Large-Scale Slat Noise Studies within the Project OPENAIR

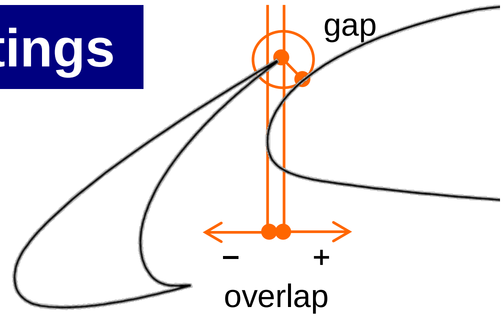
Michaela Herr, Roland Ewert, Michael Pott-Pollenske, Jan Delfs & Anton Rudenko – German Aerospace Center (DLR)

Alexander Büscher – Airbus Germany

Irene Mariotti – Airbus France

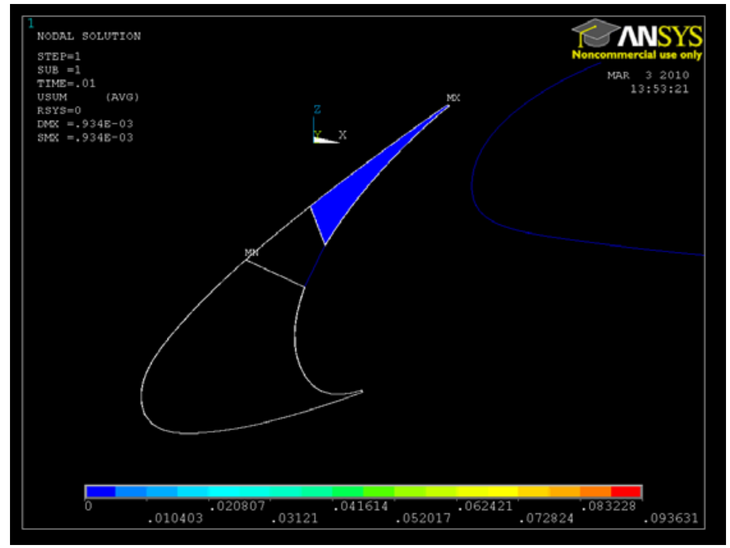
Overview on slat noise activity

slat settings



large-scale verification & CAA validation

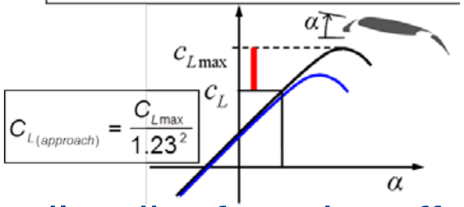
adaptive slat



Introduction: Slat noise reduction technology

- <u>Airworthiness requirements</u>

$$V_{(approach)} = 1.23\ V_{stall} = 1.23 \sqrt{\frac{2mg}{\rho A C_{L\max}}}$$



Operational aspects:

- Maximum lift determines landing speed
- Sufficient lift for <u>moderate</u> angles-of-attack to prevent tail-strike for take-off
- Low noise treatments must not affect cruise performance if not operational

Security aspects:

- Reliability
- No sudden lift/ moment changes through activation of control device

Cost aspects:

- Weight
- Structural constraints (slat tracks affect front spar position, etc.)
- Systems complexity (actuators, etc.)
- Maintenance (contamination, icing, quick access covers)

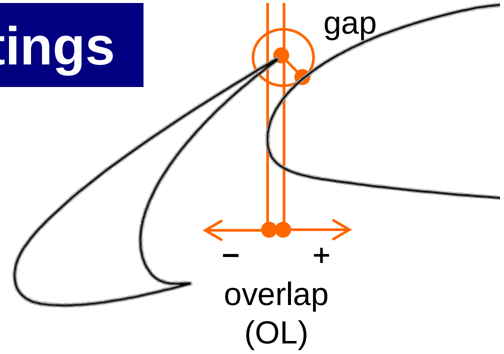
$u_\infty \sim C_{L\max}^{-1/2}$ with assumption: $\langle p^2 \rangle \sim u_\infty^5$:

→ 10 % less $C_{L\max}$ is about 5.4 % increase in landing speed = 1.1 dB noise increase!

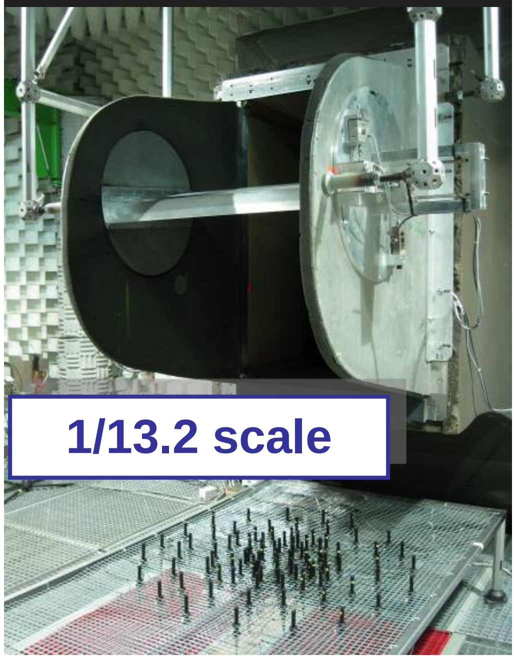
→ Cost function: $\langle p^2 \rangle \sim C_{L\max}^{-5/2}$

Background – slat settings

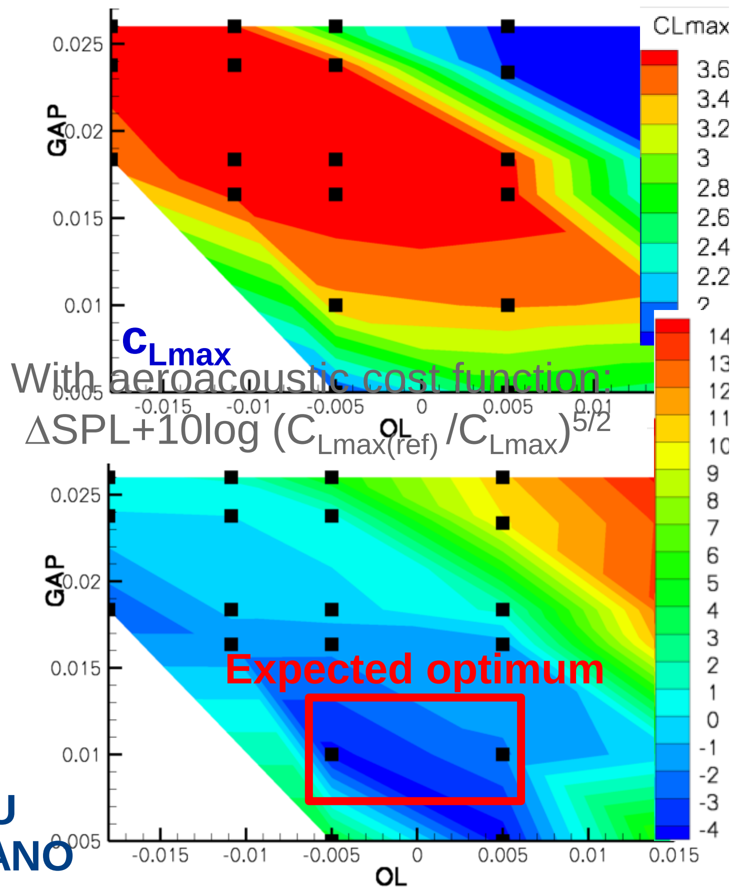
slat settings



F16 model in AWB



- Small-scale CFD/CAA 2D results from forerunner EC project T-IMPAN

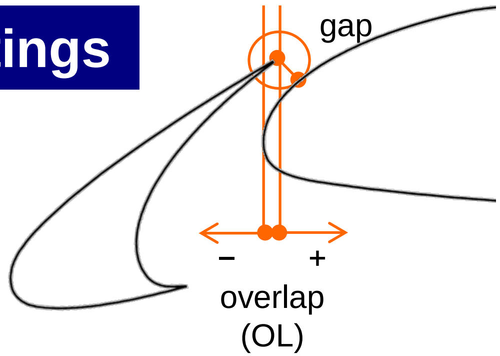


Flow: TAU
Noise: PIANO

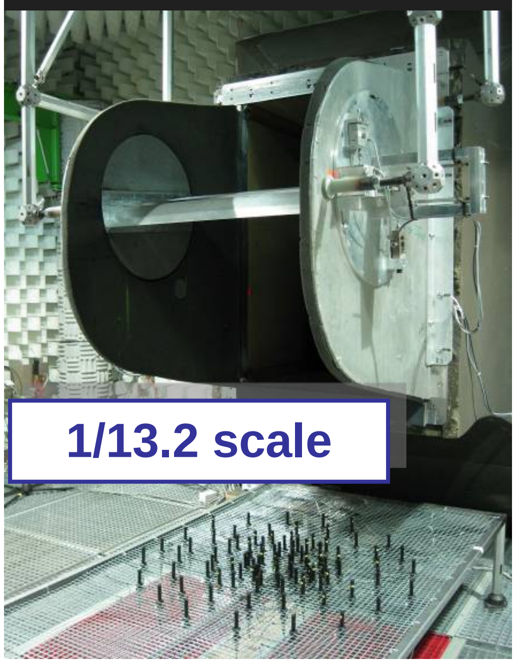
Sources: Pott-Pollenske et al. (AIAA 2003-3228), Ewert et al. (AIAA 2010-3833), Delfs (DAGA 2011)

Background – slat settings

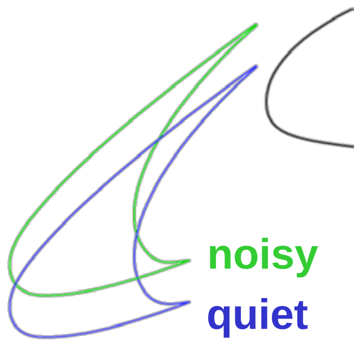
slat settings

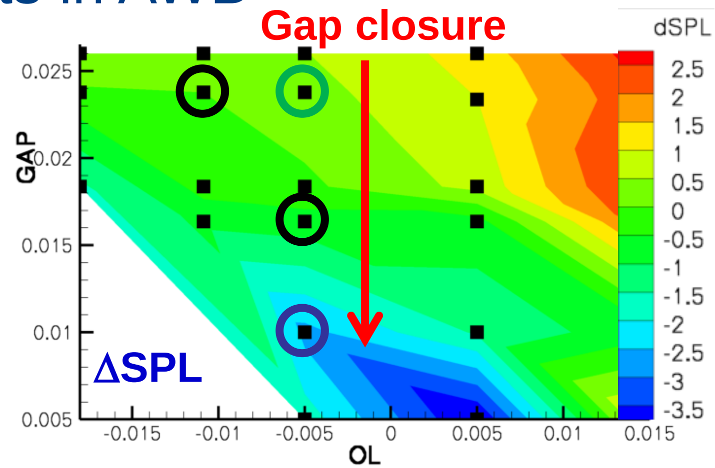


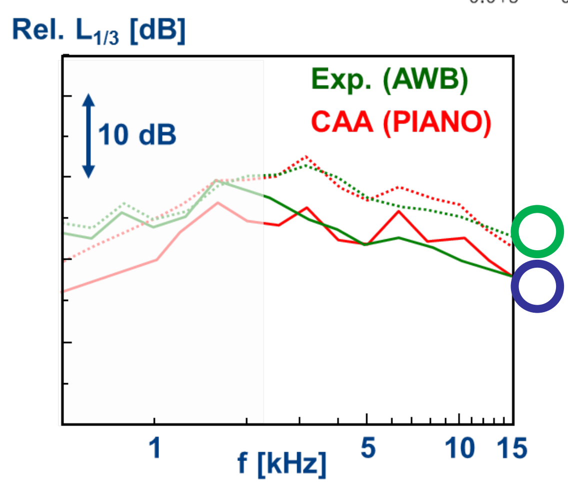
F16 model in AWB



- T-ImpAN small-scale 2D validation experiments in AWB





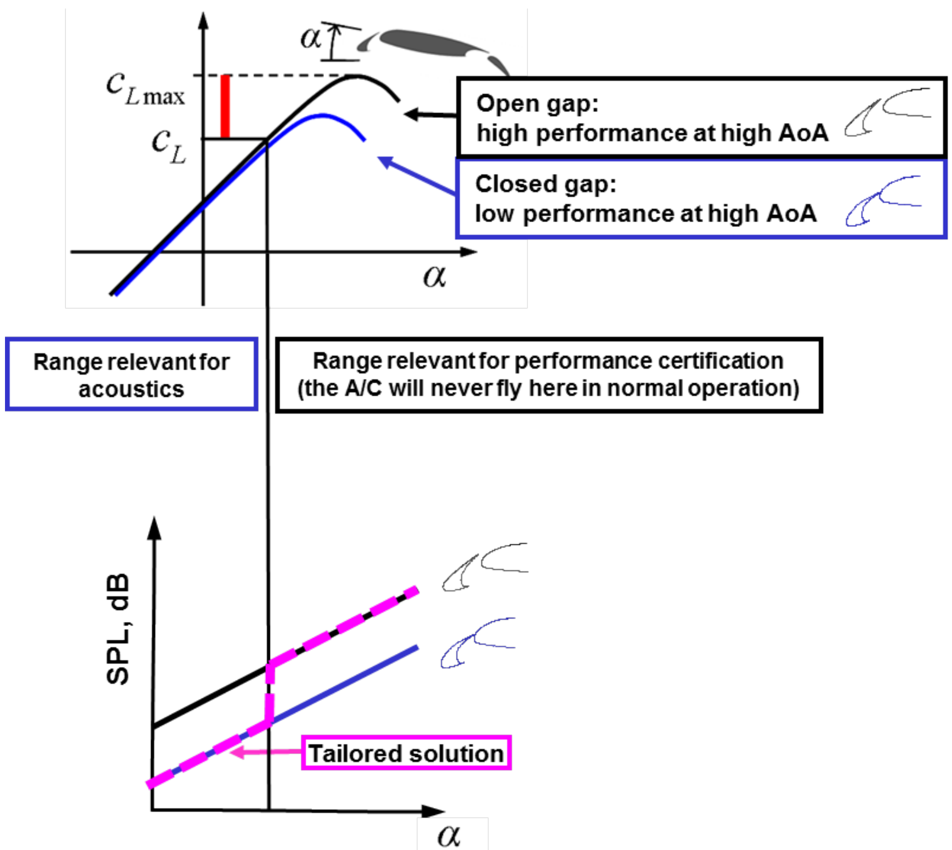


Sources: Pott-Pollenske et al. (AIAA 2003-3228), Ewert et al. (AIAA 2010-3833), Delfs (DAGA 2011)

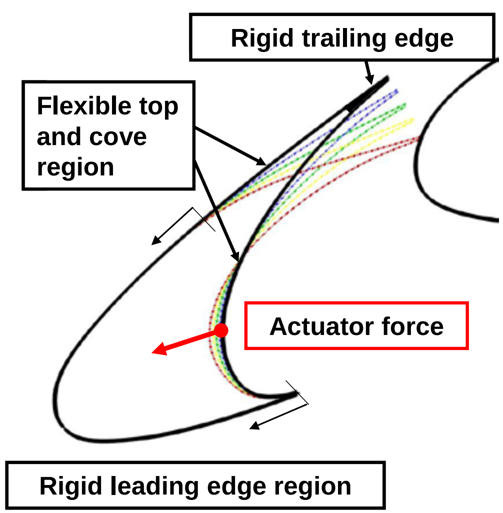
Background – adaptive slat

Adaptive slat

Quiet for small α, high aerodynamic performance (but loud) where needed = tailored solution!



- CFD/CAA 2D results from forerunner EC project NACRE:
  - 5 dB noise reduction at wing level for slatless configuration
- Expectation: closure of the gap will eliminate slat noise



Background – adaptive slat

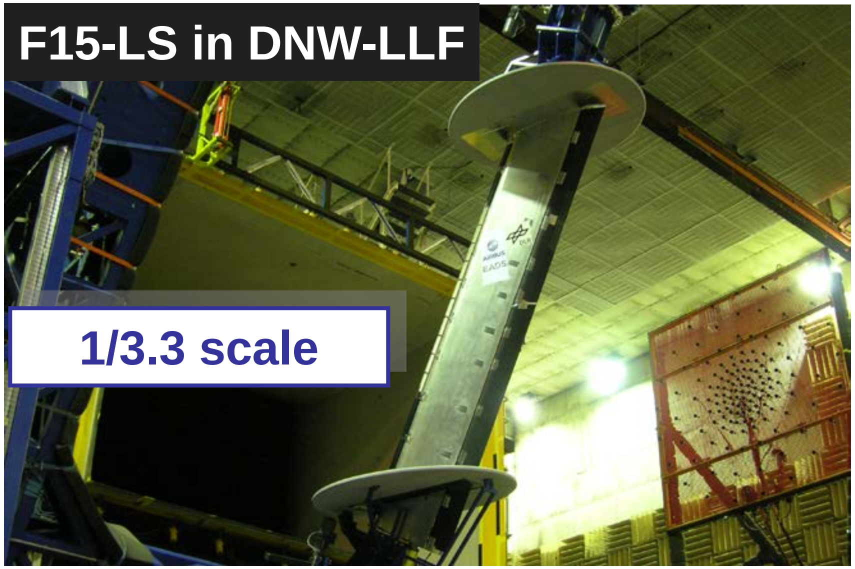
- Design requirements

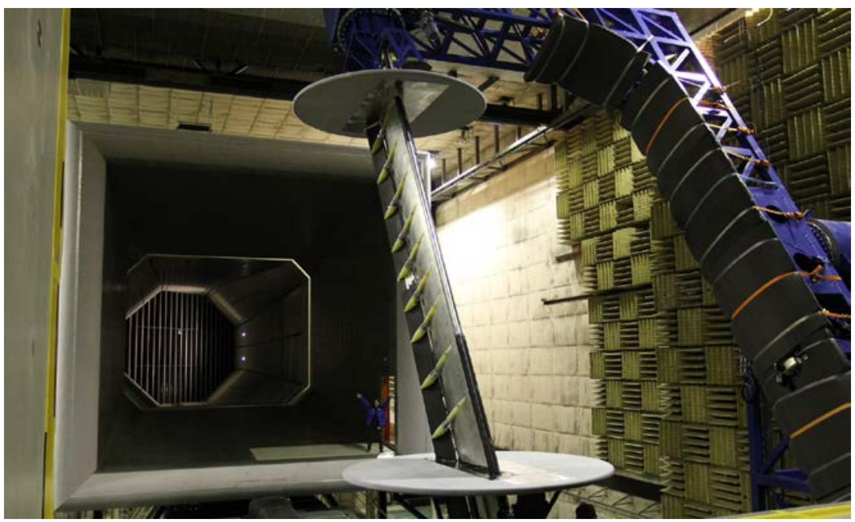
  - System safety
  - Retention of the original approach speed and thus C_{Lmax} of the conventional slat with open gap
  - Fast movement from the low-performance- to the high-performance position
  - Limited weight and complexity impact
  - Limited adverse influence on the flow (i.e. no tubes, etc. in the slat cove)

  In particular, the following requirements were deduced:

  - Extension time of order < 2 s
  - Provision of a fail-save emergency release concept (inactive system = original gap)
  - System reliability for all possible load conditions
  - Prevention of failure cases where the system jams in the morphed position

OPENAIR objectives

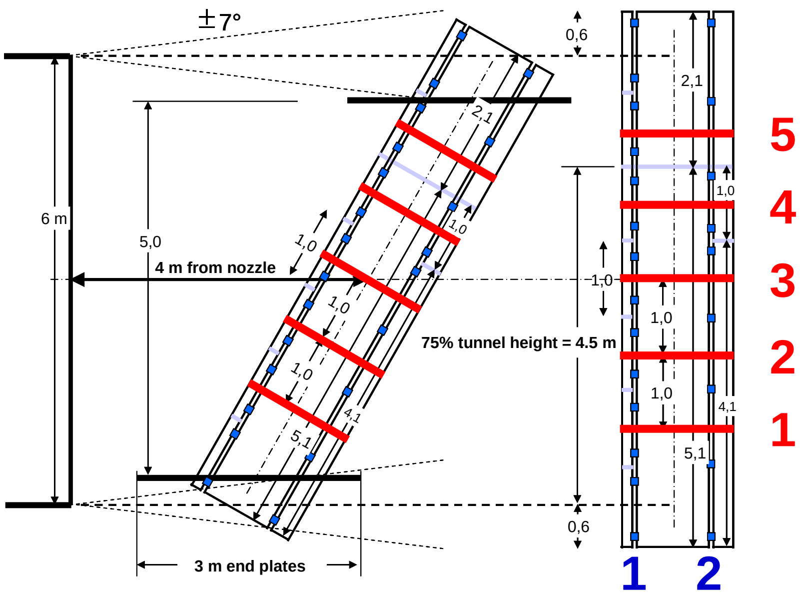


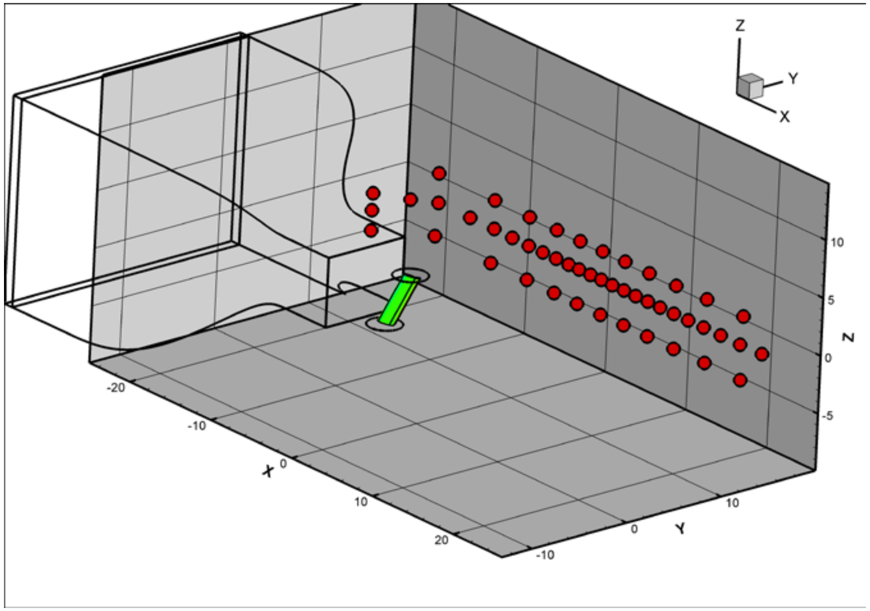


- Large-scale verification of noise benefit achieved by low-noise slat technologies at swept wing configuration
- Large-scale confirmation of TIMPAN and NACRE results at swept wing configuration
- Validation of DLR’s CAA codes for these more realistic condi-tions (extension of data bases)
- Identification of structurally feasible adaptive slat shapes
- Projection of DNW-LLF test results to flight conditions

Test setup

- Overview: Measurement instrumentation
  - F15-LS model instrumentation: 568 static pressure ports & 12 Kulite sensors in the slat cove/ slat trailing-edge region
    - Force integration along midspan section (targeted uniform distributions confirmed along F15-LS midspan region between sections 2 to 4)
  - Single FF microphones for directivity measurements (12 + 24 +12 mics.)





Test setup

- Overview: Measurement instrumentation
  - Microphone array (144 mics.) pointing at the PS for source localization
  - Array analysis:
    - Data analysis with CLEAN-SC
    - Removal of excess noise sources
    - Correction of wind-tunnel effects
    - Integration of sound pressure level spectra incl. deconvolution
    - Spectra referenced towards a constant distance
    - Adaptive slat data projected to full span

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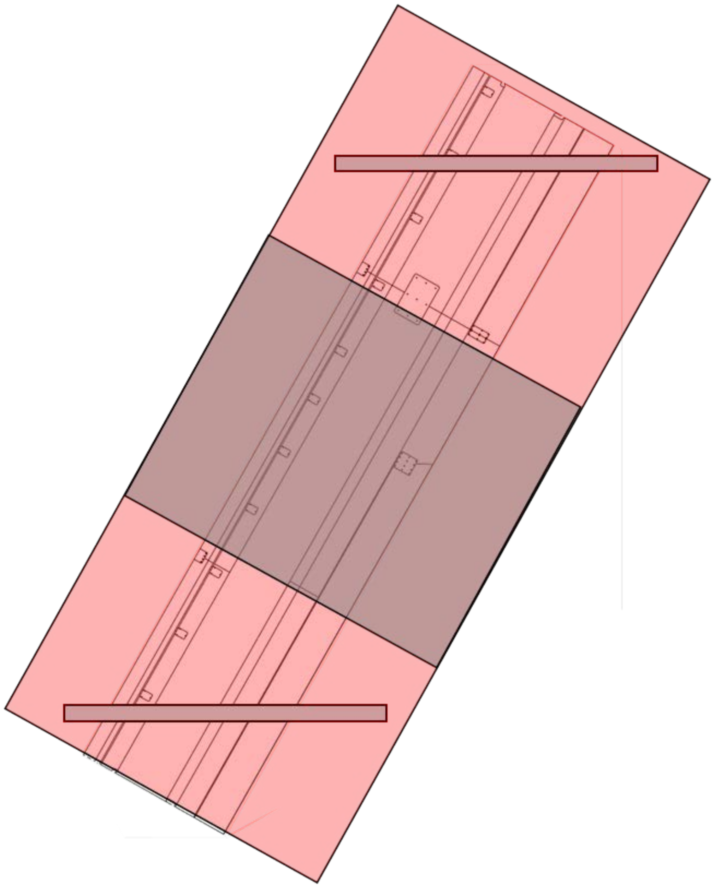

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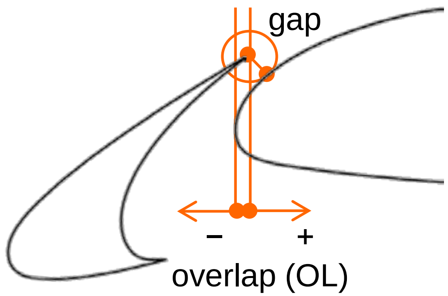
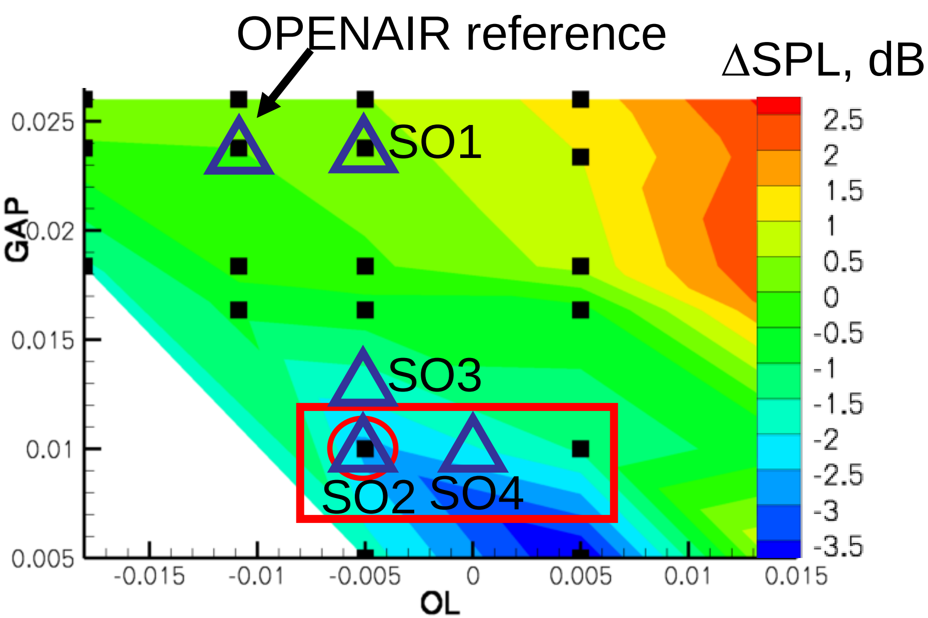
Test results: slat settings

- <u>Acoustic Assessment at wing level:</u>

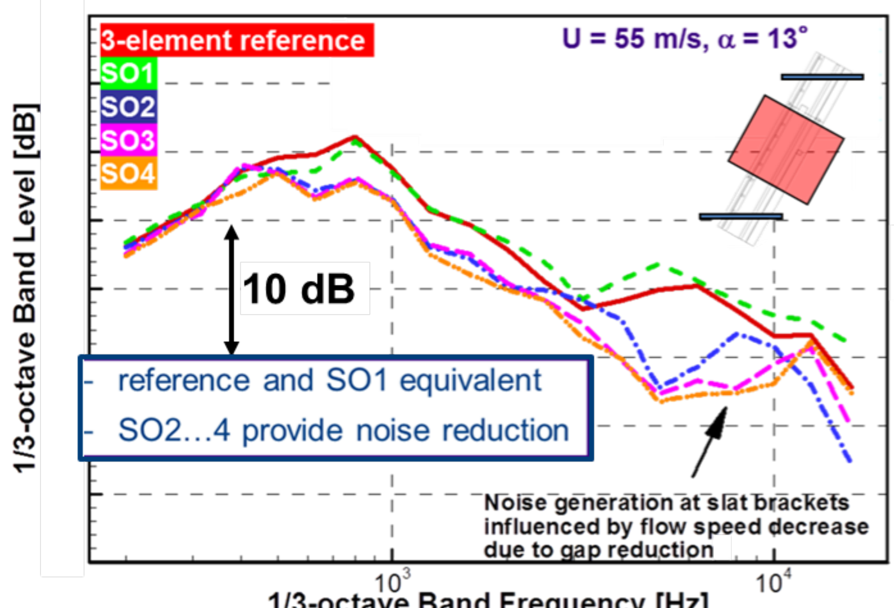
Selection of OPENAIR settings for DNW-LLF test based on TIMPAN results:

△ OPENAIR settings SO1…SO4





Array spectra, overhead position



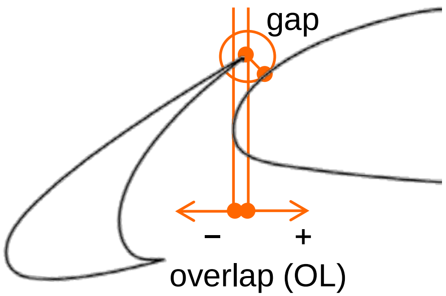
➢ Similar trends observed at F15-LS large-scale model as in TIMPAN (2D F16 small scale model).

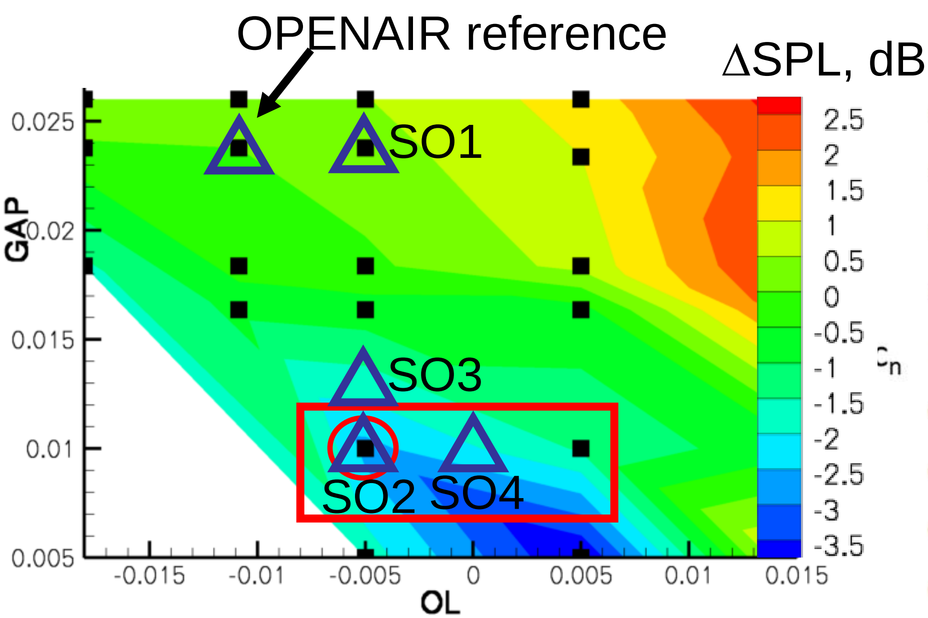
Test results: slat settings

- <u>Aerodynamical assessment:</u>

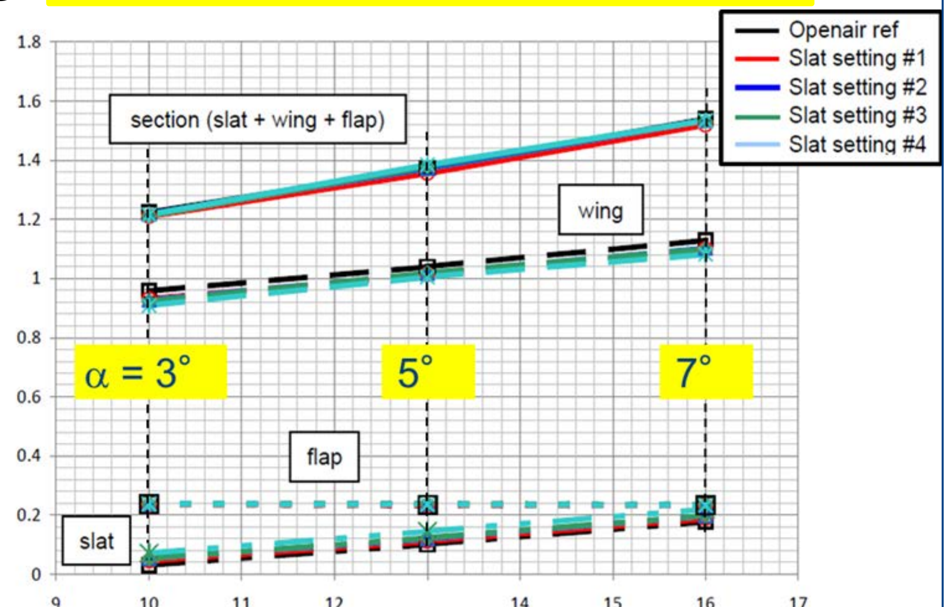
Selection of OPENAIR settings for DNW-LLF test based on TIMPAN results:

△ OPENAIR settings SO1…SO4





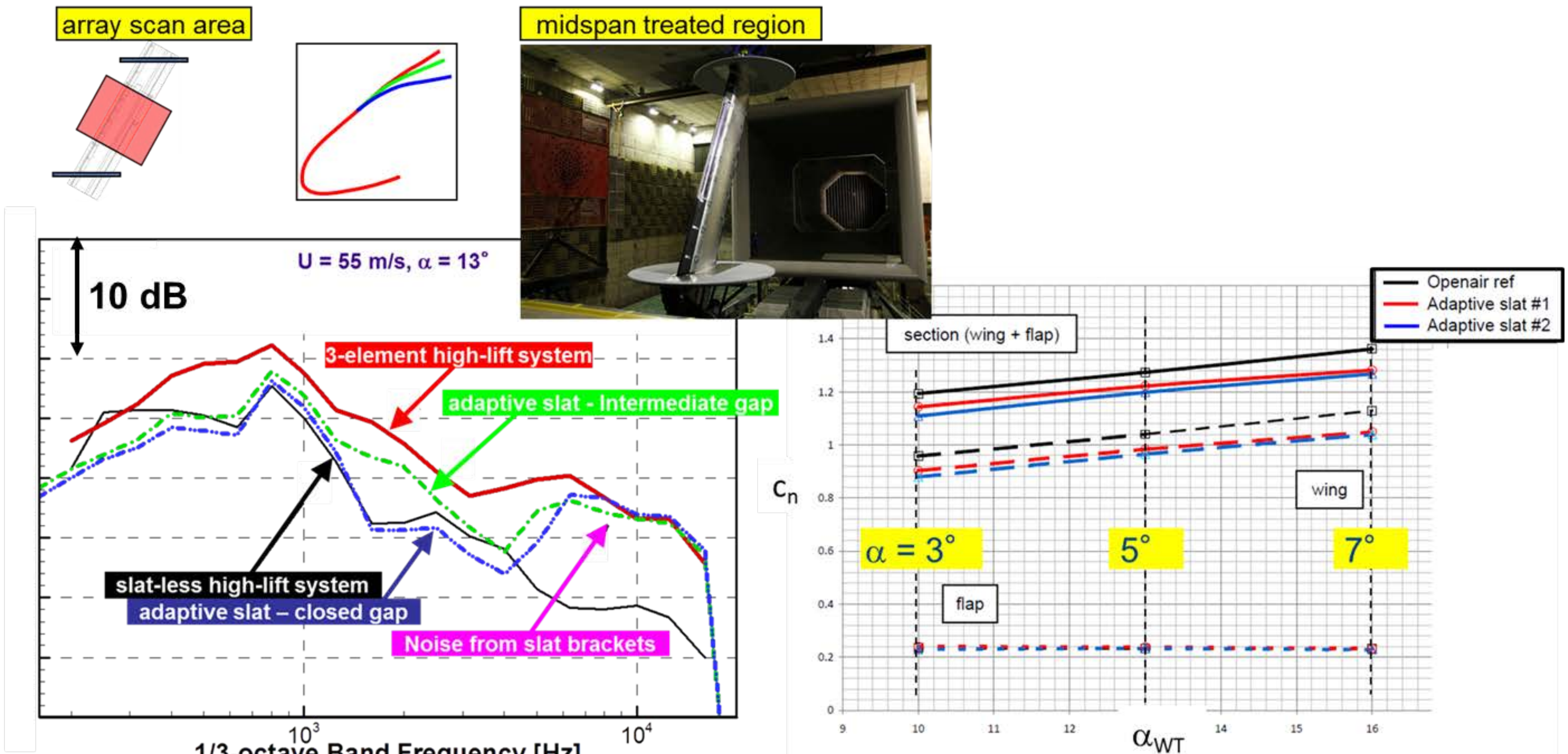
Integrated normal force coefficients



➢ Maximum noise reduction of ~3 dB at wing level with no significant lift penalty at test angles-of-attack (restricted to linear region of lift polar).

Test results: adaptive slat

- Acoustic & aerodynamic assesment (at wing level):



- ➢ Full elimination of slat noise by gap closure → noise benefit according to simulation results (NACRE: 5 dB noise reduction at wing level).
- ➢ Adaptive slat causes lift penalty at the main element, however, per definition c_{Lmax} remains unaffected.

Test results: adaptive slat

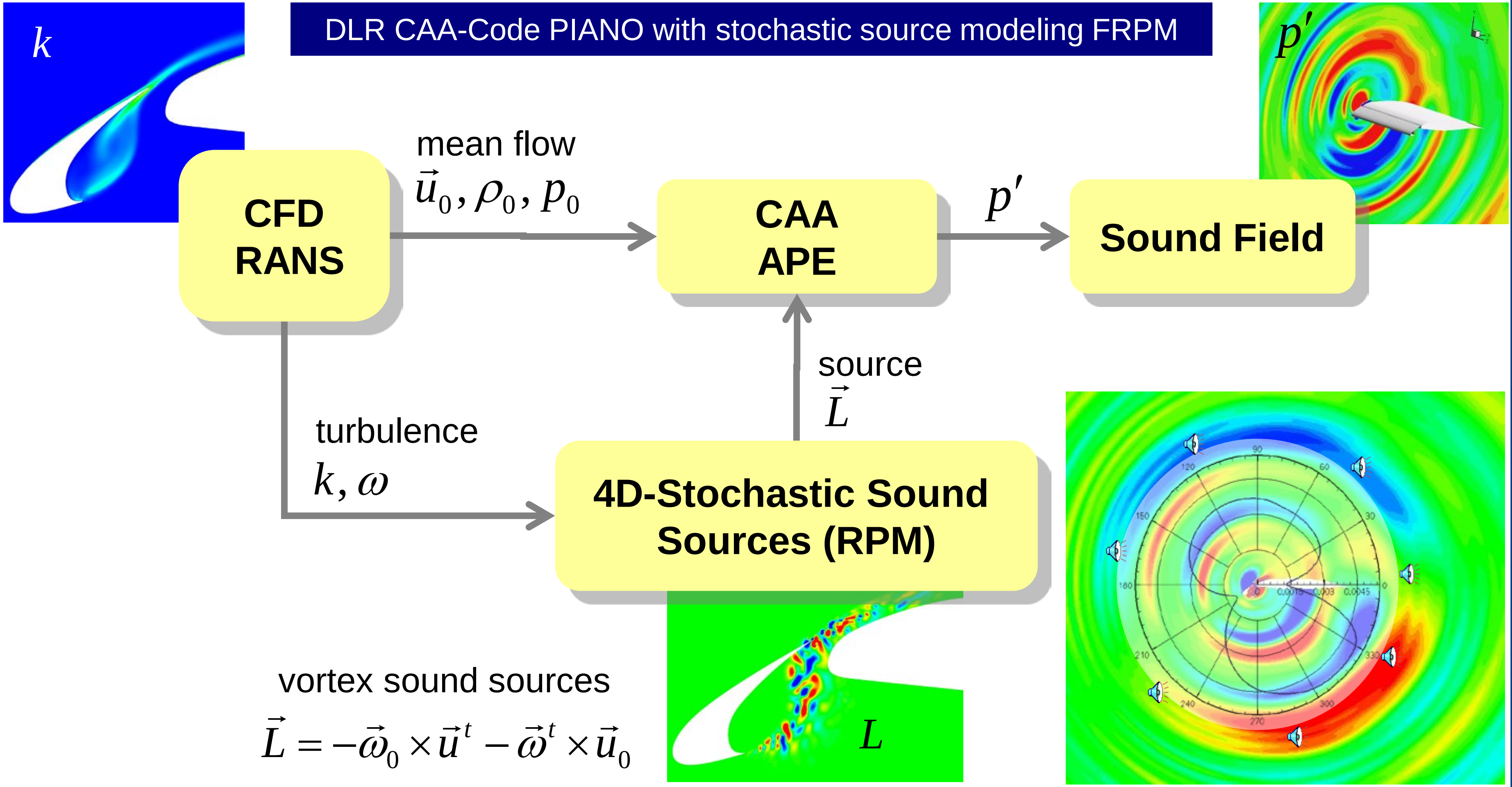
- Transposition of DNW-LLF results to flight conditions:

Maximum A/C noise reduction in terms of approach certification EPNL (typical SMR platform):

  - Slat settings: -0.5 EPNdB
  - Adaptive Slat (sealed gap): -0.6 EPNdB

Test results: CAA validation

- Used CAA approaches:



Ewert, 2005/06

Test results: CAA validation

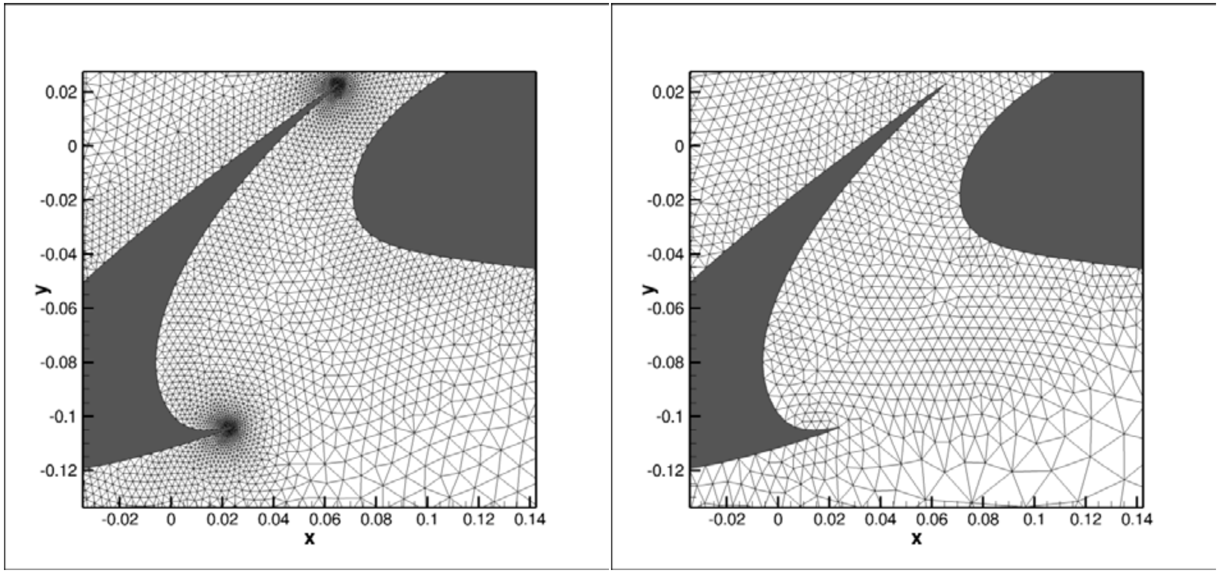
- <u>Used CAA approaches:</u>

New DLR DG (Discontinuous Galerkin) Code DISCO with FRPM

- DISCO works on unstructured grids based on triangular elements → more convenient on complex structures than structured ones, i.e. desirable for industrial use.

DISCO meshes

with blunt TE — with sharp TE



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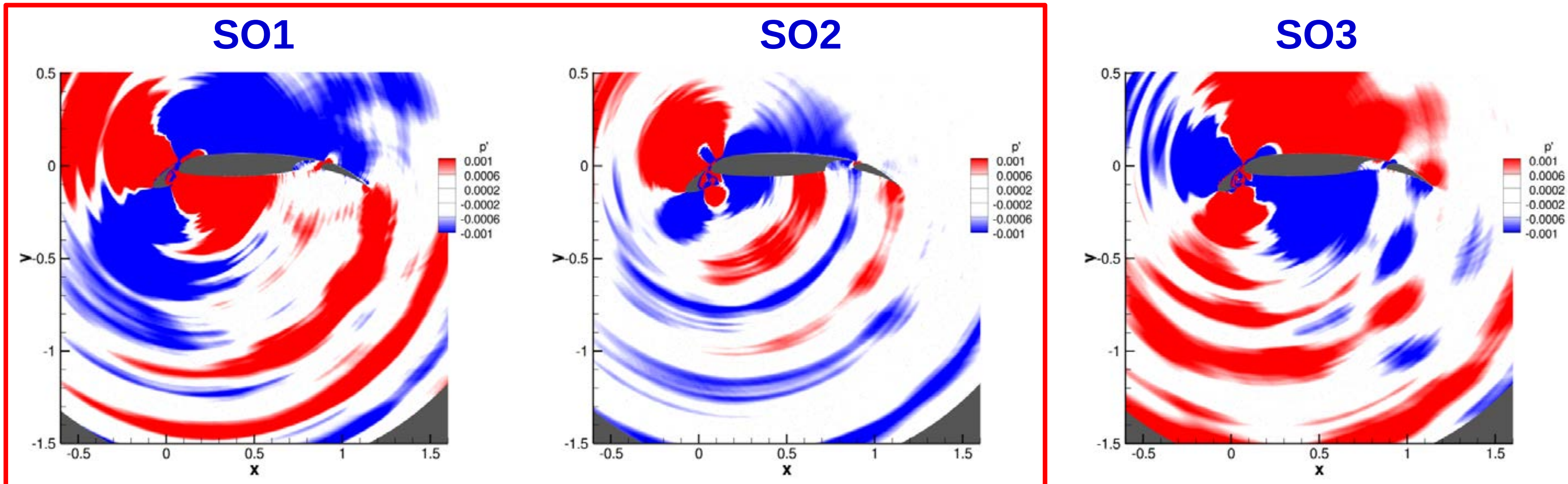
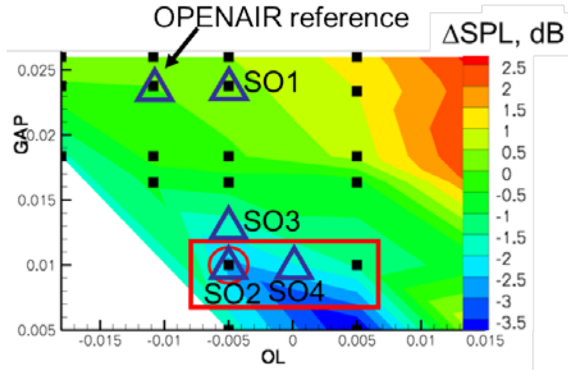
  - DISCO works on unstructured grids based on triangular elements → more convenient on complex structures than structured ones, i.e. desirable for industrial use.
  - Predicted snap shots of sound propagation for settings SO1…SO3:

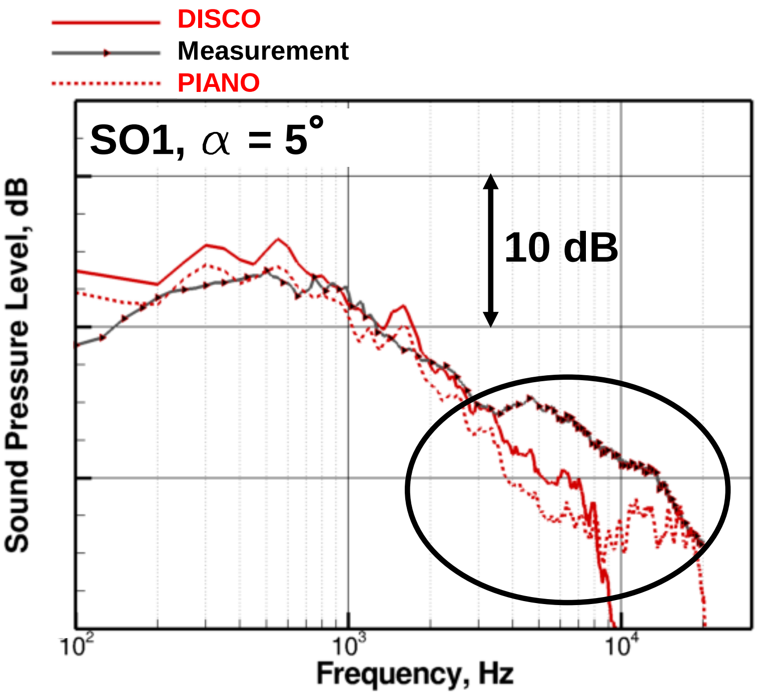


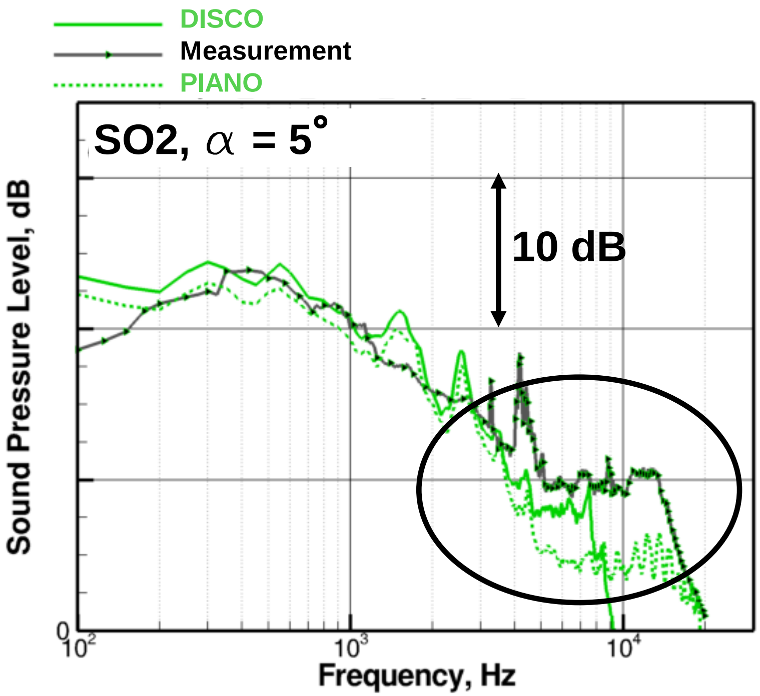
Test results: CAA validation

- Settings SO1 vs. SO2:

re. nb spectra (array), overhead position





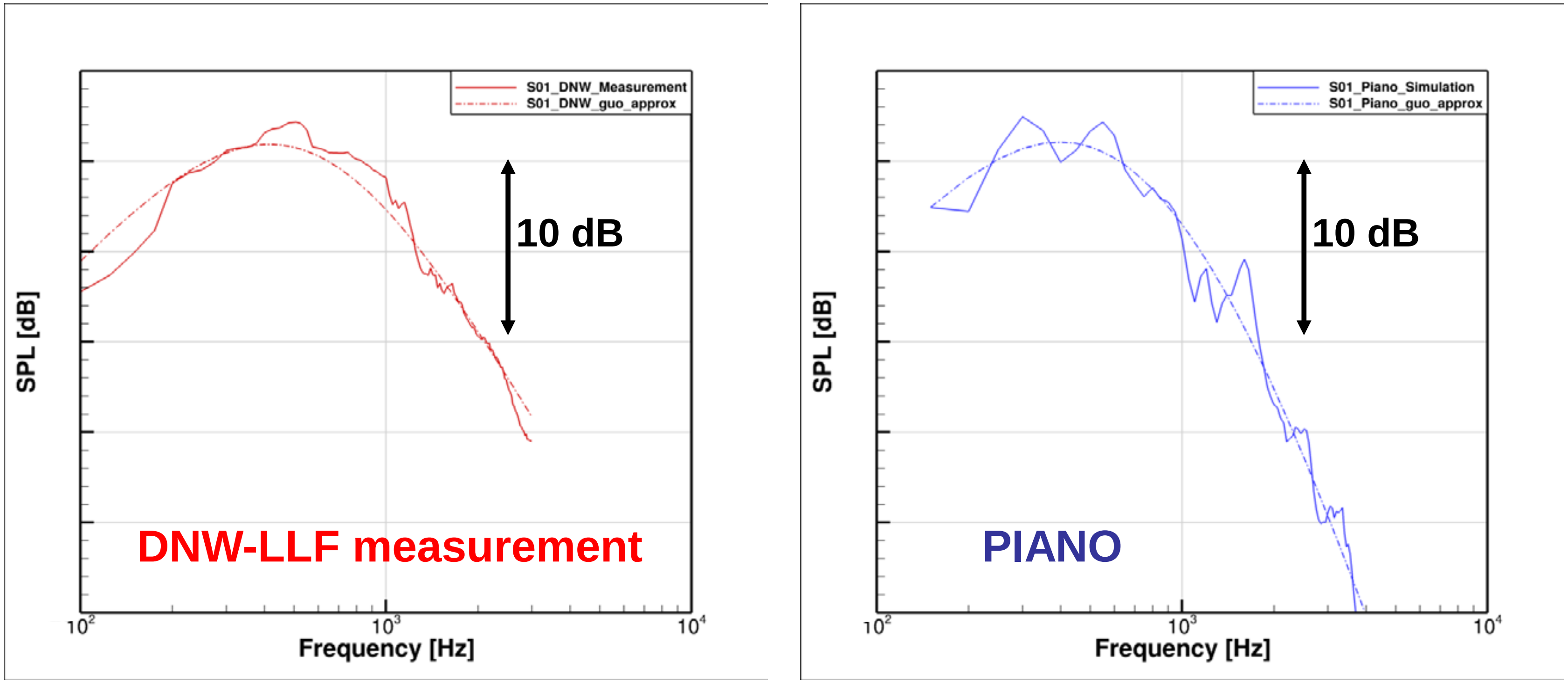


➢ PIANO and DISCO predictions provide identical trends (ΔSPL as measured).

Test results: CAA validation

- Slat setting SO1: Check for spectral shape functions according to semi-empirical slat noise prediction by Guo, 2012

re. nb spectra (array), overhead position



Test results: CAA validation

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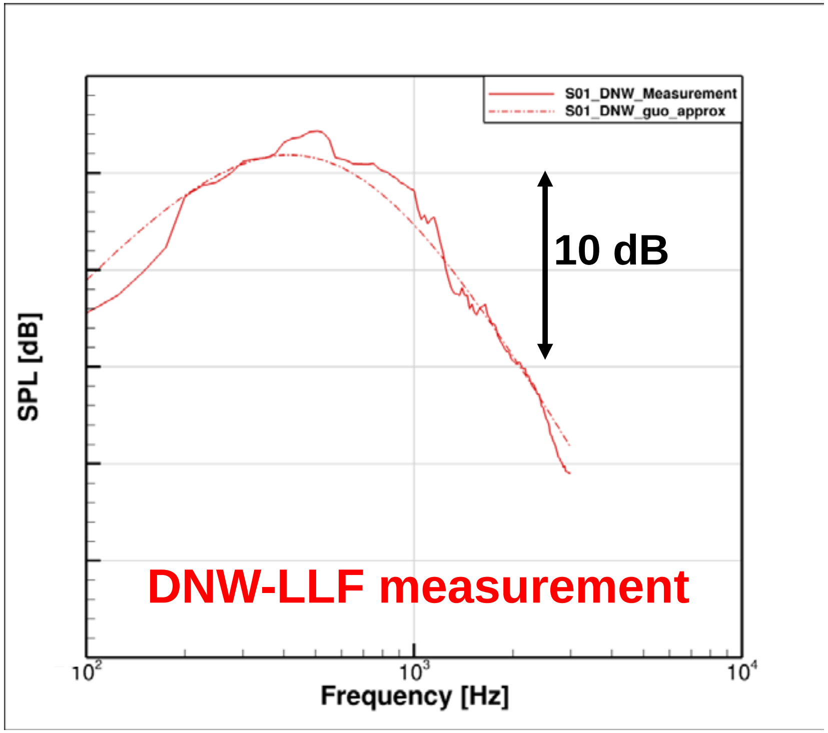

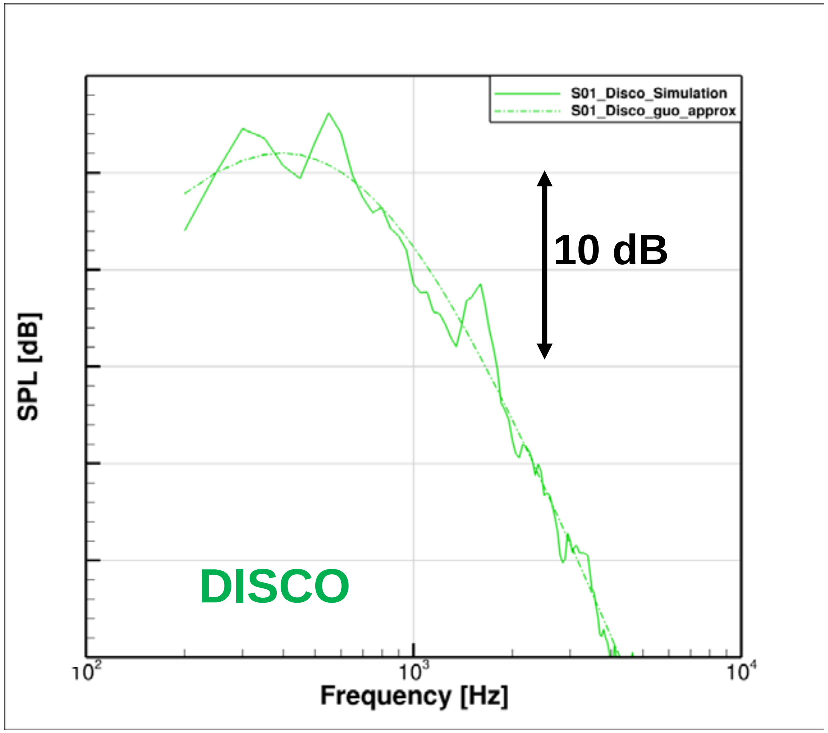

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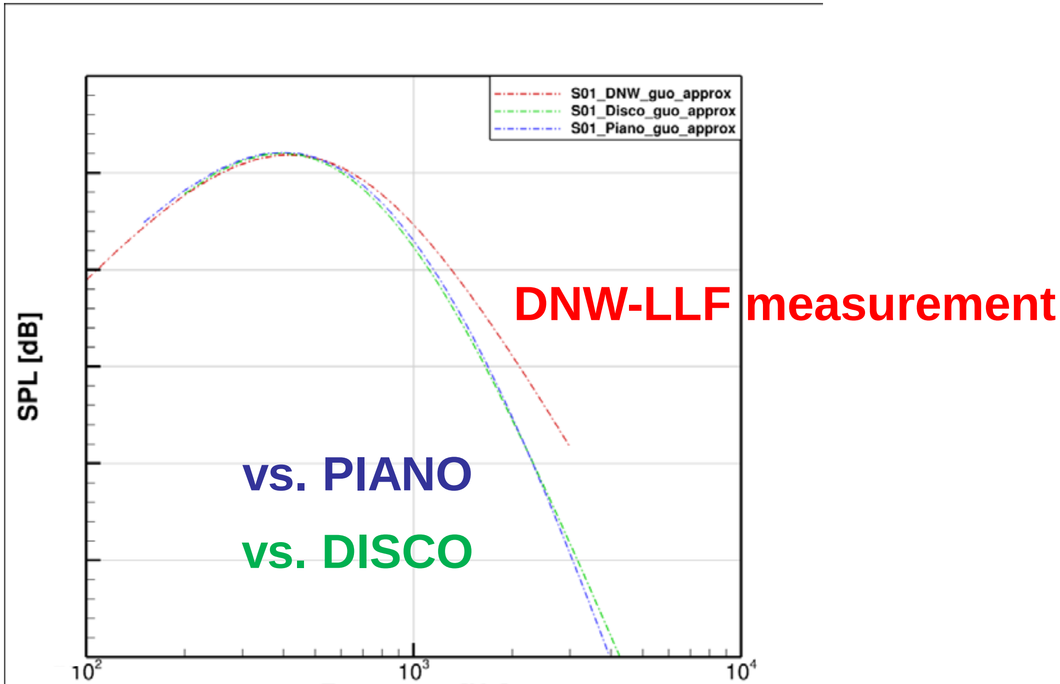

- PIANO and DISCO predictions provide identical spectral shape functions.
- Differences compared to measurements are suspected to be caused by track noise in the measurements.

Summary & Conclusions

- Large-scale slat noise tests and simulation results within OPENAIR have been presented; two low-noise concepts were considered:
  - slat setting variations & adaptive slat

- DNW-LLF noise assessment confirmed former TIMPAN & NACRE results at wing level:
  - -2–3 dB for the best slat setting (broad optimum: SO2/SO4)
  - -5 dB for the adaptive slat with sealed gap

- Projection to flight provided the following noise reduction results (typical SMR platform, approach certification noise levels):
  - -0.5 EPNdB for the best slat setting
  - -0.6 EPNdB for the adaptive slat with sealed gap

- CAA results applying the new DLR DG code DISCO have been conducted, showing very good agreement with PIANO simulations

Thank you for your attention!

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