CEAS-ASC Workshop 12.-13.10.2023, Budapest
"Aeroacoustics of Electrically Driven Air Vehicles: Towards a Green and Quiet Aviation"

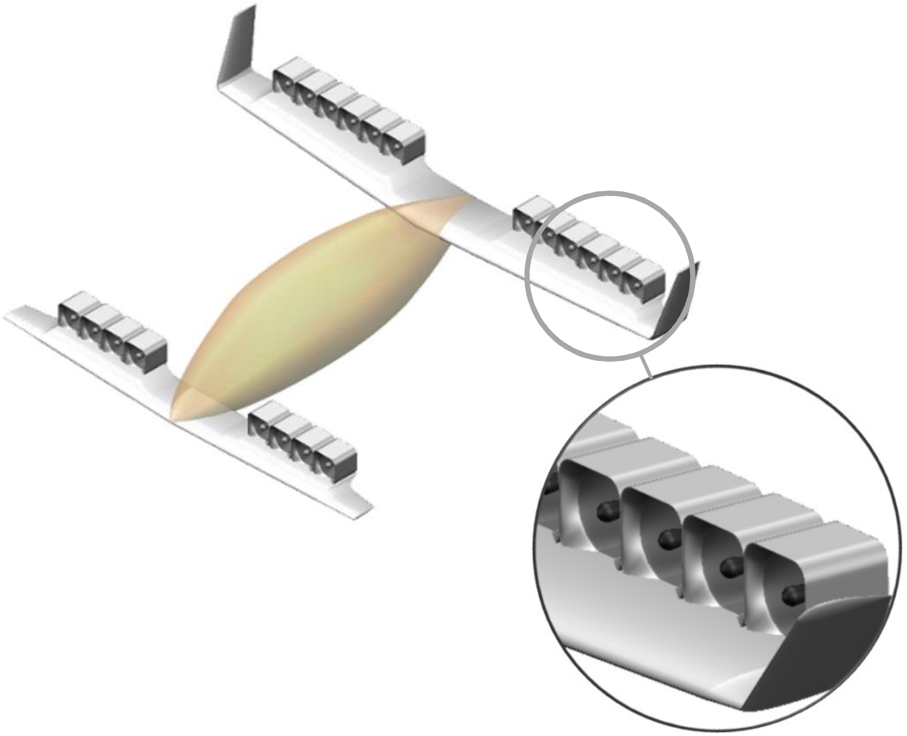
CRAFT TEST RIG FOR ASSESSING THE AEROACOUSTIC IMPACT OF FANS OF ELECTRICALLY POWERED URBAN/REGIONAL AIRCRAFT

Ulf Tapken, Stephen Schade, Lukas Klähn, Luciano Caldas, Angelo Rudolphi, Maximilian Behn, Robert Meyer

Institute of Propulsion Technology, Engine Acoustics Department, Berlin

DLR

Noise emission from fans is a crucial point in the acceptance of UAM & RAM vehicles



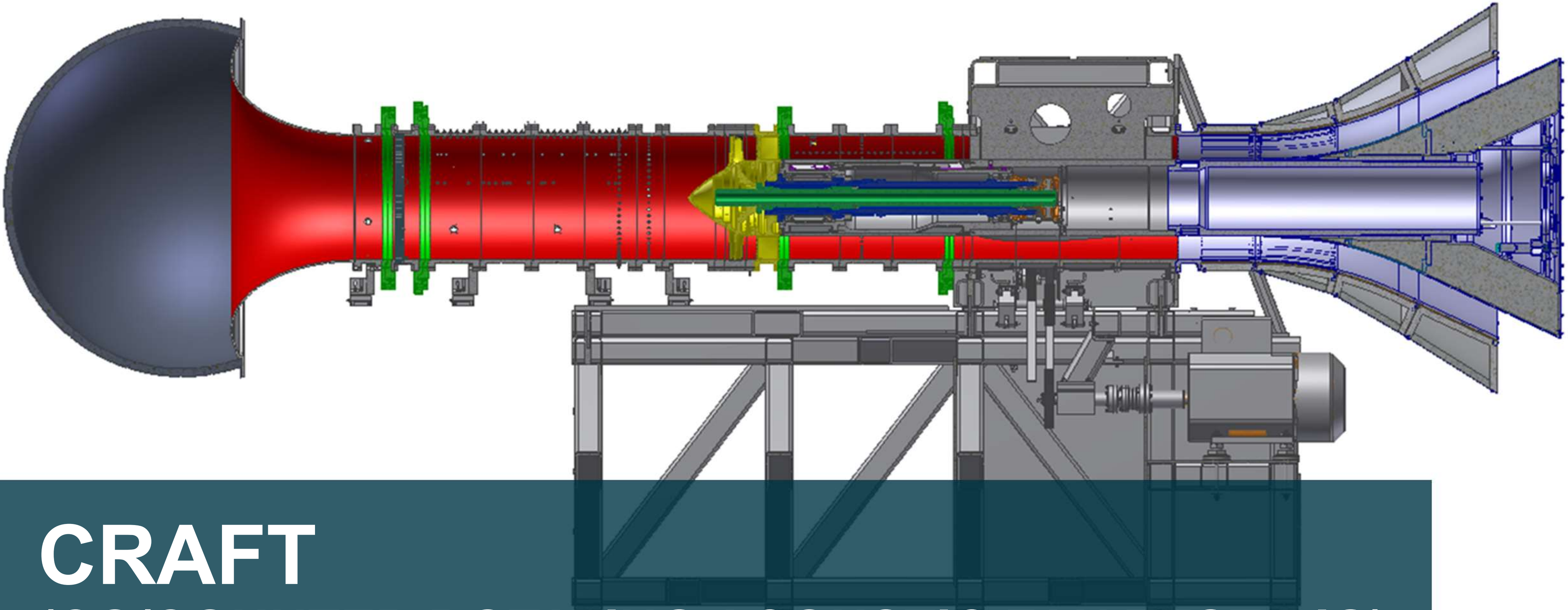
Sketch of vehicle configuration
with simplified fan housings contour
(credits: P. Ratei, SL-AES)

DLR project VIRLWINT (2023-2026)

objective: evaluation of noise perception

Experimental assessment of fan noise

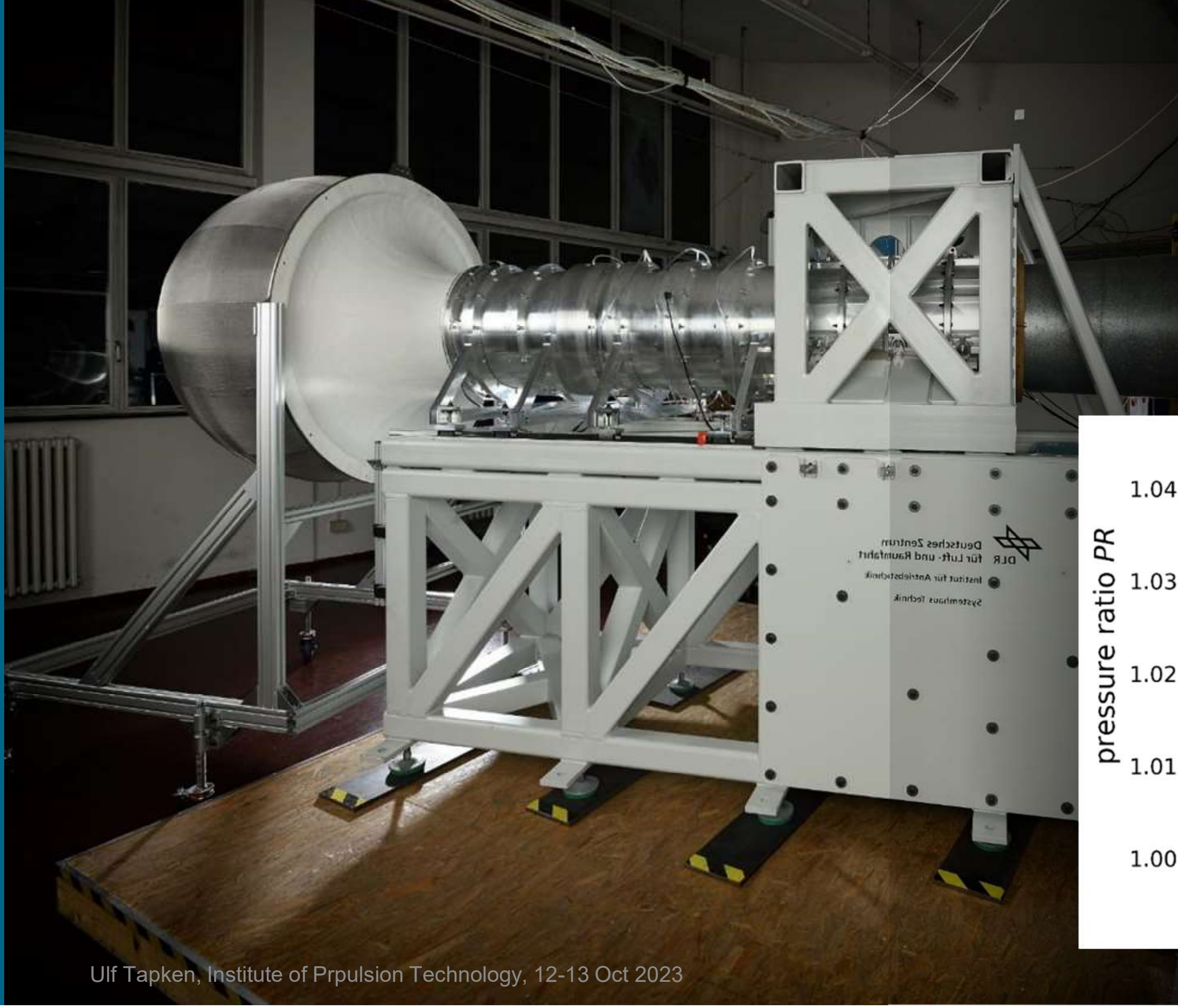
- fan test bench
- fans with different acoustic signatures
- impact of inflow distortions due to propulsor installation



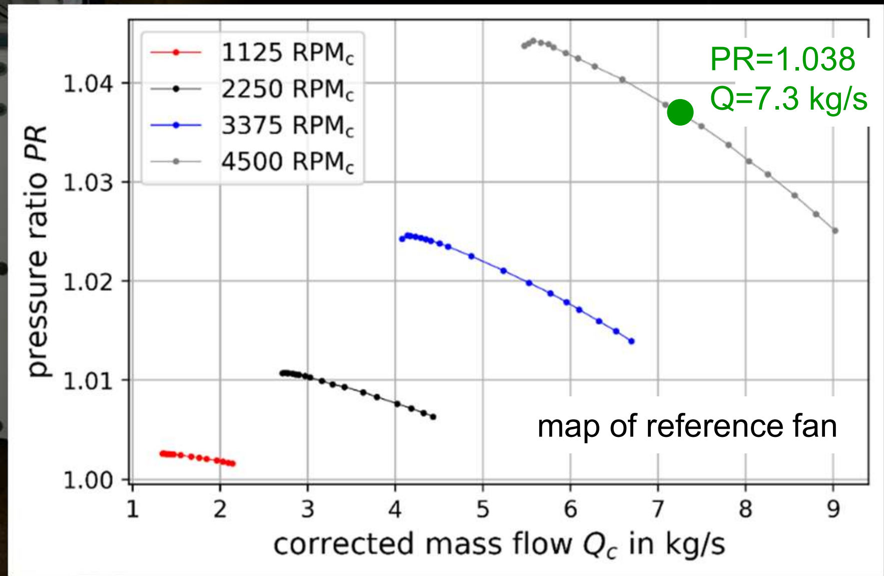
CRAFT
(CO/COUNTER ROTATING ACOUSTIC FAN TEST RIG)

Test conditions representative for ducted fans of UAM / RAM

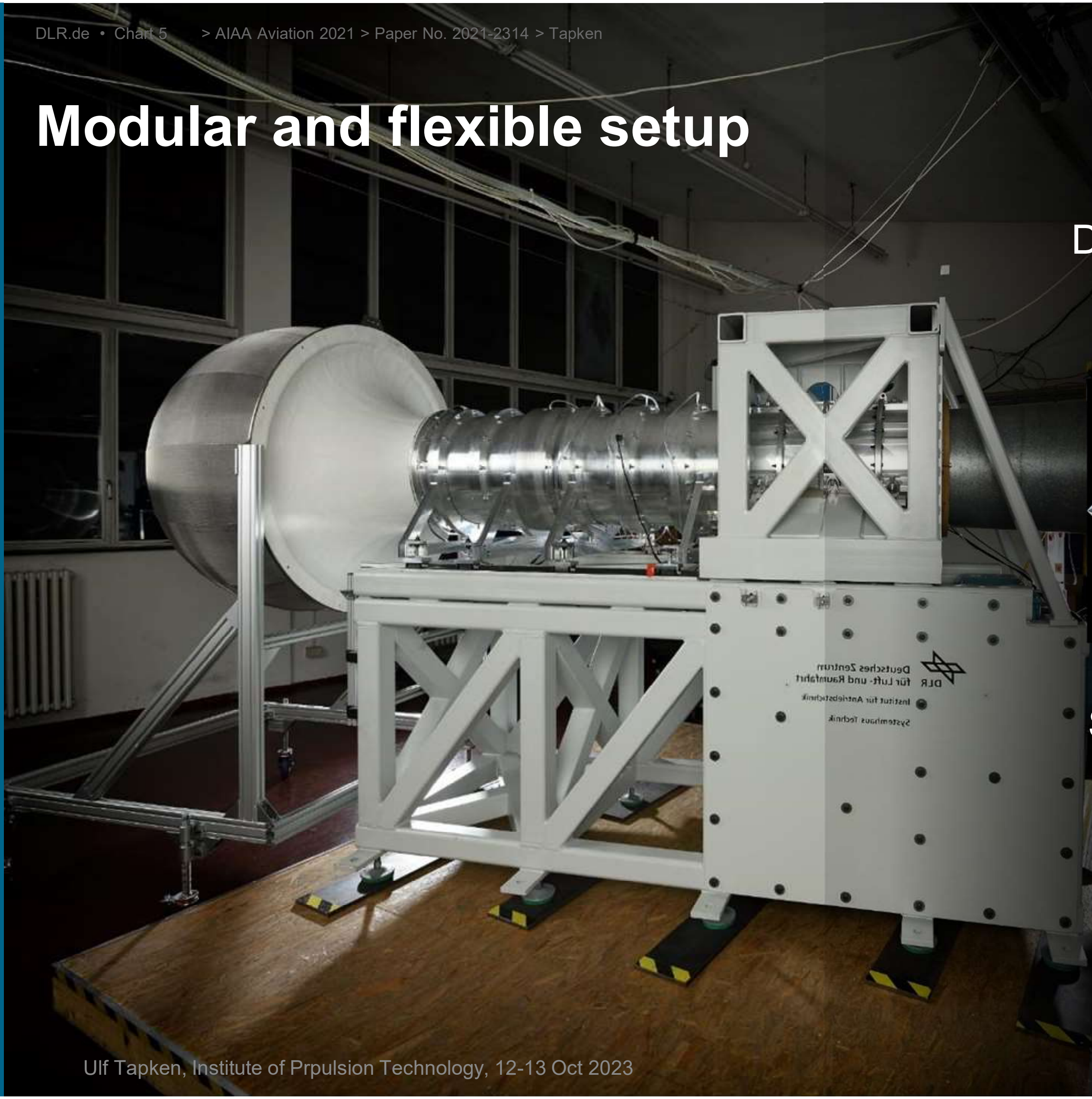
DLR



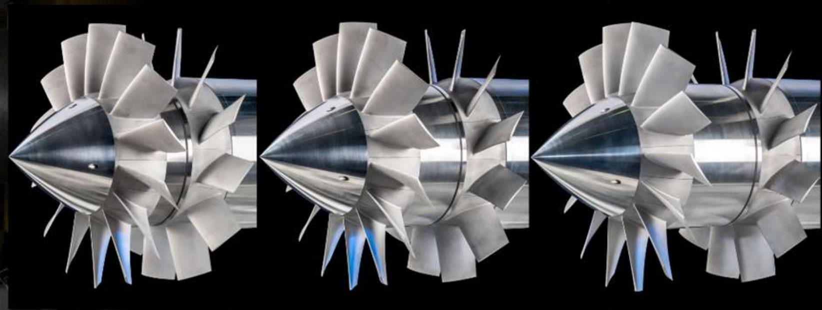
- fan diameter 453 mm
- shaft power 25 kW / 25 kW
- fan speed 1000 … 4500 rpm
- max. blade tip Mach number 0.31
- tip clearance 0.6 mm



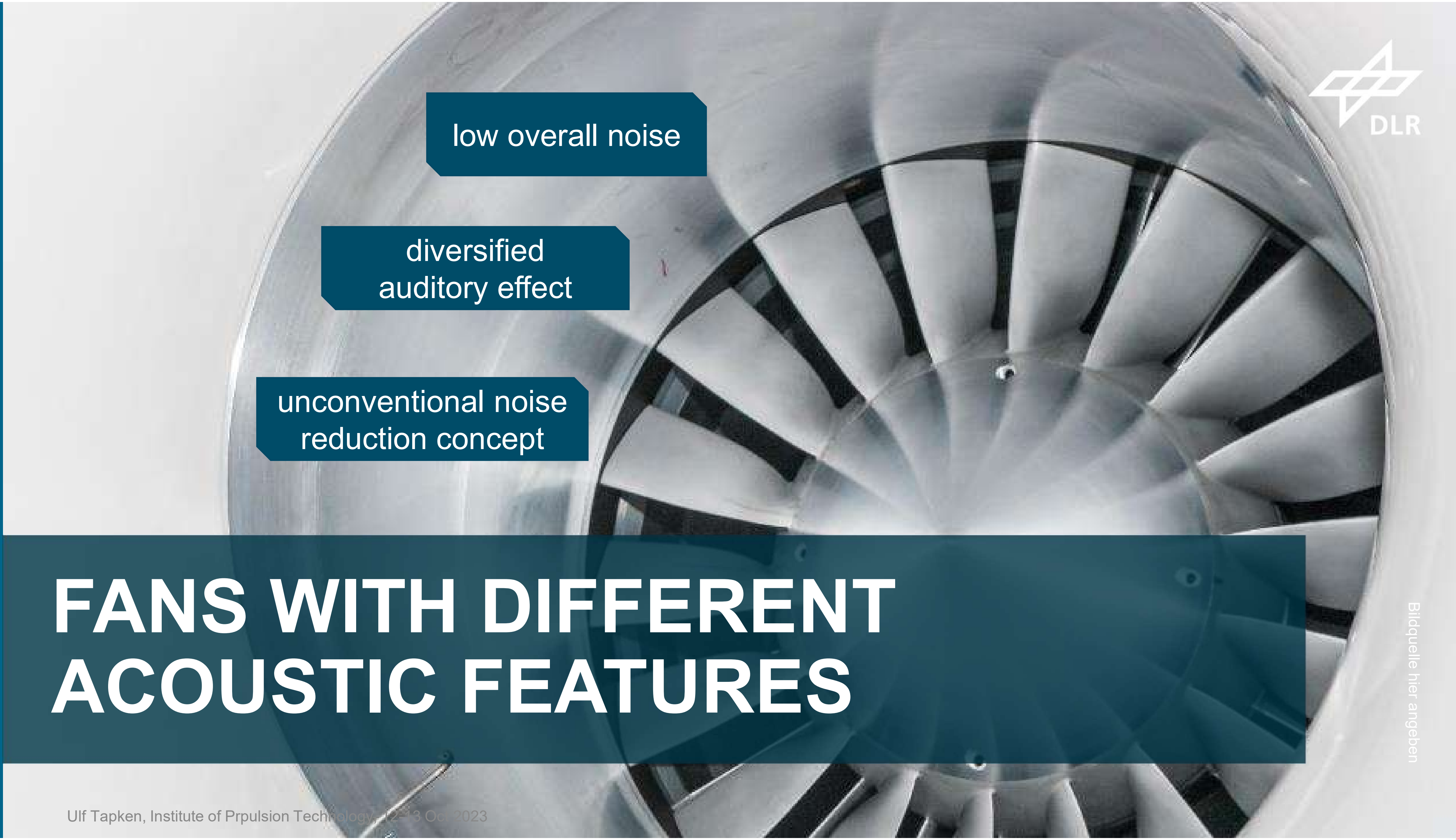
Modular and flexible setup



Discrimination of source mechanisms by
- distance variation
- isolated rotor operation



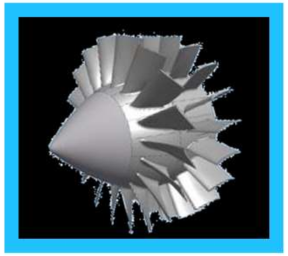
Stator casing with exchangeable vanes


low overall noise
diversified auditory effect
unconventional noise reduction concept
FANS WITH DIFFERENT ACOUSTIC FEATURES
DLR
Bildquelle hier angeben

Derivation of low noise designs

Reference fan

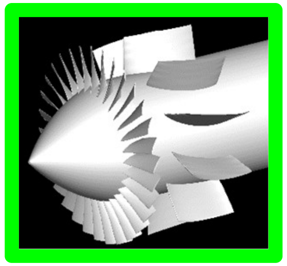
18 rotor blades
21 stator vanes



Low noise fan 1

31 rotor blades
10 stator vanes

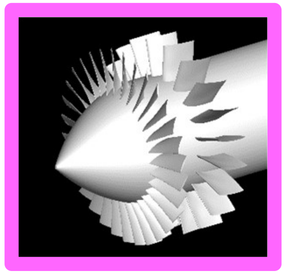
BPF weak



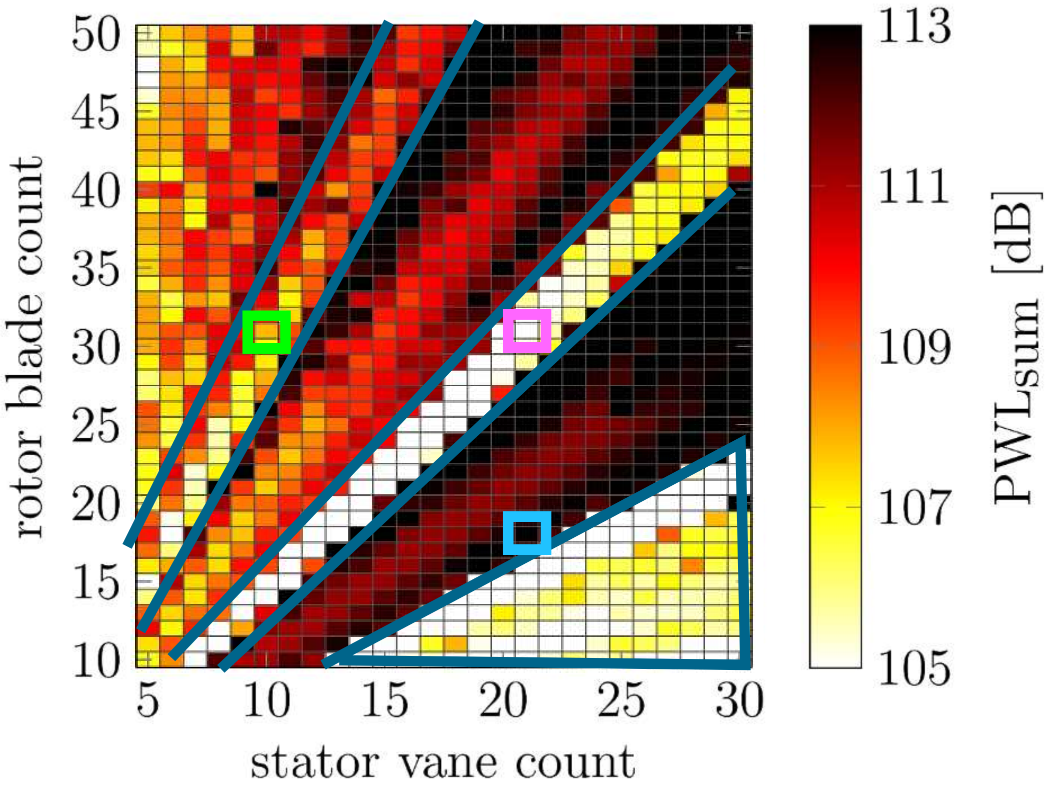
Low noise fan 2

31 rotor blades
21 stator vanes

BPF cut-off

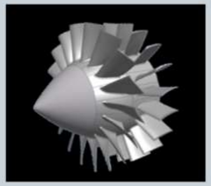
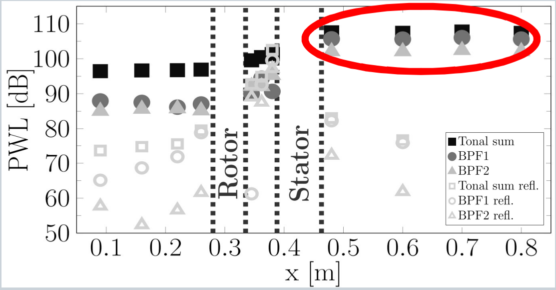
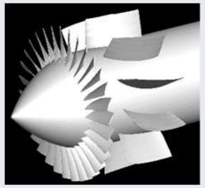
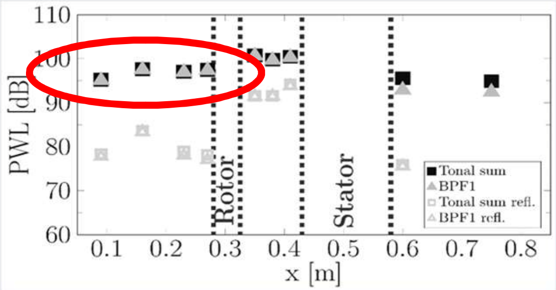
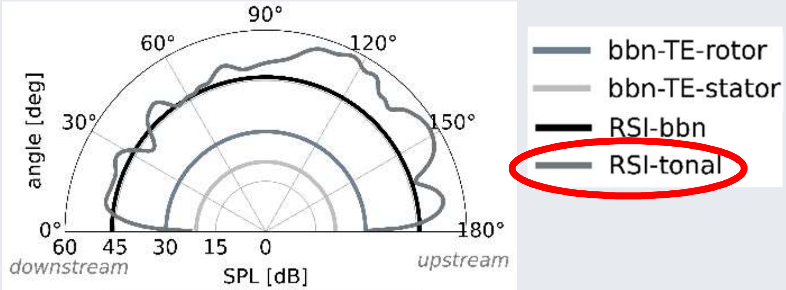
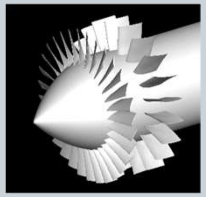
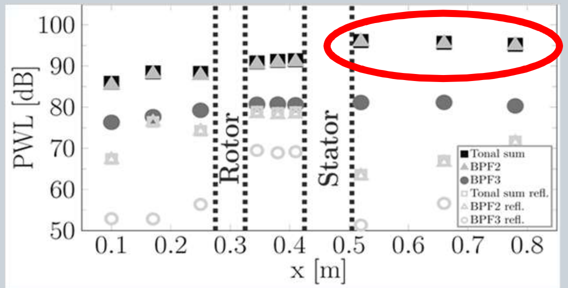
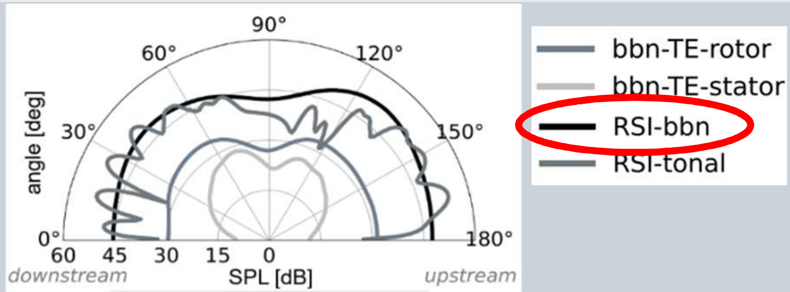


Sound power level cumulated for 3 OP
over RSI tonal, RSI BBN

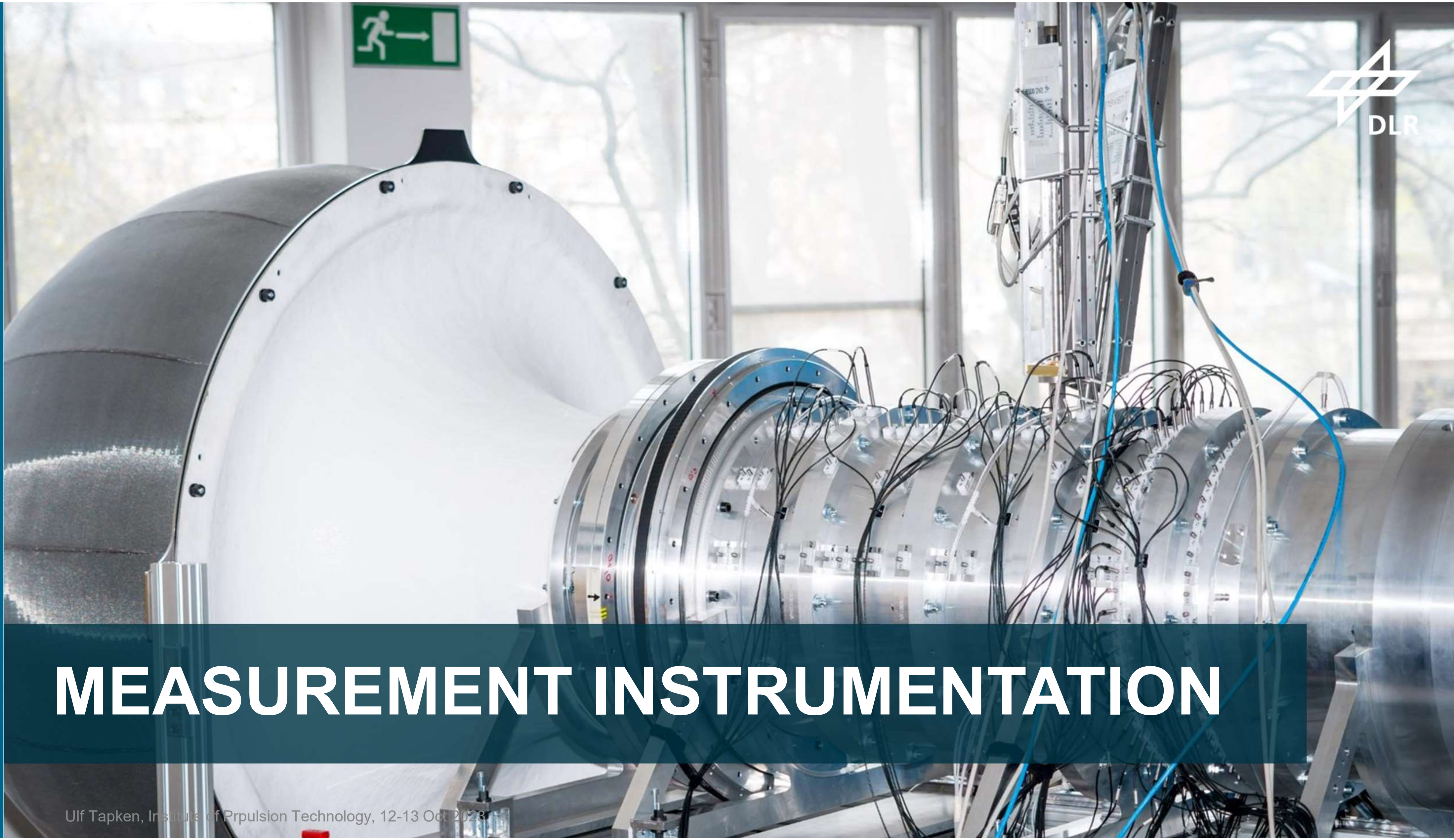


S. Schade et al: Smart blade count selection to align modal propagation angle with stator stagger angle for low-noise fan stage designs, DLRK 2023

Characteristics with regard to noise perception

Fan	lowest blade tone	tonal dominance upstream vs downstream	relation tonal to broadband noise radiation
Reference B=18 V=21 	BPF 1.35 kHz		
Low Noise 1 B=31 V=10 	BPF 2.325 kHz		
Low Noise 2 B=31 V=21 	2 BPF 4.65 kHz		

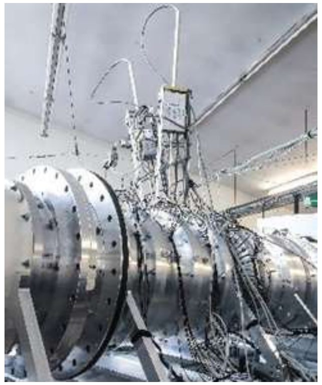
S. Schade et al: Smart blade count selection to align modal propagation angle with stator stagger angle for low-noise fan stage designs, DLRK 2023



MEASUREMENT INSTRUMENTATION

Aerodynamic instrumentation

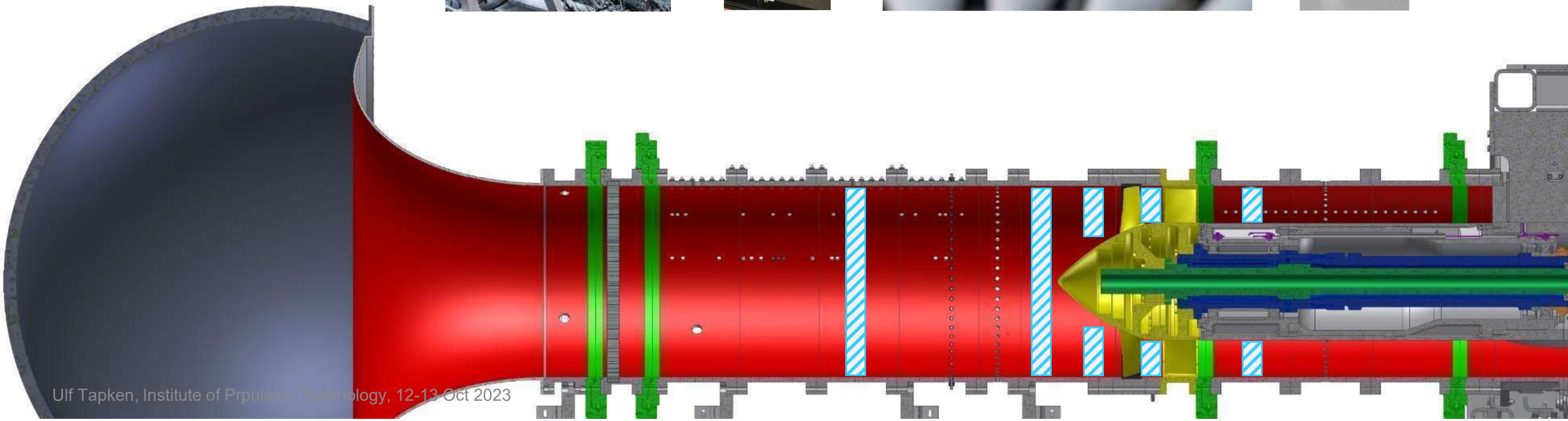
radial and azimuthal traverse



total pressure rakes

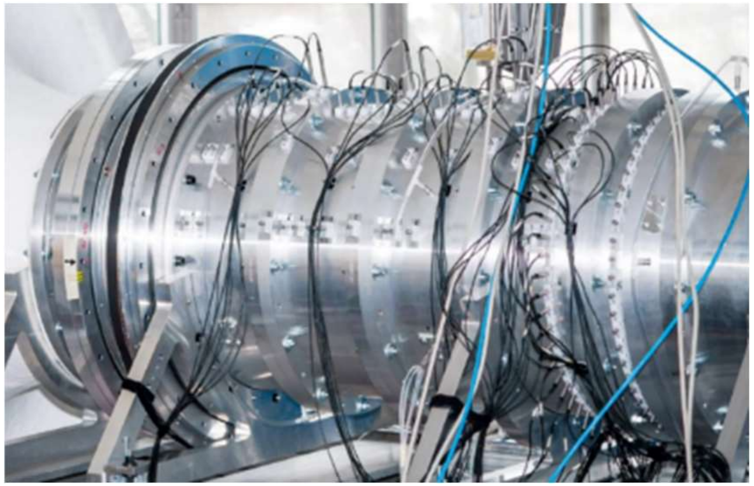
hotwire x-probes

5-hole probe

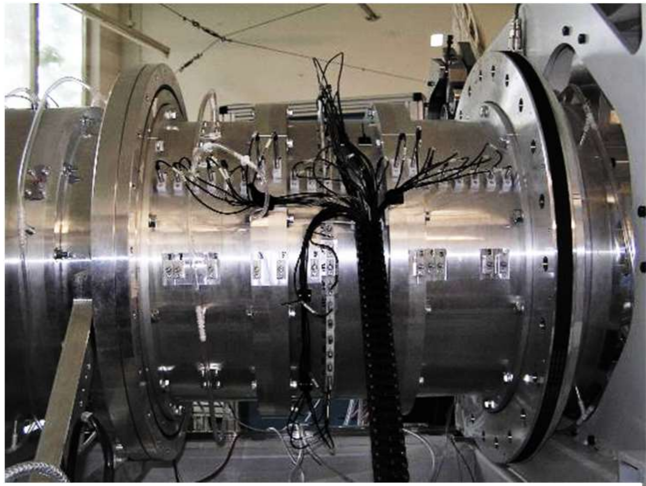


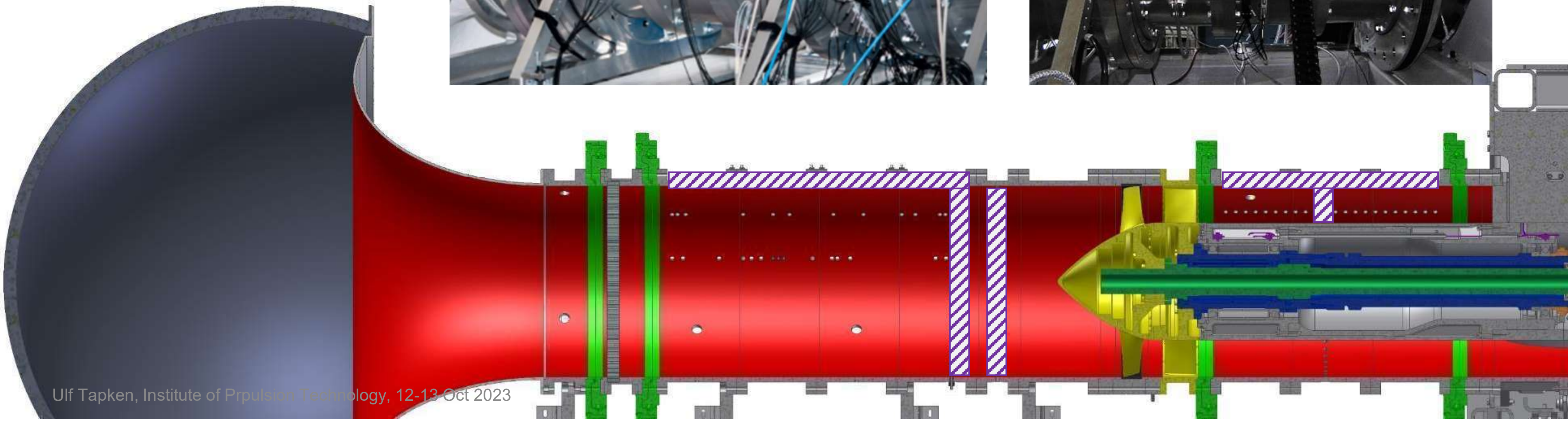
Acoustic instrumentation

upstream mode detection arrays

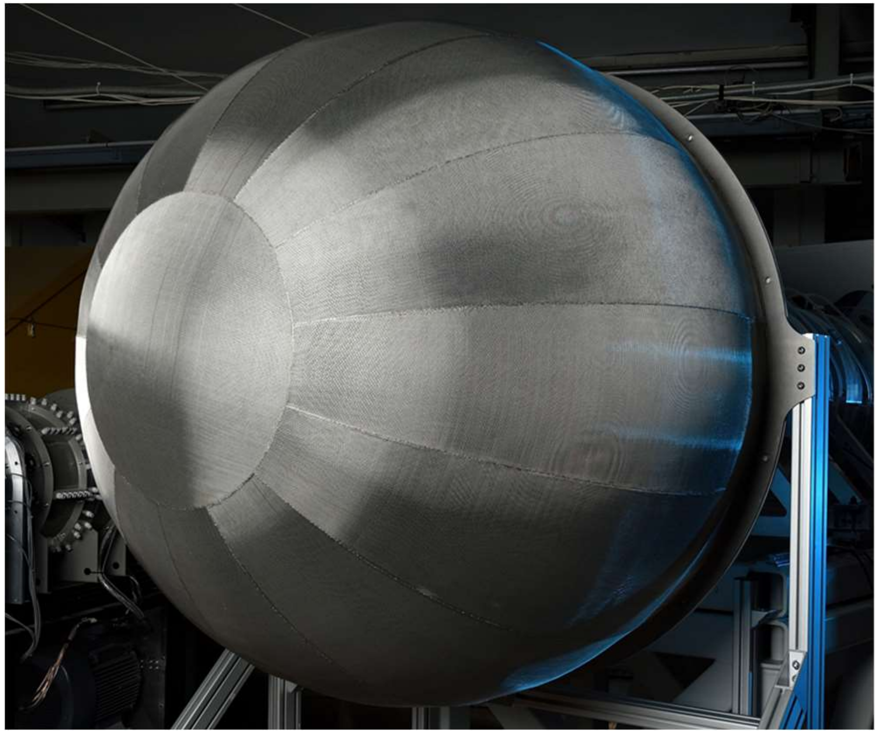


downstream mode detection arrays

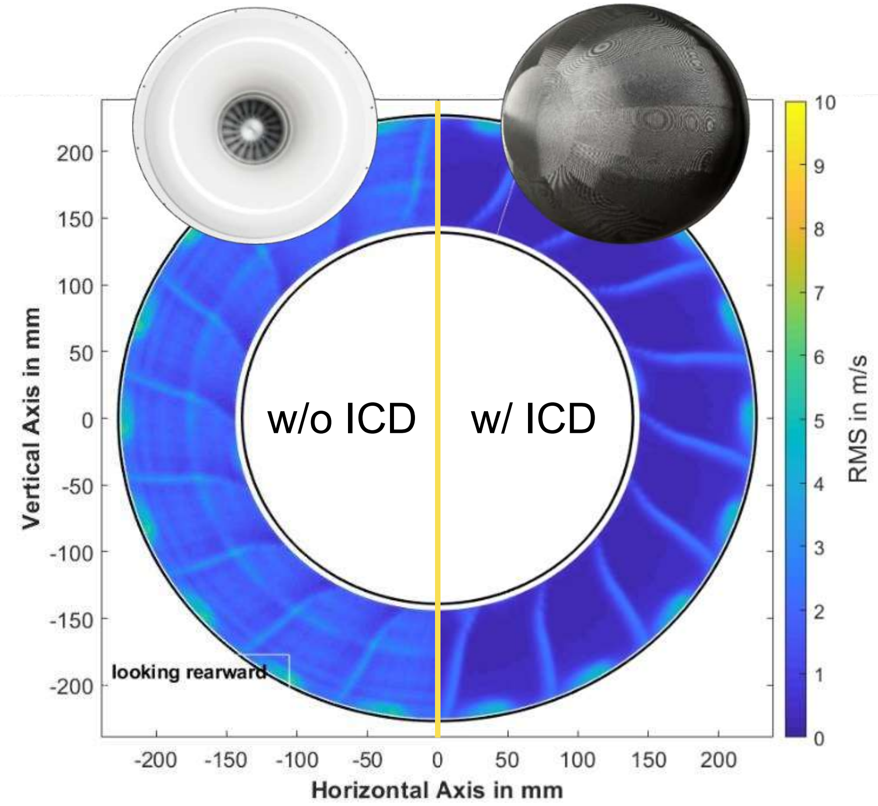


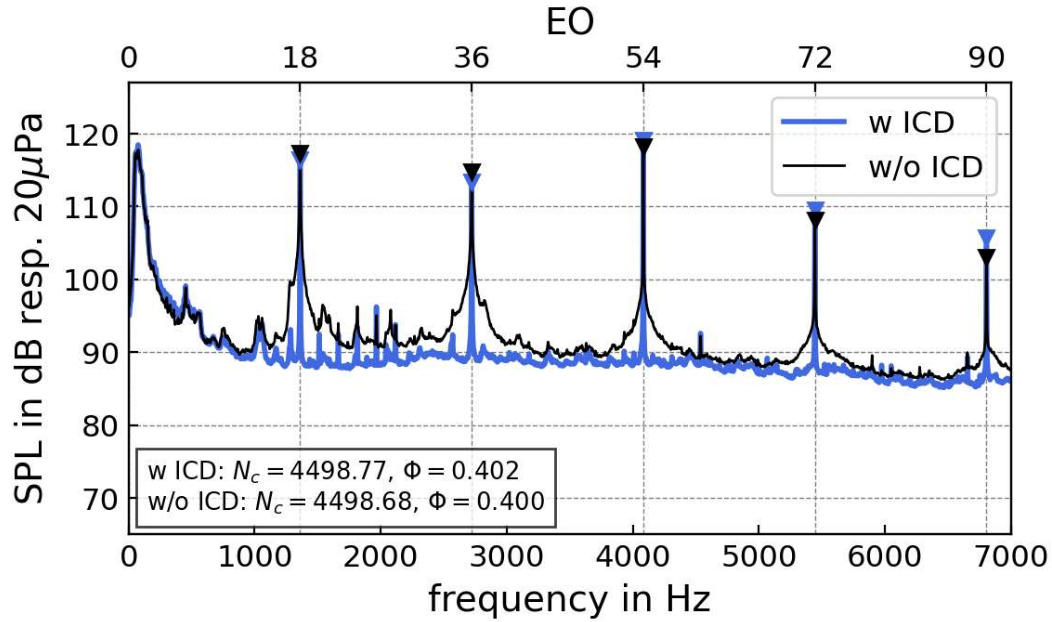


Inflow control device (ICD) establishing clean base inflow

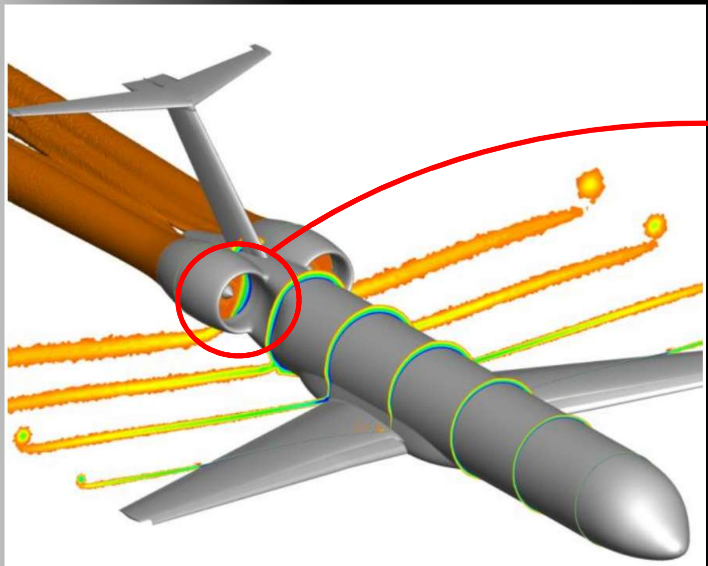


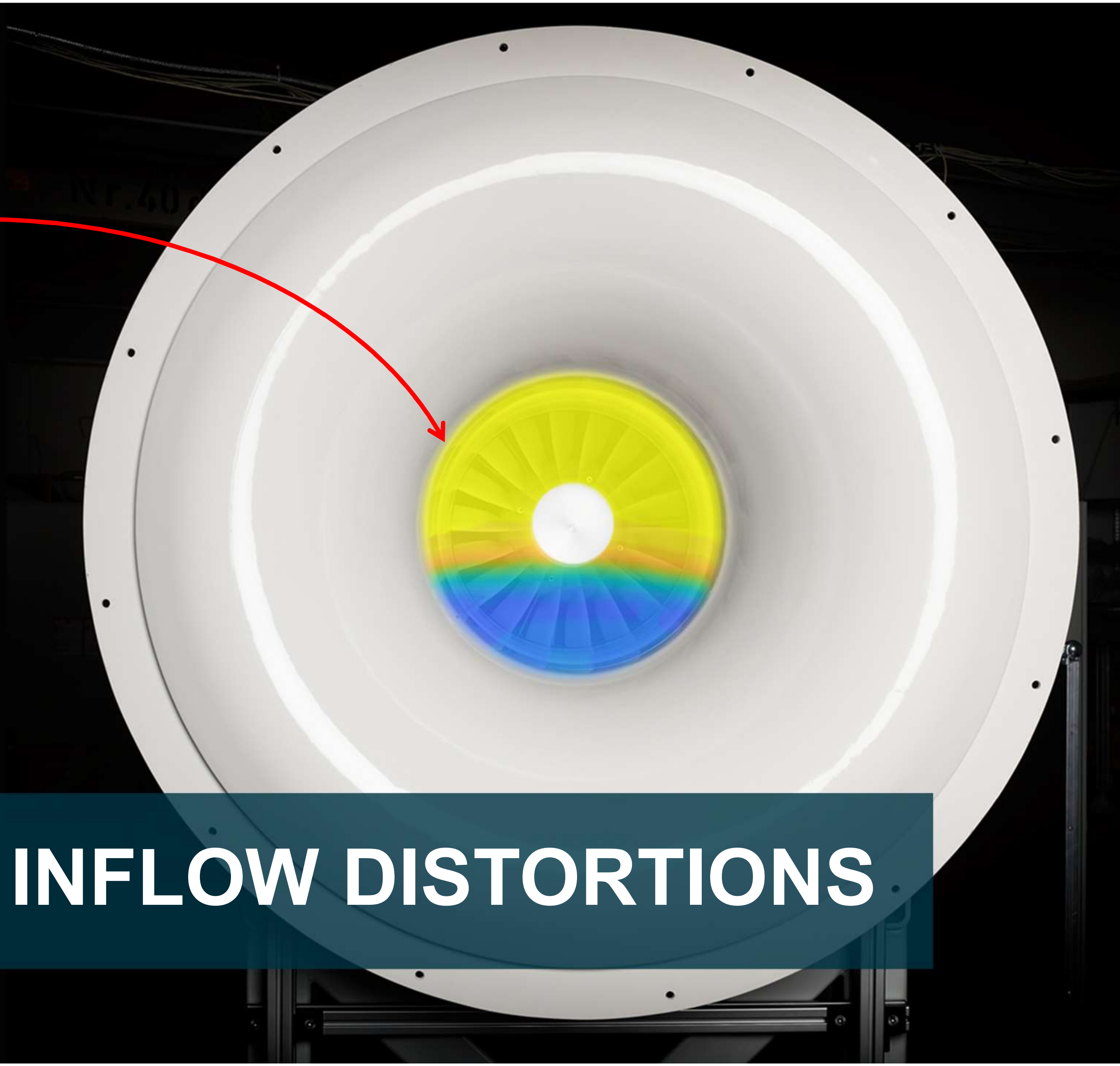
ICD impact on flow field and fan noise generation





- reduction of non-representative noise components
- stabilization of rotor-coherent source mechanisms

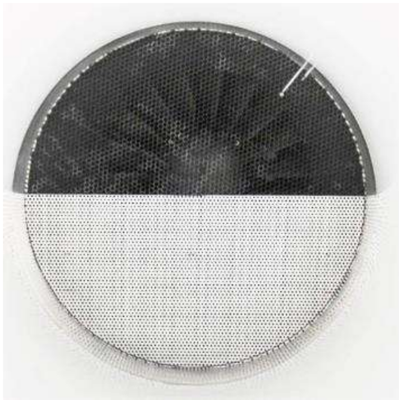


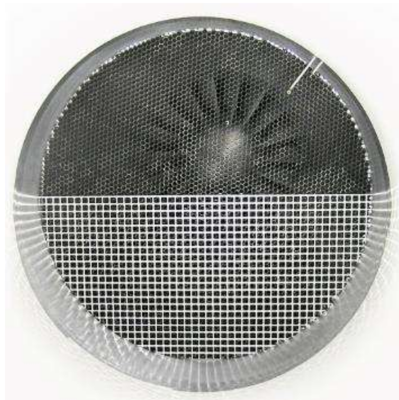


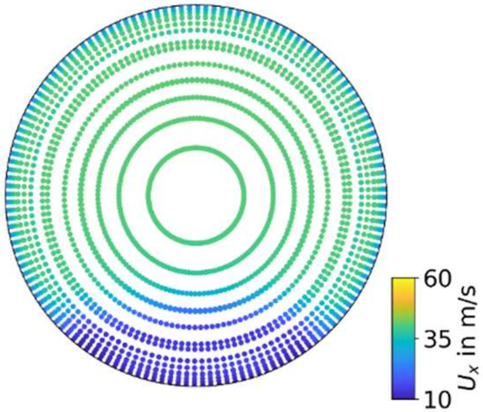
GENERATION OF INFLOW DISTORTIONS

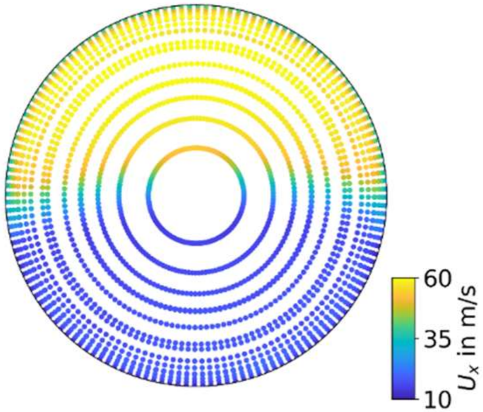
First tests with perforated distortion fences

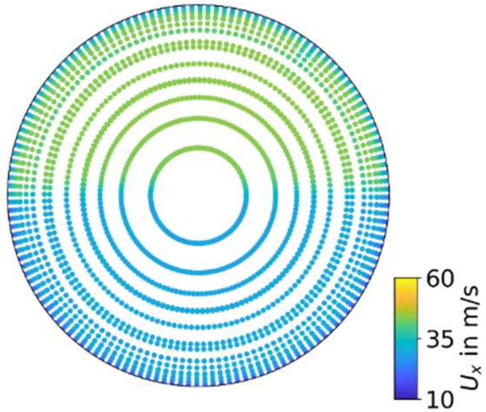
fence height 20% opening ratio 33%	→	fence height 50% opening ratio 33%	→	fence height 50% opening ratio 64%



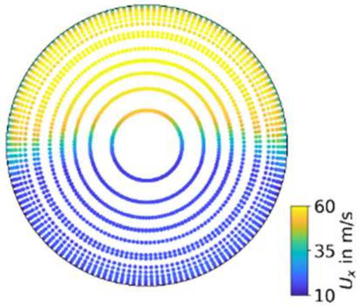




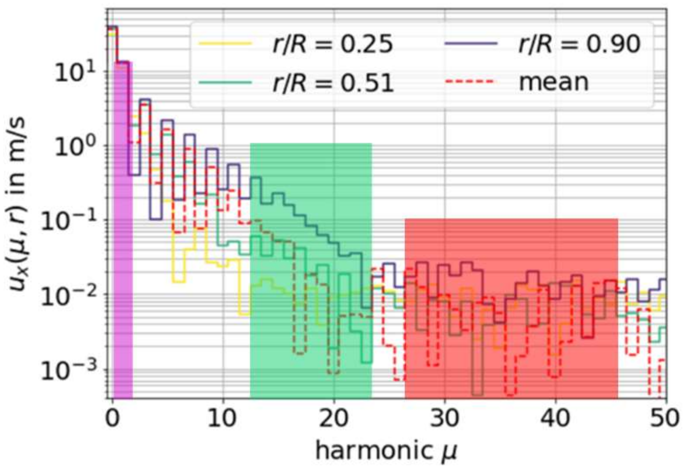




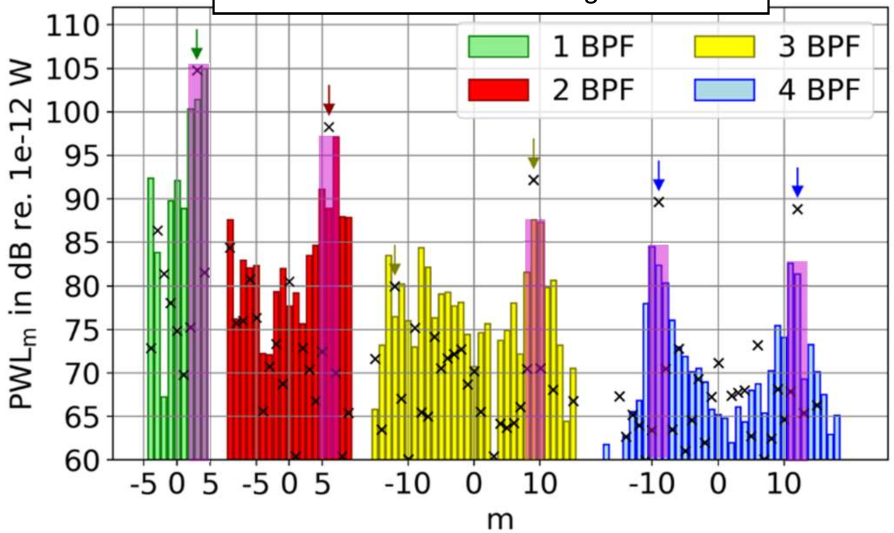
Impact of disturbed mean flow profile on fan tones



circumferential harmonics of the flow disturbance @ ADP



Outlet, downstream propagation @ ADP
x denote baseline configuration



- rotor/stator interaction is modified

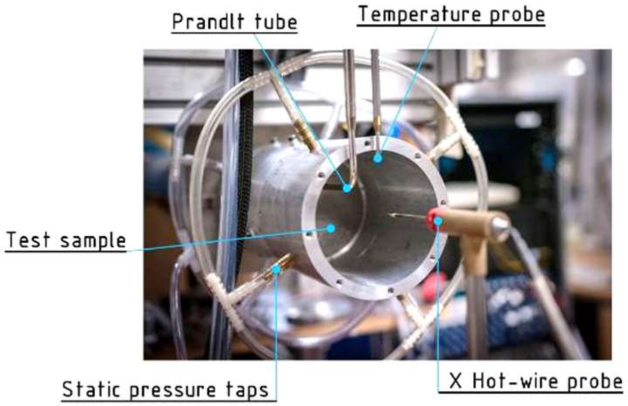
$$m_{RSI,\mu} = (-)hB + kV \pm \mu$$

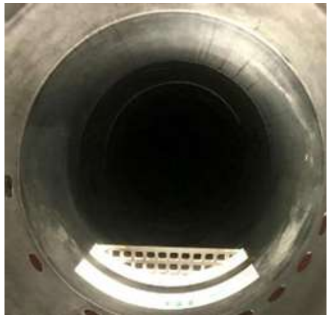
- disturbed-inflow/rotor interaction results in

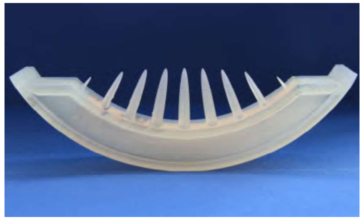
$$m_{BLI} = (-)hB \pm \mu$$

Development of devices for BLI representative mean inflows

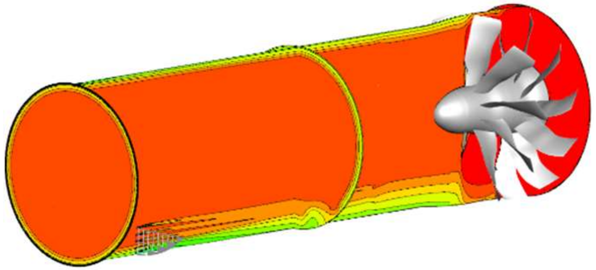
Experimental study of different concepts

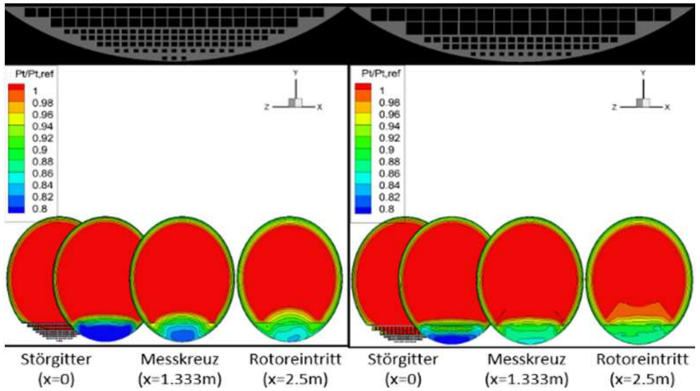


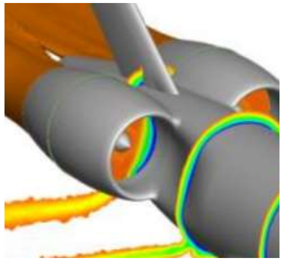




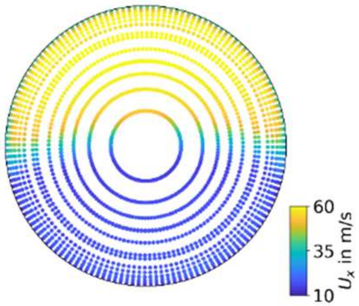
CFD optimization



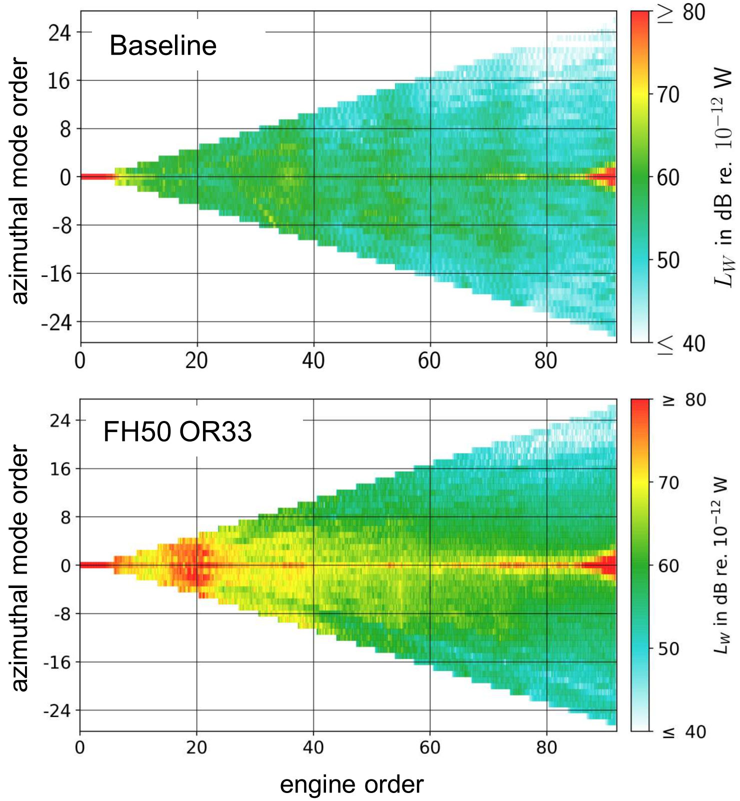




Impact of increased turbulent inflow on fan broadband noise

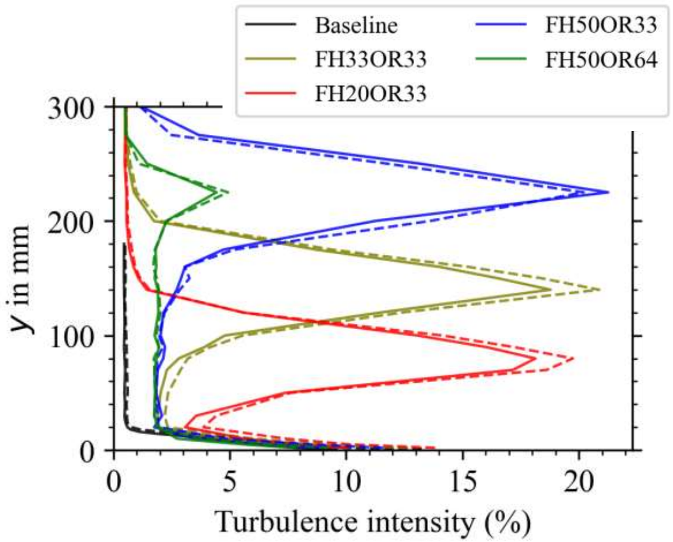


sound power of upstream modes in inlet @ ADP

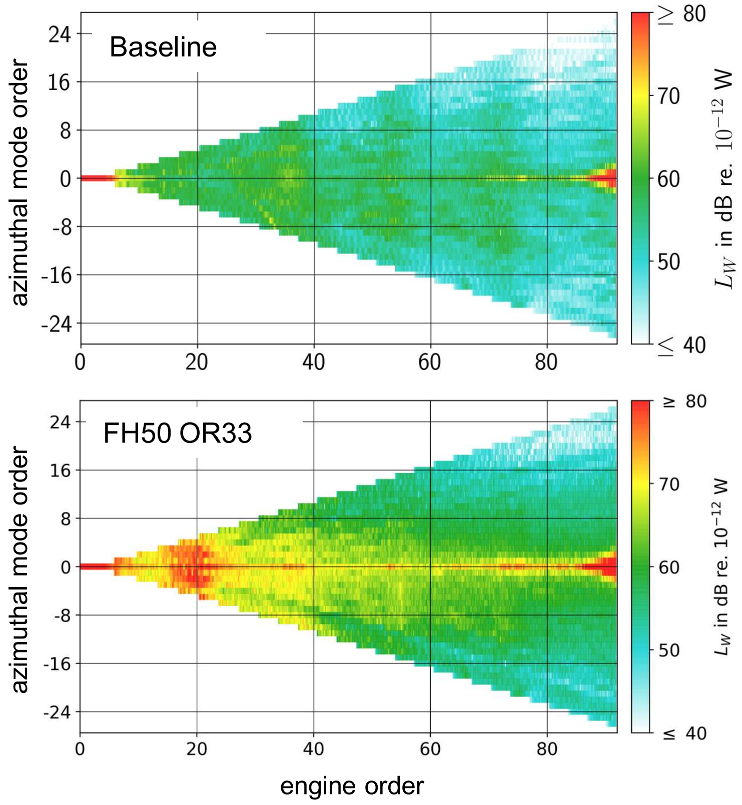


- turbulent-inflow/rotor interaction results in broad sound power increase
- modified rotor/stator interaction plus rotor shielding leads to increase of co-rotating modes

Impact of increased turbulent inflow on fan broadband noise



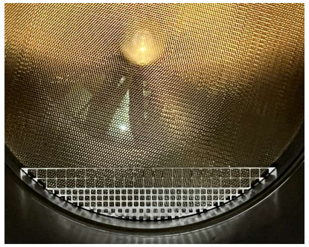
sound power of upstream modes in inlet @ ADP

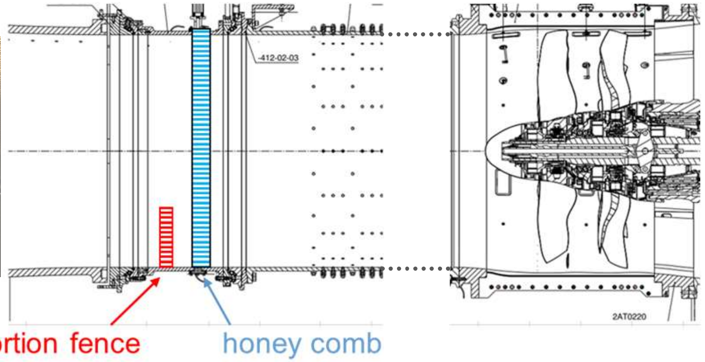


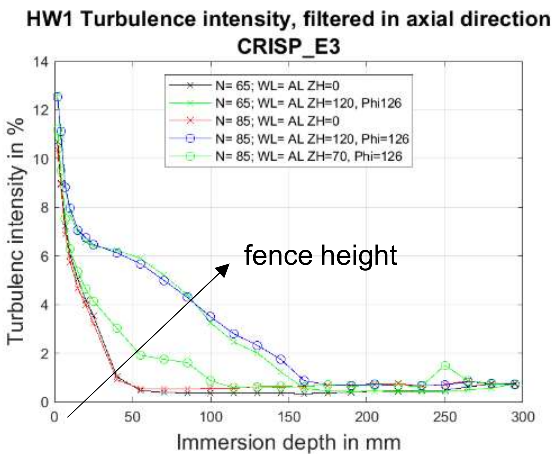
- turbulent-inflow/rotor interaction results in broad sound power increase
- modified rotor/stator interaction plus rotor shielding leads to increase of co-rotating modes

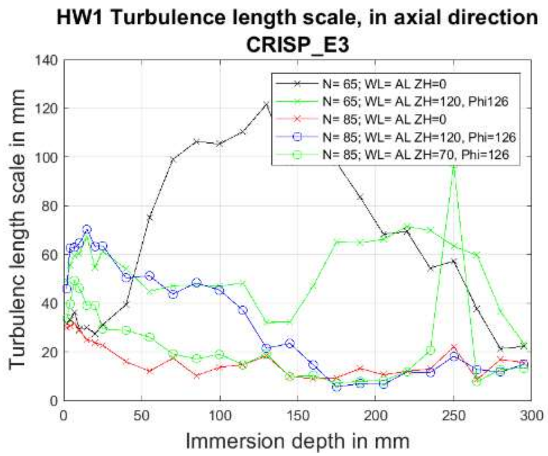
Challenge: Generation of specific turbulence characteristics

Objective: realistic turbulence profile









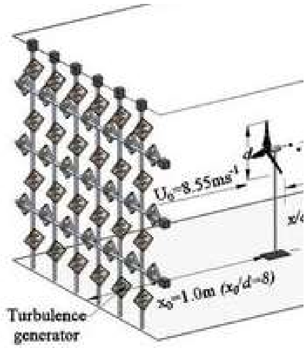
Objective: Controlled generation of turbulence

- absolute length scales
- relation of lenght scales (anisotropy)
- spectral shape

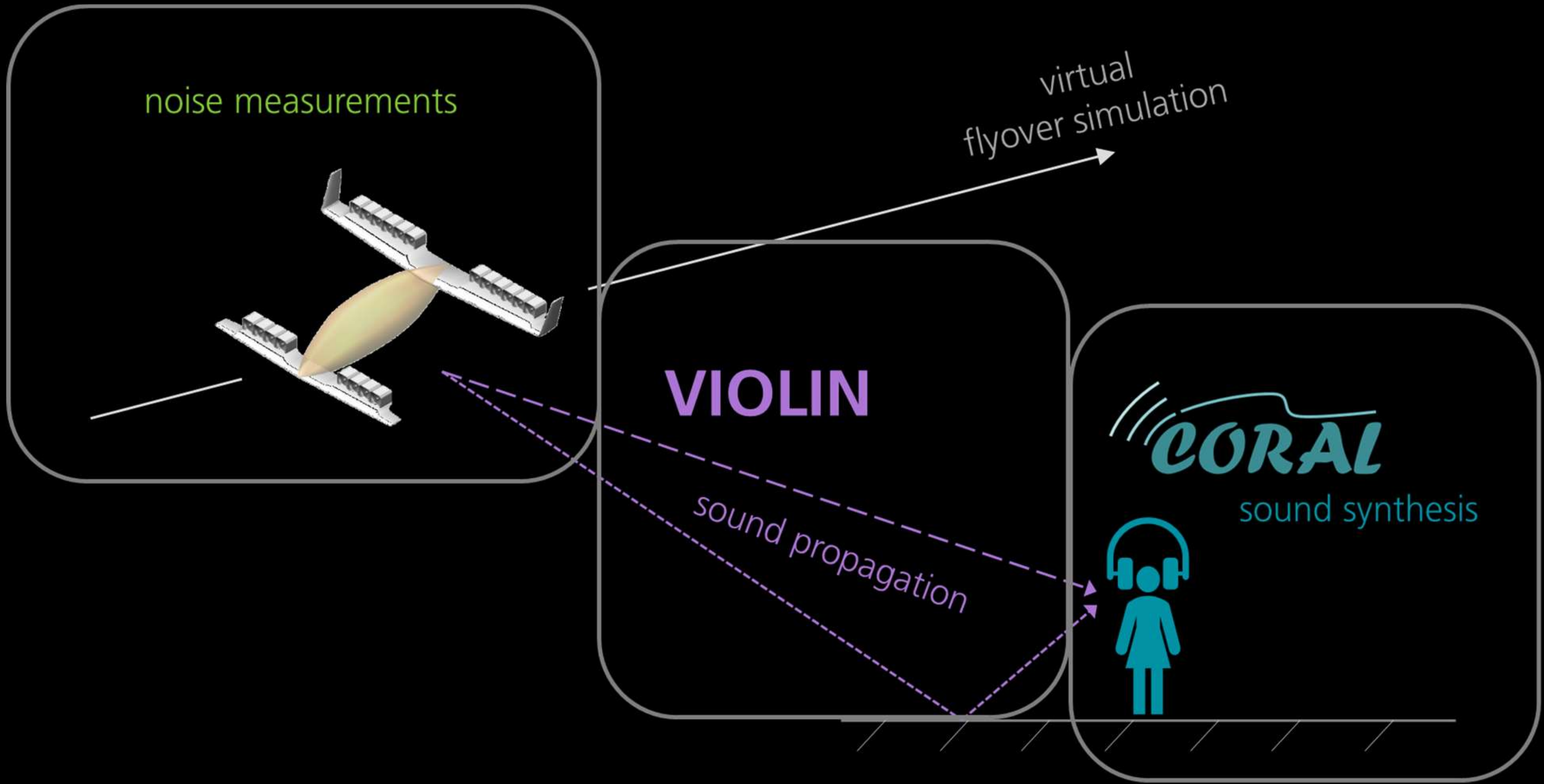
to investigate impact on noise

- spectral coherence
- broadband … narrowband components
- excited noise levels

→ develop and test suitable devices

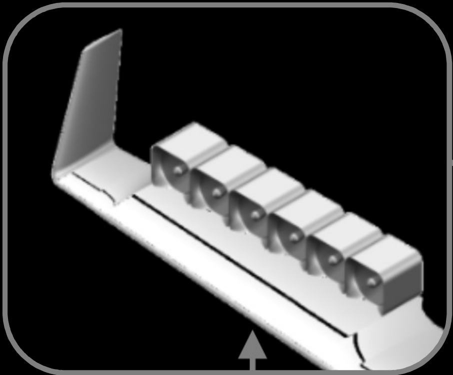


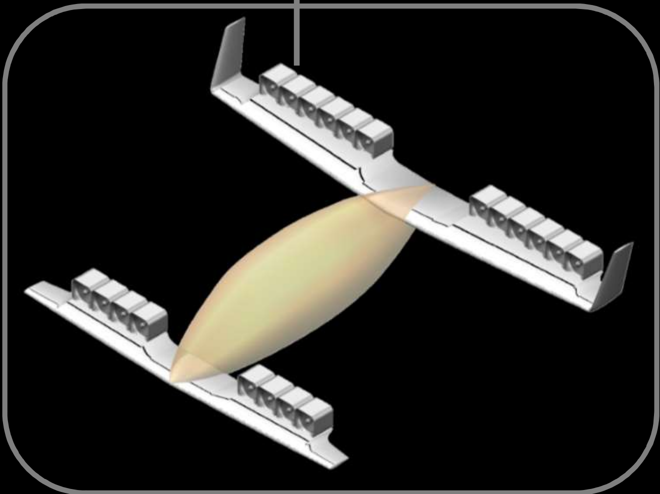
source: Y. Jin, DOI: 0.3390/en9100830



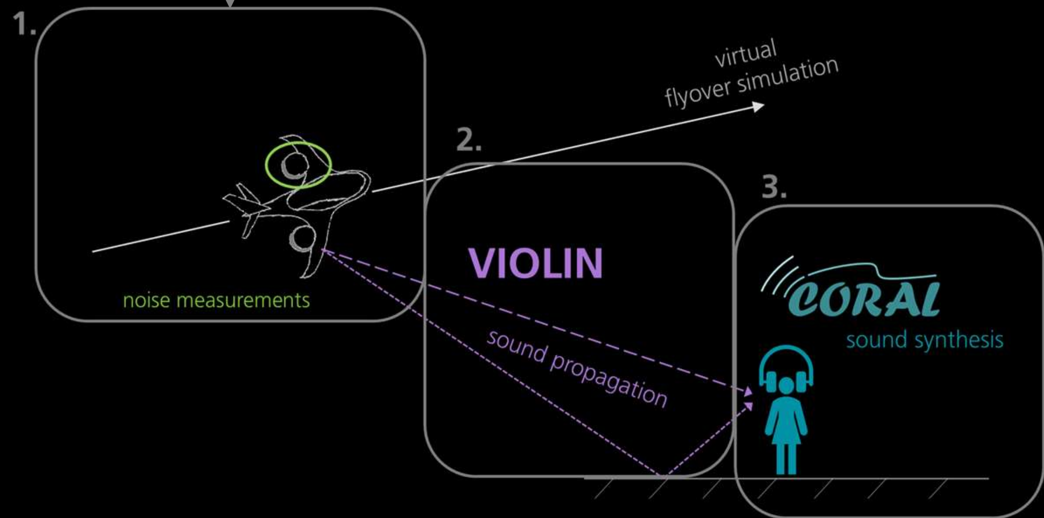
AURALIZATION OF ENGINE NOISE

Simulation of distributed fan configuration as input for auralization





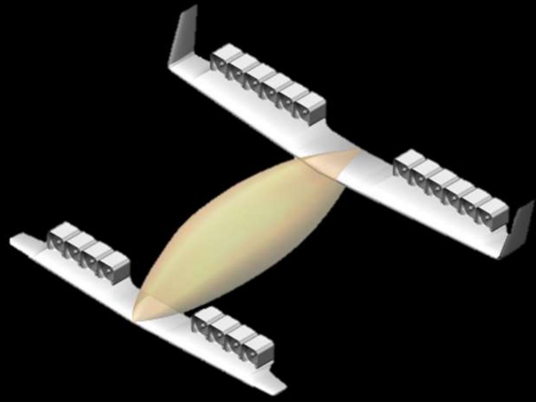
multiple measurements with small individual detunings of test conditions



SUMMARY

Bildquelle hier angeben

Opportunities offered by test bench CRAFT



- Test conditions representative for fans of UAM / RAM
- Fans with different acoustic/auditory signatures
- Measurement of fan aero-acoustics in high resolution and with highlighting specific noise sources by test set-up variations
- Inflow distortion devices to evaluate engine integration effects
  - Challenge: generation of specific turbulence characteristics
- Data for validations and for psychoacoustic assessments
- Investigation of noise reduction concepts e.g. by flow control

Contact: ulf.tapken@dlr.de

[1] Klähn, Lukas und Caldas, Luciano und Meyer, Robert und Moreau, Antoine und Tapken, Ulf (2023) Experimental Investigation of Inflow-Distortion-Induced Tonal Noise in a Sub-Sonic Fan Test Rig. In: 29th International Congress on Sound and Vibration, ICSV 2023. 29th International Congress on Sound and Vibration, 09.-13. Jul. 2023, Prag, Tschechische Republik. ISBN 978-801103423-8. ISSN 2329-3675.

[2] L. Caldas, S. Kruck, L. Klähn, A. Rudolphi, R. Meyer, L. Enghardt and U. Tapken. (2022) *Construction and Assessment of an Inflow-Control-Device for a Low-Speed Aeroacoustic Fan Rig.* AIAA Journal 2022 60:9, 5299-5312, DOI: 10.2514/1.J061729

[3] U. Tapken, R. Meyer, L. Caldas, L. Klähn, M. Behn, A. Rudolphi, R. Jaron, A. Moreau, and L. Enghardt. (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. März 2021, Delft, Niederlande.

[4] U. Tapken, L. Caldas, R. Meyer, M. Behn, L. Klähn, R. Jaron and A. Rudolphi. (2021) *Fan test rig for detailed investigation of noise generation mechanisms due to inflow disturbances.* AIAA 2021-2314. AIAA AVIATION 2021 FORUM. August 2021. DOI: 10.2514/6.2021-2314

[5] L. Caldas, L. Klähn, R. Meyer and U. Tapken. *Measurements of fan inflow distortion noise generation in a low speed fan - part I: aerodynamic analyses*, AIAA 2022-2944. 28th AIAA/CEAS Aeroacoustics 2022 Conference. June 2022. DOI: 10.2514/6.2022-2944

[6] L. Klähn, L. Caldas and U. Tapken. *Measurements of fan inflow distortion noise generation in a low speed fan - part II: acoustic analyses*, AIAA 2022-2945. 28th AIAA/CEAS Aeroacoustics 2022 Conference. June 2022. DOI: 10.2514/6.2022-2945

[7] L. Klähn, L. Caldas, R. Meyer, A. Rudolphi, A. Moreau, und U. Tapken. (2022): *Experimentelle Untersuchung der Auswirkung von Einlaufstörungen auf die Aeroakustik einer Rotor-Stator-Konfiguration am Fan-Prüfstand CRAFT*. Deutsche Gesellschaft für Luft- und Raumfahrt - Lilienthal-Oberth e.V. DOI: 10.25967/570161

[8] L. Klähn, A. Moreau, L. Caldas, R. Meyer, und U. Tapken. (2021) *Interpretation von Breitbandgeräusch-Messungen am Fan-Prüfstand CRAFT mithilfe analytischer Modelle*. In: Fortschritte der Akustik - DAGA 2021, Wien, Österreich. ISBN 978-3-939296-18-8.

[9] L. Klähn, A. Moreau, L. Caldas, R. Jaron and U. Tapken. *Advanced analysis of fan noise measurements supported by theoretical source models*. International Journal of Aeroacoustics. 2022; 21(3-4): 239-259. DOI: 10.1177/1475472X221093703

[10] L. Klähn, A. Moreau, L. Caldas and U. Tapken. (2022): Assessment of In-Duct Fan Broadband Noise Measurements in a Modern Low-Speed Test Rig. FAN 2022 – International Conference on Fan Noise, Aerodynamics, Applications and Systems, Senlis, Frankreich, DOI: 10.26083/tuprints-00021709

[11] S. Schade, R. Jaron, A. Moreau: Smart blade count selection to align modal propagation angle with stator stagger angle for low-noise fan stage designs, DLRK 2023