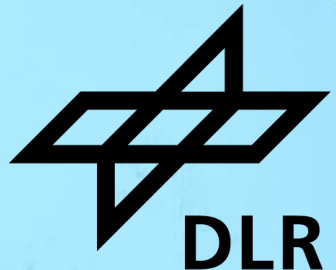


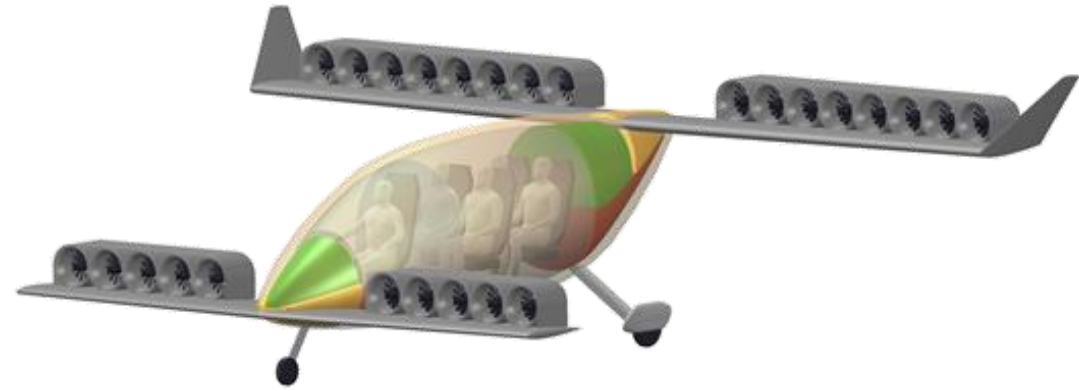
NUMERICAL ASSESSMENT OF ACOUSTIC MODE REFLECTIONS IN A LOW- SPEED FAN TEST RIG

Tobias Blaschke, Sébastien Guerin, Antoine Moreau, Wolfram Köhler, Lukas Klähn
DLR Institute of Propulsion Technology, Engine Acoustics Department, Berlin



Motivation

- UAMs with fixed wings, distributed propulsion
 - low-speed fan design
 - acceptance by the public: noise!
- DLR Engine Acoustics research:
 - Sound source excitation and radiation
 - Sound propagation: transmission, reflection, scattering
 - ...
 - CRAFT-rig

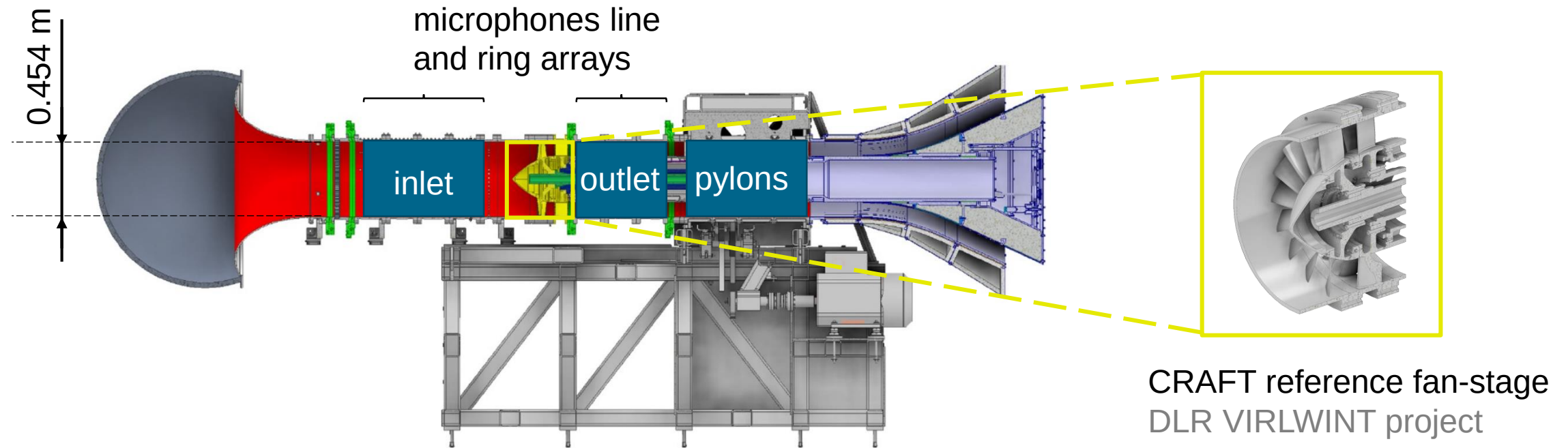


© DLR project Virlwint
sketch of tilt duct vehicle configuration
with simplified fan housings contour
(Credits: P. Ratei, SL-AES)

- 1 CRAFT-Rig
- 2 Numerical setup
- 3 Results
- 4 Summary



CRAFT-Rig (Co/Counter Rotating Acoustic Fan Test Rig)

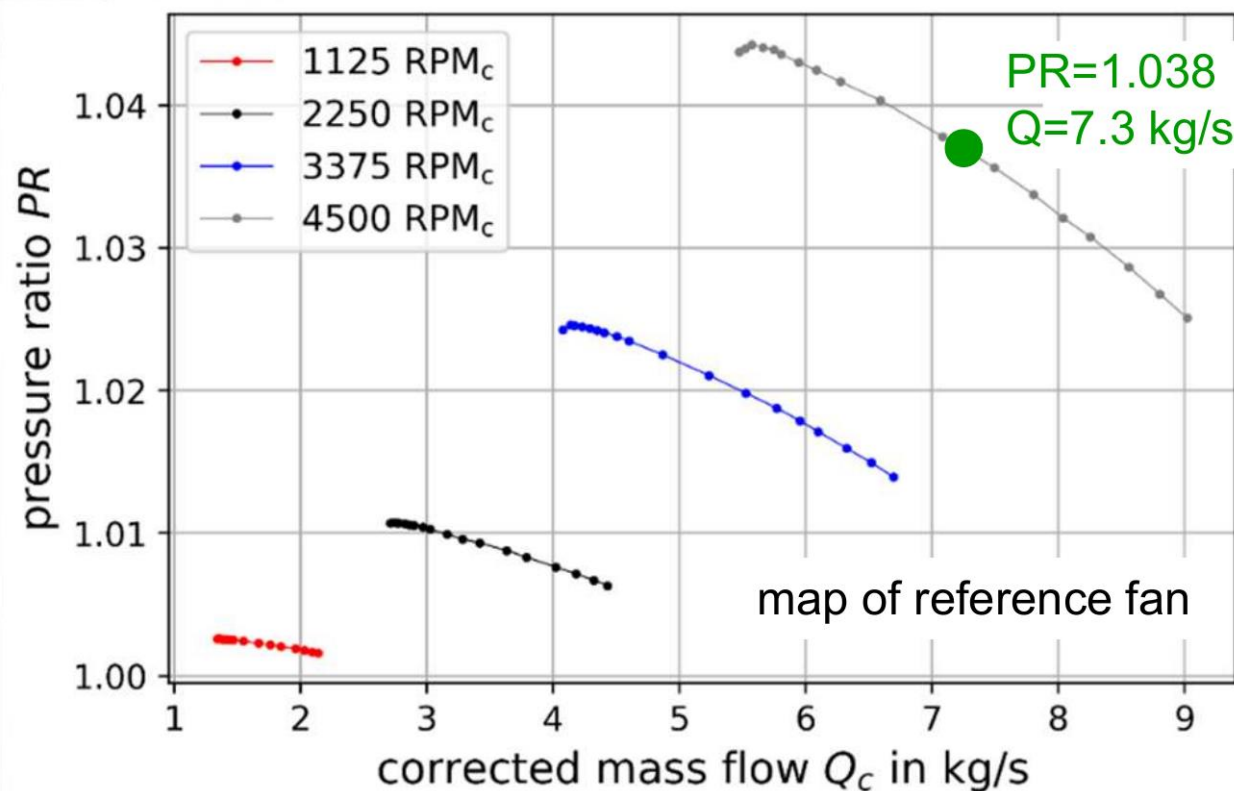


CRAFT-Rig of the DLR Institute
of Propulsion Technology

[6] Tapken, U., Caldas, L., Meyer, R., Behn, M., Klähn, L., Jaron, R., Moreau, A., Enghardt, L. (2021). New test facility to investigate the noise generated by shrouded fans for small aircraft applications. DICUAM 2021 - Delft International Conference on Urban Air-Mobility, 15.-17. March 2021, Delft, Netherlands.

Design Point (DP):

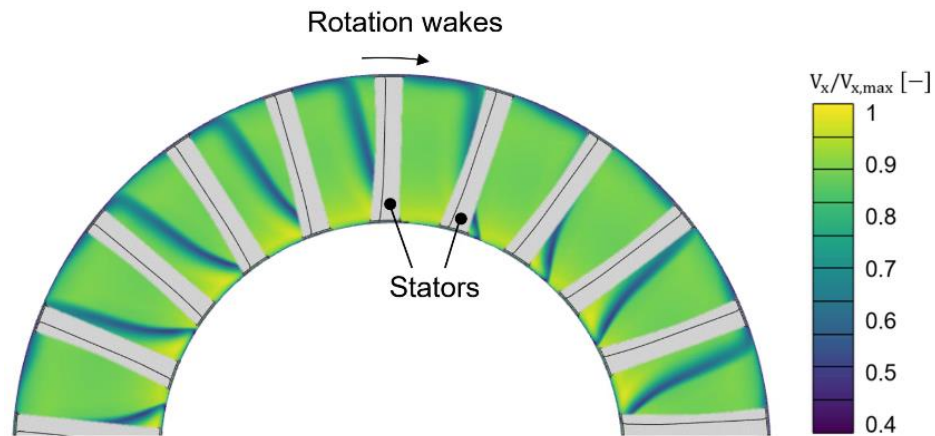
	value
flow coefficient: $\phi = \frac{U_x}{U_{tip}}$	0.33
Ma_{tip}	0.31
$Ma_{x,outlet}$	0.17



[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

Rotor-stator interactions

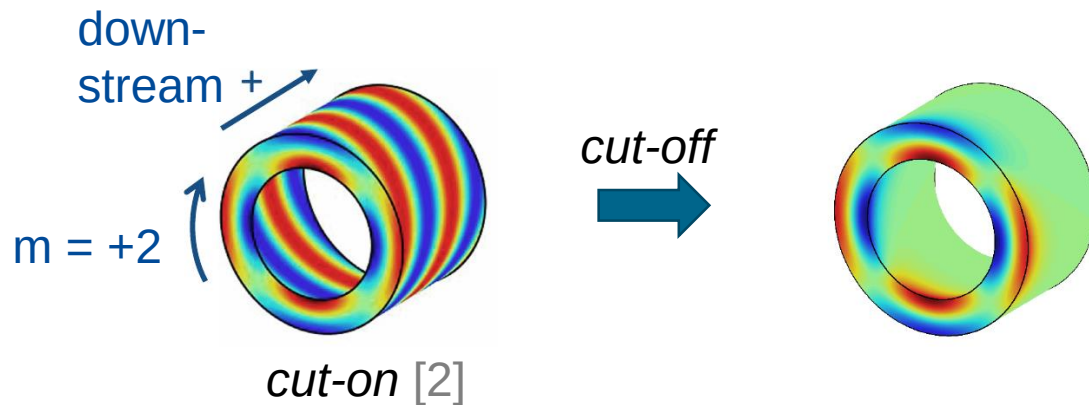
→ excitation of Tyler-Sofrin (TS) modes / spinning modes



Velocity deficits of rotor wakes.
View upstream. [2]

Rotor-stator interactions

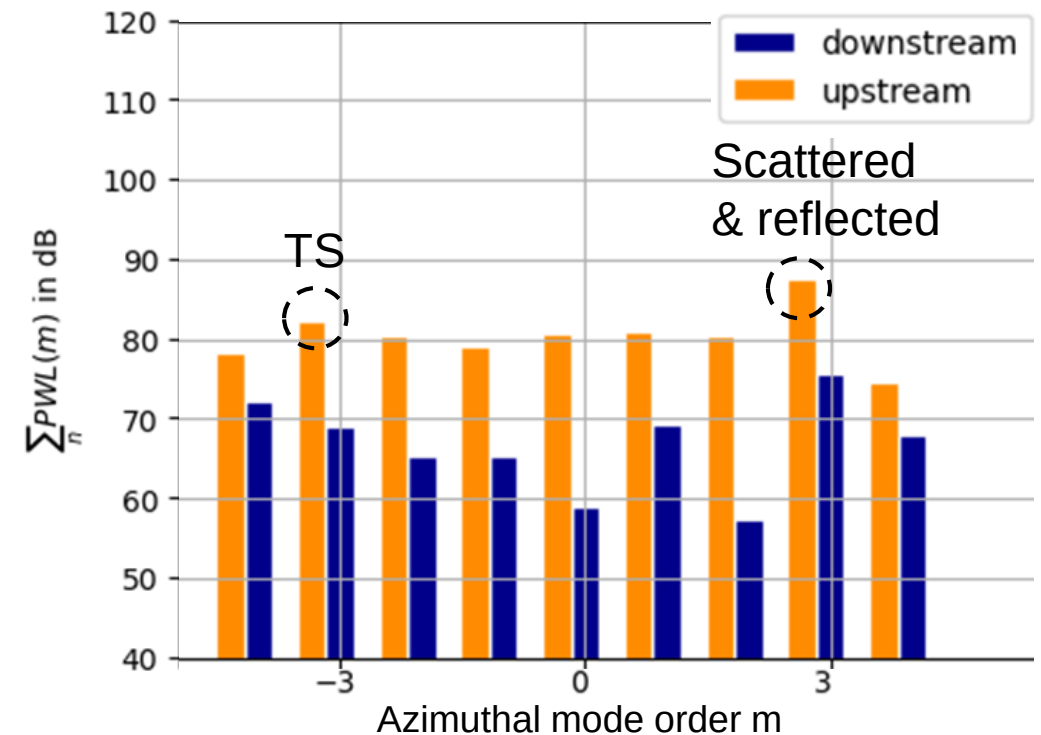
→ excitation of Tyler-Sofrin (TS) modes / spinning modes



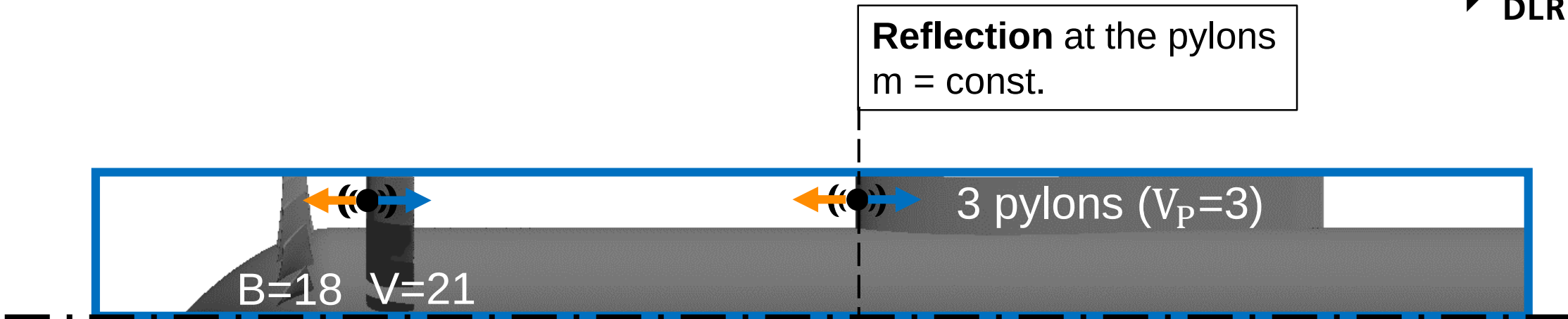
Blade Passing Frequency (BPF):

$$\text{BPF} = h \cdot B \cdot f_{\text{rotor}} \quad \text{with } h \in \mathbb{N}$$

measurement data



CRAFT: measurement data at the inlet
 (1BPF, DP, reference fan-stage)



Tyler-Sofrin modes:

$$m = h \cdot B - k \cdot V$$

with $k \in \mathbb{Z}; h \in \mathbb{N}$

k:\h:	1
0	18
1	-3
2	-24

cut-on TS-mode
(1BPF, DP)

Scattering at the pylons:

...

$m = -6$

$m = 0$

$m = +3$

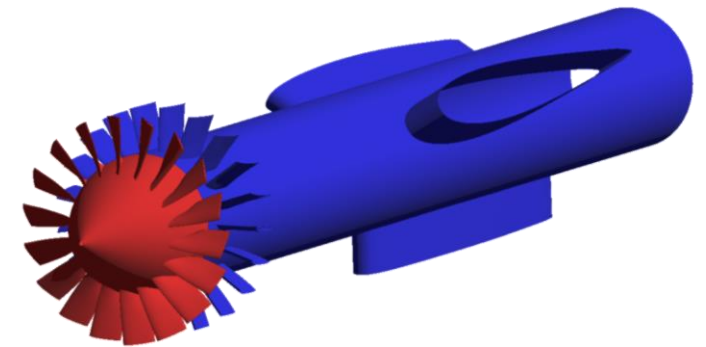
$m = +6$

...

$m_{\text{scattered}} = m + k \cdot V_P$
with $V_P = 3$ (pylons)

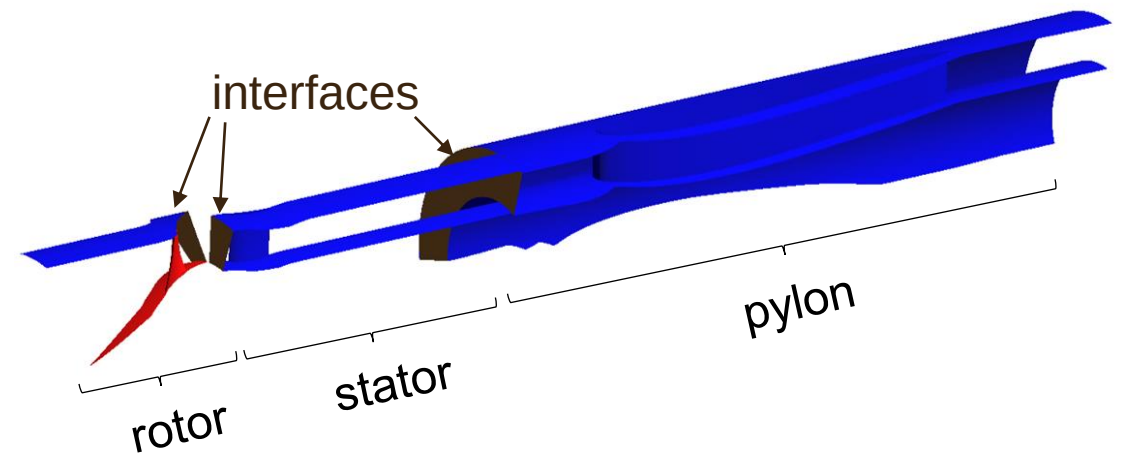
cut-on scattered modes
(1BPF, DP)

- 1 CRAFT-Rig
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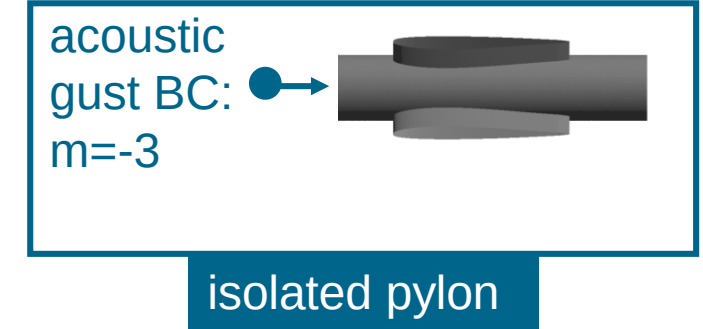
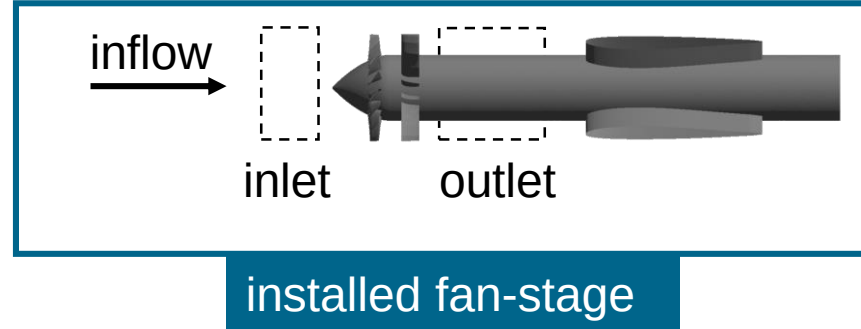
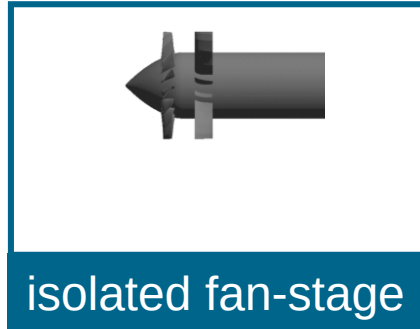
Numerical setup

- Framework/solver: TRACE
 - Steady: RANS
 - Unsteady: HB (Harmonic Balance) method:
hybrid frequency domain method [1]
 - simulation of tonal noise
 - coupling of acoustic modes
- Postprocessing: Connect3D [8]



computational setup: one
passage per domain

Numerical setup



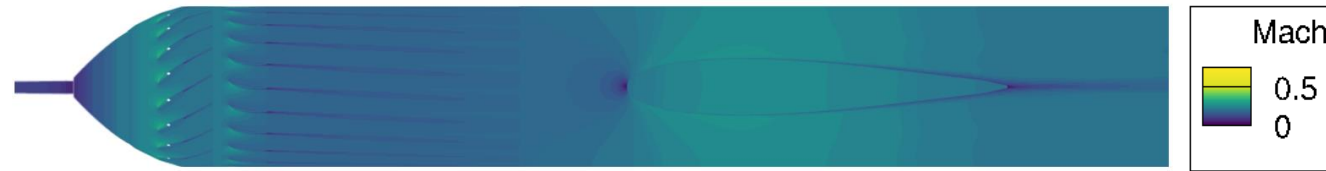
→ Limitation to 1BPF (1350 Hz) in subsequent analysis

- 1 CRAFT-Rig
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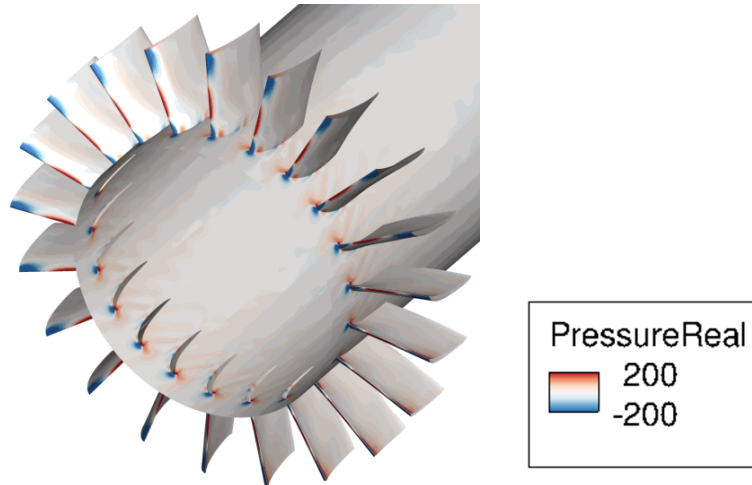
Results

steady: RANS



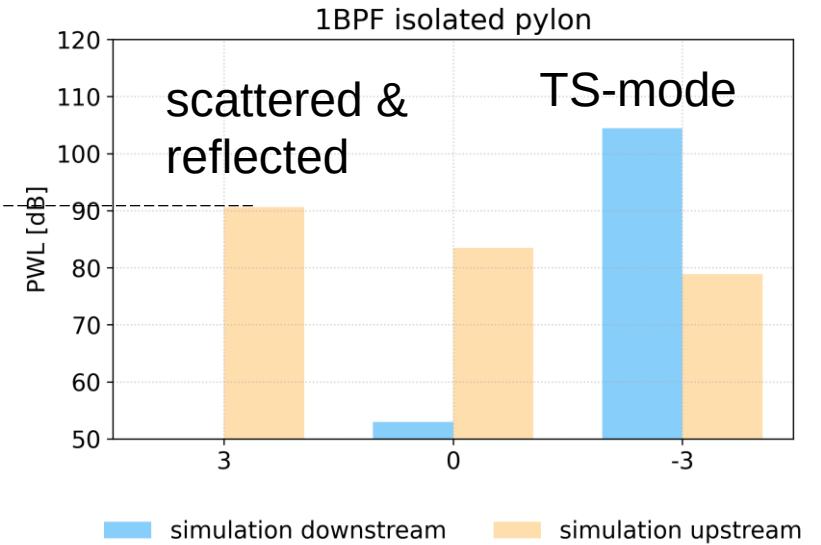
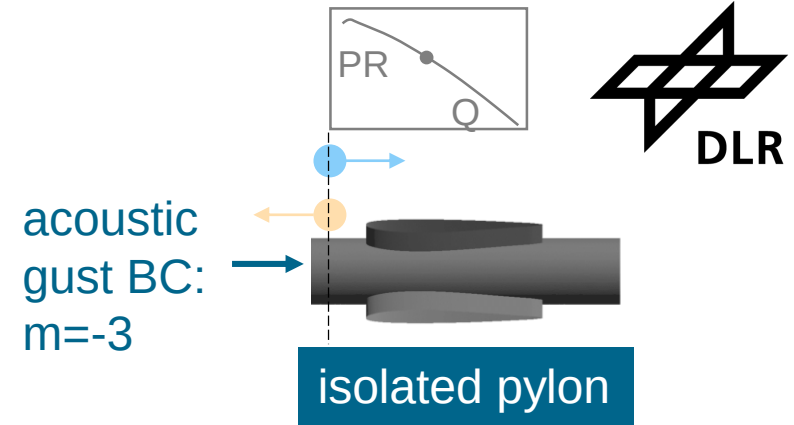
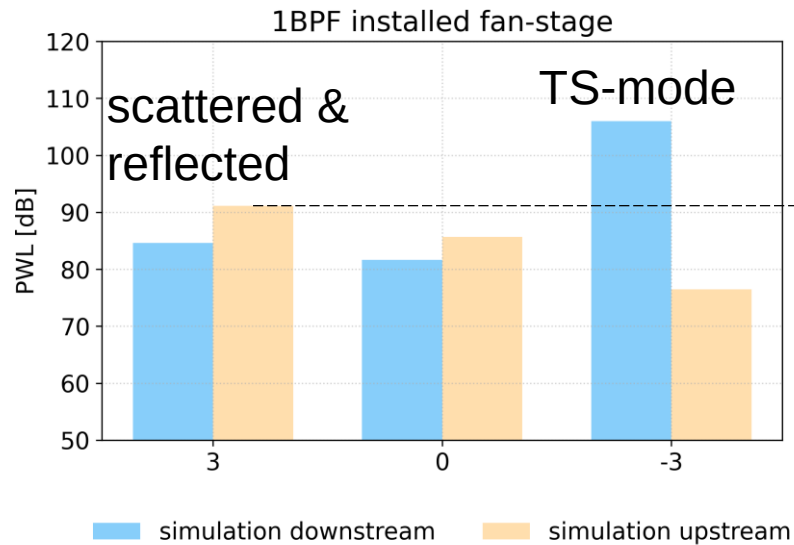
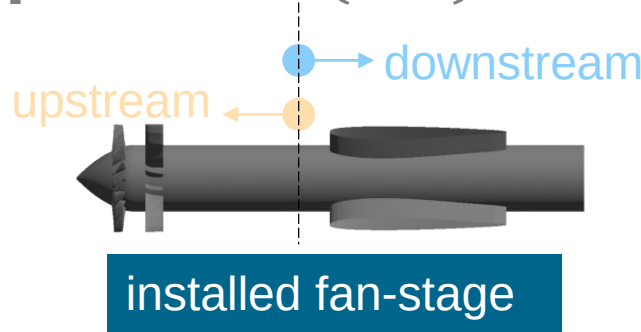
Mach-number at 50 % rel. height

unsteady: HB

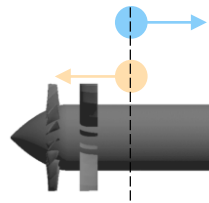
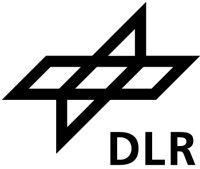
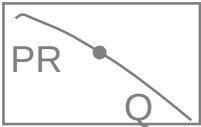


sound sources: unsteady
pressure on vanes. stator domain

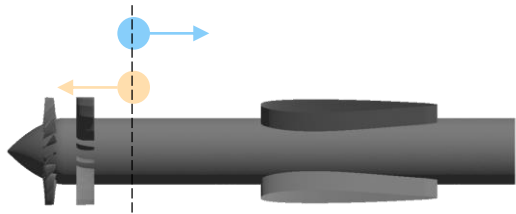
Results – simulation, $\phi = 0.33$ (DP)



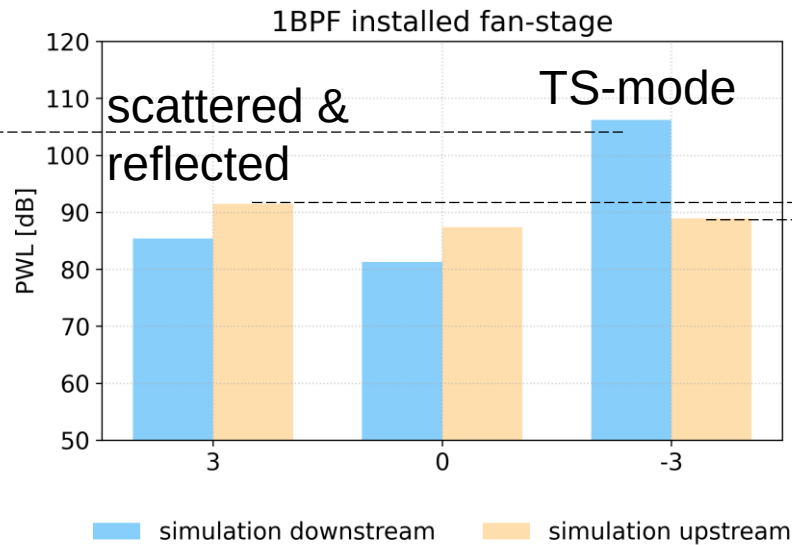
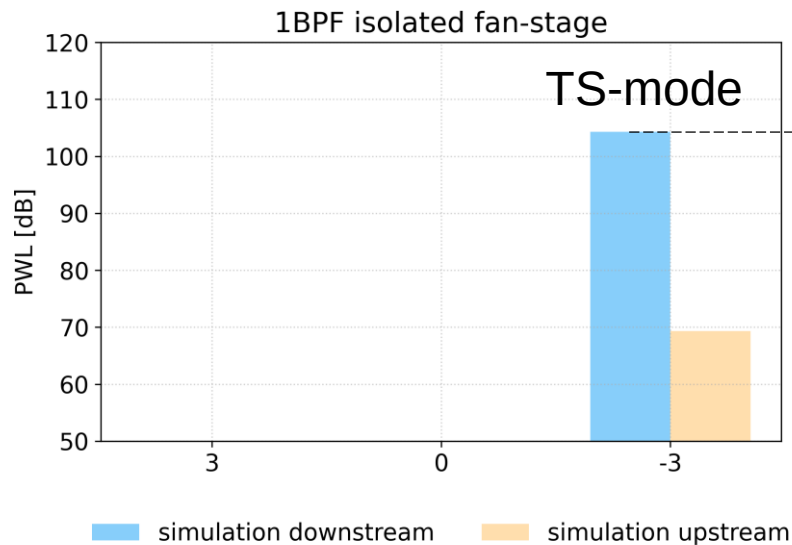
Results – simulation, $\phi = 0.33$ (DP)



isolated fan-stage



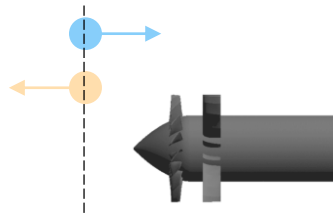
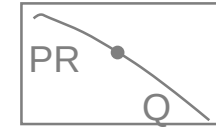
installed fan-stage



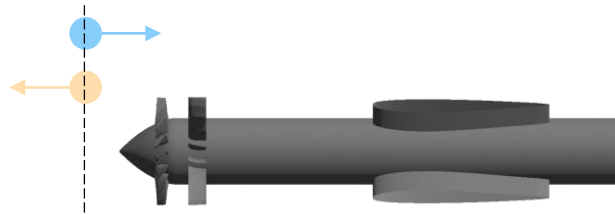
+2.6 dB

$$\Delta_{PWL} = PWL_{m=+3}^- - PWL_{m=-3}^-$$

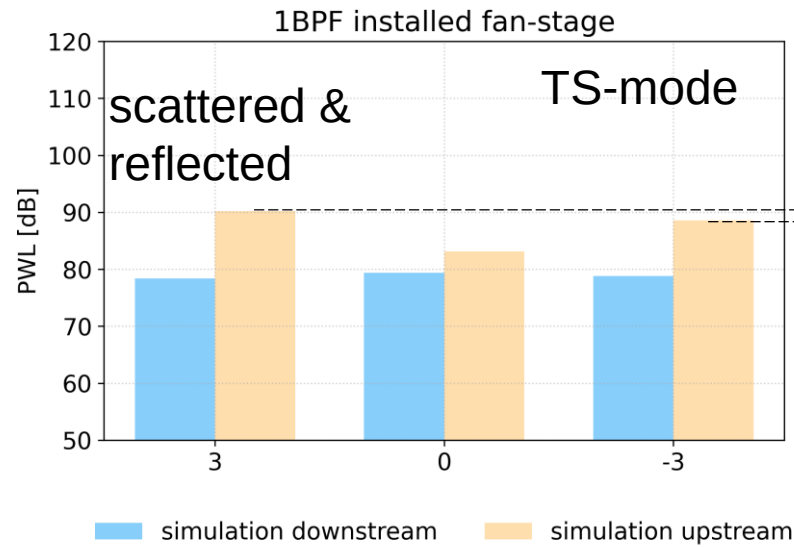
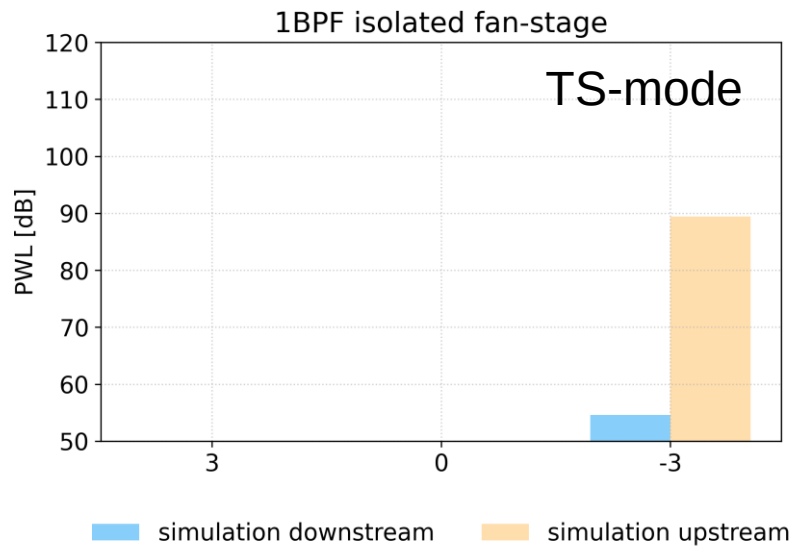
Results – simulation, $\phi = 0.33$ (DP)



isolated fan-stage



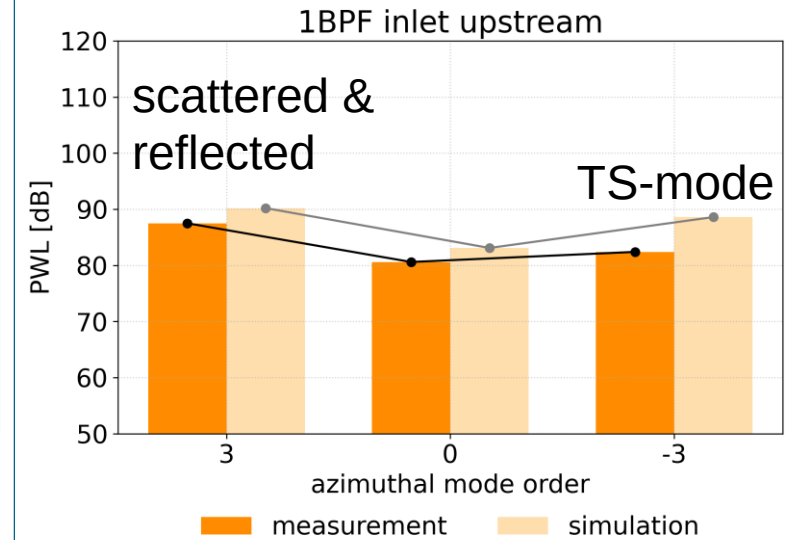
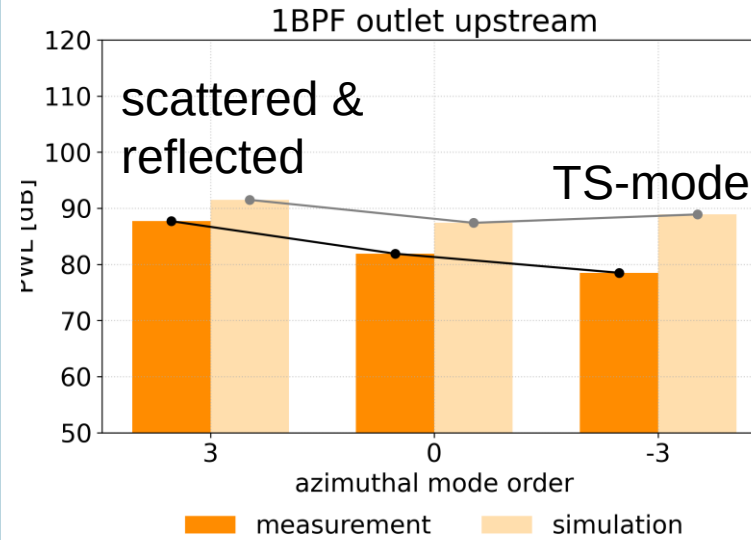
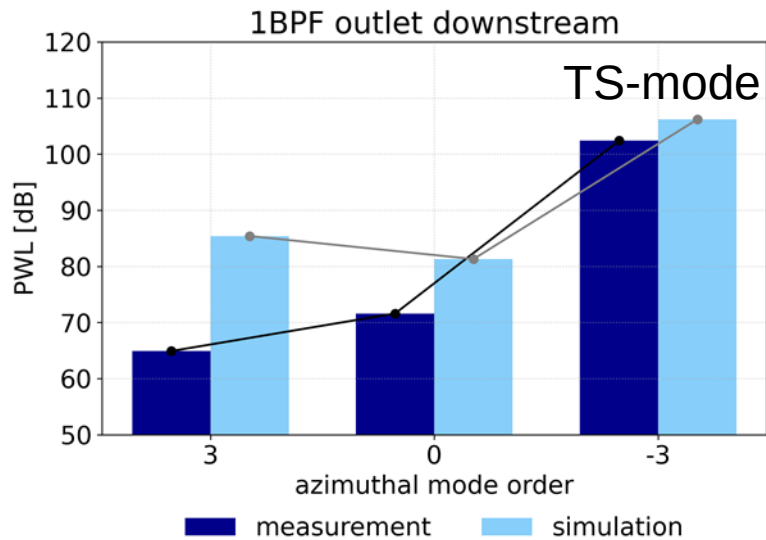
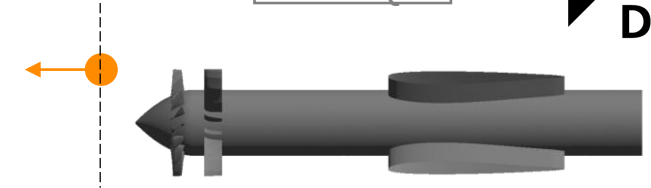
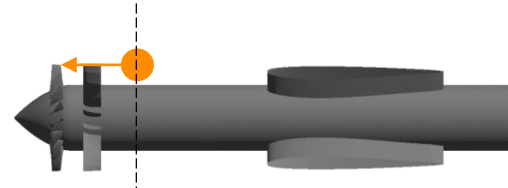
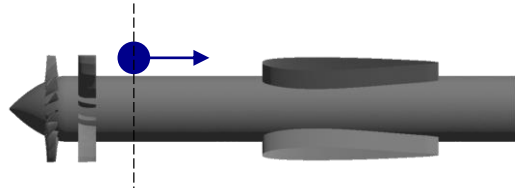
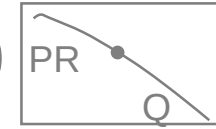
installed fan-stage



+1.5 dB

$$\Delta_{PWL} = PWL_{m=+3}^- - PWL_{m=-3}^-$$

Results – measurements & simulation, $\phi = 0.33$ (DP)



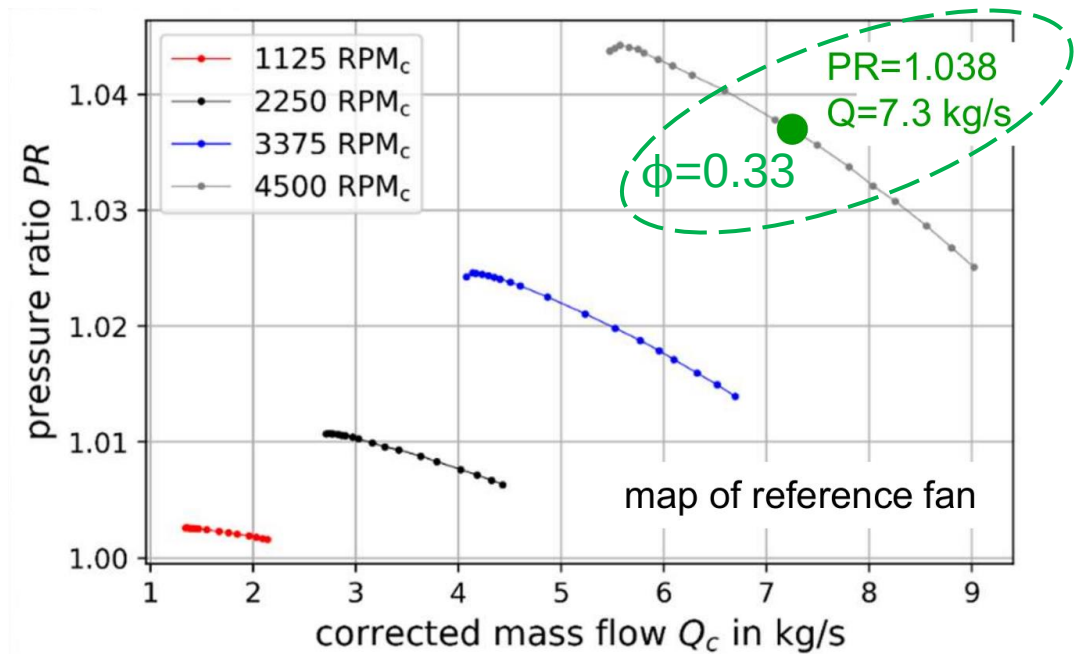
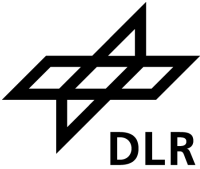
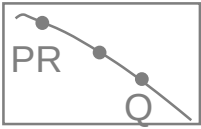
→ scattered & reflected mode
m=+3 is dominant

→ $\Delta_{PWL, meas} = +5.1$ dB

$\Delta_{PWL, sim} = +1.5$ dB

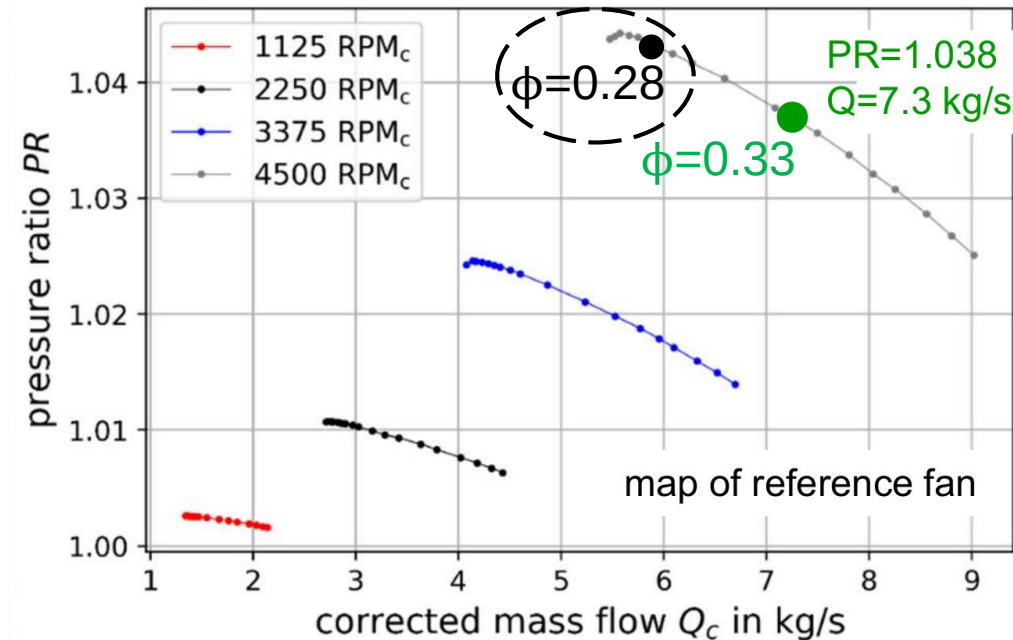
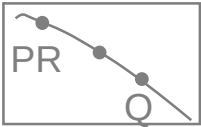
$\Delta_{PWL} = PWL_{m=+3} - PWL_{m=-3}$

Results – Operating Points



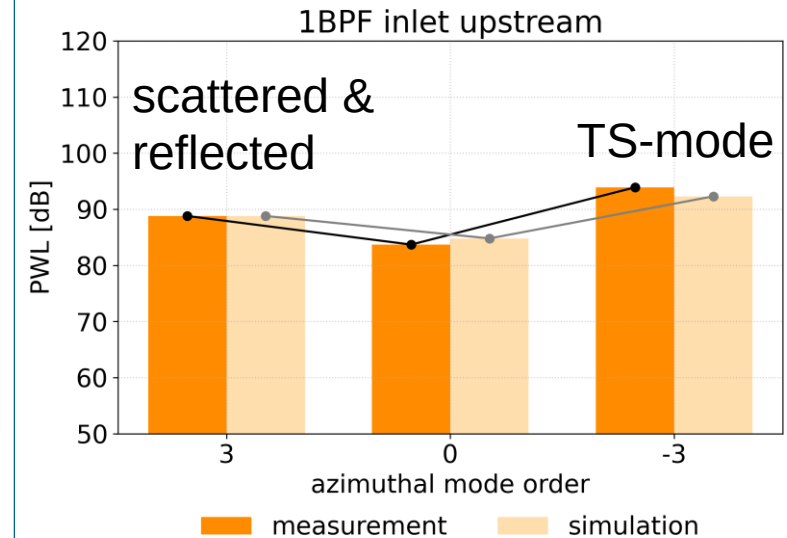
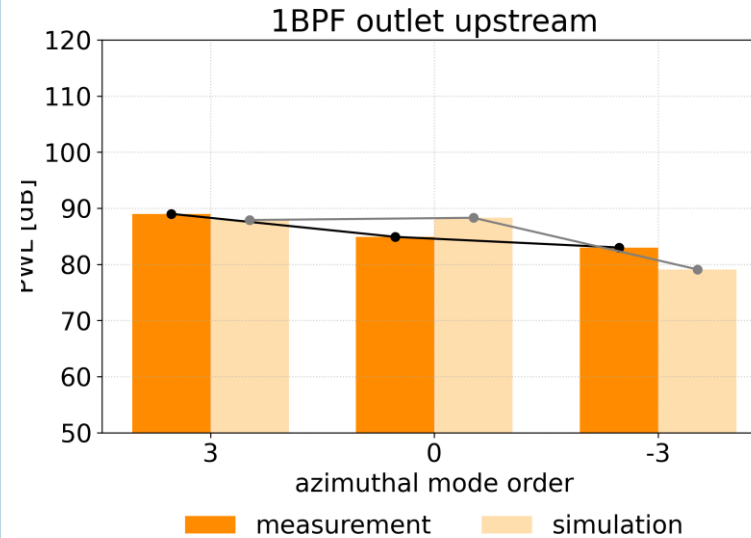
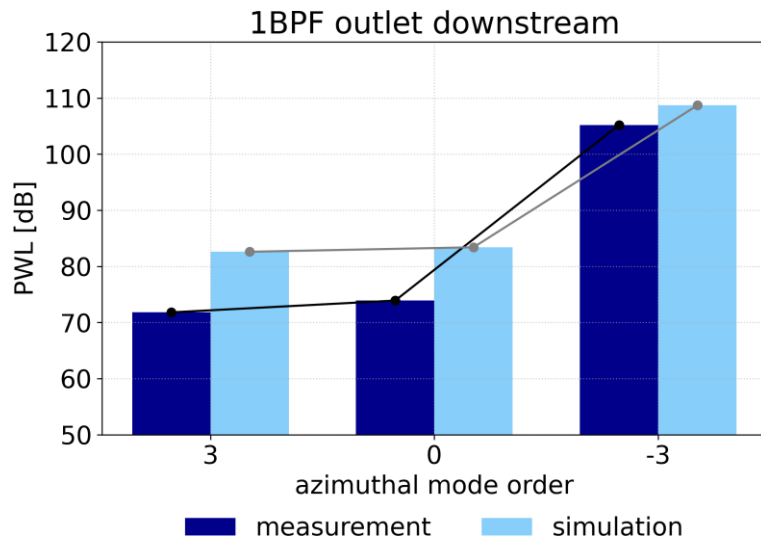
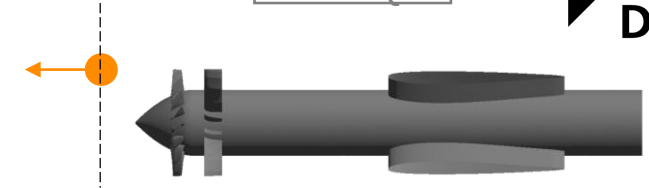
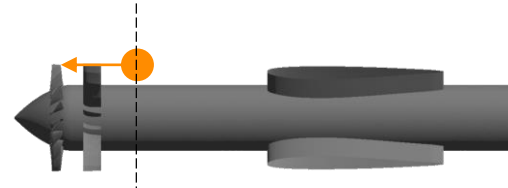
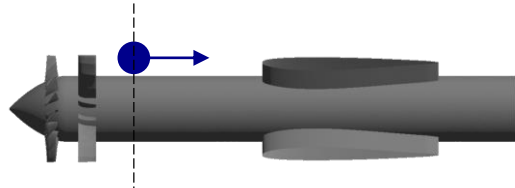
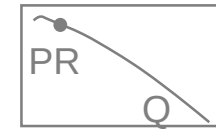
[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

Results – Operating Points



[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

Results -measurements & simulation, $\phi = 0.28$



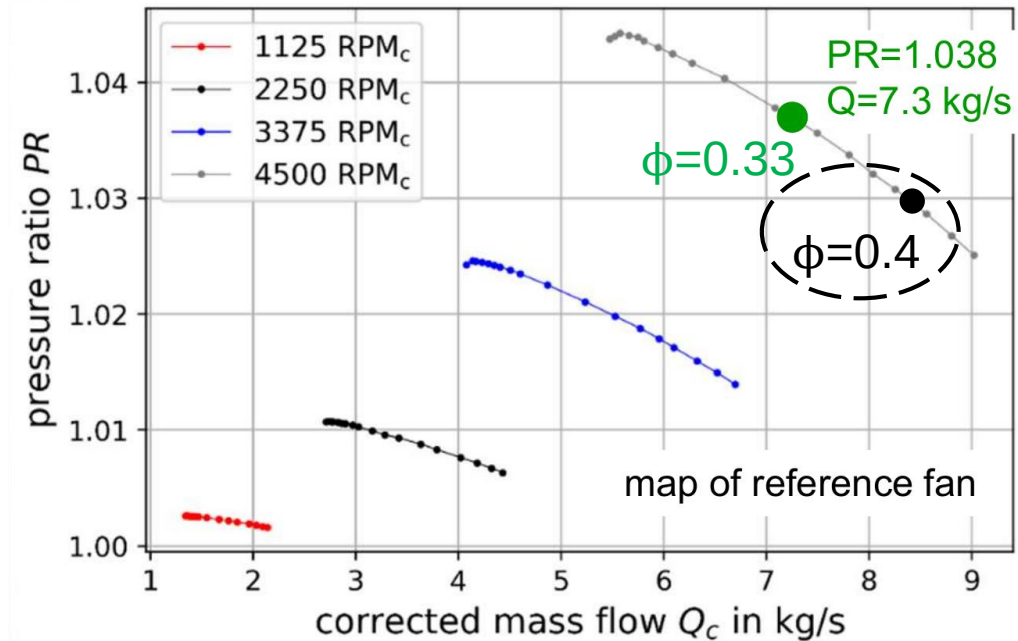
→ TS-mode $m=-3$ is dominant

→ $\Delta_{PWL, meas} = -5.1 \text{ dB}$

$\Delta_{PWL, sim} = -3.4 \text{ dB}$

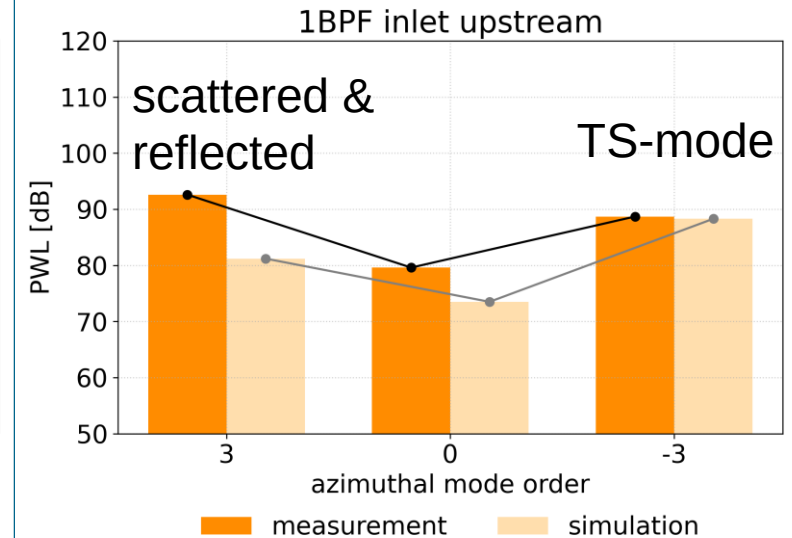
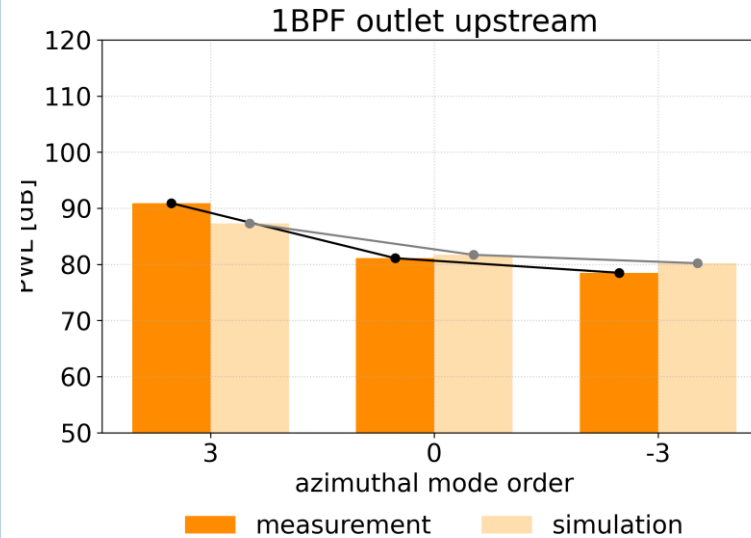
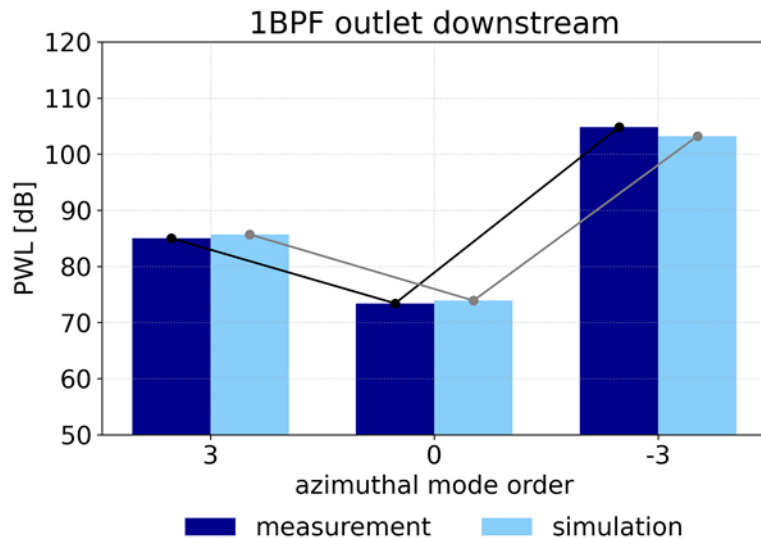
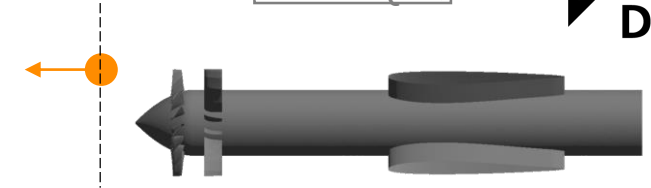
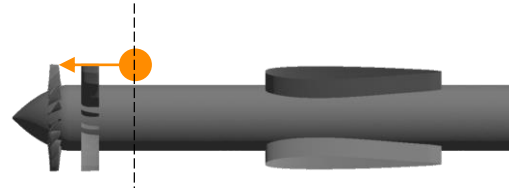
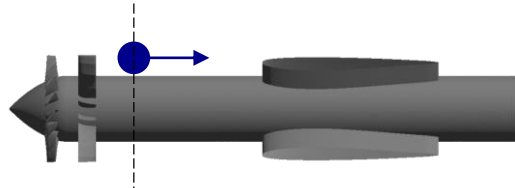
$$\Delta_{PWL} = PWL_{m=+3}^- - PWL_{m=-3}^-$$

Results – Operating Points



[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

Results -measurements & simulation, $\phi = 0.4$

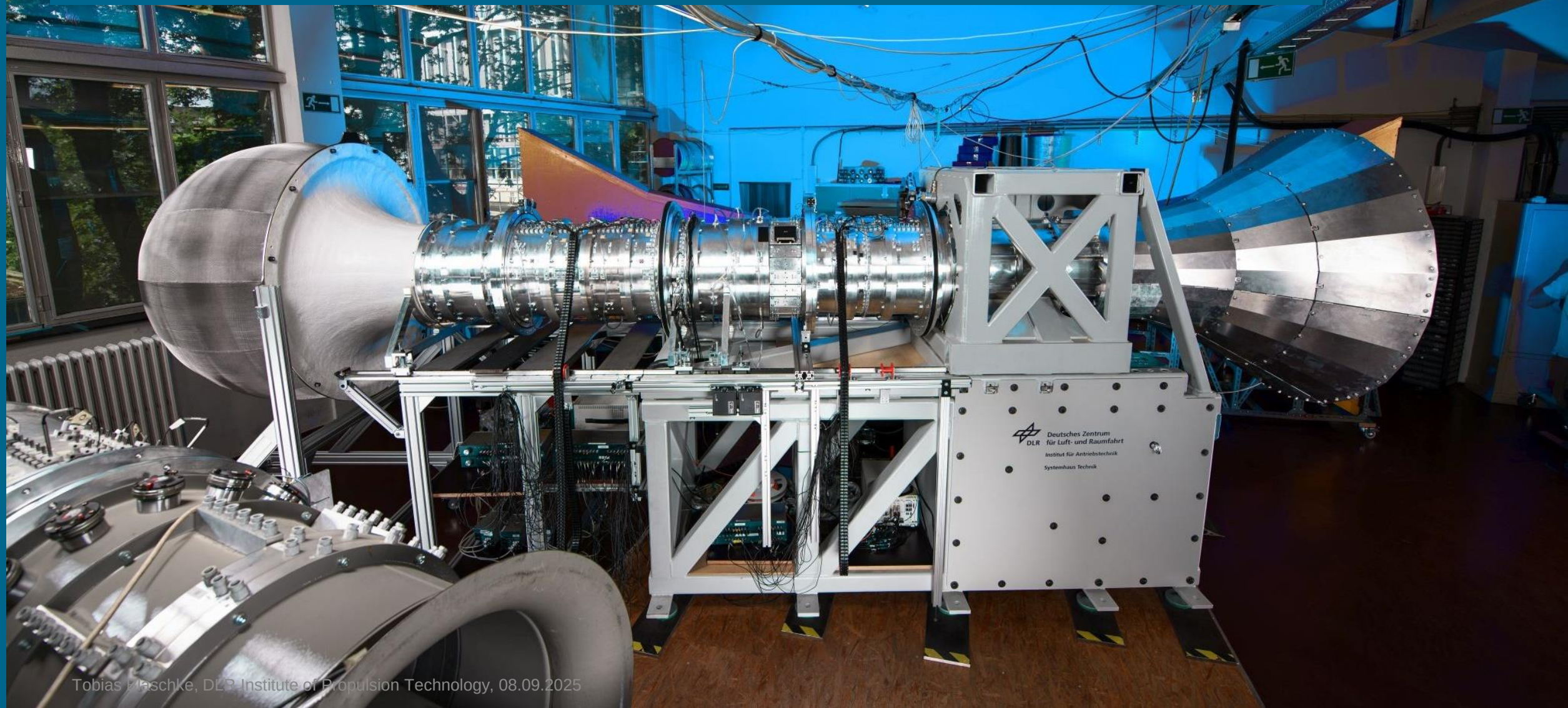


- exp.: scattered & reflected mode $m=+3$ is dominant
- $\Delta_{PWL, meas} = +3.9$ dB
- $\Delta_{PWL, sim} = -7.2$ dB
- Different prediction with CFD

- 1 CRAFT-Rig**
- 2 Numerical setup**
- 3 Results**
- 4 Summary**

- Simulation of acoustic mode reflections due to installation effects of a low-speed fan stage into an the CRAFT-rig
- Comparison to measurement data
 - ↳ validation of simulation results
 - ↳ strongest acoustic mode reflection effects at the pylons at the DP
 - ↳ physics of acoustic mode propagation effects - reflection, transmission, scattering

THANK YOU FOR YOUR ATTENTION



Topic: Numerical Assessment of acoustic mode reflections in a low-speed fan test rig

Date: September 08, 2025

Event: 18th DEGA Symposium: „Acoustics of Drones and Urban Air Mobility Vehicles“

Location: Berlin Adlershof DLR

Authors: Tobias Blaschke, Sébastien Guerin, Antoine Moreau, Wolfram Köhler, Lukas Klähn

DLR Institute: Propulsion Technology

Image sources: All images „DLR (CC BY-NC-ND 3.0)“ unless otherwise stated

- [1] Frey, C. ; Ashcroft, G. ; Kersken, H.-P. ; Voigt, C. : A harmonic balance technique for multistage turbomachinery applications. In: Turbo Expo: Power for Land, Sea, and Air American Society of Mechanical Engineers, 2014
- [2] Blaschke, T.: Prediction of tonal rotor-stator interaction noise of an acoustic fan test rig with the harmonic balance method. Masterthesis, Institute of Turbomachinery and Flight Propulsion, Technical University of Munich (2024).
- [3] Klähn, L., Caldas, L., Meyer, R., Rudolphi, A., Moreau, A., & Tapken, U. (2022). Experimentelle Untersuchung der Auswirkung von Einlaufstörungen auf die Aeroakustik einer Rotor-Stator-Konfiguration am Fan-Prüfstand CRAFT. Deutsche Gesellschaft für Luftund Raumfahrt, DLRK, 27(29.9), 2022.
- [4] Pilgrim, J., Behn, M., & Tapken, U. (2023). Validierung eines analytischen Modells zur Schallausbreitung durch eine Fanstufe. DAGA 2023, 522-525.
- [5] Schade, S. (2025). Design of Low-Noise Fan Engines for Urban Air Mobility and Sound Quality Analysis Using Virtual Flyovers (Doctoral dissertation, Technische Universität Berlin).
- [6] Tapken, U., Caldas, L., Meyer, R., Behn, M., Klähn, L., Jaron, R., Moreau, A., Enghardt, L. (2021). New test facility to investigate the noise generated by shrouded fans for small aircraft applications. DICUAM 2021 - Delft International Conference on Urban Air-Mobility, 15.-17. March 2021, Delft, Netherlands.
- [7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.
- [8] Tapken, U., & Behn, M. (2025). Influence of foam-resin lining on the reflections and scattering of acoustic modes at pylons in a flow duct. Proceedings of DAS | DAGA 2025.
- [9] Weckmüller, C. ; Fritzsche, A. ; Guérin, S. : Extended Multi-Plane Pressure Mode Matching for CFD/CAA Coupling. In: Proceedings of the NAG/DAGA 2009 International Conference on Acoustics Bd. 3 German Acoustical Society (DEGA) Rotterdam, The Netherlands, 2009, S. 1244–1247