DLR’s Laser Sound Source, a Status Review

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Institute of Aerodynamics and Flow Technology

Technical Acoustics Branch

HAWT Workshop

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DLR

Structure of my talk …

(1)

Impulsive laser sound source: our setup and source characteristics

(2)

How we currently use the impulsive laser sound source

- Demonstration of the **reliability** of tools capable of predicting the effects of propulsion system installation (through impulse testing, i.e. Green's function determination)

(3)

Past and current efforts towards facility calibration/characterization

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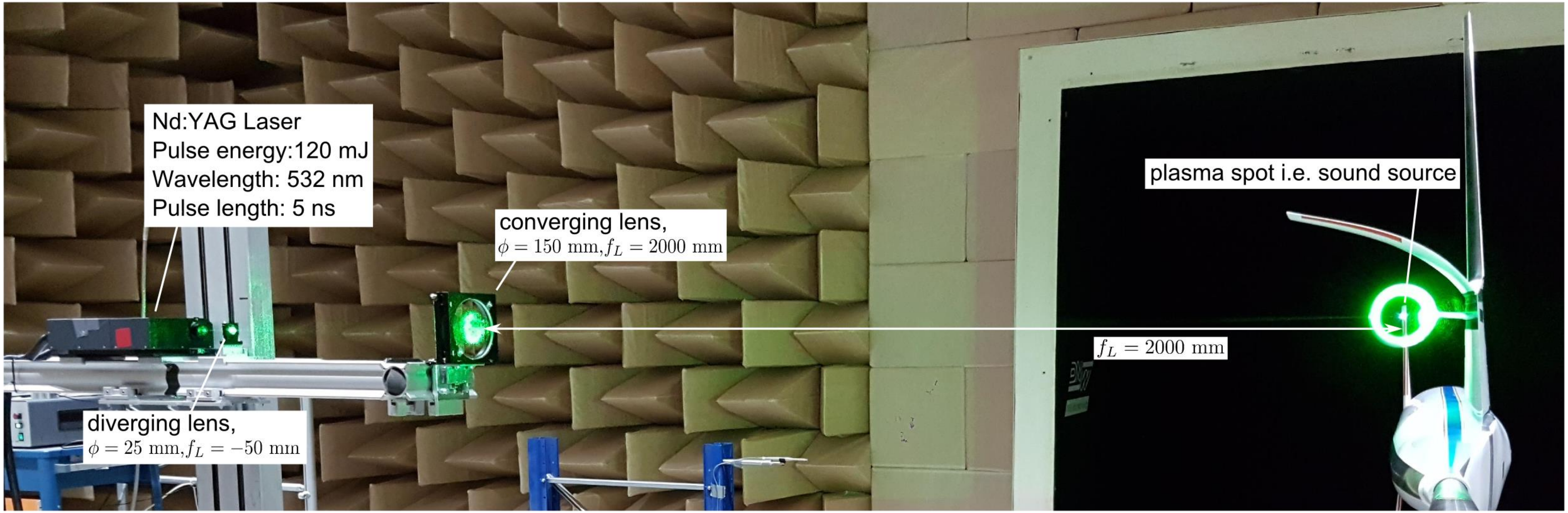
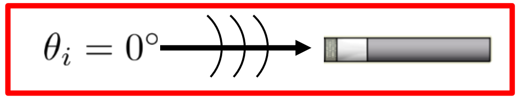
Impulsive laser sound source: our setup

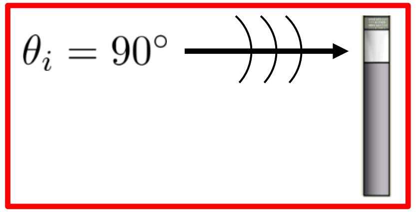


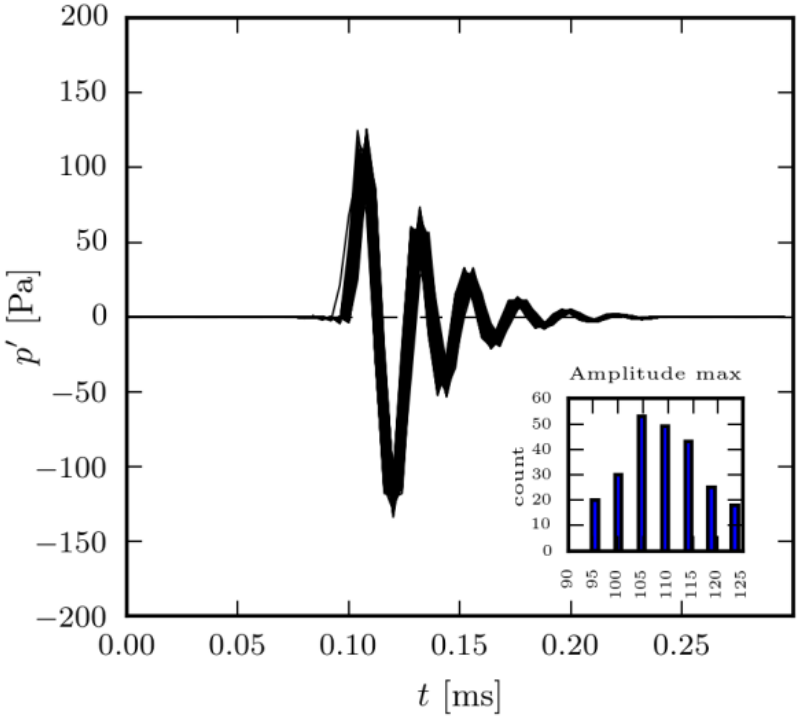
Rossignol, Delfs , 22nd AIAA/CEAS Aeroacoustics 2016

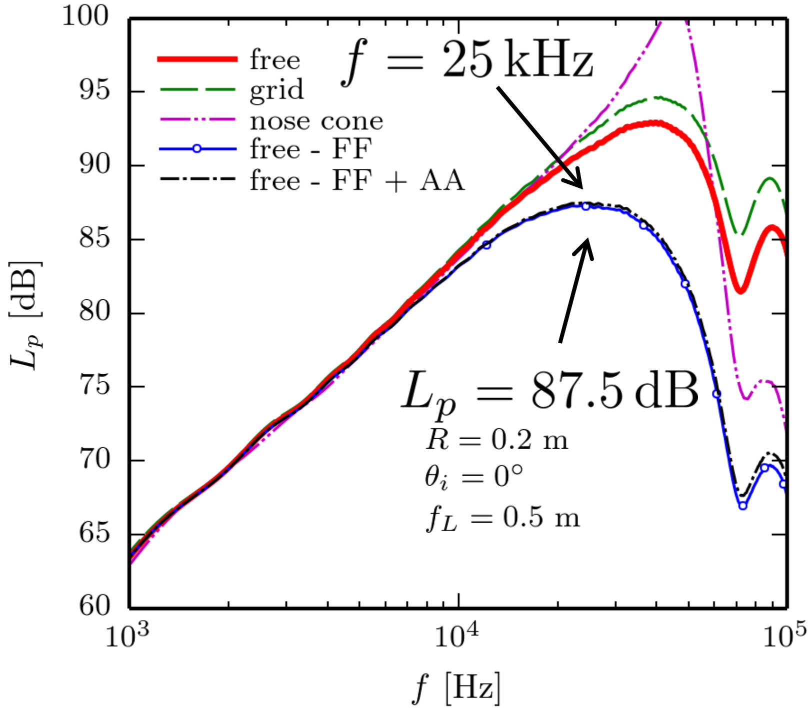
Impulsive laser sound source: source characteristics

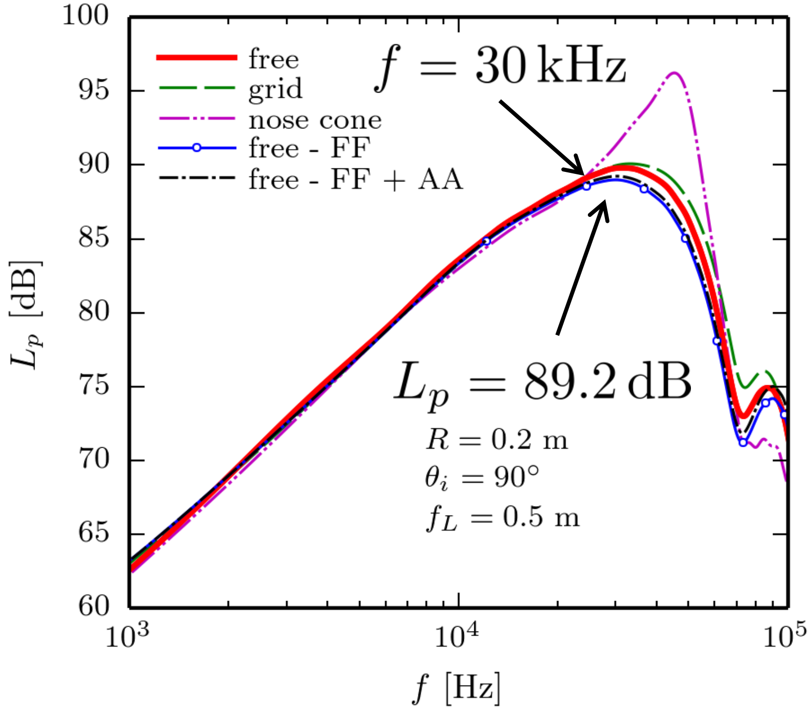
Data acquisition/processing: microphone corrections











Time domain

Frequency domain

Rossignol, Delfs , 22nd AIAA/CEAS Aeroacoustics 2016

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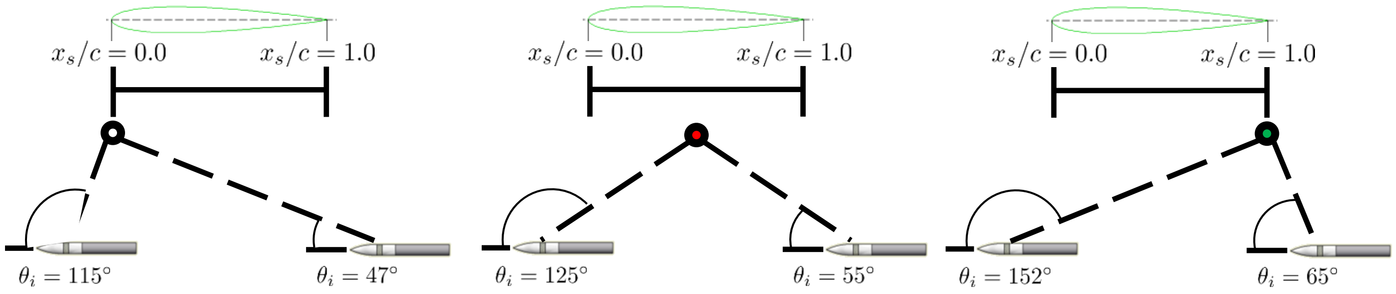
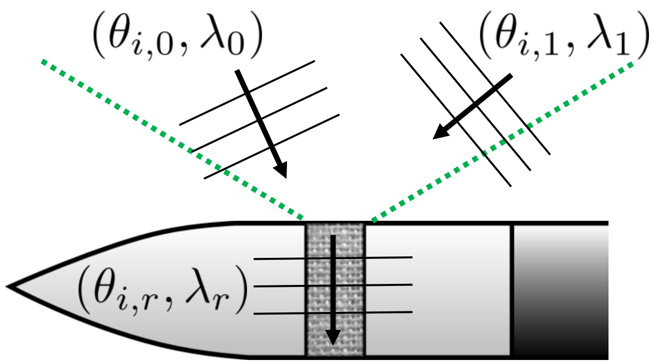
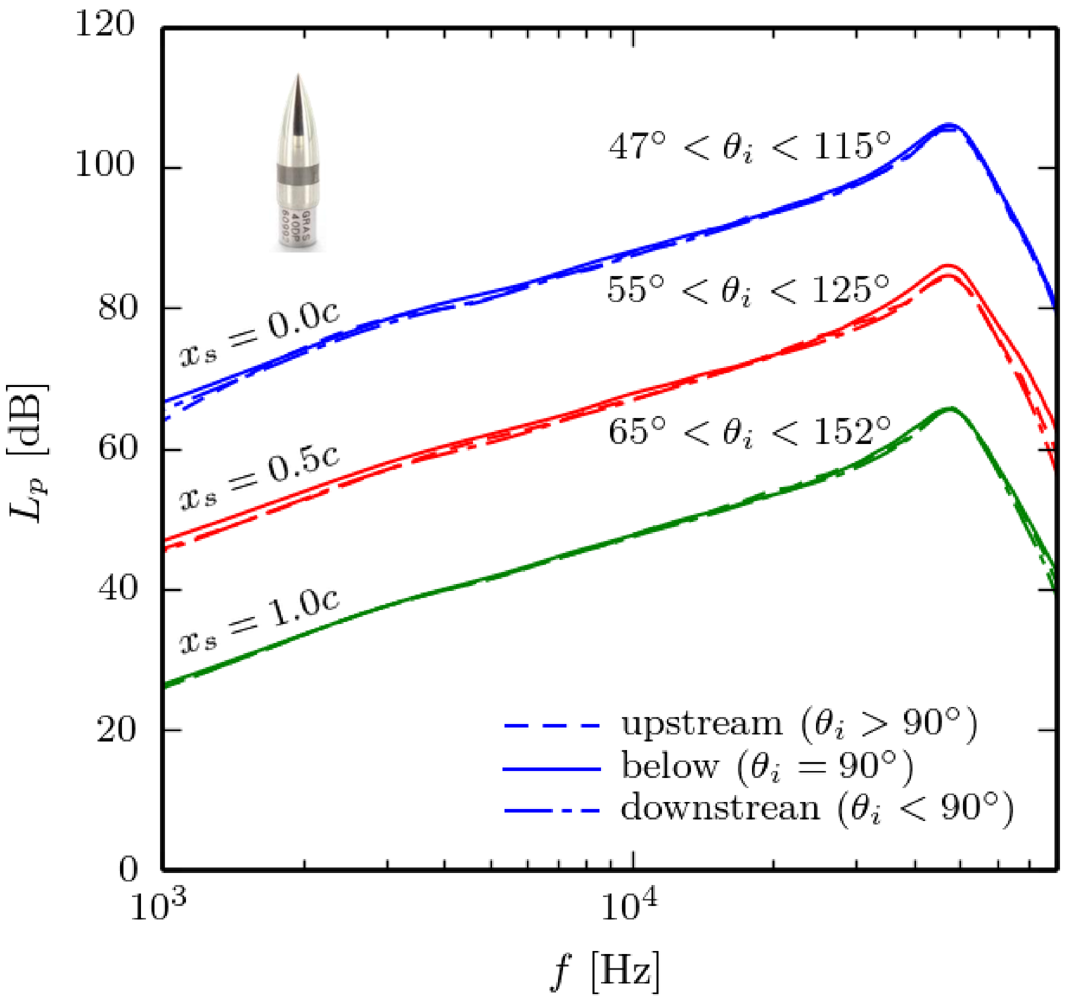
Data acquisition/processing: microphone corrections



*** Nose cone removes dependency on θ_i (!)



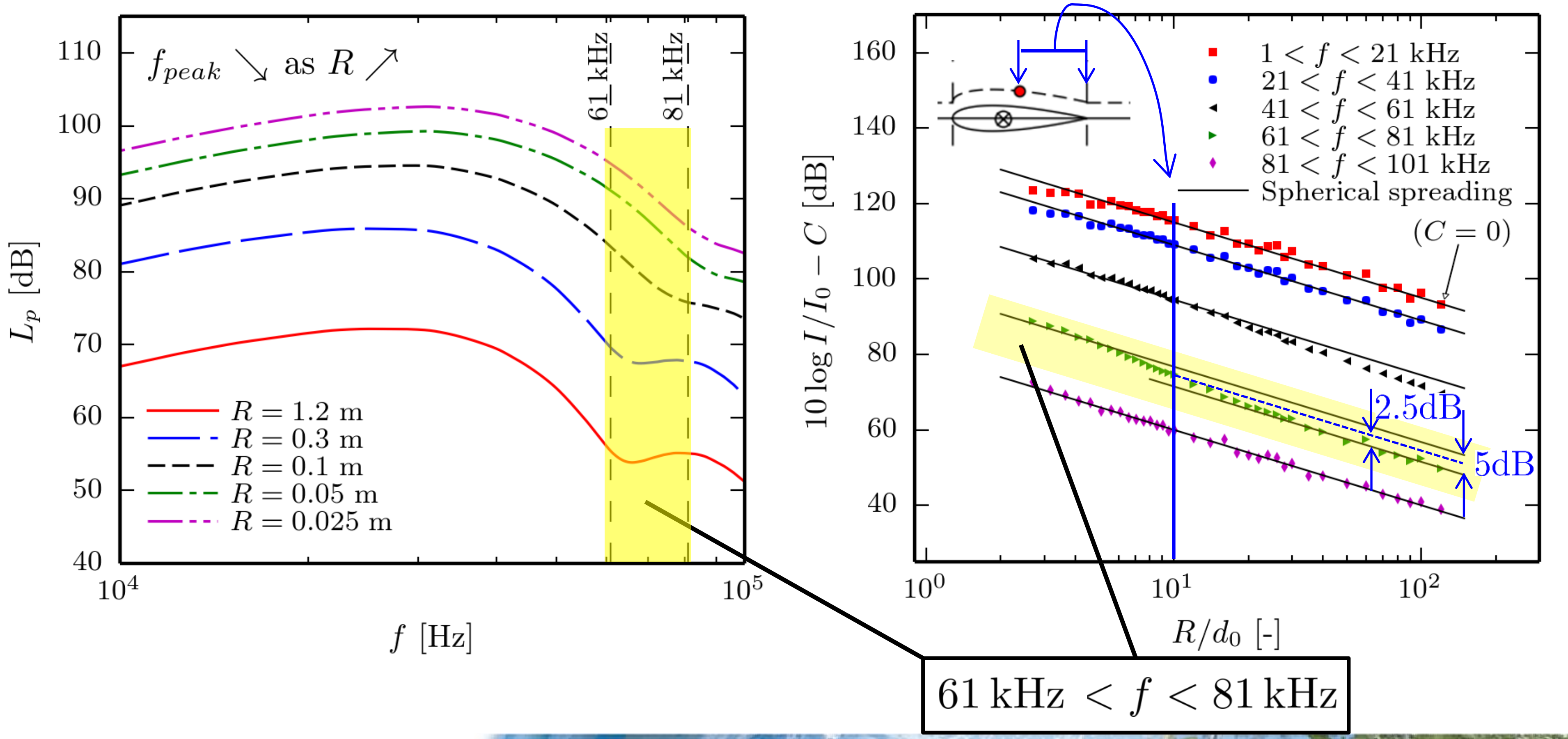


Rossignol, Delfs , 22nd AIAA/CEAS Aeroacoustics 2016

Impulsive laser sound source: source characteristics

Source non-linearities

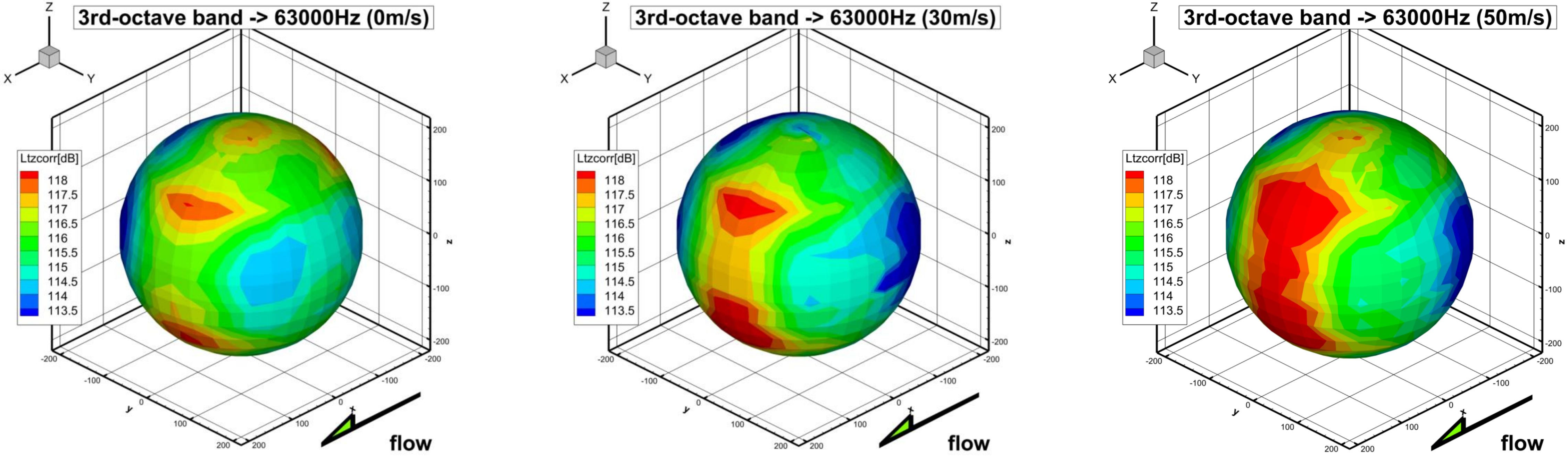
Reference level at mic. too low by approx. 2.5 dB → higher attenuation magnitude



Boden et al., Internoise 2006

Impulsive laser sound source: source characteristics

Source convection effects



- Succesive measurements without flow and with flow
- Source directivity measurements with nose cone (in-flow) vs. velocity (R = 200 mm)

Rossignol, Delfs , 21nd AIAA/CEAS Aeroacoustics 2015

Impulsive laser sound source: source characteristics

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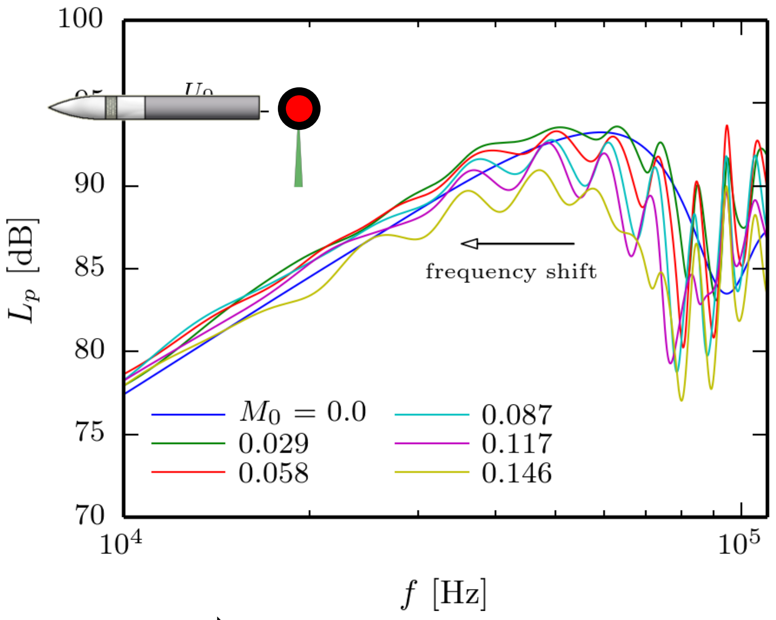
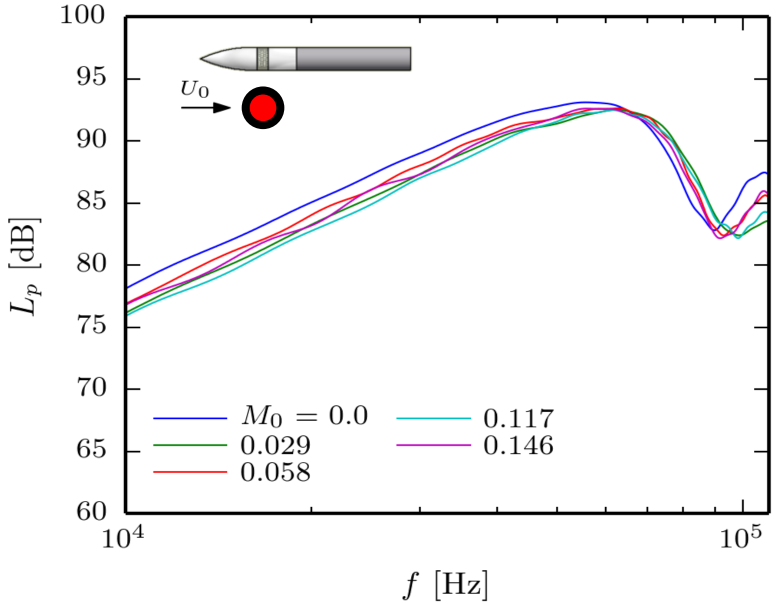
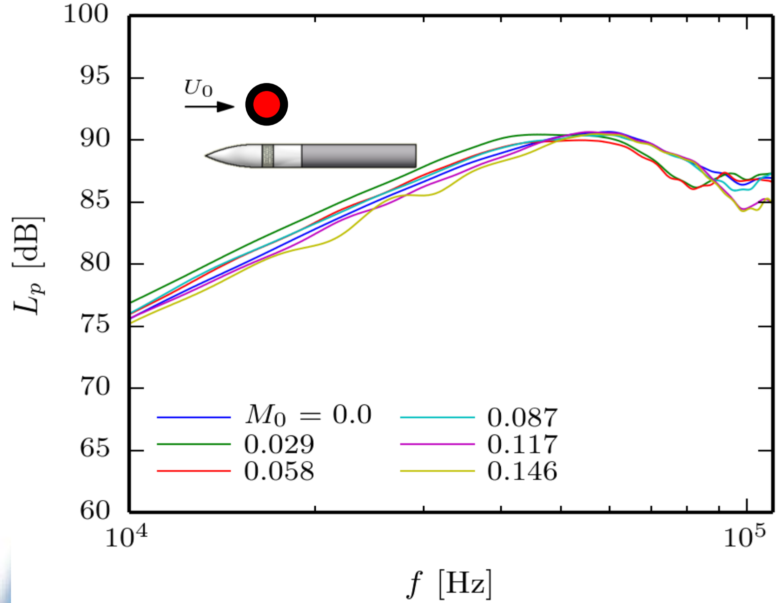
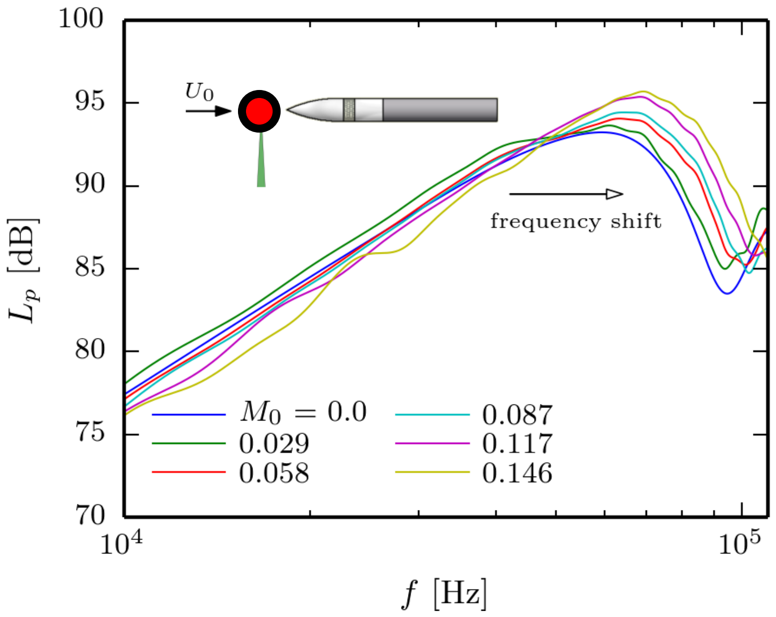








Flow

Rossignol, Delfs , 21nd AIAA/CEAS Aeroacoustics 2015

Impulsive laser sound source: source characteristics

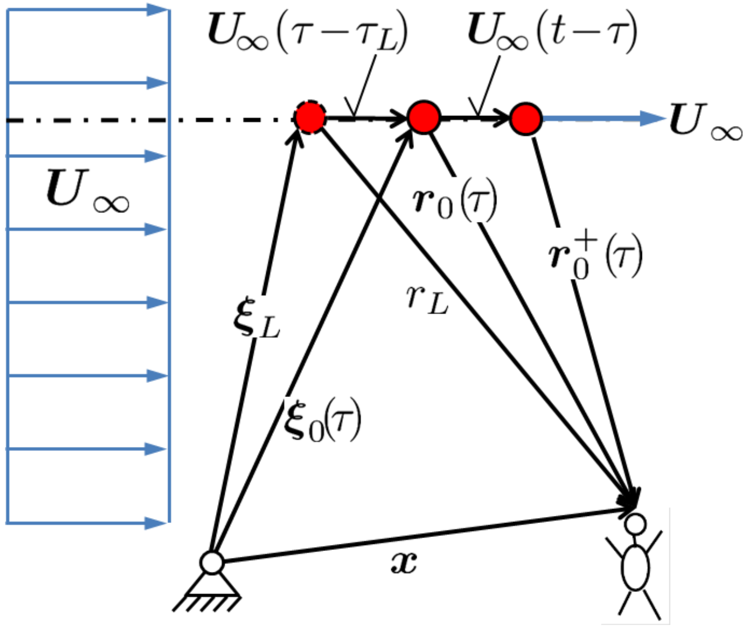
Source modelling

(1) Assume (ideal) moving point heat release source for the pressure pulse

(2) Find solution to convecting wave equation for source term in (1)

$$\frac{1}{a_\infty^2}\frac{D_\infty^2 p'}{Dt^2} - \Delta p' = \frac{a_\infty^2}{\gamma - 1}\frac{D_\infty \dot{\vartheta}'}{Dt}; \; \dot{\vartheta}' = \delta(\boldsymbol{\xi} - \boldsymbol{\xi}_0)\vartheta_p(\tau)$$

$$p'(\boldsymbol{x}, t) = \frac{\gamma - 1}{a_\infty^2}\frac{1}{4\pi r_0^+}\frac{d\vartheta_p}{d\tau}; \qquad \rho' = p'/a_\infty^2$$



$$\frac{d\boldsymbol{\xi}_0}{d\tau} = \boldsymbol{U}_\infty = a_\infty \boldsymbol{M}$$

Rossignol, Delfs , 21nd AIAA/CEAS Aeroacoustics 2015

Solution of the wave equation: the pulse pressure field

Pressure

$$p'(\boldsymbol{x},t) = \frac{\gamma - 1}{4\pi a_\infty^2} \frac{1 - M^2}{\left(\sqrt{(\boldsymbol{M}\cdot\boldsymbol{r}_0)^2 + (1 - M^2)\boldsymbol{r}_0^2} - \boldsymbol{M}\cdot\boldsymbol{r}_0\right)} \frac{\partial \vartheta_p}{\partial \tau}$$

Downstream: $C = 1 + M$ Upstream: $C = 1 - M$

Doppler shift

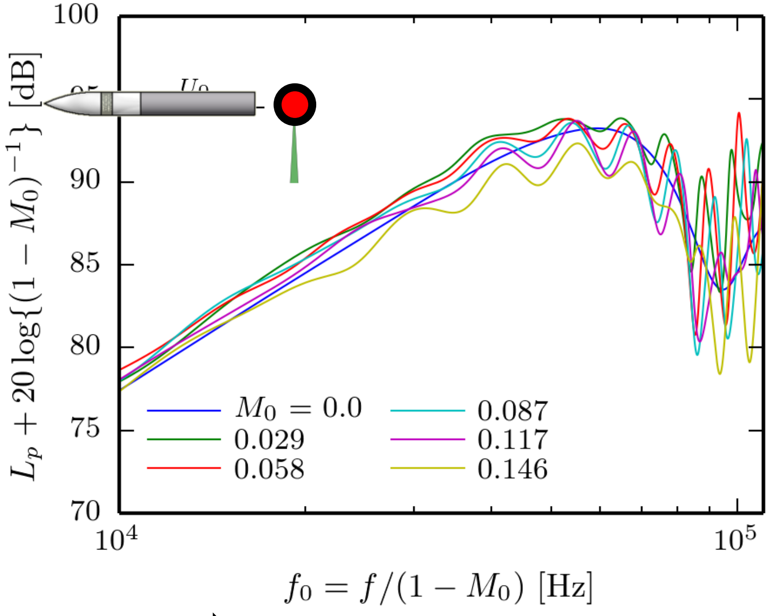
$$\frac{\omega}{\omega_0} = \frac{\partial p'}{\partial t} \Big/ \frac{\partial p'}{\partial \tau} = \frac{\partial \tau}{\partial t} = \frac{r_0^*}{r_0^+} = \frac{(1 - M^2)\sqrt{M_{r_0}^2 + 1 - M^2}}{\left(\sqrt{M_{r_0}^2 + 1 - M^2} - M_{r_0}\right)}$$

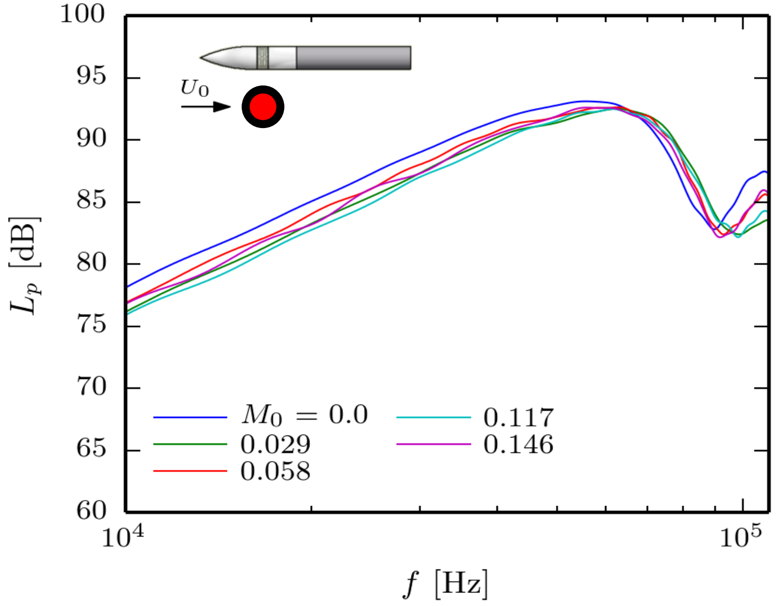
Downstream: $D = 1 + M$ Upstream: $D = 1 - M$

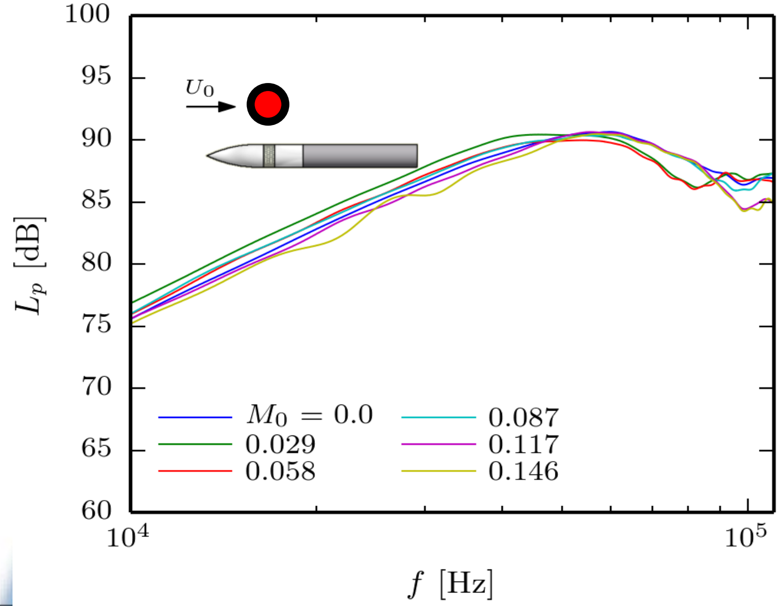
Rossignol, Delfs , 21nd AIAA/CEAS Aeroacoustics 2015

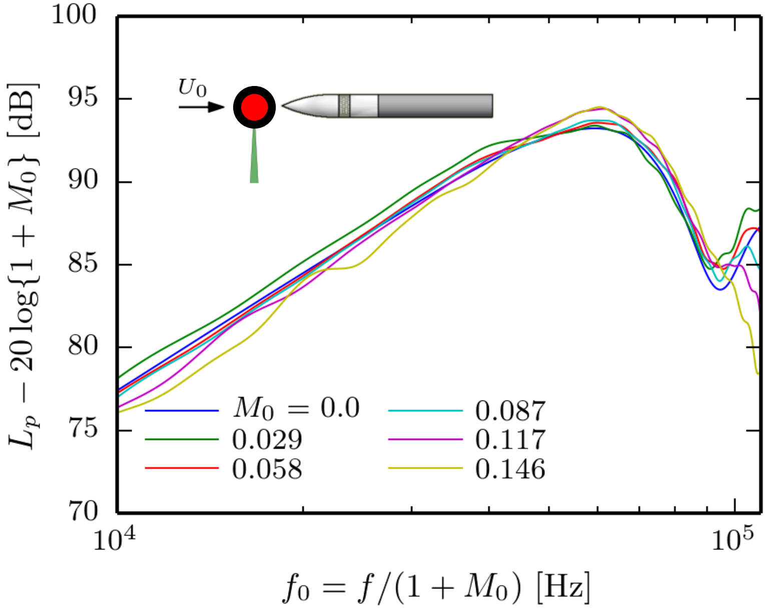
Impulsive laser sound source: principles and characteristics

Source convection effects









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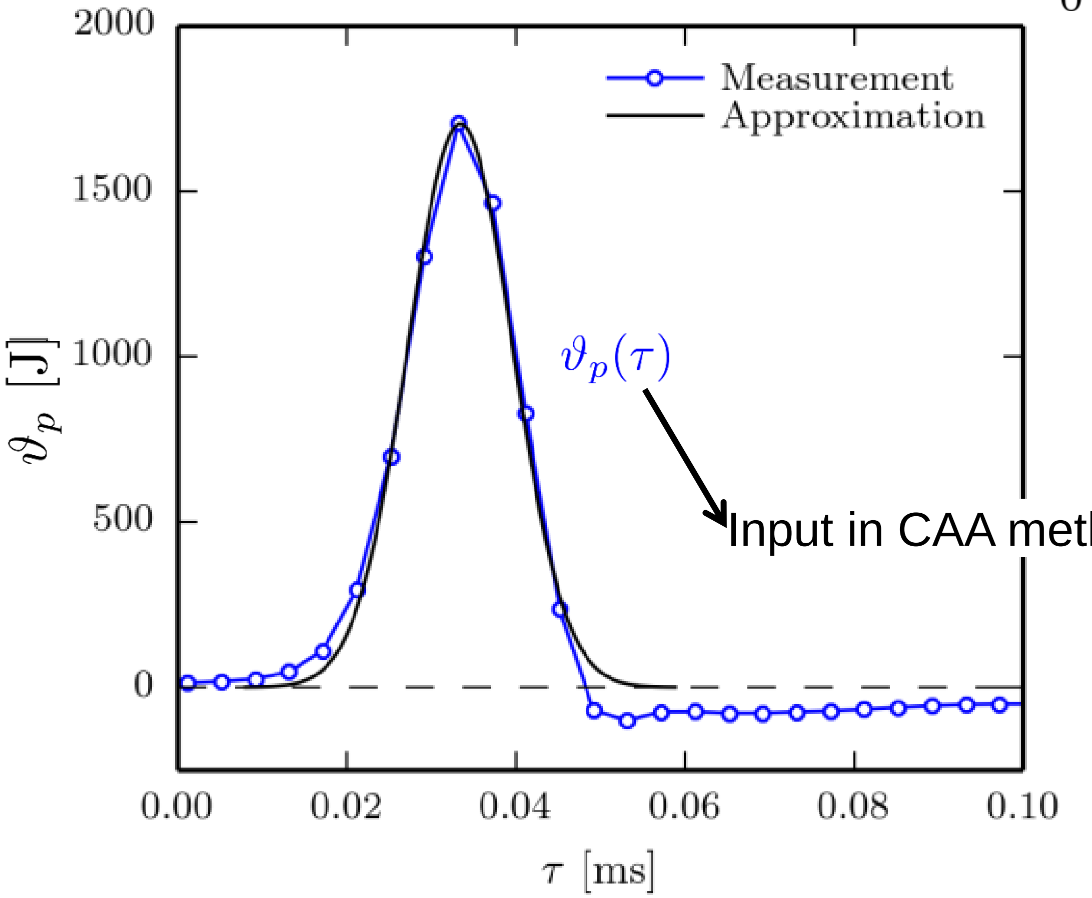
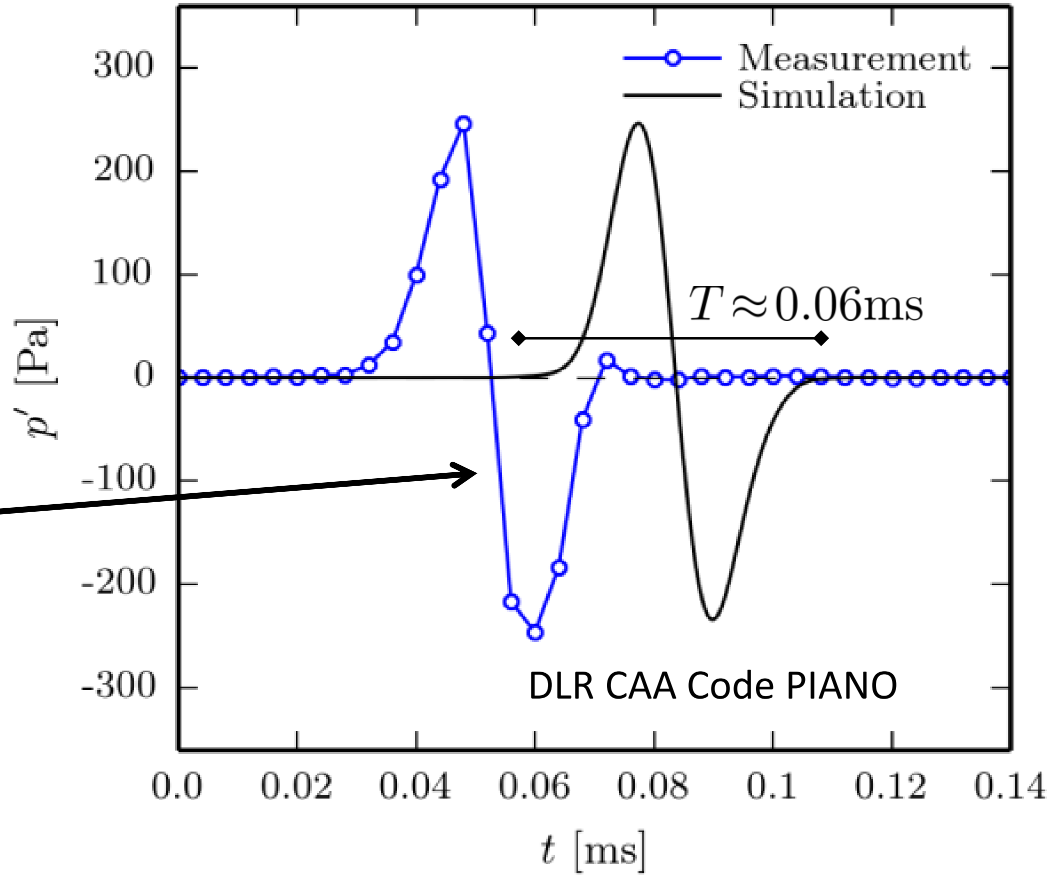
$$\frac{a_\infty^2 4\pi}{(\gamma-1)} \int_0^\tau r_0^+ \, p'(\boldsymbol{x},t)\, d\tau = \vartheta_p(\tau);$$

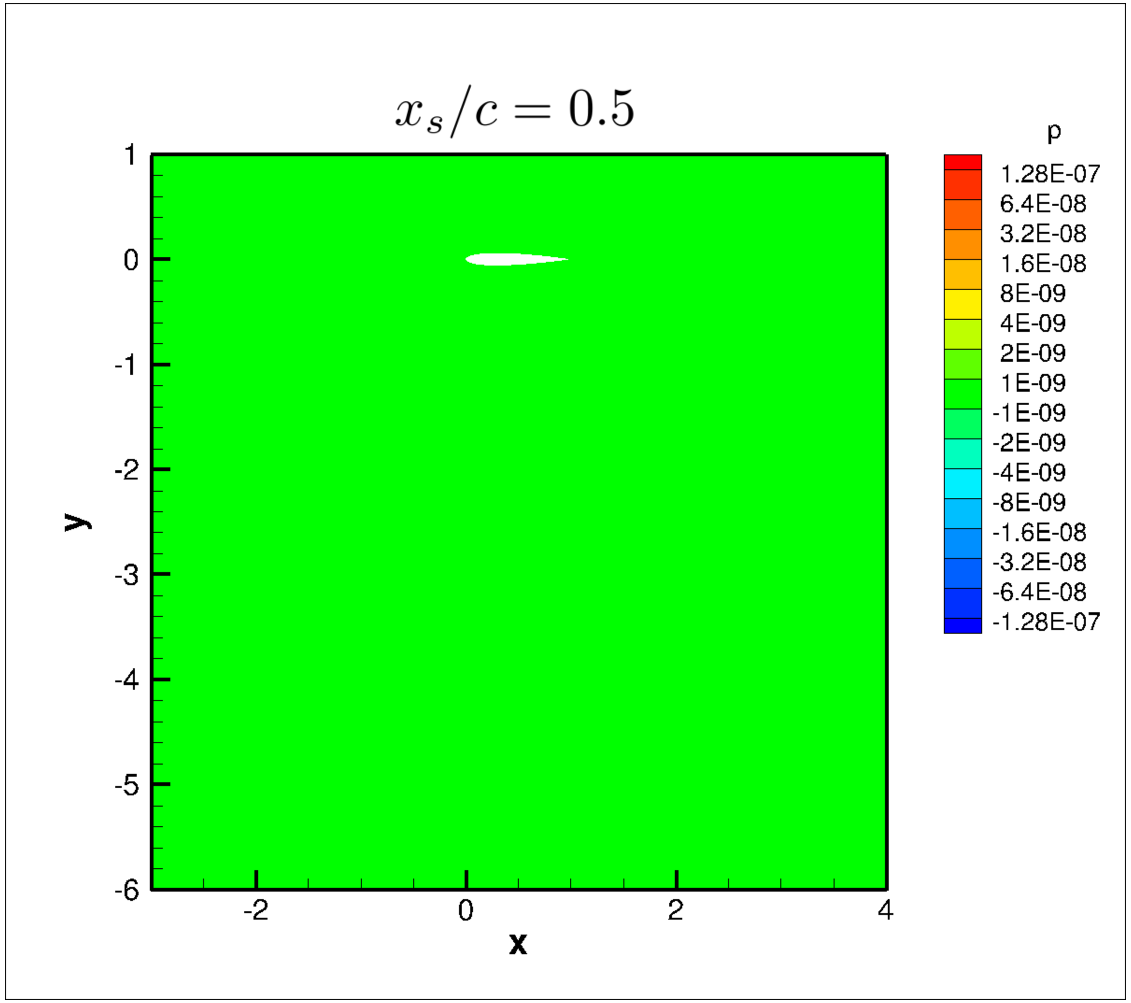


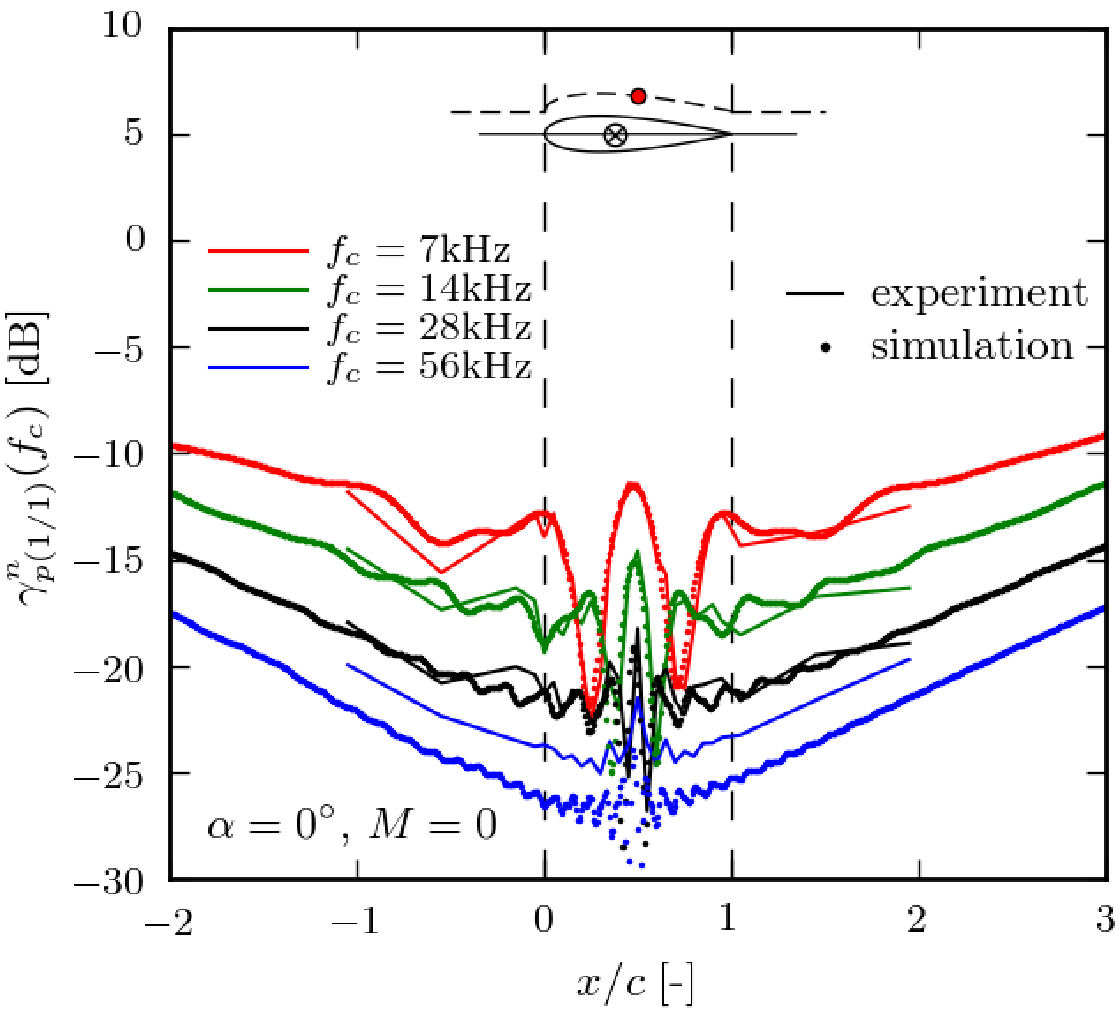


Representation of acoustically relevant part of the laser heat release source function with Gaussian

time signal of pressure pulse num. simulations vs. experiment

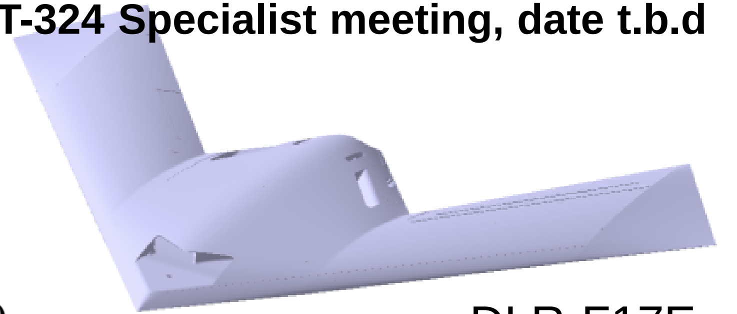
Acoustic scattering at NACA0012 profile
Numerical simulations





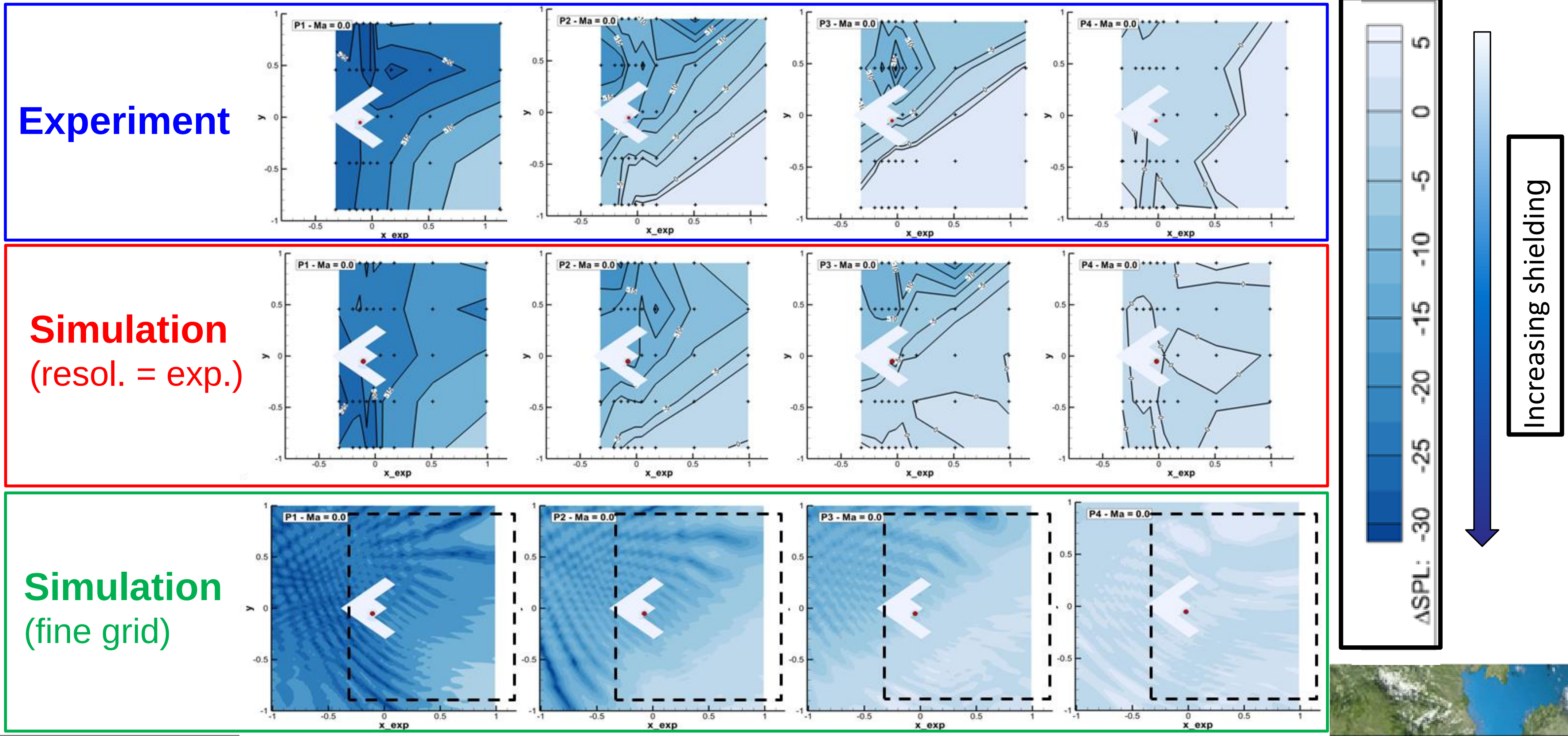
Rossignol et al., STO-AVT-324 Specialist meeting, date t.b.d

Acoustic scattering from „complex“ aircraft geometries, i.e. noise shielding



DLR-F17E SACCON

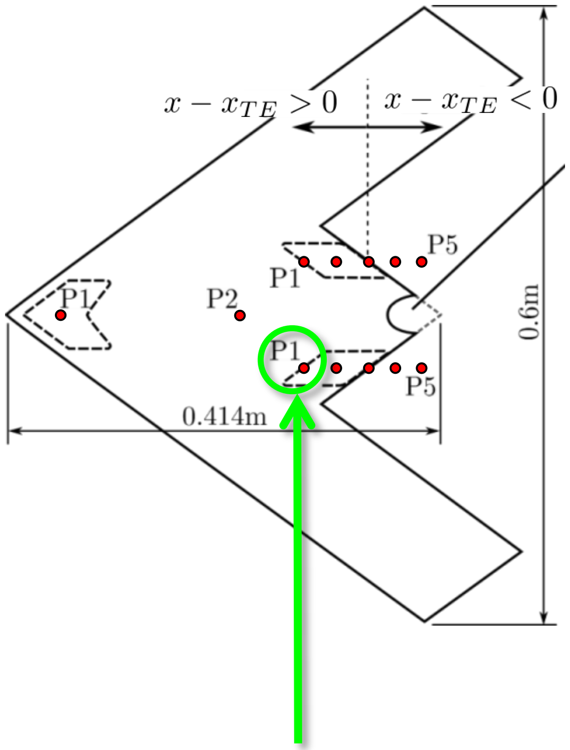
Experiment vs. Simulations $f_c = 28\,\mathrm{kHz},\ M = 0.0$

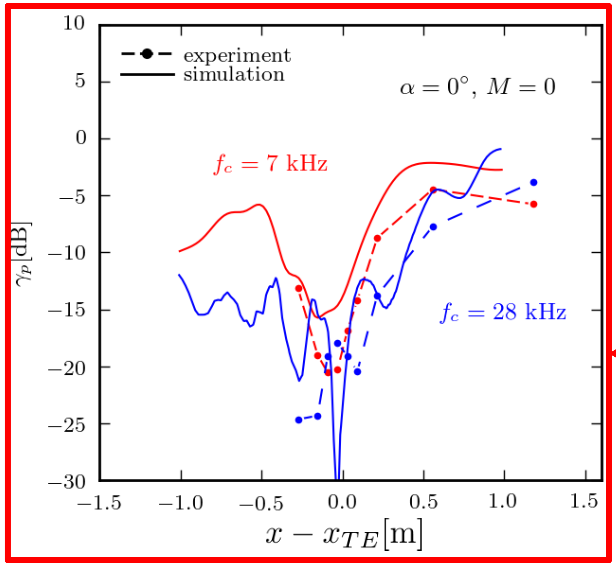


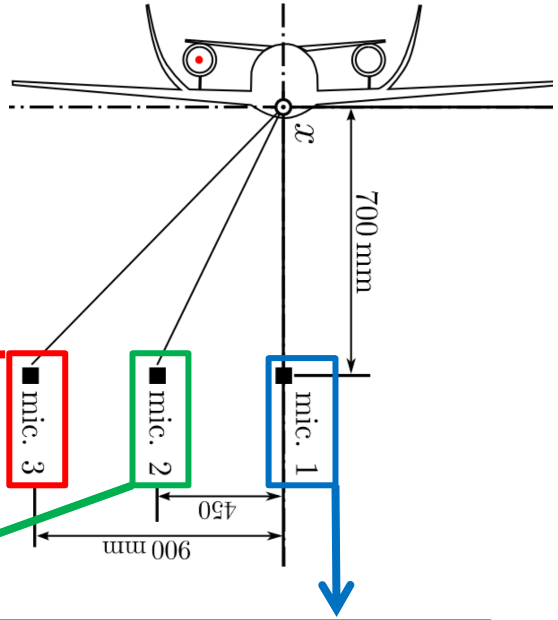
Acoustic scattering from „complex“ aircraft geometries,

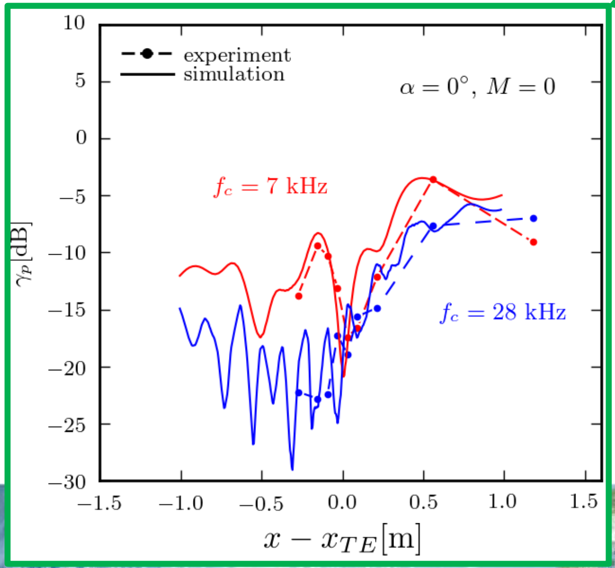
BEM simulation vs. Experimental results

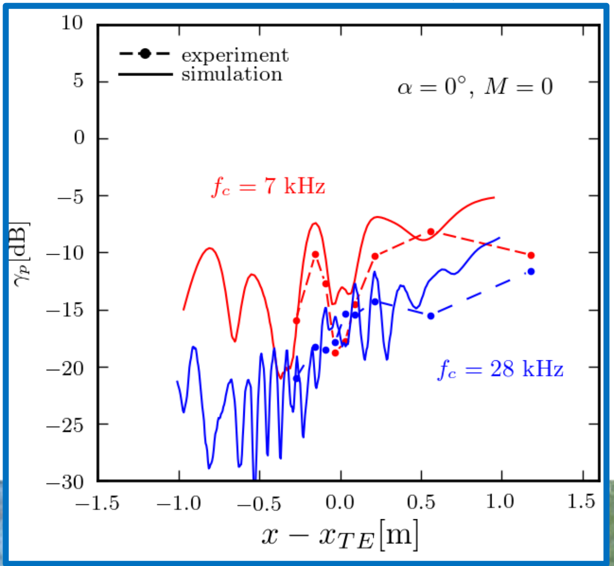
SACCON (DLR-F17E) shielding





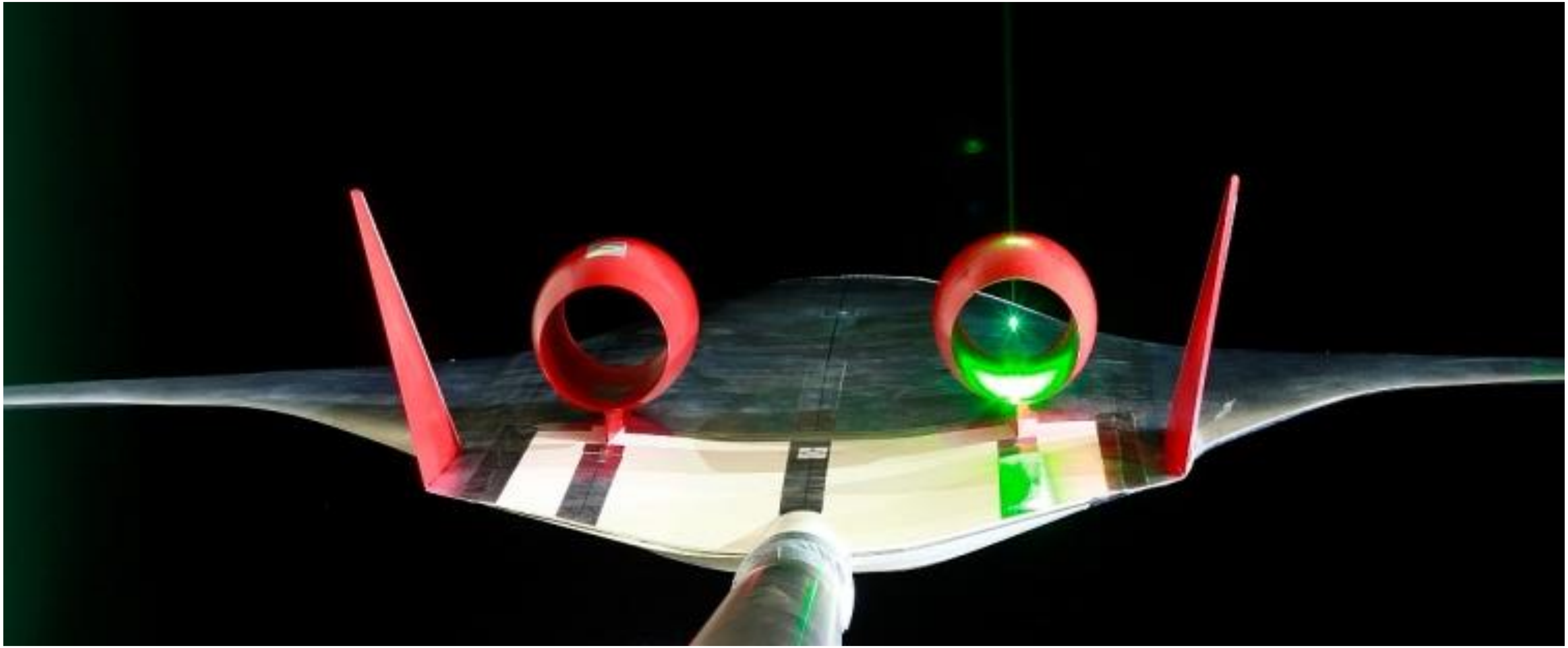






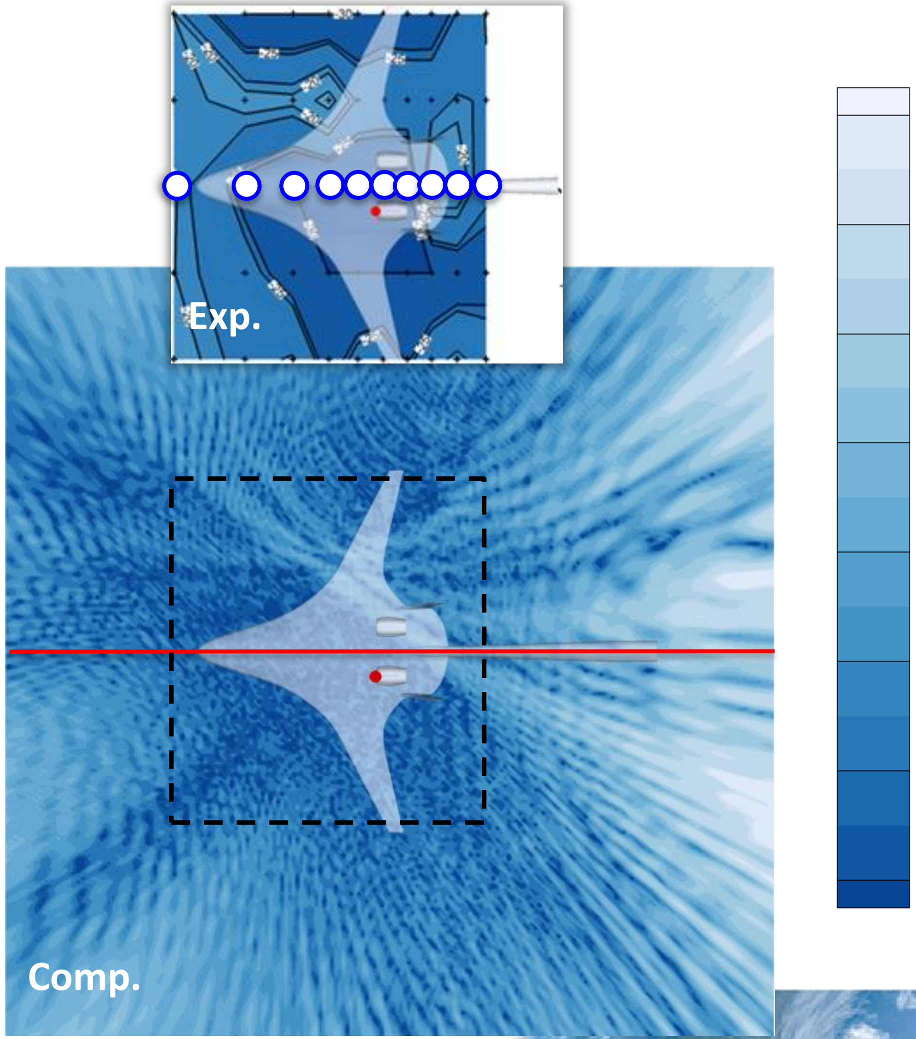
Acoustic shielding at NASA N2A HWB, as part of NATO AVT 233

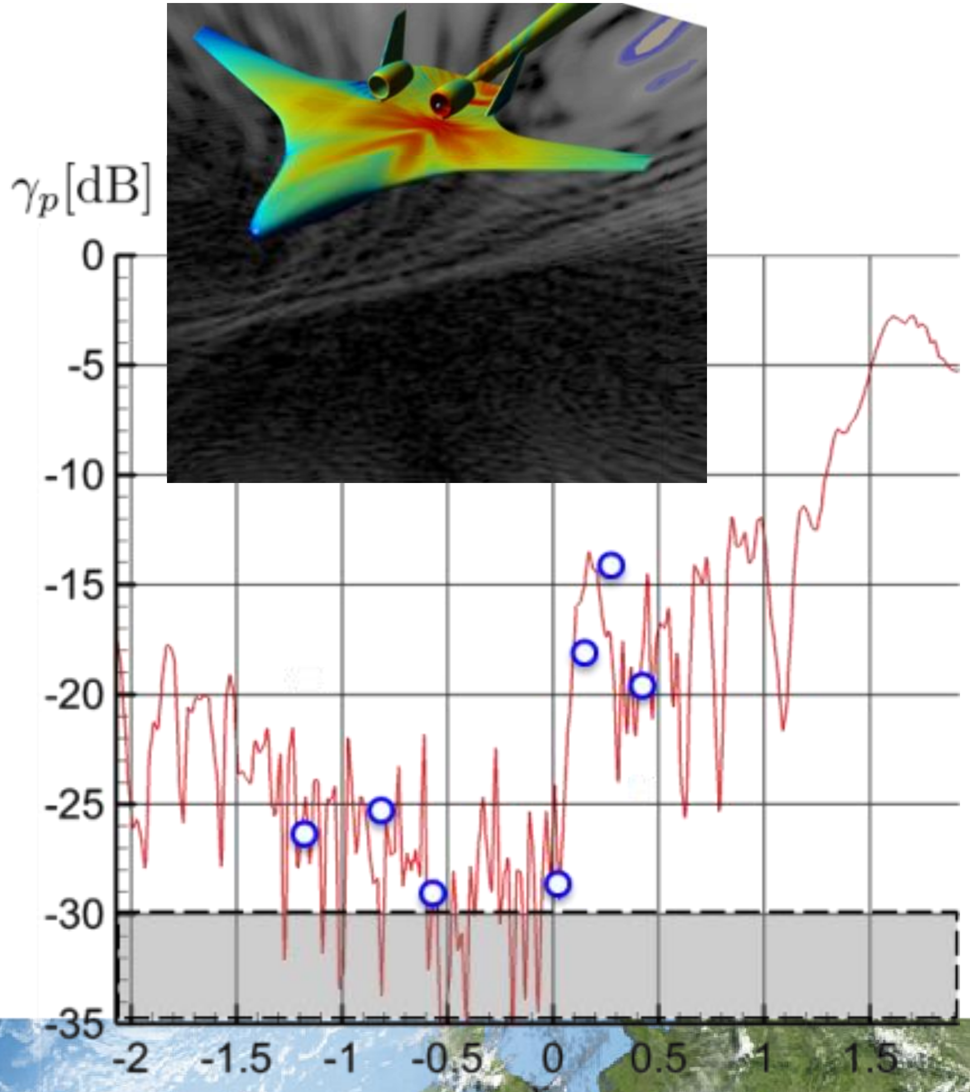
BEM simulation vs. experimental results



Acoustic shielding at NASA N2A HWB, as part of NATO AVT 233

BEM simulation vs. experimental results





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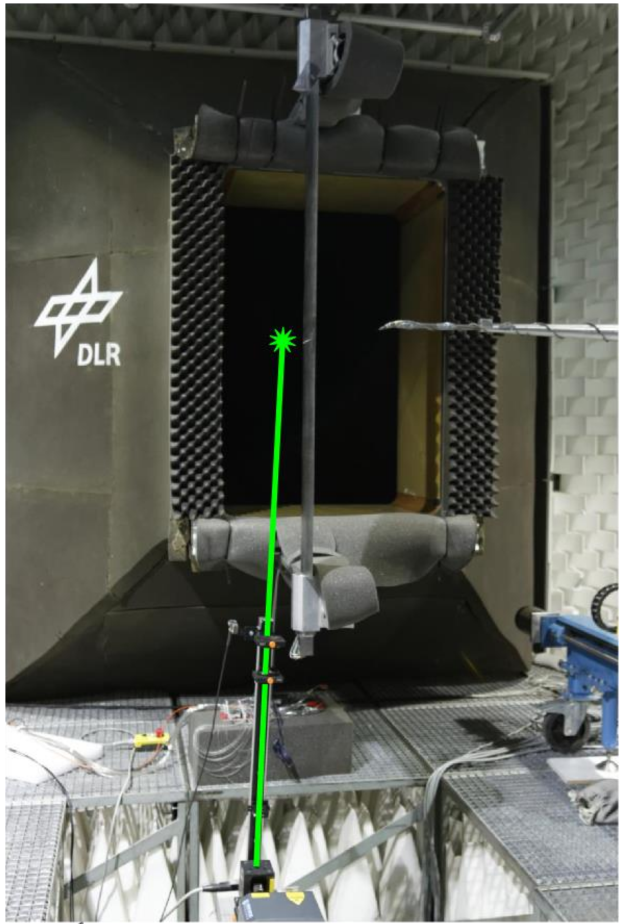
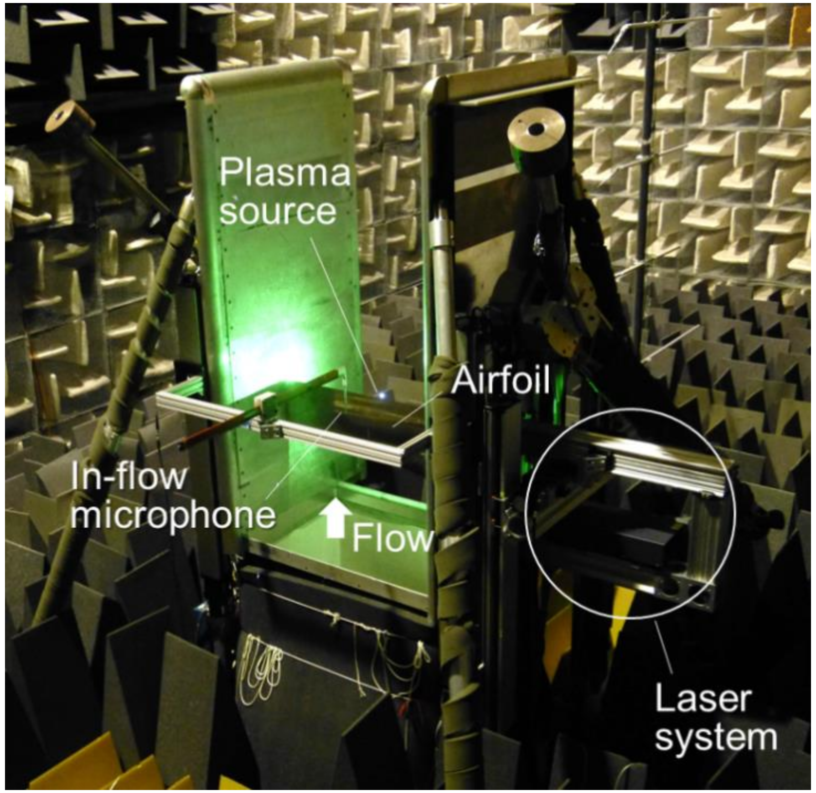
Sound shielding from a NACA0012 profile (collaborative effort STO AVT 233)
→ Facility-to-facility comparisons AWB (DLR) – NASA (QFF) – ONERA (F2)

DLR-AWB

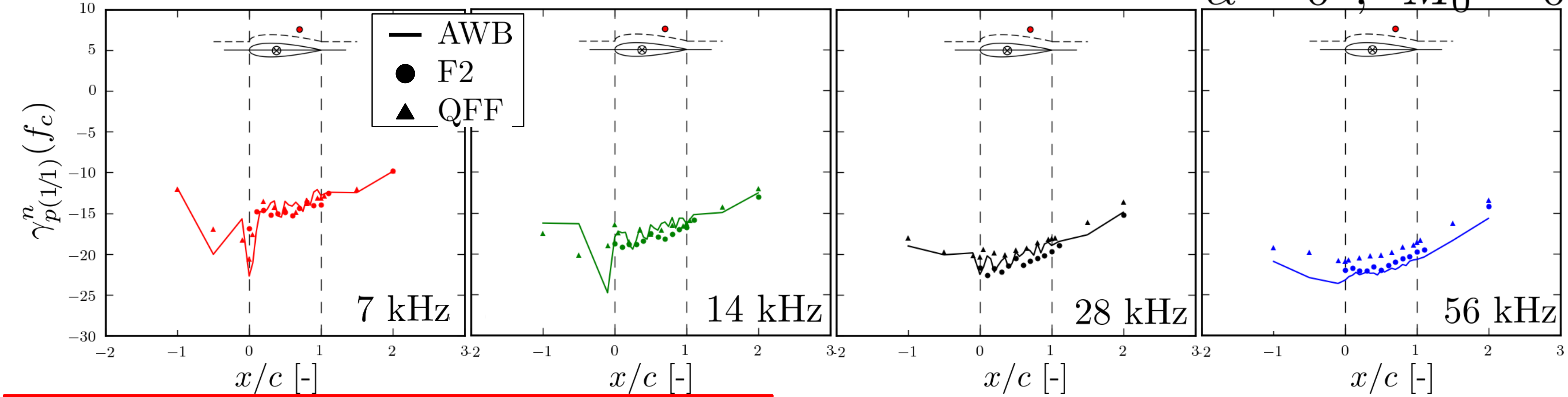


NASA-QFF



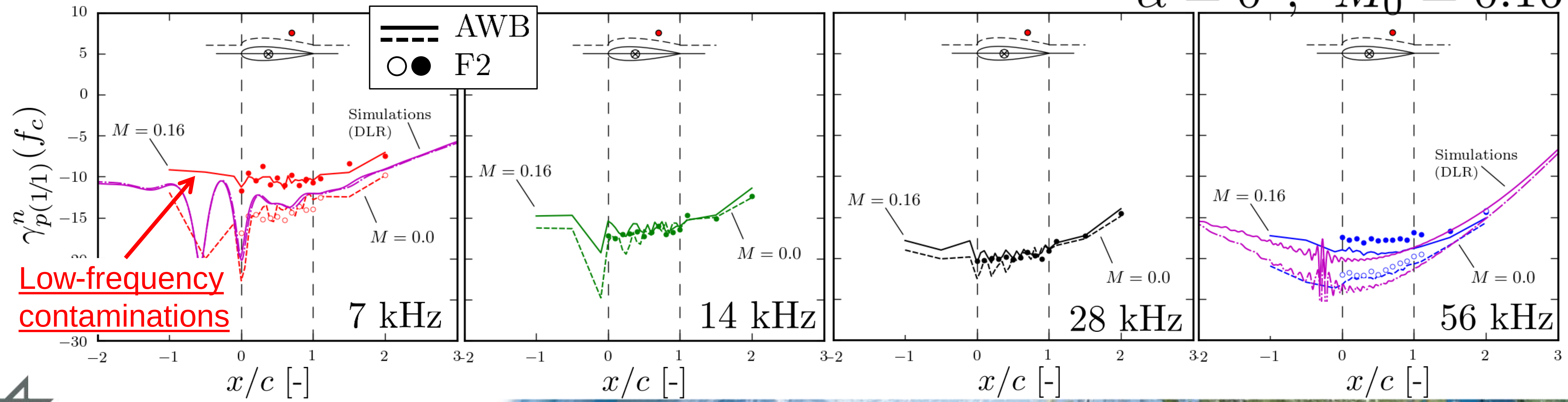
ONERA-F2

$\alpha = 0°, \quad M_0 = 0$



→ Definition of common grounds for data presentation!

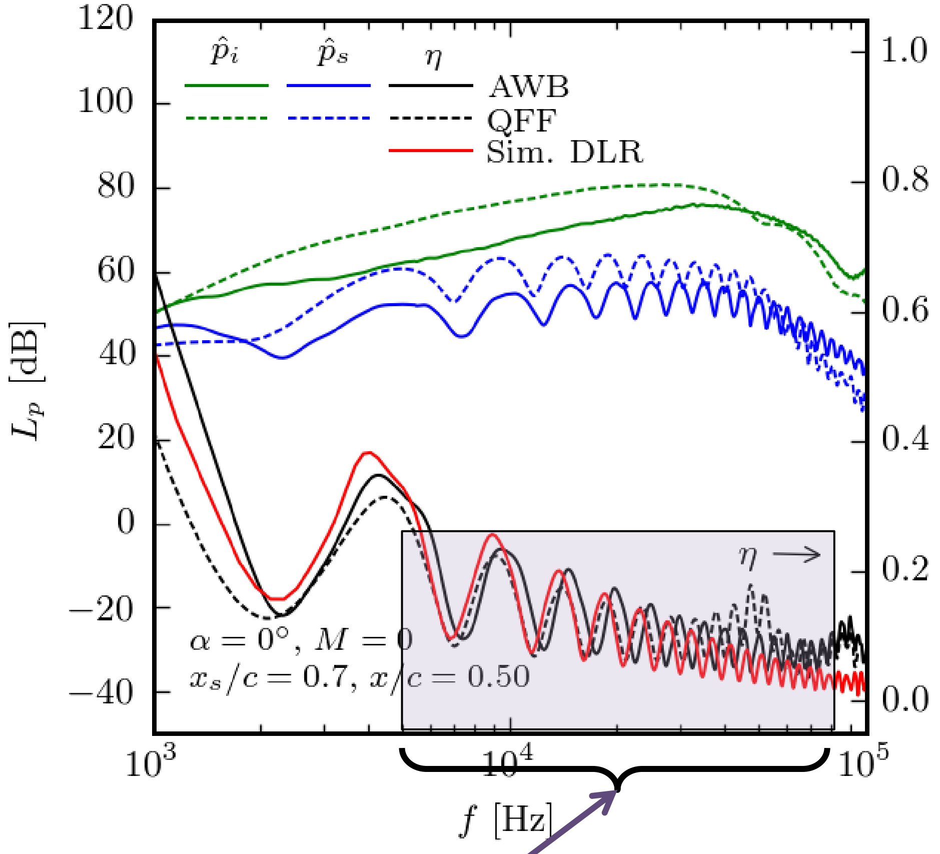
$\alpha = 0°, \quad M_0 = 0.16$



Cross-facility validation of aeroacoustic testing facilities

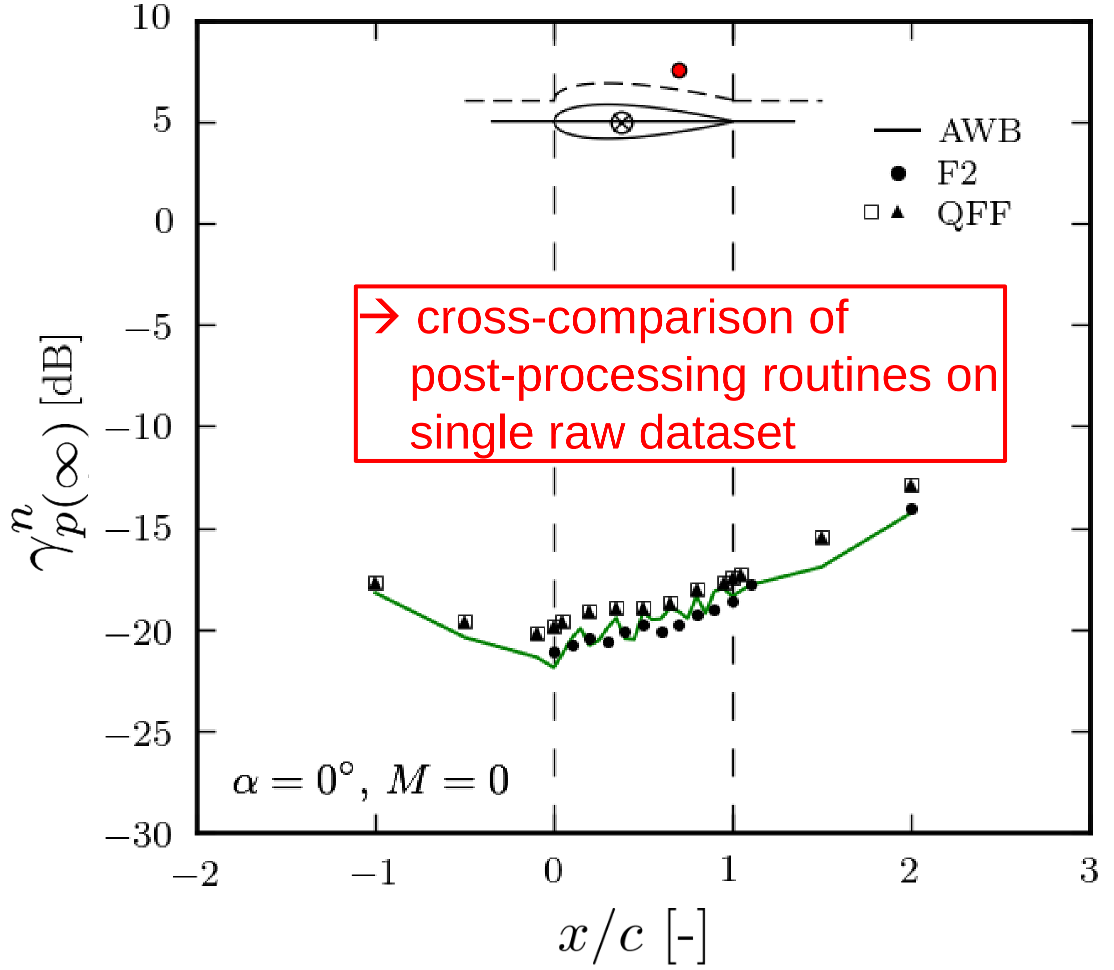
AWB vs. QFF

$5\ \text{kHz} \leq f_c \leq 80\ \text{kHz}$



$$\gamma^n_{p(\infty)} = 20 \lg \eta^n_{(\infty)}$$

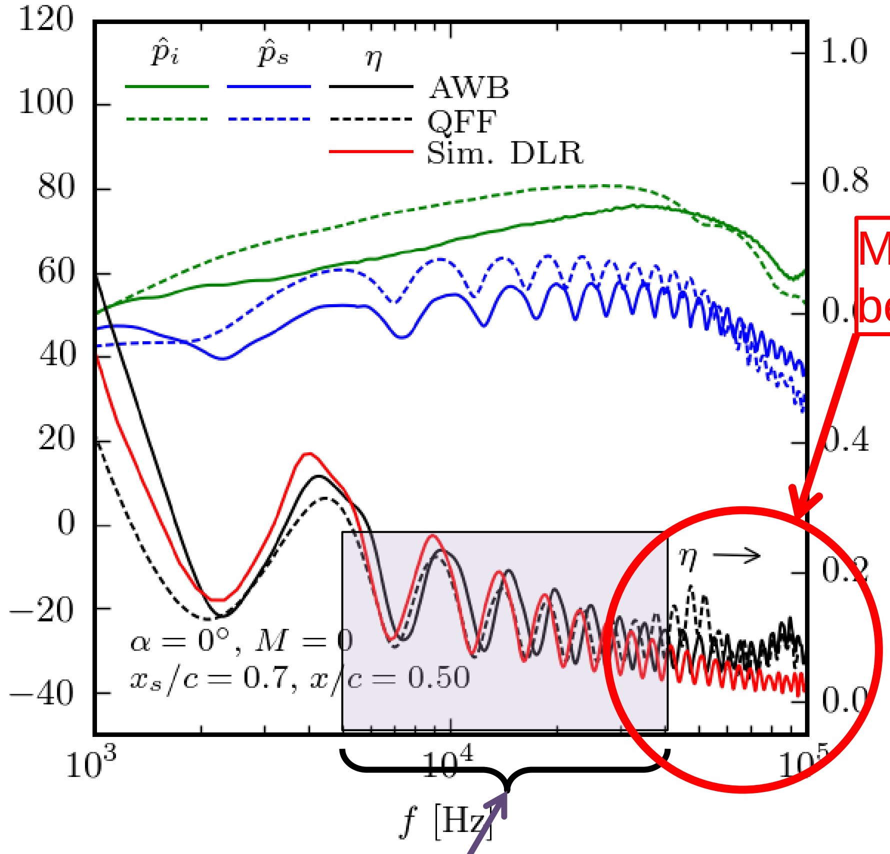
Overall normalized attenuation level



Cross-facility validation of aeroacoustic testing facilities

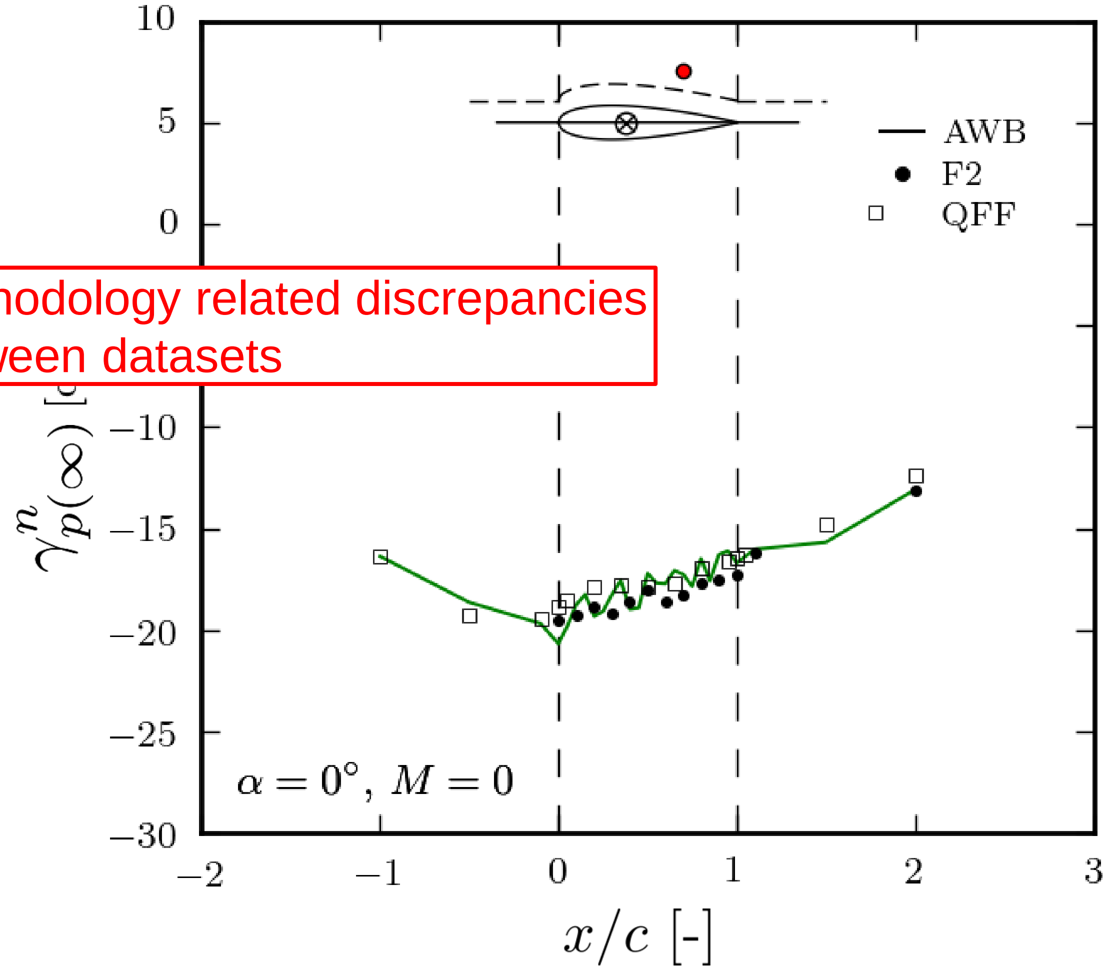
AWB vs. QFF

$5\ \mathrm{kHz} \leq f_c \leq 40\ \mathrm{kHz}$

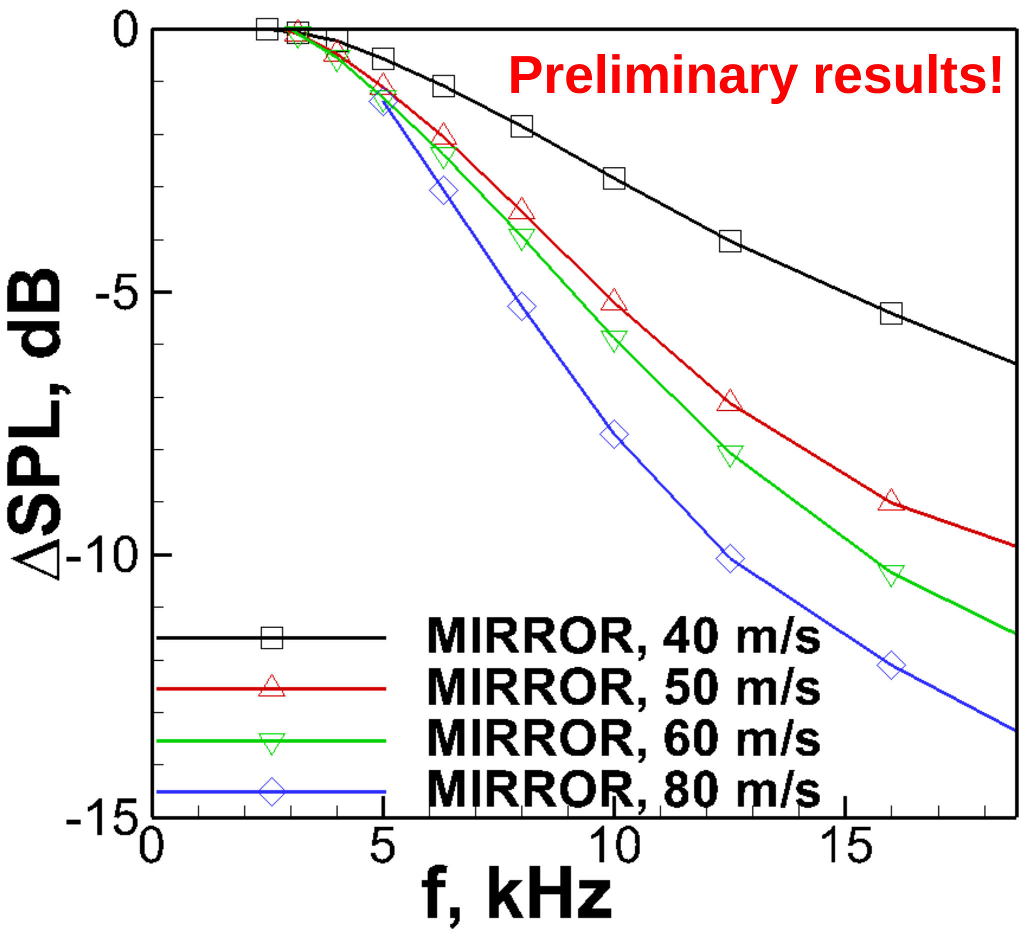


$$\gamma^n_{p(\infty)} = 20 \lg \eta^n_{(\infty)}$$

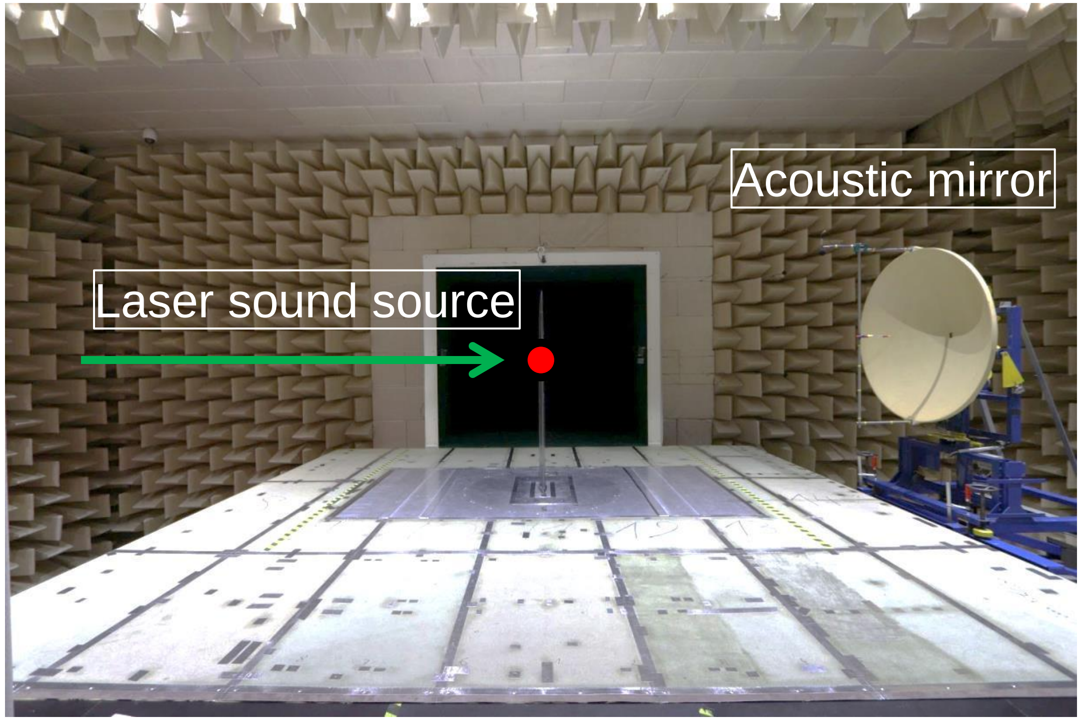
Overall normalized attenuation level



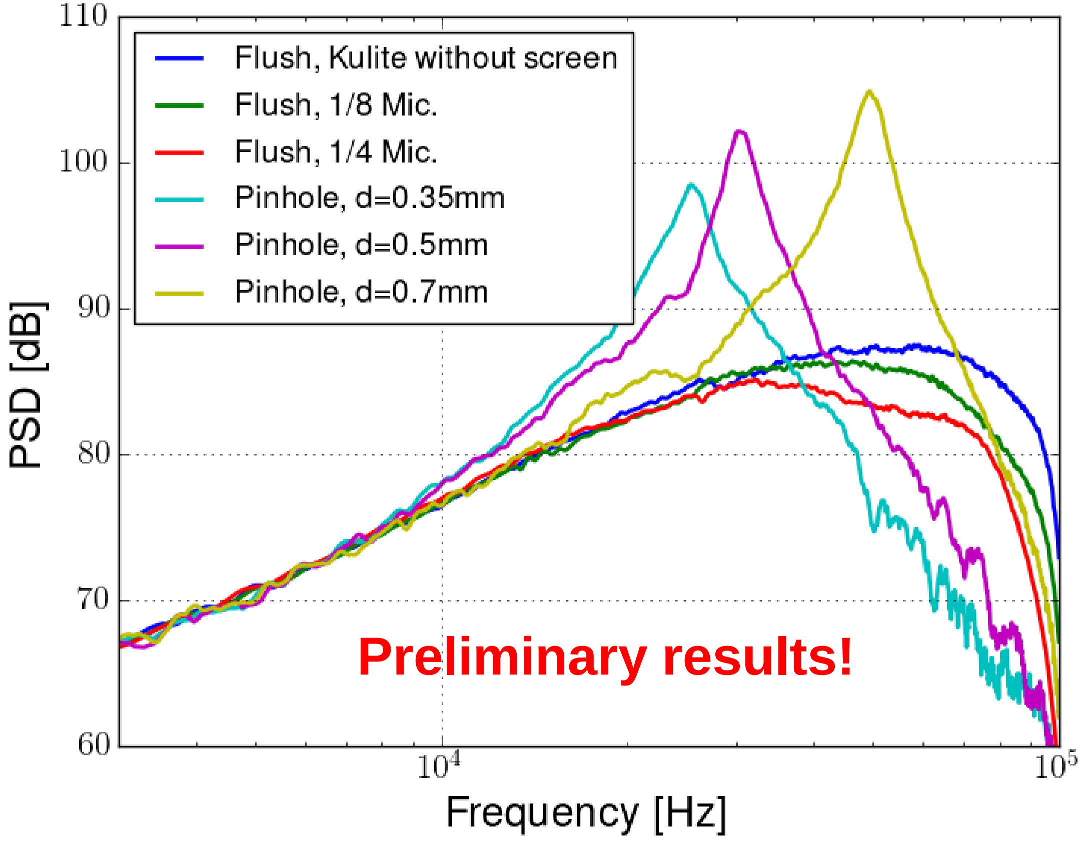
Calibration of measurement system response function (gain and resolution), quantification of shear-layer transmission effects



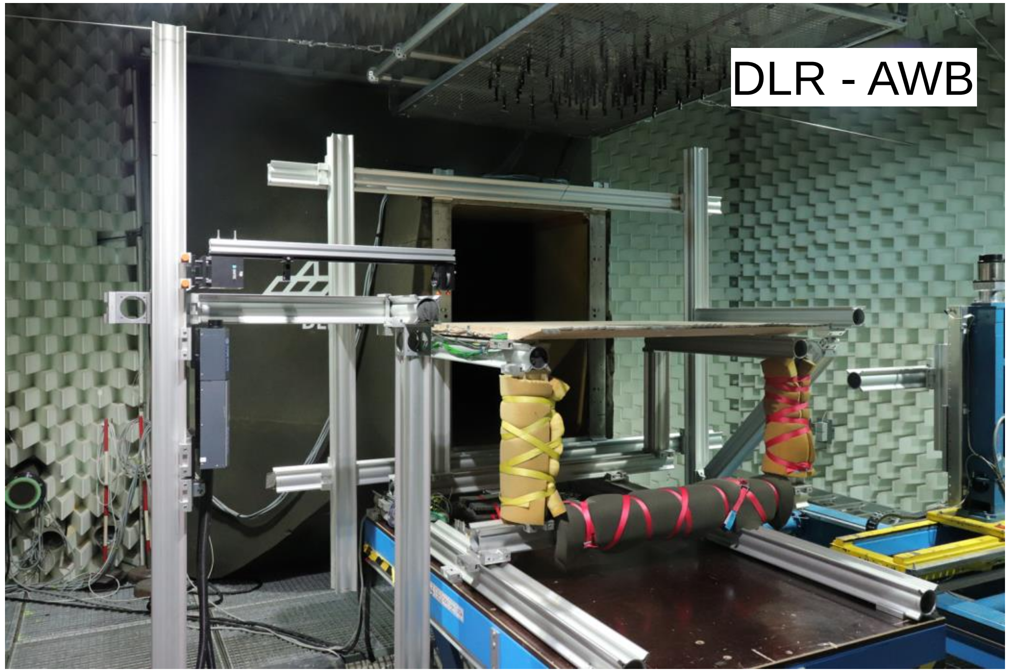
DNW-NWB ¾ open anechoic empty test section



Calibration of installed „near field“ sensors for unsteady surface pressure measurements



Generic sensor setup



- Determination of installed sensor resonance frequency
- Determination of sensor transfer function

Conclusions and perspectives

Where do we stand:

- **In-flow measurements only**; avoid dealing with tunnel boundary effects → wander and spread (Bahr, 2018)
- DLR-AWB has no Kevlar-walled test section!

- Effort mainly focused on:
  - Acoustic impulse characterization of objects, i.e. noise attenuation/shielding/scattering
  - Understanding of „in-flow“ source propagation characteristics
  - Theoretical representation of the laser sound source
  - Demonstration of the reliability of numerical simulation tools for the prediction of propulsion system installation effects

What‘s next:

- Quantification of shear-layer transmission effects in open section wind tunnels
- Calibration of unsteady surface pressure sensors
- Calibration of acoustic measurement systems, i.e. phased microphone arrays and acoustic mirrors

Conclusions and perspectives

- **Quantitatively cross comparing and therefore validating acoustic facilities (should we be pushing for a standard of some sort?, what measurements would be in the standard?)**
    - High importance of collaborative exchange of raw and processed datasets (here as well!)
    - Green’s function determination with and without objects as a propagation evaluation standard (i.e. with a defined/controlled source)?
    - Inflow (convection/diffraction/Reynolds number effects) vs. out-of-flow (acoustic boundary conditions effects, i.e. Kevlar vs. shear-layers)? → see procedure by Bahr et al. 2018 and Szoke et al. 2020

Conclusions and perspectives

- **Evaluating/validating acoustic boundary corrections for Kevlar-walled (and perhaps non-Kevlar walled) facilities**
  - Impulsive laser sound source testing has unique advantages in that respect
  - Application to both type of facility (Bahr et. al. 2018, Szoke et al. 2020)
  - Coupling of impulse source simulation methodology (Rossignol, Delfs, 2015 and Mößner, 2018) with experimental Kevlar wall transfer function?

Conclusions and perspectives

- **Green's function determination with model configurations, and anything else with strategic relevance to the group.**

  - Calibration of focusing measurement system response functions (phased array, acousic mirror)
  - Calibration of installed near-field sensors?
  - Calibration of phased array directivity? (issue mentioned during Tuesday session)

Highly relevant aspects w.r.t facility-to-facility comparisons of airfoil acoustics

  - One Drawback of the laser source method (in our experience):
    - →strong dependency of repeatability on laser energy output stability over time (of course!)
    - →this often requires fine tuning of laser internal components
    - →With older laser, regular maintenance intervals
    - →Optical setup for larger scale (> ~1.5 m optical path) wind tunnel has to rely on special optics

References

1. Máté Szoke, Christopher J. Bahr, Florence V. Hutcheson, William J. Devenport, *„Characterization of Hybrid Wind Tunnel Environments Using Laser-Induced Acoustic Sources“,* AIAA 2020-1253, 2020, https://doi.org/10.2514/6.2020-1253
2. J. Delfs, M. Mößner, and K.-S. Rossignol, *“Influence of flow on noise shielding”*, STAB congress, Darmstadt, Germany, October 2018
3. Christopher J. Bahr, Florence V. Hutcheson and Daniel J. Stead, *„Assessment of Unsteady Propagation Characteristics and Corrections in Aeroacoustic Wind Tunnels Using an Acoustic Pulse“*, 2018 https://doi.org/10.2514/6.2018-3118
4. Karl-Stéphane Rossignol, Jan Delfs, Denis Gély, and Jean Bulté, Florence Hutcheson. *"Experimental Investigations on Noise Shielding: Dependency on Reference Noise Source and Testing Environment"*, Proceedings of the 24th AIAA/CEAS Aeroacoustics Conference, AIAA AVIATION Forum, (AIAA 2018-2820), https://doi.org/10.2514/6.2018-2820
5. Karl-Stéphane Rossignol and Jan Delfs. *"Analysis of the Noise Shielding Characteristics of a NACA0012 2D Wing"*, AIAA 2016-2795, 22nd AIAA/CEAS Aeroacoustics Conference, Mai 2016, Lyon, France
6. Karl-Stéphane Rossignol, Jan Delfs, and Fritz Boden. *"On the Relevance of Convection Effects for a Laser-Generated Sound Source"*, AIAA 2015-3146, 21st AIAA/CEAS Aeroacoustics Conference, AIAA Aviation, June 2015, Dallas, TX, USA