best add-on solution to be tested at the wing tip config. in DNW-NWB







Assessment of TE add-ons @ 3D tip models

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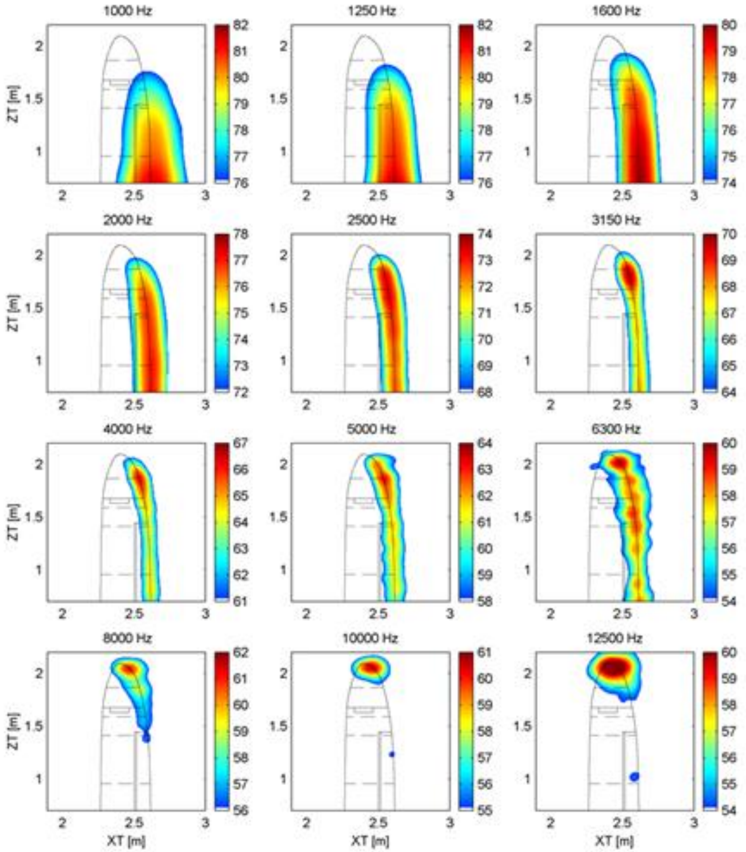
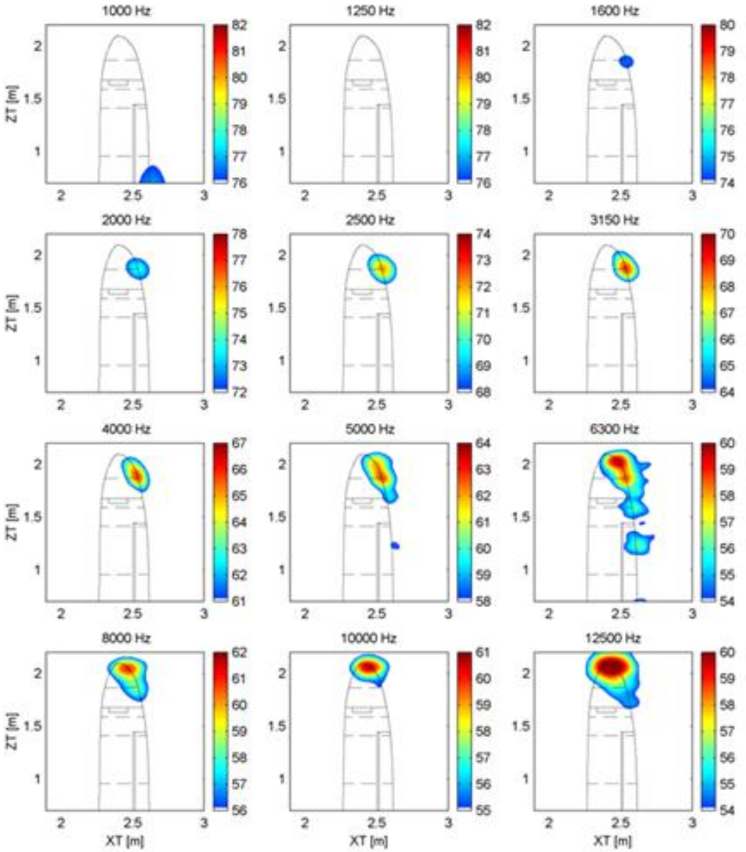
u_∞ = 80 m/s
α = 3.1°

RoH-W-18%c37 FUL



RoH-W-18%c37 FUL + brush



→ Verification of noise reduction technology: ~6 dB noise reduction by brush add-ons

DLR

Assessment of TE add-ons @ 3D tip models

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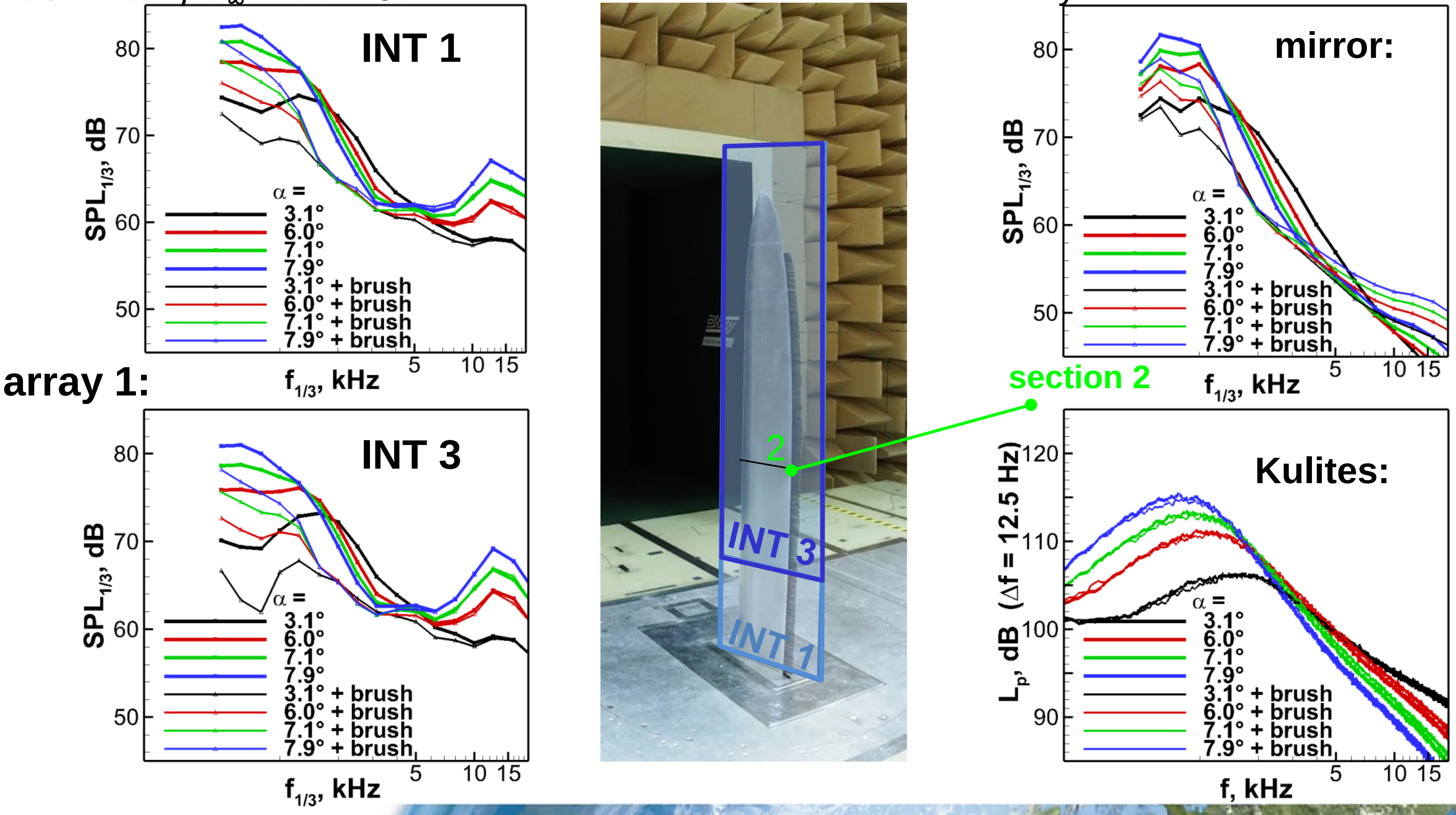
RoH-W-18%c37 FUL; u_∞ = 80 m/s

→ 4–6 dB noise reduction by brush add-ons



Assessment of TE add-ons @ 3D tip models

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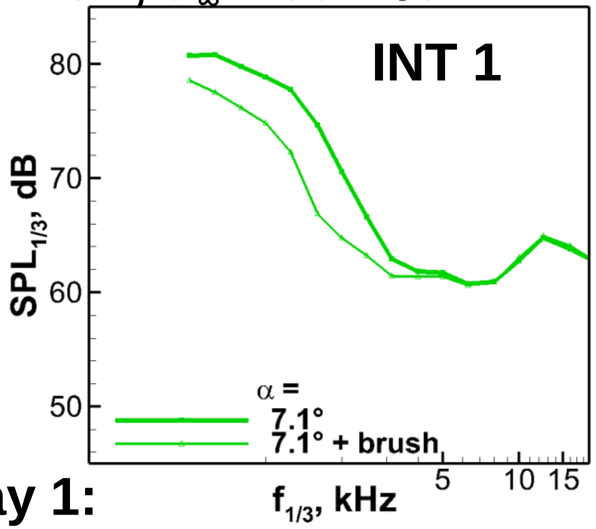
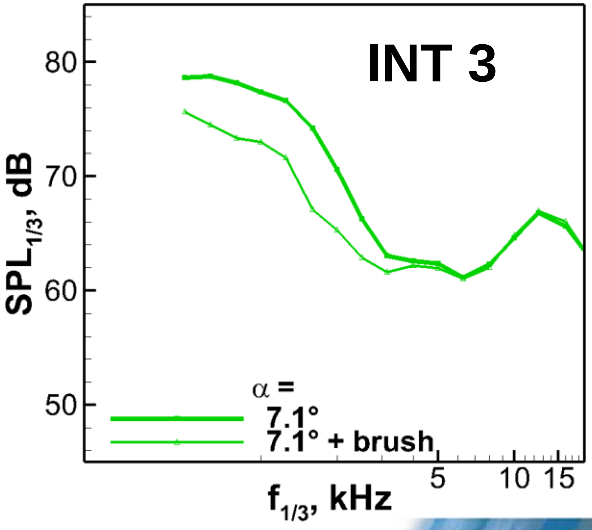
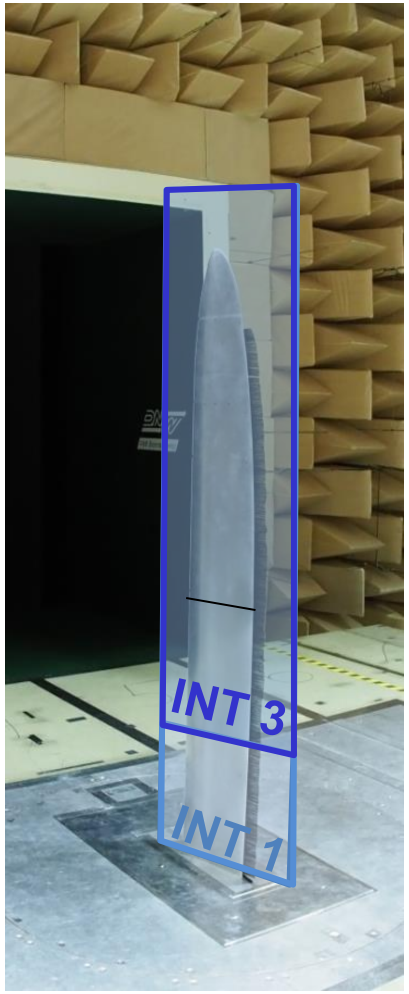
RoH-W-18%c37 FUL; u_∞ = 80 m/s

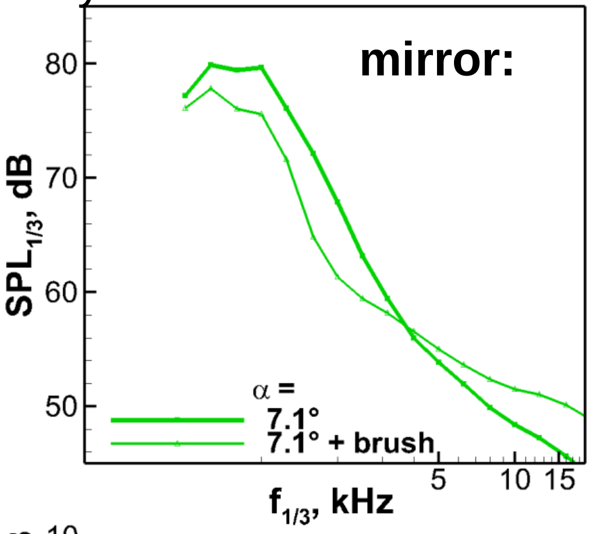
→ 4–6 dB noise reduction by brush add-ons

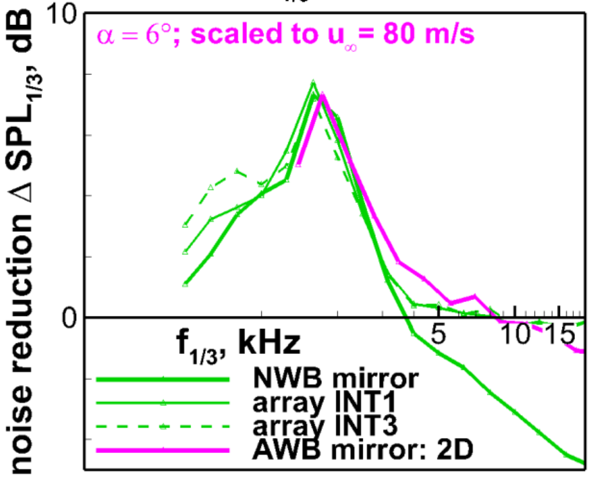


array 1:









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Summary & Outlook

- A first assessment of numerical vs. experimental data from the BELARWEA project has been reported.
  - Blind predictions for a new airfoil contour RoH-W-18%c37 are almost perfectly confirmed by measurements at 2D airfoil sections in AWB.
  - The expected noise reduction effect was also represented in respective measurements at 3D tip models in DNW-NWB (consistent picture when comparing all applied measurement technos.).
  - The 3-dB-noise reduction target could be achieved at the 3D tip models in DNW-NWB; TEN peak levels were reduced by 2–2.5 dB (new airfoil contour at design conditions) plus 4–6 dB (additional peak noise reduction by means of TE brushes).
- Note: The experimental data base is far more extensive when compared to the selection shown here! Further post-processing and data analysis are necessary to make use of the full extent of the collected test data
- Future use of the data for 3D code development & validation

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Thank you for your attention!

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