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

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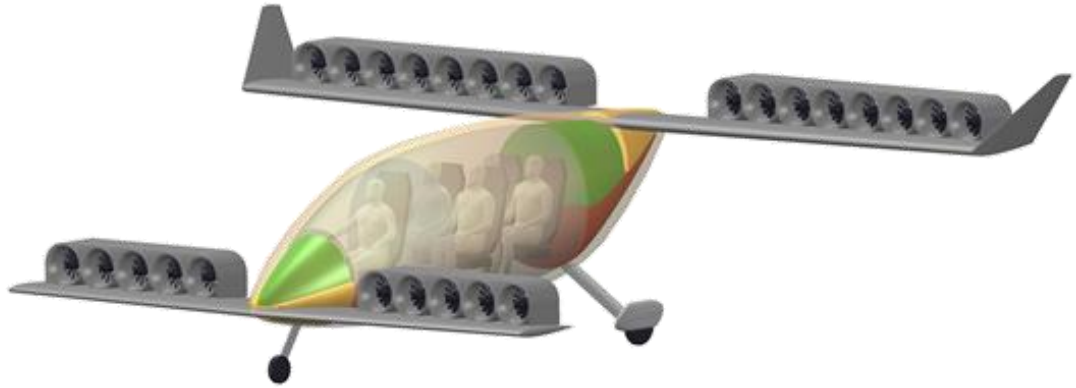
Motivation

- 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

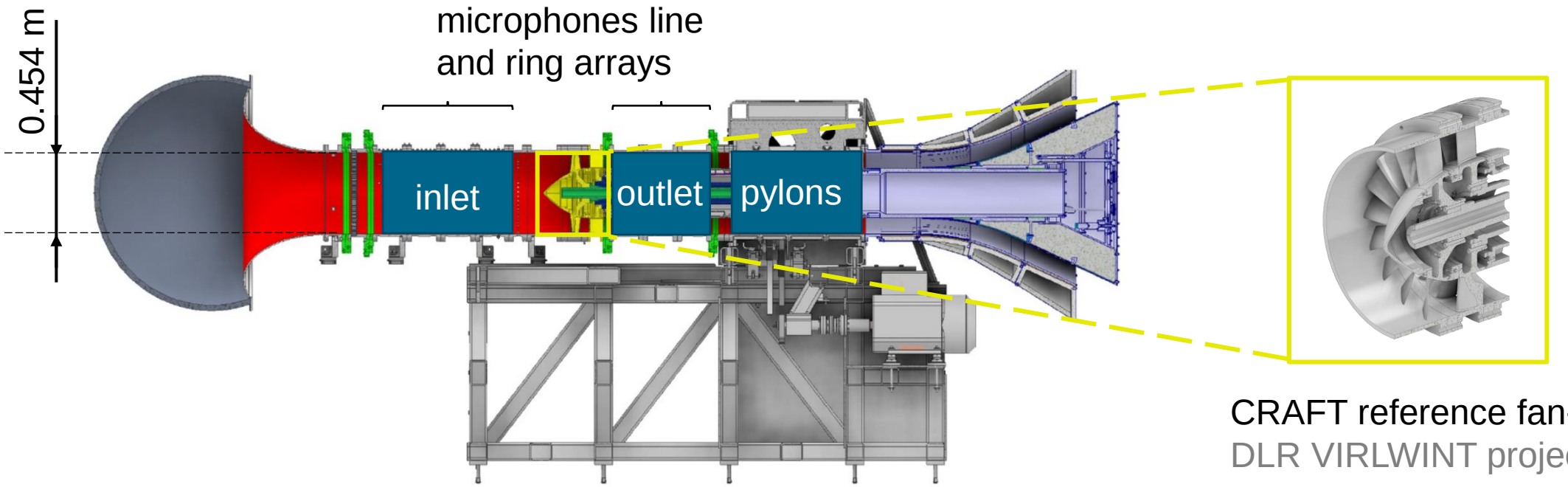
  …

  → CRAFT-rig



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

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



CRAFT-Rig of the DLR Institute
of Propulsion Technology

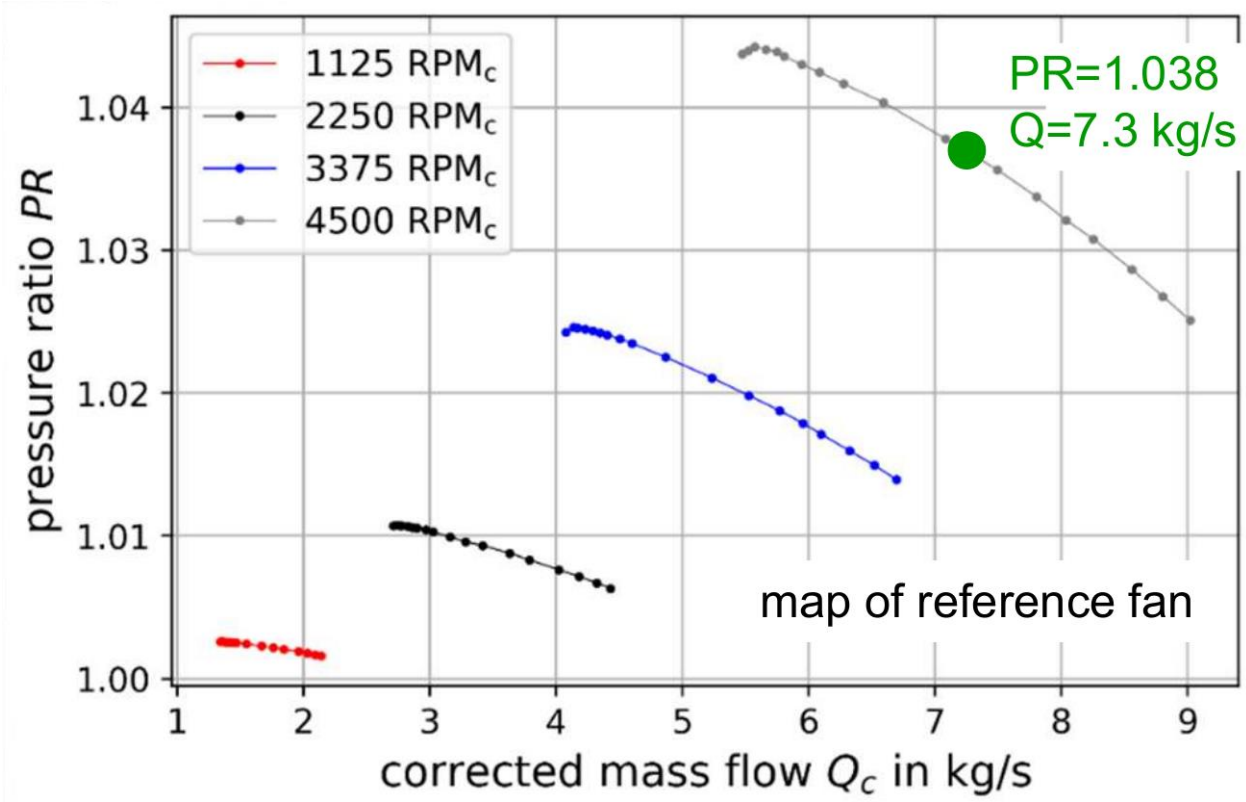
CRAFT reference fan-stage
DLR VIRLWINT project

[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.

CRAFT-Rig

Design Point (DP):

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

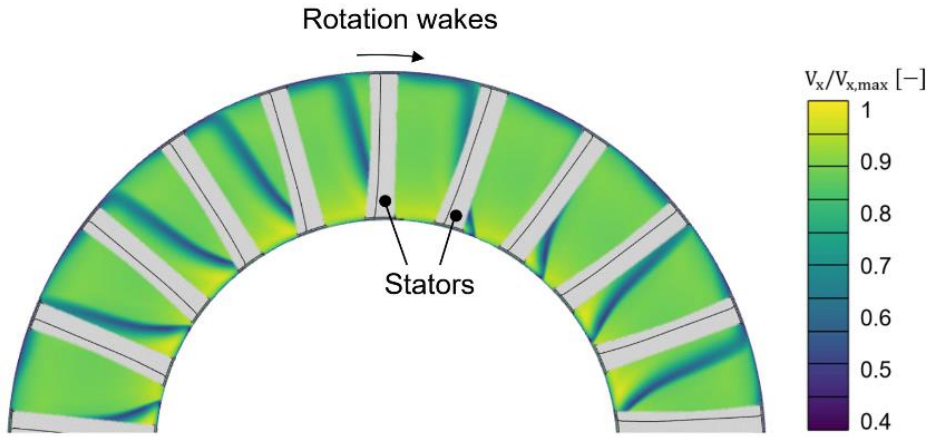


[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

CRAFT-Rig

Rotor-stator interactions

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

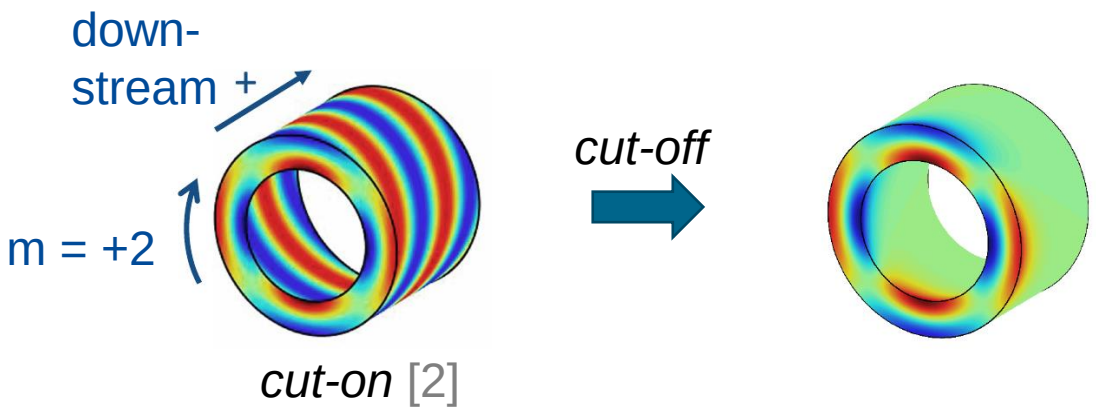


Velocity deficits of rotor wakes.
View upstream. [2]

CRAFT-Rig

Rotor-stator interactions

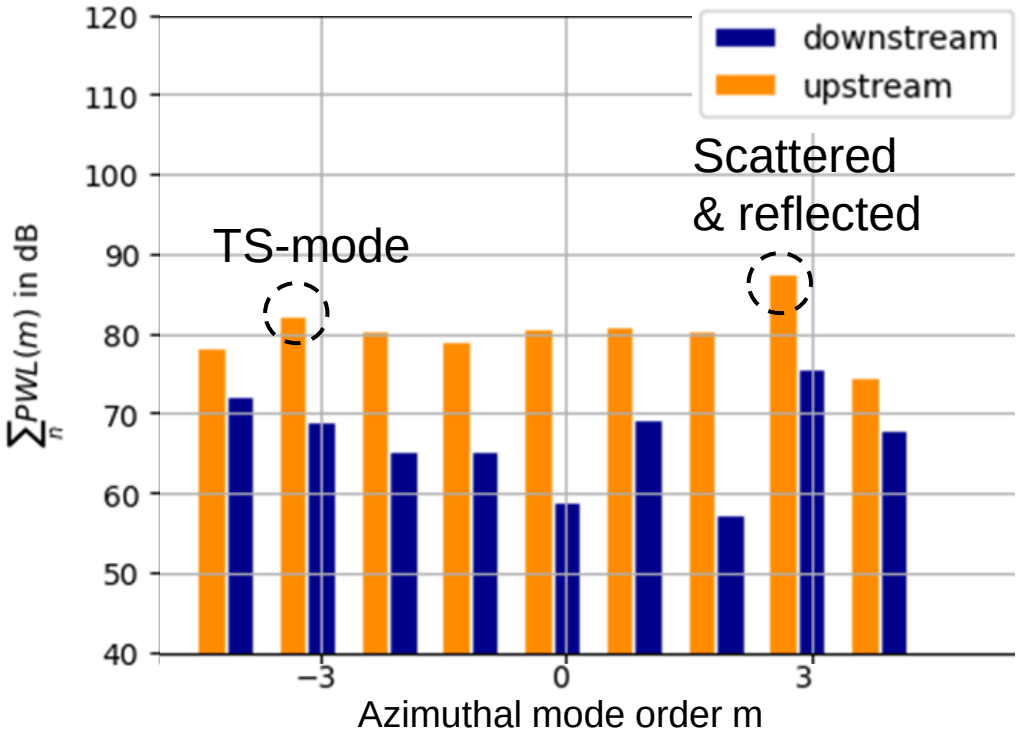
→excitation of Tyler-Sofrin (TS) modes / spinning modes



Blade Passing Frequency (BPF):

$BPF = h \cdot B \cdot f_{rotor}$ with $h \in \mathbb{N} \setminus \{0\}$

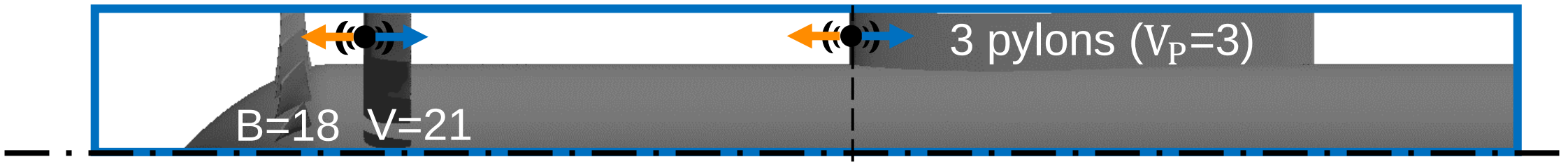
measurement data



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

CRAFT-Rig

Reflection at the pylons
m = const.



Tyler-Sofrin modes:

$$m_{RSI} = h \cdot B - k \cdot V$$

with $h \in \mathbb{N}\backslash\{0\}$; $k \in \mathbb{Z}\backslash\{0\}$

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

Scattering at the pylons:

…
m = -6
m = 0
m = +3
m = +6
…

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

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

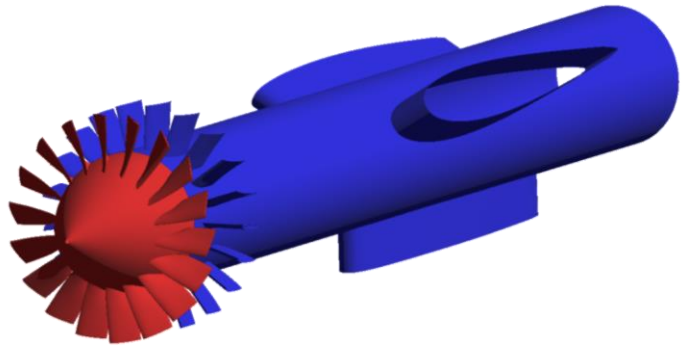
cut-on scattered modes
(1BPF, DP)

1 CRAFT-Rig

2 Numerical setup

3 Results

4 Summary

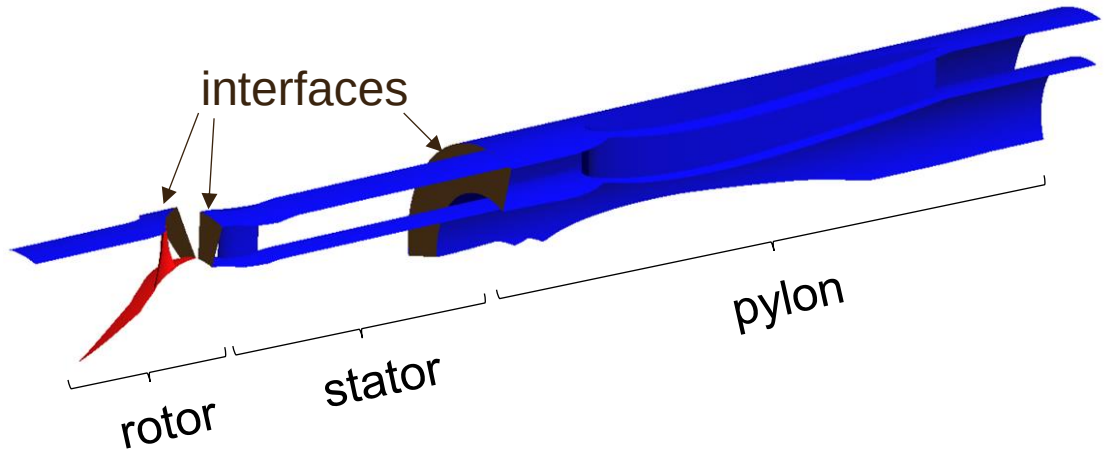


Numerical setup

- Framework/solver: TRACE
  - Steady: RANS
  - Unsteady: HB (Harmonic Balance) method:
    hybrid frequency domain method [1]

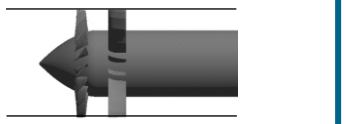
    → simulation of tonal noise

    → coupling of acoustic modes
- Postprocessing: Connect3D [8]

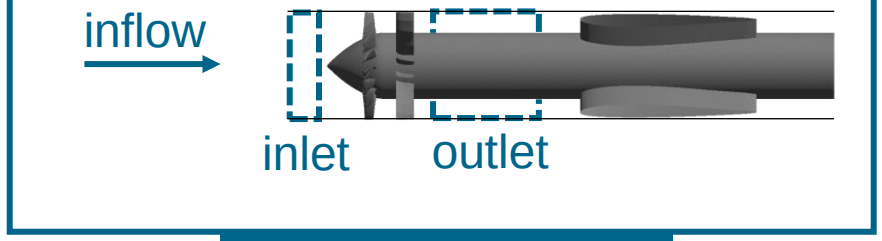


computational setup: one passage per domain

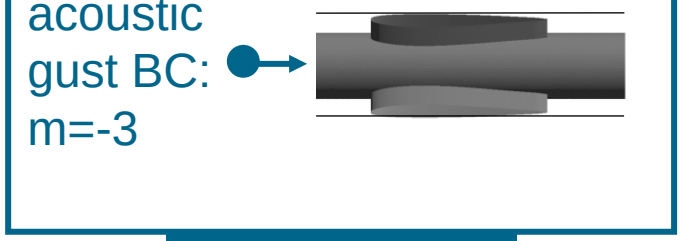
Numerical setup



isolated fan-stage



installed fan-stage



isolated pylon

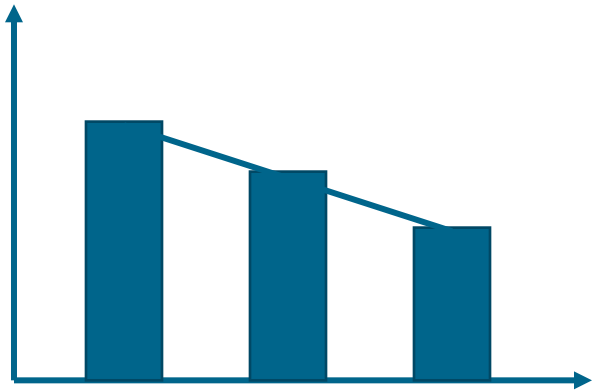
→ Limitation to 1BPF (1350 Hz) in subsequent analysis

1 CRAFT-Rig

2 Numerical setup

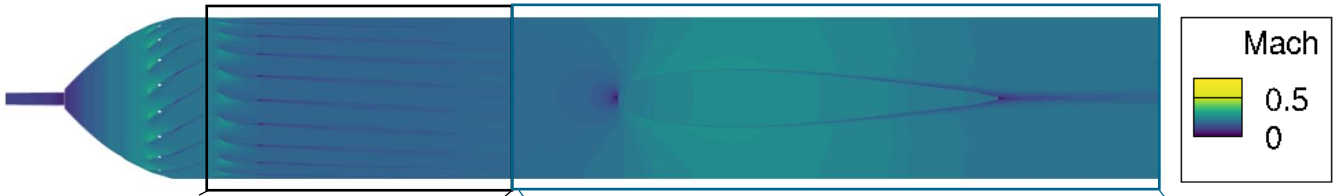
3 Results

4 Summary



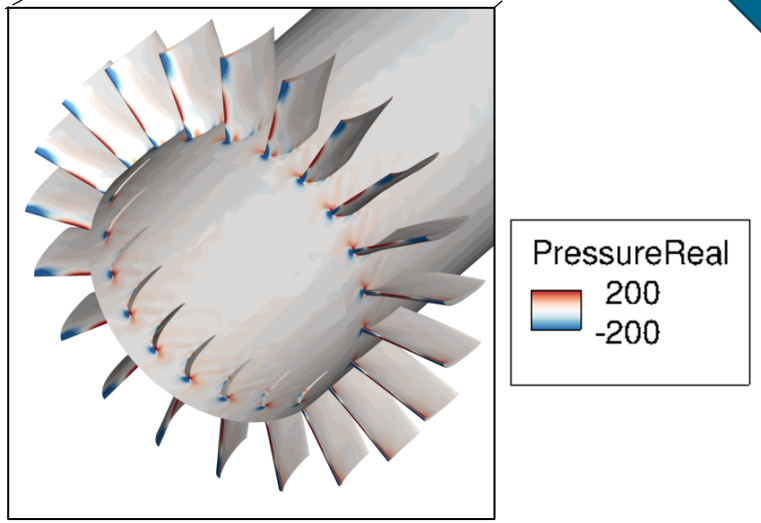
Results - visualization

steady: RANS

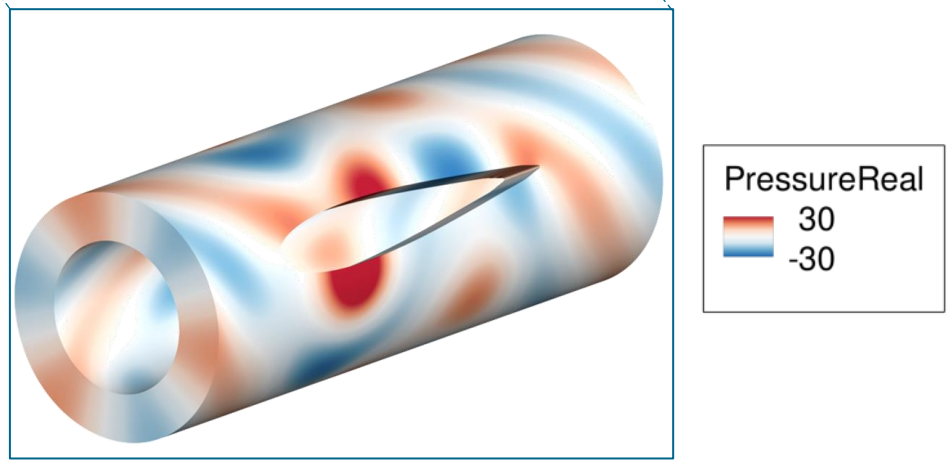


Mach-number ($\mathrm{Ma}_{\mathrm{rel}}$ in rotor domain)

unsteady: HB

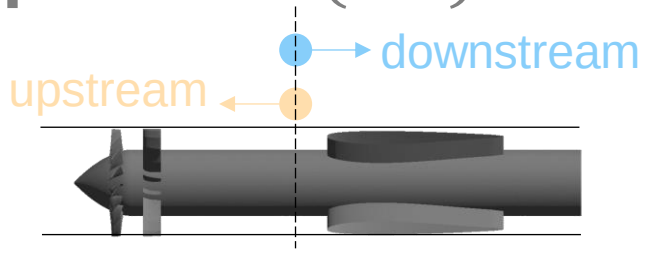


sound sources: unsteady pressure on vanes. stator domain, 1BPF.

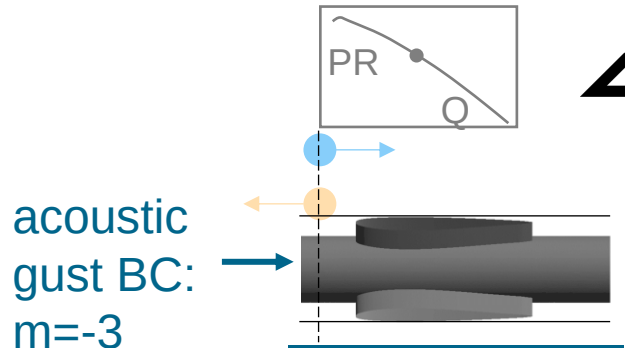


isolated pylon: real part of pressure fluctuations. 1BPF

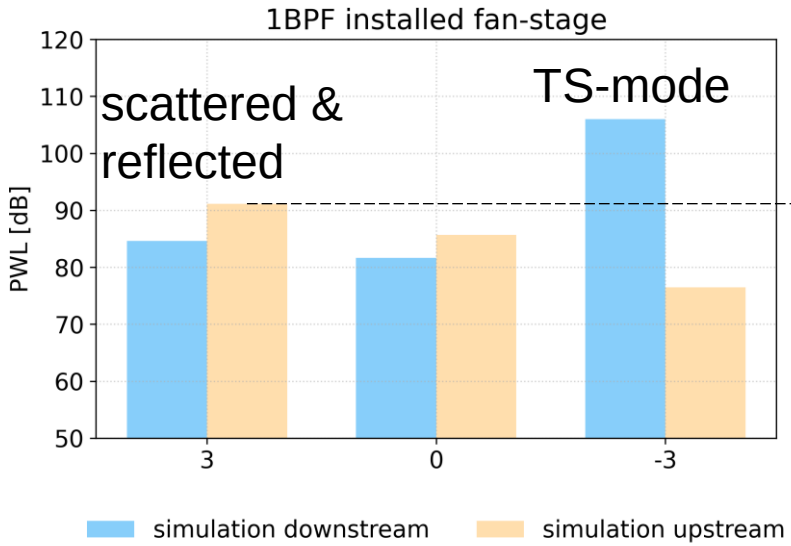
Results – simulation, $\phi = 0.33$ (DP)

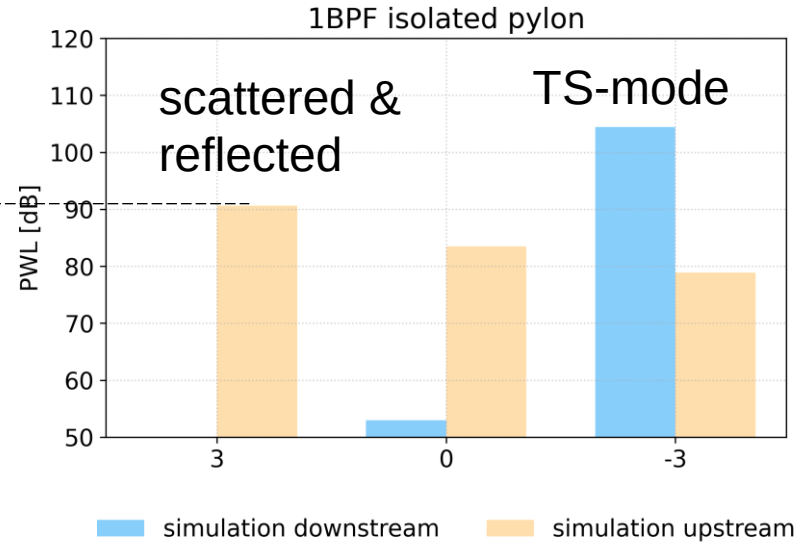


installed fan-stage



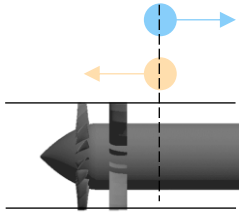
isolated pylon



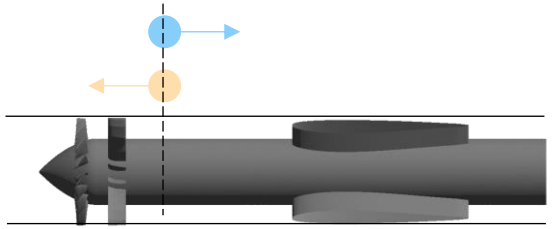


→ similar PWLs of scattered & reflected modes

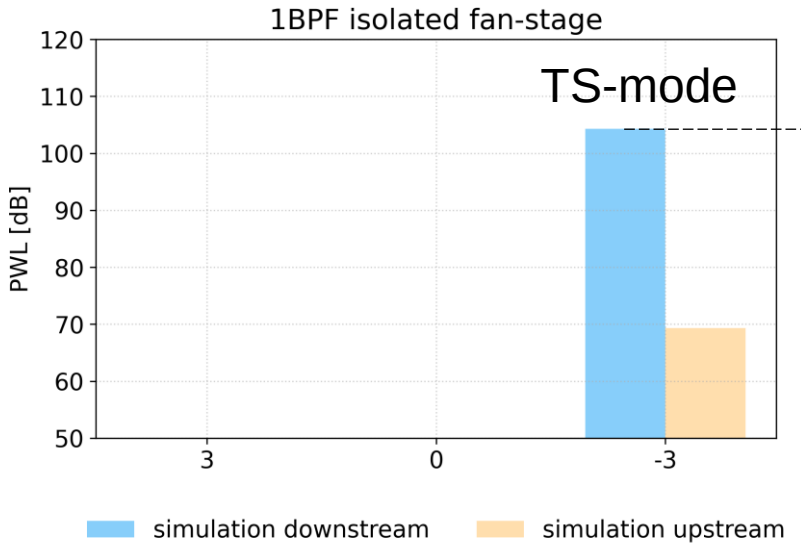
Results – simulation, $\phi = 0.33$ (DP)

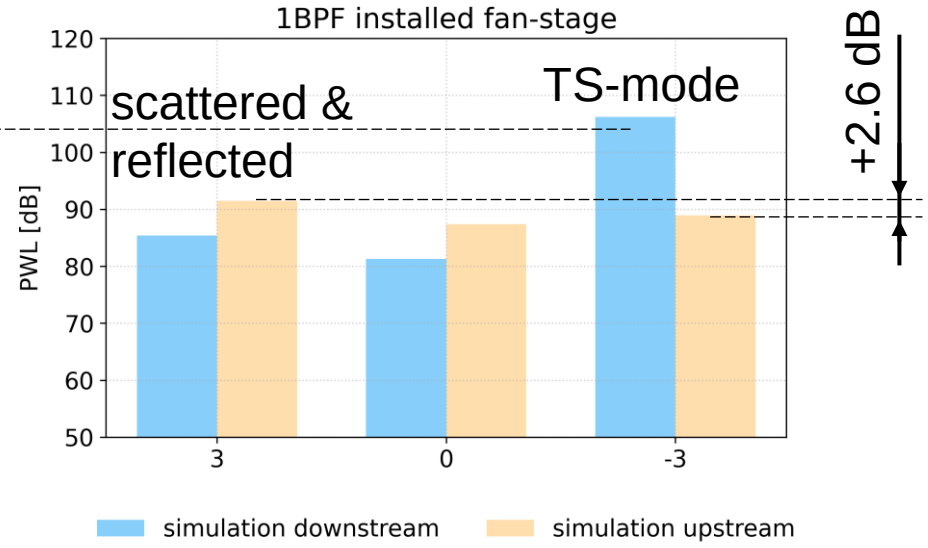


isolated fan-stage



installed fan-stage

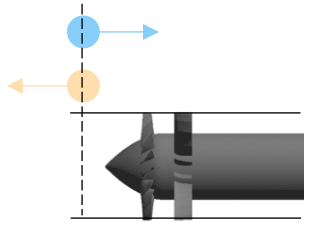




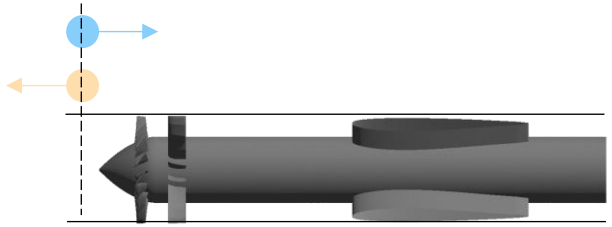
$$\Delta_{\mathrm{PWL}} = \mathrm{PWL}^{-}_{\mathrm{m}=+3} - \mathrm{PWL}^{-}_{\mathrm{m}=-3}$$

→ scattered & reflected mode is dominant

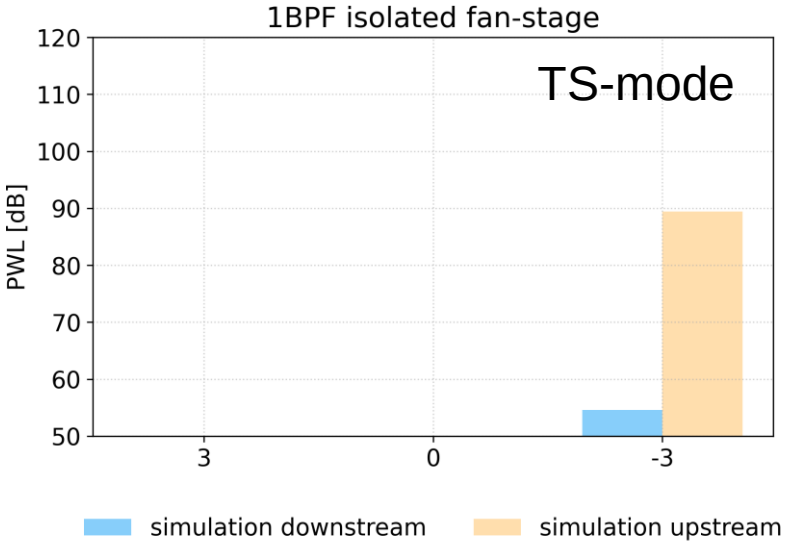
Results – simulation, $\phi = 0.33$ (DP)

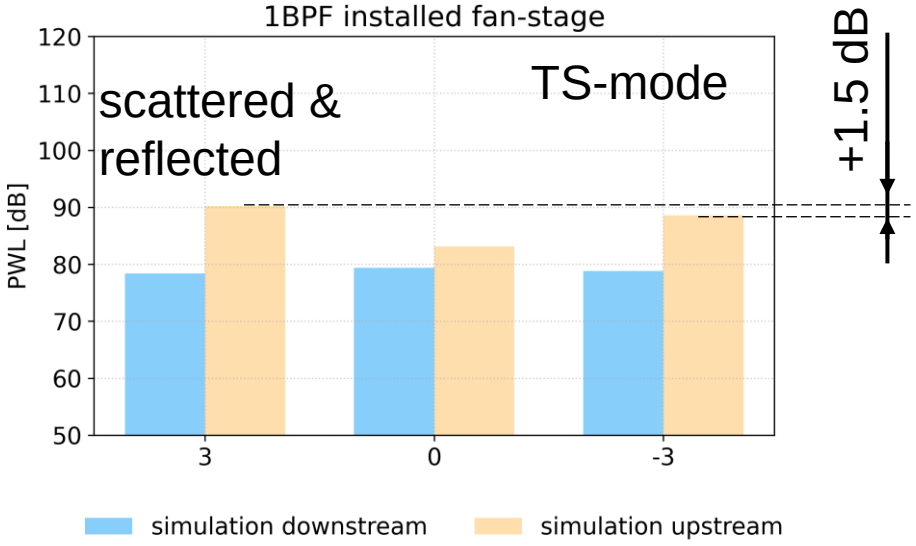


isolated fan-stage



installed fan-stage

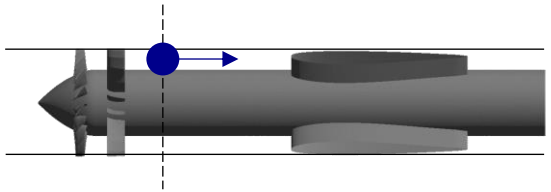


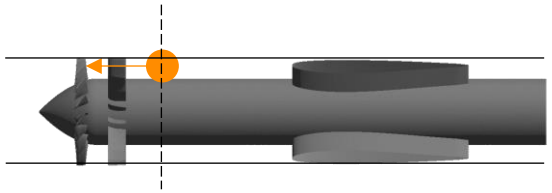


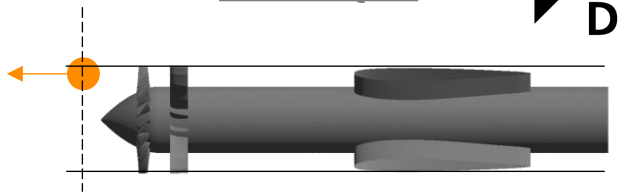
$$\Delta_{PWL} = PWL^{-}_{m=+3} - PWL^{-}_{m=-3}$$

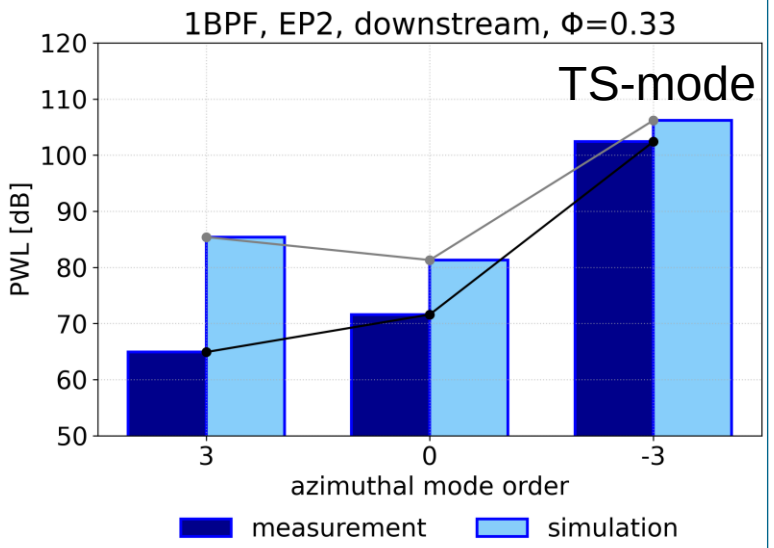
→ scattered & reflected mode is dominant

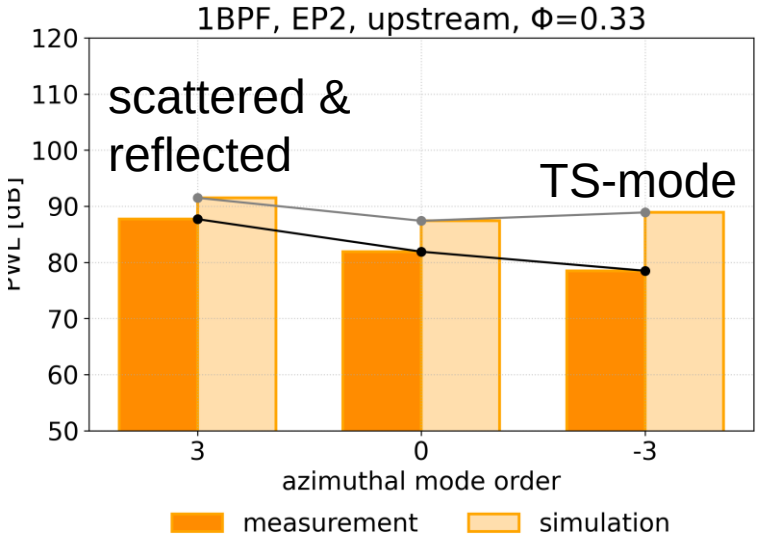
Results – measurements & simulation, $\phi = 0.33$ (DP)

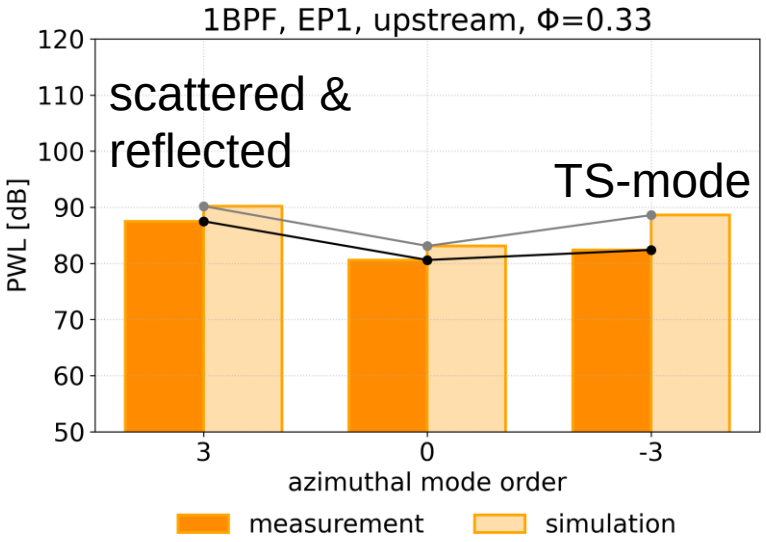












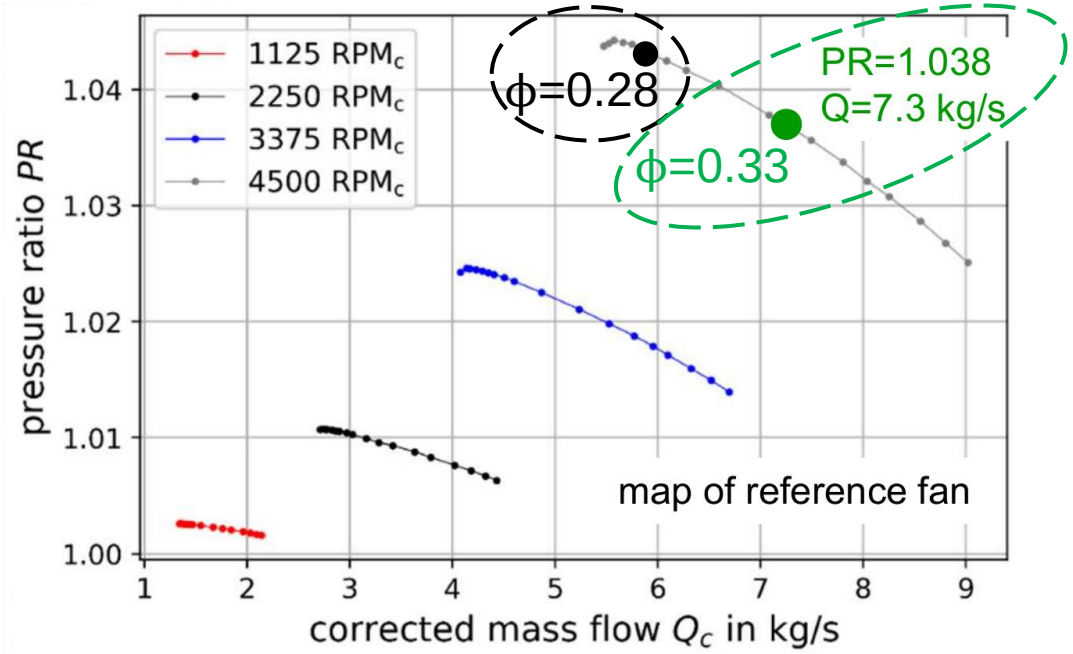
→ scattered & reflected mode m=+3 is dominant

→ $\Delta_{PWL,meas}$ = +5.1 dB

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

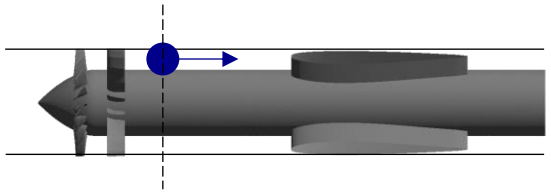
$\Delta_{PWL} = PWL^{-}_{m=+3} - PWL^{-}_{m=-3}$

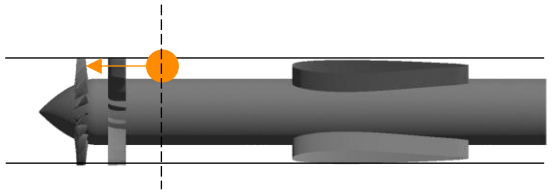
Results – Operating Points

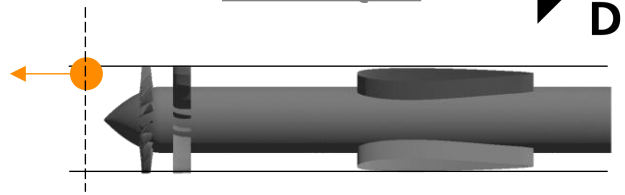


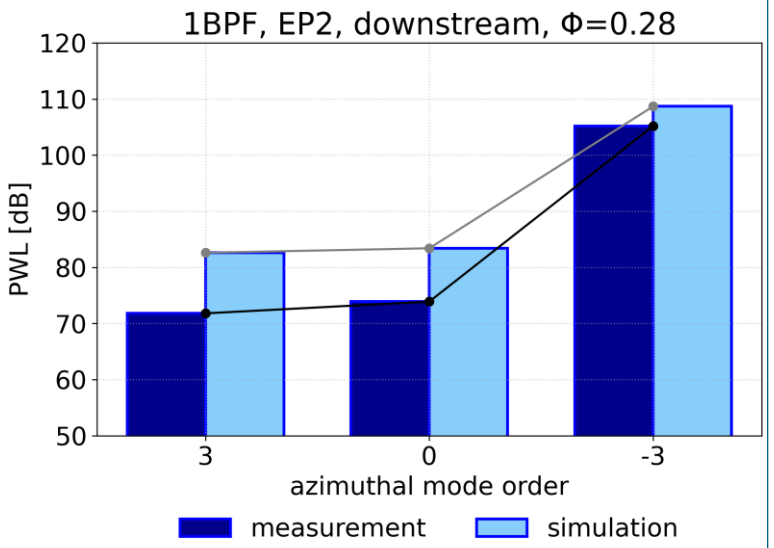
[7] Tapken, U., Schade, S., Klähn, L., Rudolphi, A., Behn, M., & Meyer, R. (2023). CRAFT test rig for assessing the aeroacoustic impact of fans of electrically powered urban/regional aircraft. CEAS-ASC Workshop 2023 Budapest.

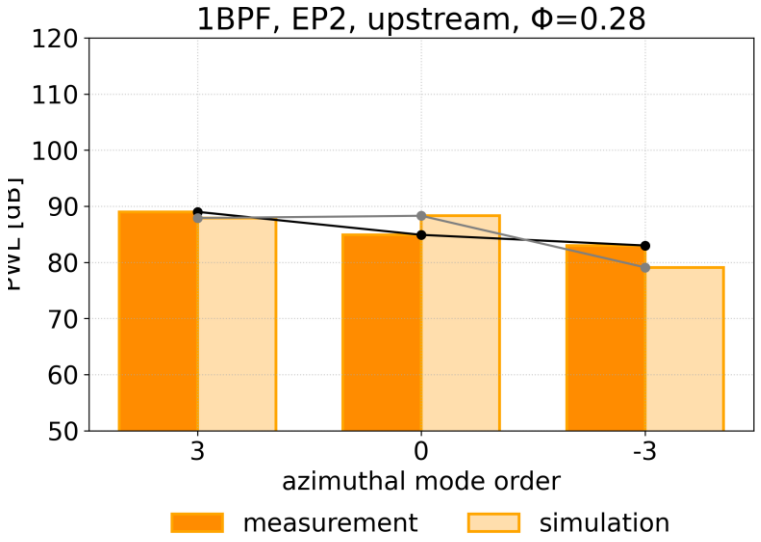
Results -measurements & simulation, $\phi = 0.28$

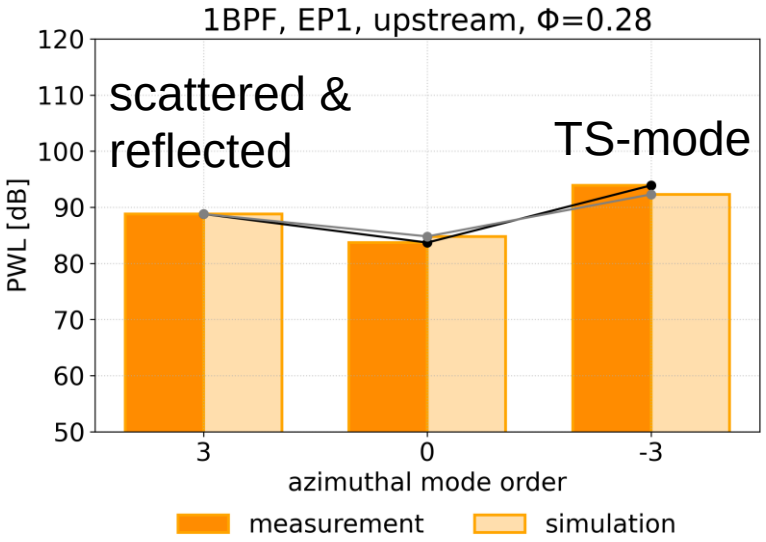












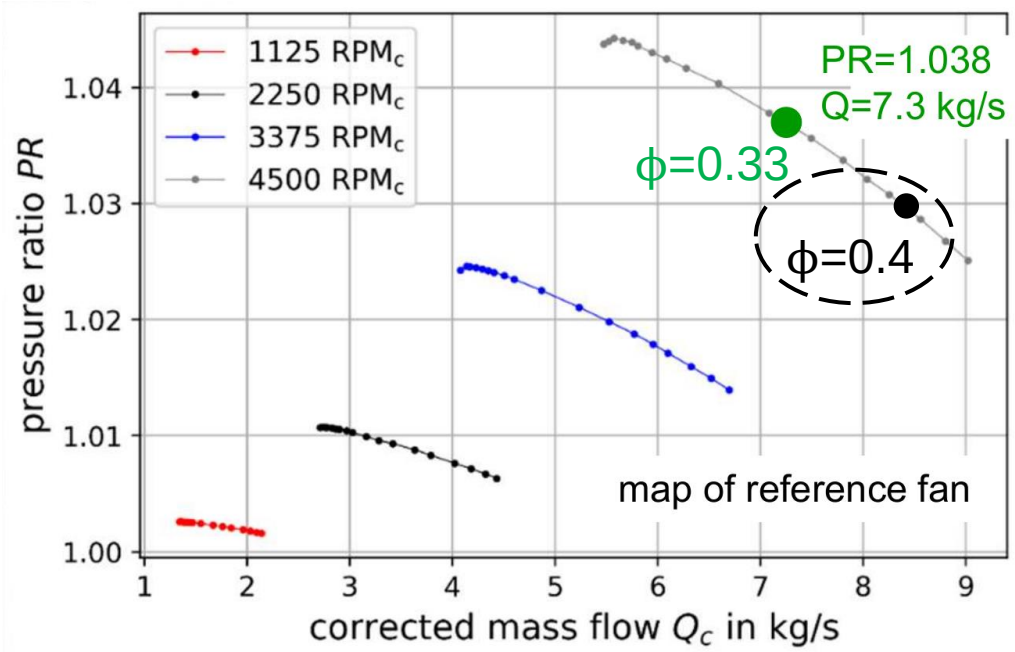
→ TS-mode m=-3 is dominant

→ $\Delta_{PWL,meas}$ = -5.1 dB

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

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

Results – Operating Points



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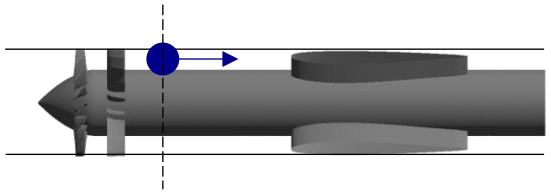
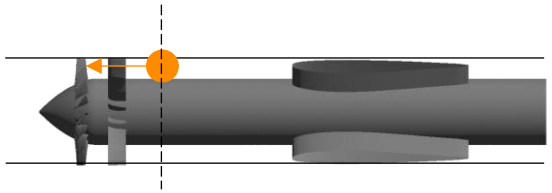
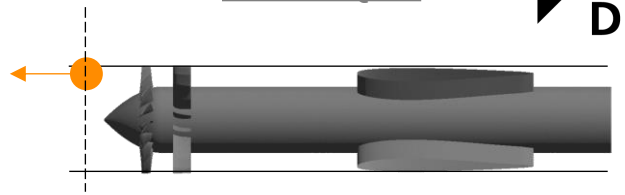
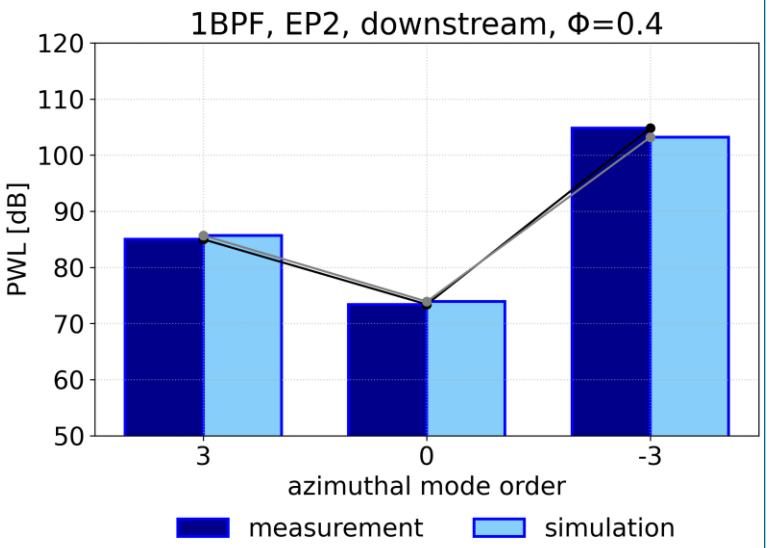
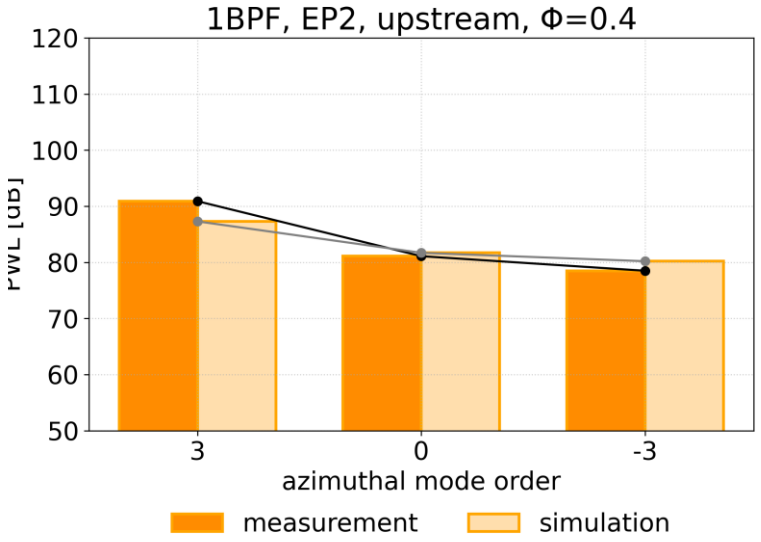
Results -measurements & simulation, $\phi = 0.4$

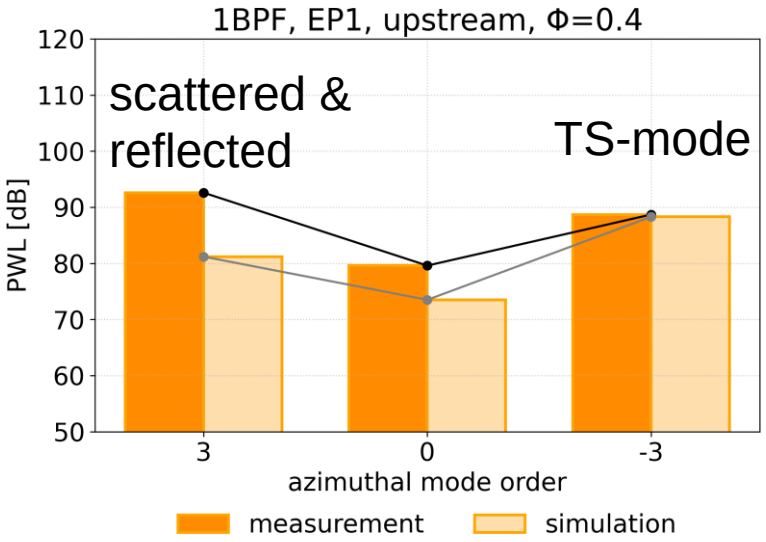












→ exp.: scattered & reflected
mode m=+3 is dominant

→ $\Delta_{PWL,meas}$ = +3.9 dB
$\Delta_{PWL,sim}$ = -7.2 dB

→ Different prediction with CFD

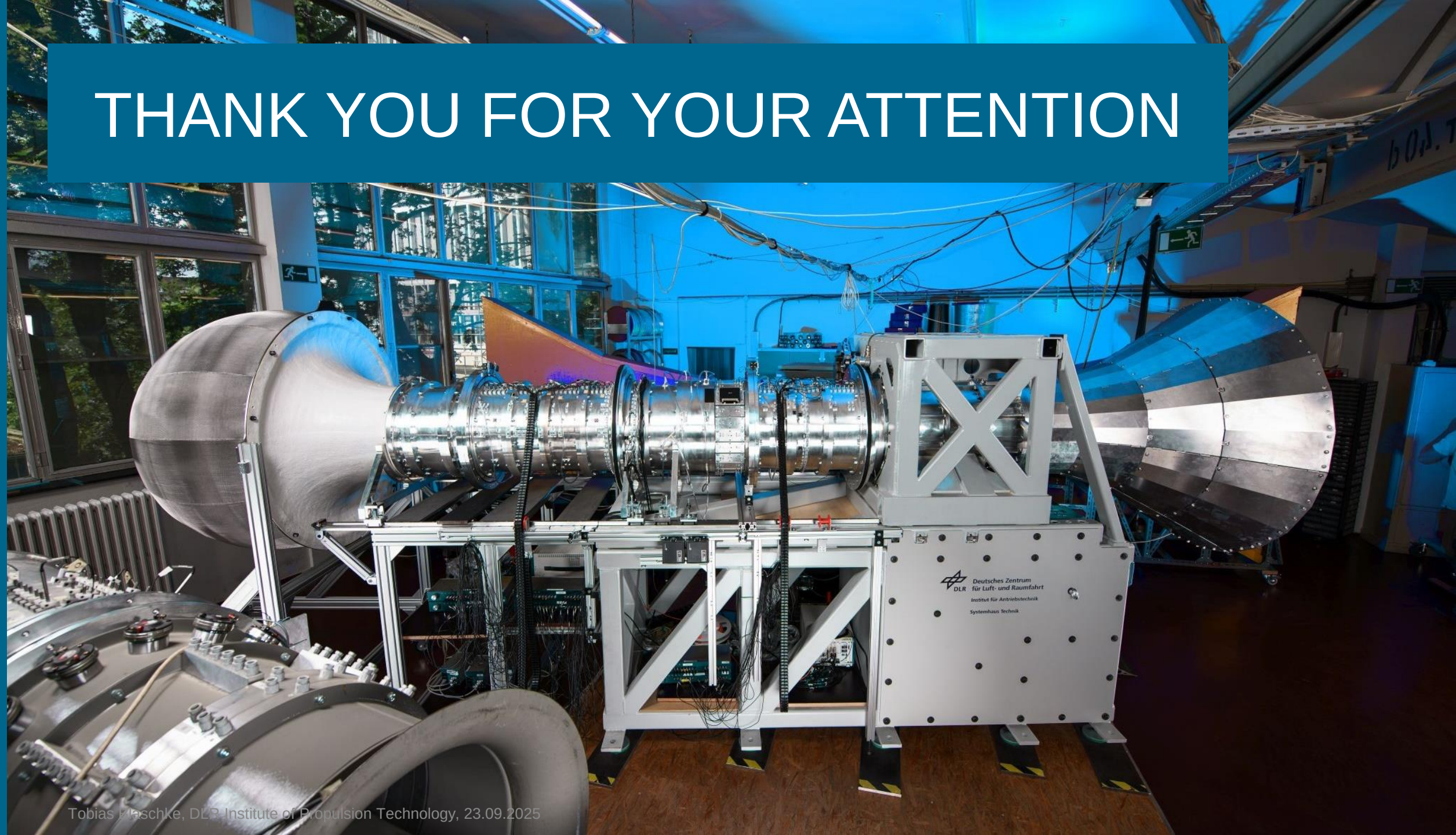
Summary

→ 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 possible
- ↳ strongest acoustic mode reflection effects at the pylons at the DP
- ↳ understanding of physics of acoustic mode propagation effects - scattering, reflection and transmission

THANK YOU FOR YOUR ATTENTION



Imprint

Topic:	Numerical Assessment of acoustic mode reflections in a low-speed fan test rig
Date:	September 23, 2025
Event:	DLRK – Deutscher Luft- und Raumfahrt Kongress
Location:	Augsburg
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