Technische Universität Braunschweig

IFAS Institut für Flugantriebe und Strömungsmaschinen

INFRa Rig + Propulsion Test Facility (PTF)

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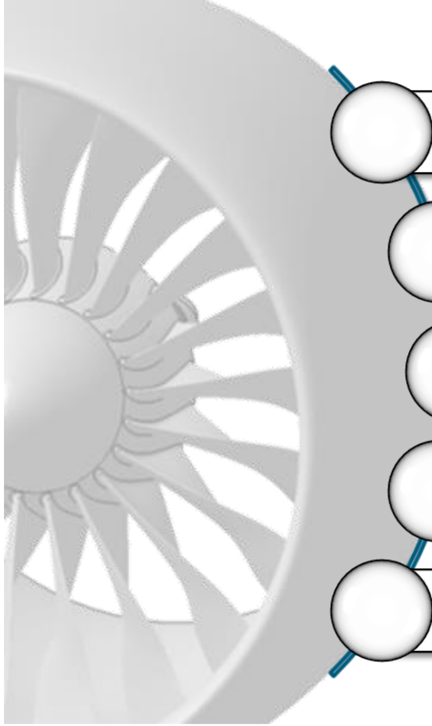
Institute of Jet Propulsion and Turbomachinery

TU Braunschweig

CA3ViAR Dissemination Event, 6. September 2022

Agenda

- Motivation / Introduction
- PTF Layout and Specs
- INFRa Rig
- Measurement Technology
- Status Quo



- **Motivation / Introduction**
- PTF Layout and Specs
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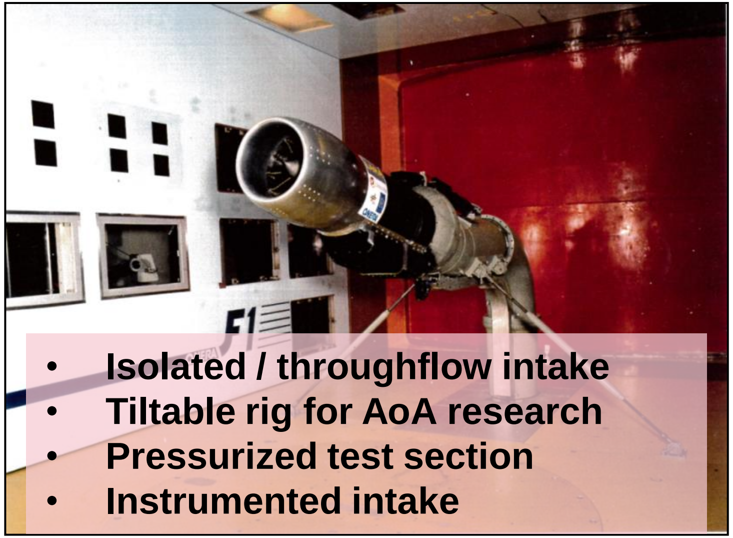
Motivation

- Improve propulsive efficiency
- Larger nacelles, shorter Intakes
- Focus: Fan intake interaction
- Safe operation on entire flight envelope
- Off-design (distortion, CW, high AoA)

Fig 1: Rolls-Royce Ultrafan [1]

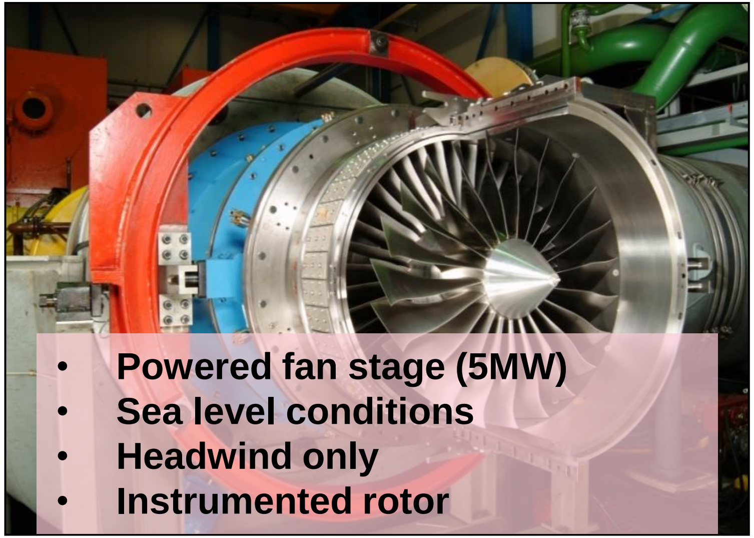
Motivation

Intake tests (ONERA F1)



- Isolated / throughflow intake
- Tiltable rig for AoA research
- Pressurized test section
- Instrumented intake

Fan stage test rig (DLR Cologne)



- Powered fan stage (5MW)
- Sea level conditions
- Headwind only
- Instrumented rotor

How to combine these disciplines into one experimental setup?

Fig. 2: Photos of ONERA F1 [2] and fan stage test rig [3]

PTF - Layout

- Main Windtunnel (Eiffel Configuration).......1.056 KW
- Closed Crosswind Tunnel..............................160 KW
- Powered Propulsor (E-Machine)..............2.000 KW

Key components:

F1: Fan-rig drive

F2: Windtunnel headwind

F3: Windtunnel crosswind

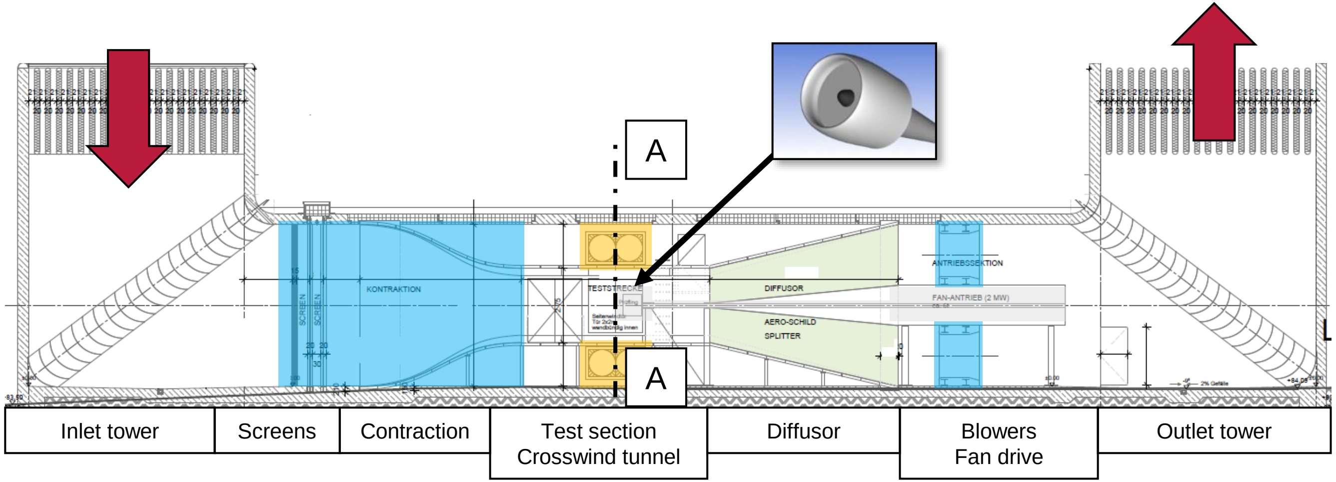


Fig. 3: Facility layout, cross section

PTF - CAD Model

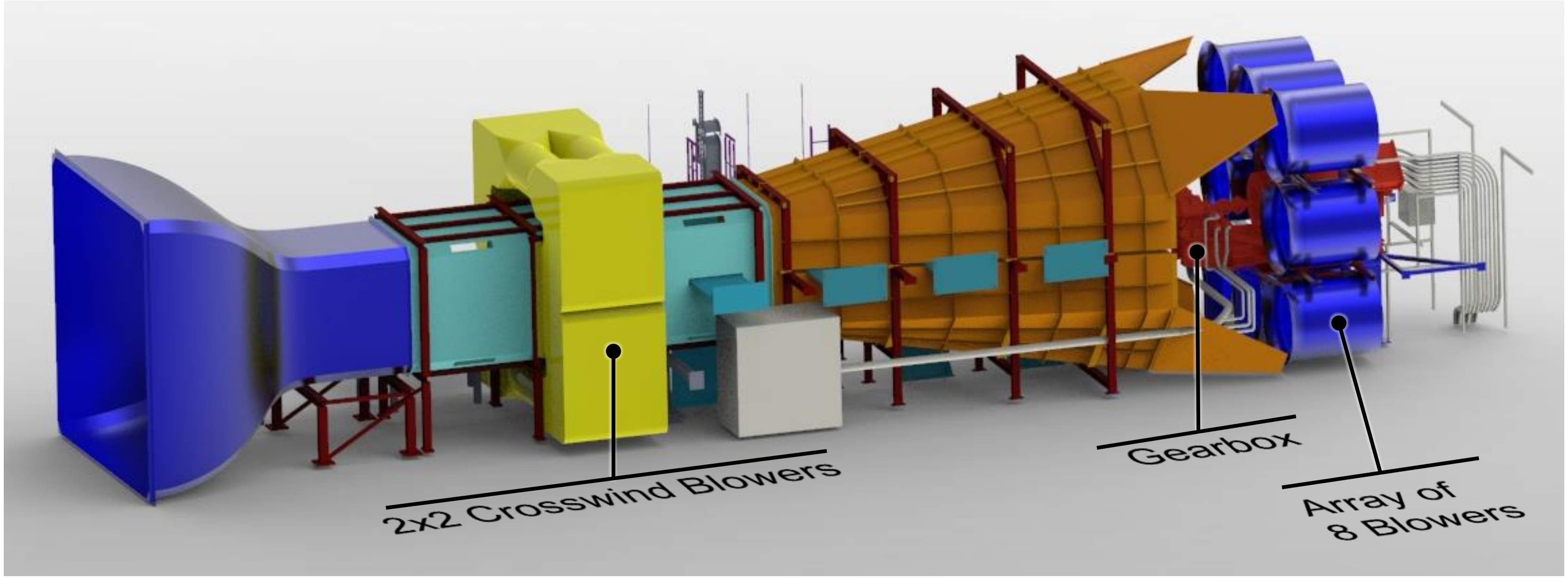


Fig. 4: Facility mock-up without concrete shell

PTF - Crosswind Concept

Crosswind duct

- Flow enters the crosswind duct through door 1
- Flow is divided into an upper and a lower flow
- Duct is powered by four blowers
- Flow enters the test section through door 2

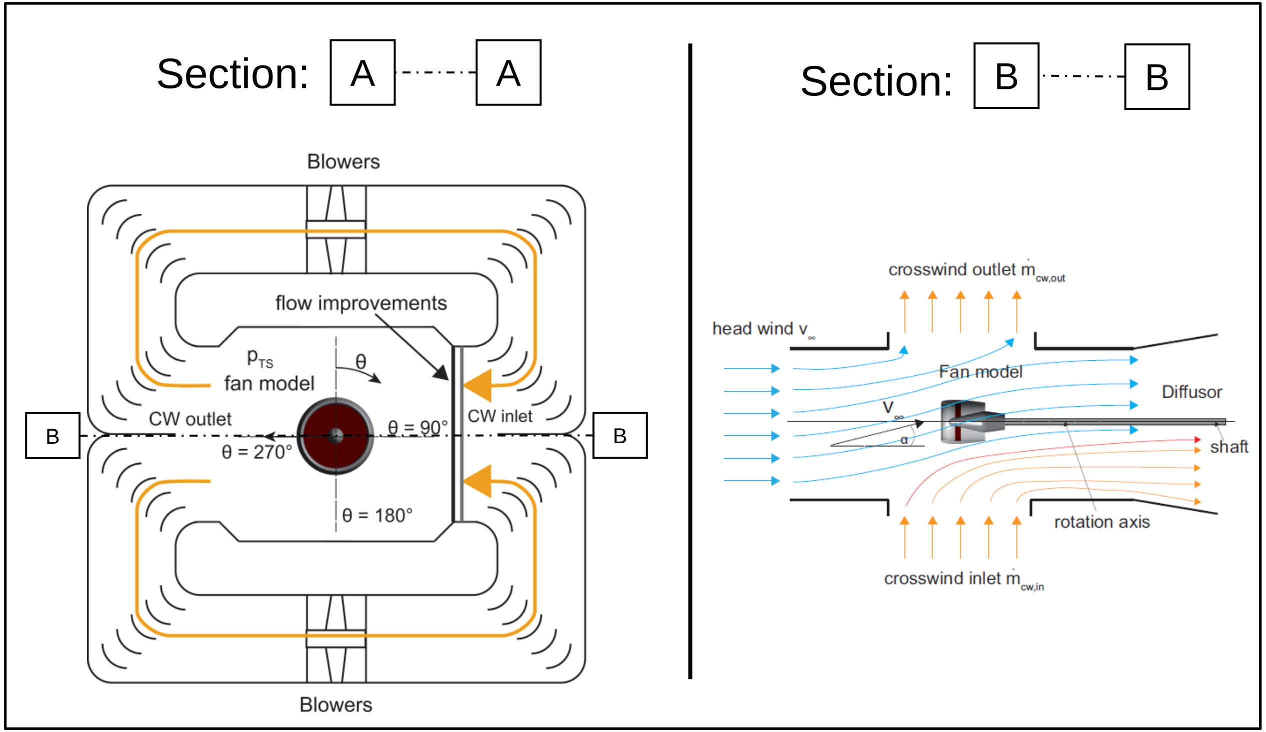


Fig. 5: Cross sections of crosswind duct

PTF - Generation of Inlet Distortions:

- Combination of incoming flow $\mathbf{v}_\infty$ und crosswind flow $\mathbf{v}_{CW}$
- Crosswind flow leads to a **blocking area**
- Blocking area leads to an angle of attack **α** for the incoming flow
- Angle of attack **α** leads to diffusor inlet separations of the test object
- **Crosswind mass flow & shear layer** must not enter the test object
- Crosswind angle **α** can be increased up to 90° (without main flow)

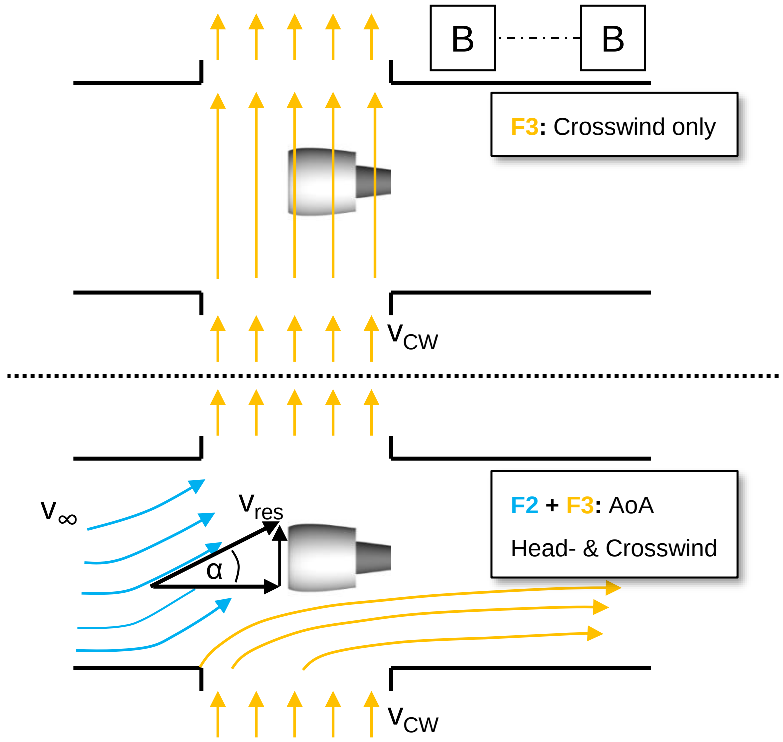


Fig. 6: Crosswind concept

PTF - Test Section (with Mock-Up)

Key parameters:

Test section Ma	0.2 (WT only)	
Max. crosswind velocity	40 kts (CW only)	
Fan drive power	2.000 kW	
Max. rotational speed	11.000 rpm	
Fan diameters	< 700 mm	
Test section area	2.4 m x 2.4 m	(7.8 ft)
Test section length	7 m	(23 ft)
Crosswind area	2 m x 2 m	(6.5 ft)

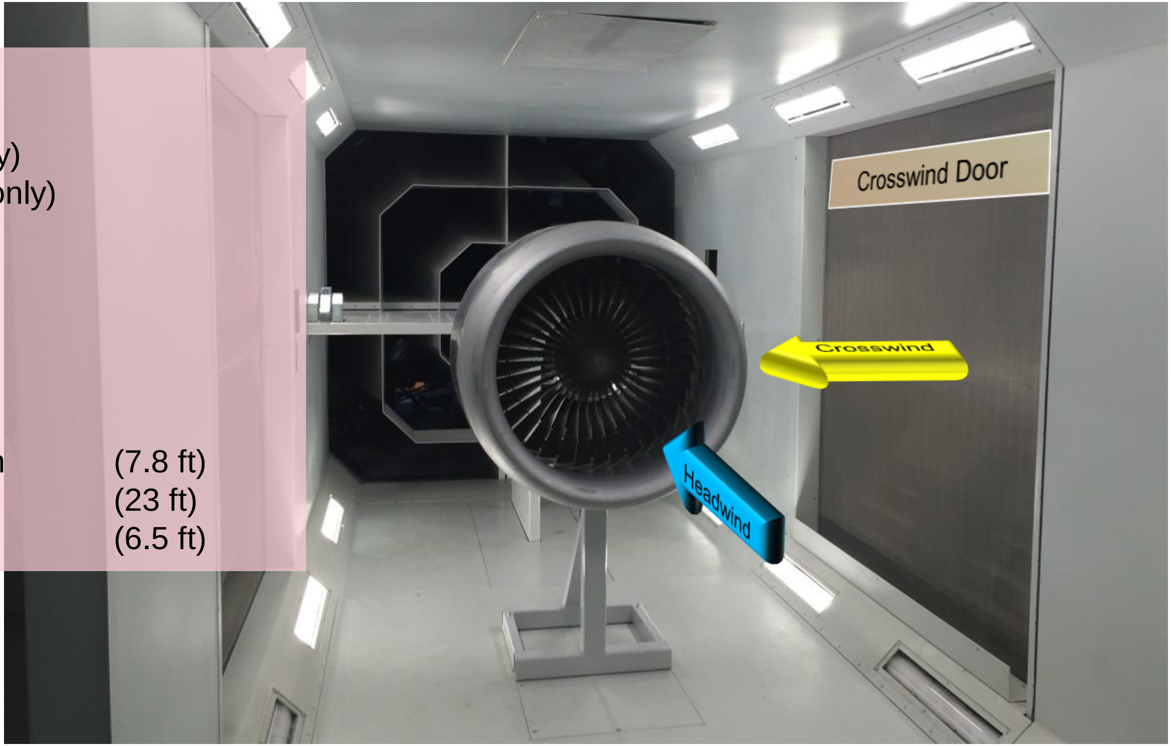


Fig. 7: Facility layout with mock-up

PTF - Test Section Dimensions

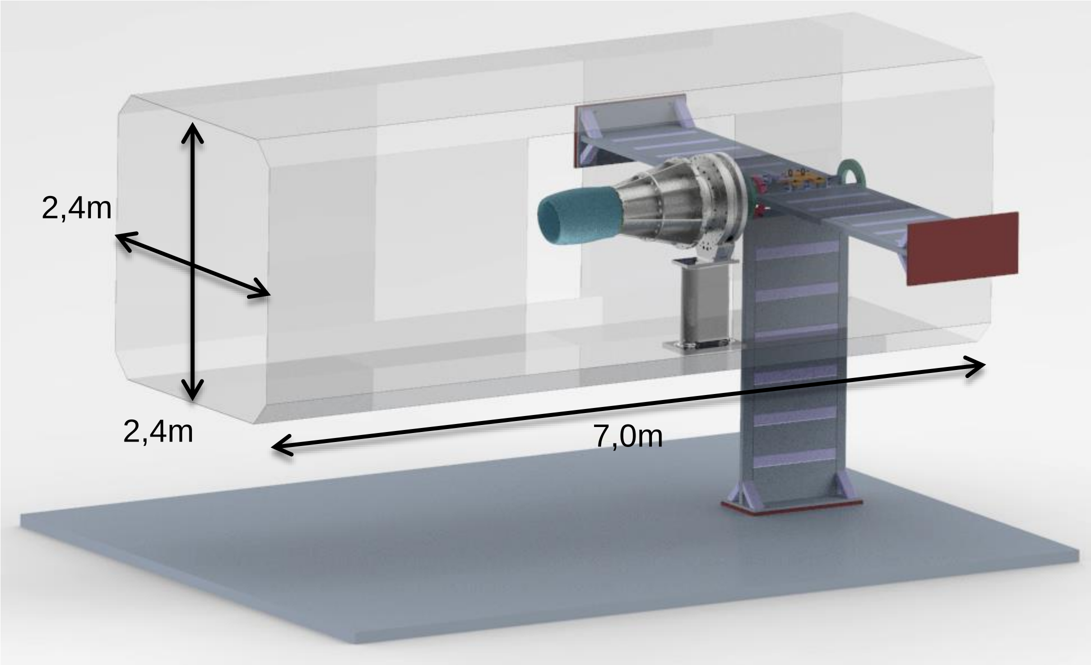


Fig. 8: Facility test section with aspirated intake setup

Fig. 9: Photo of aspirated intake

Setup for Aspirated Intake Tests

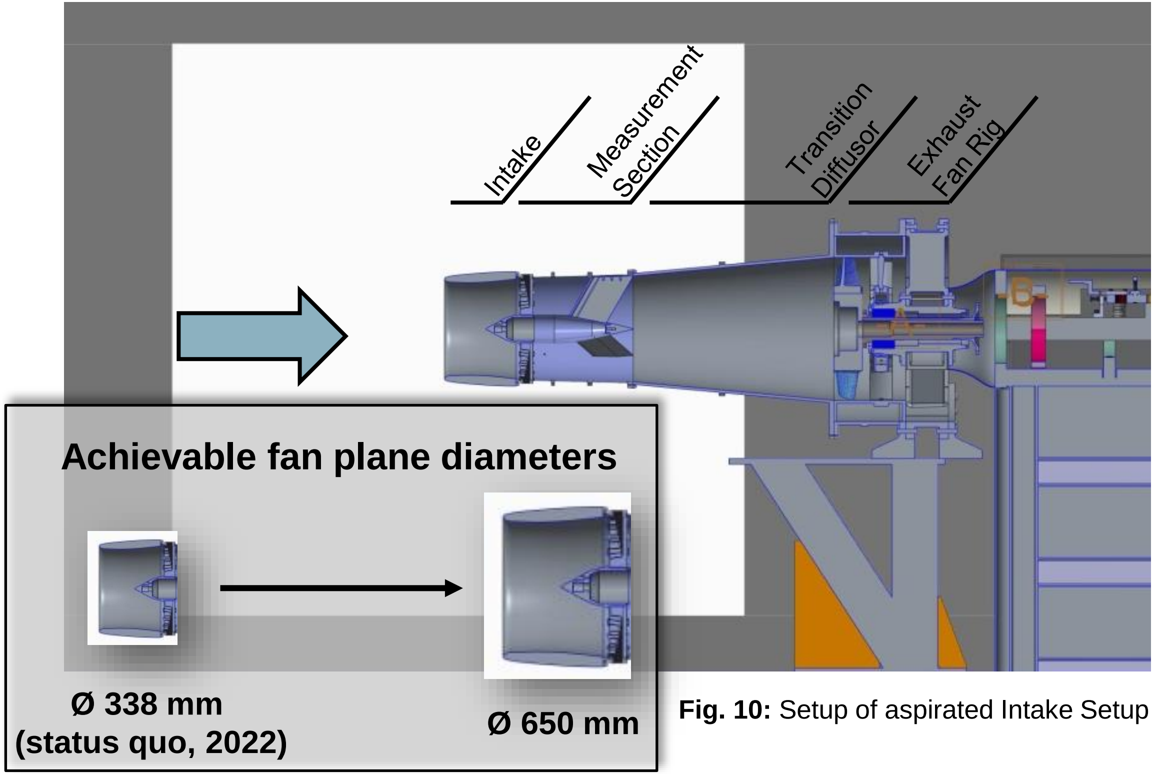


Fig. 10: Setup of aspirated Intake Setup

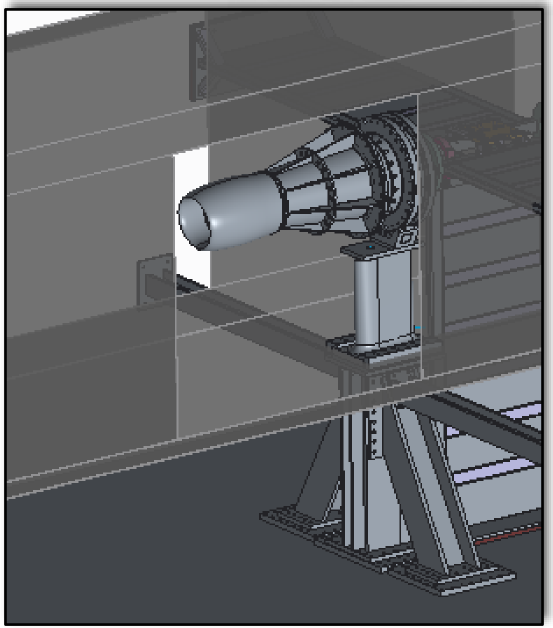
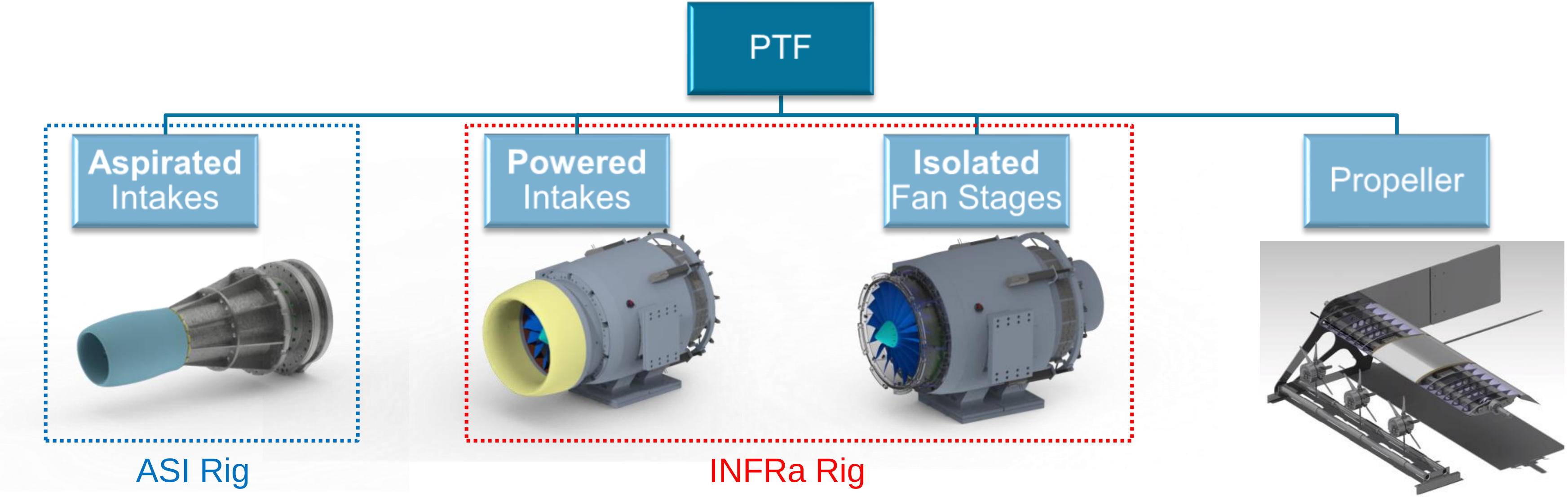


Fig. 11: Aspirated intake setup in test tunnel

Experimental spectrum



- Isolated intake investigations
- Testing of various measurement techniques

- Coupled Investigations of the fan-intake system
- Technology carrier for various fan stages and intakes
- Aerodynamic, aeroelastic and aeroacoustic measurements

- Investigation of distributed propulsion and propellers

Fig. 12: PTF experimental spectrum

INFRa – Rig: Overview

- Generic, non-IP-protected test vehicle
- Cold engine cycle
- Modularity
- Close coupling of fan and intake aerodynamics
- Fan throttling
- Increased size (fan Ø650mm)
- More extensive DAQ
    - Kulites
    - Fan monitoring (telemetry, strain gauges, …)
    - TT / TC
    - Measurement Rakes (compressor performance)
    - PIV / DIC

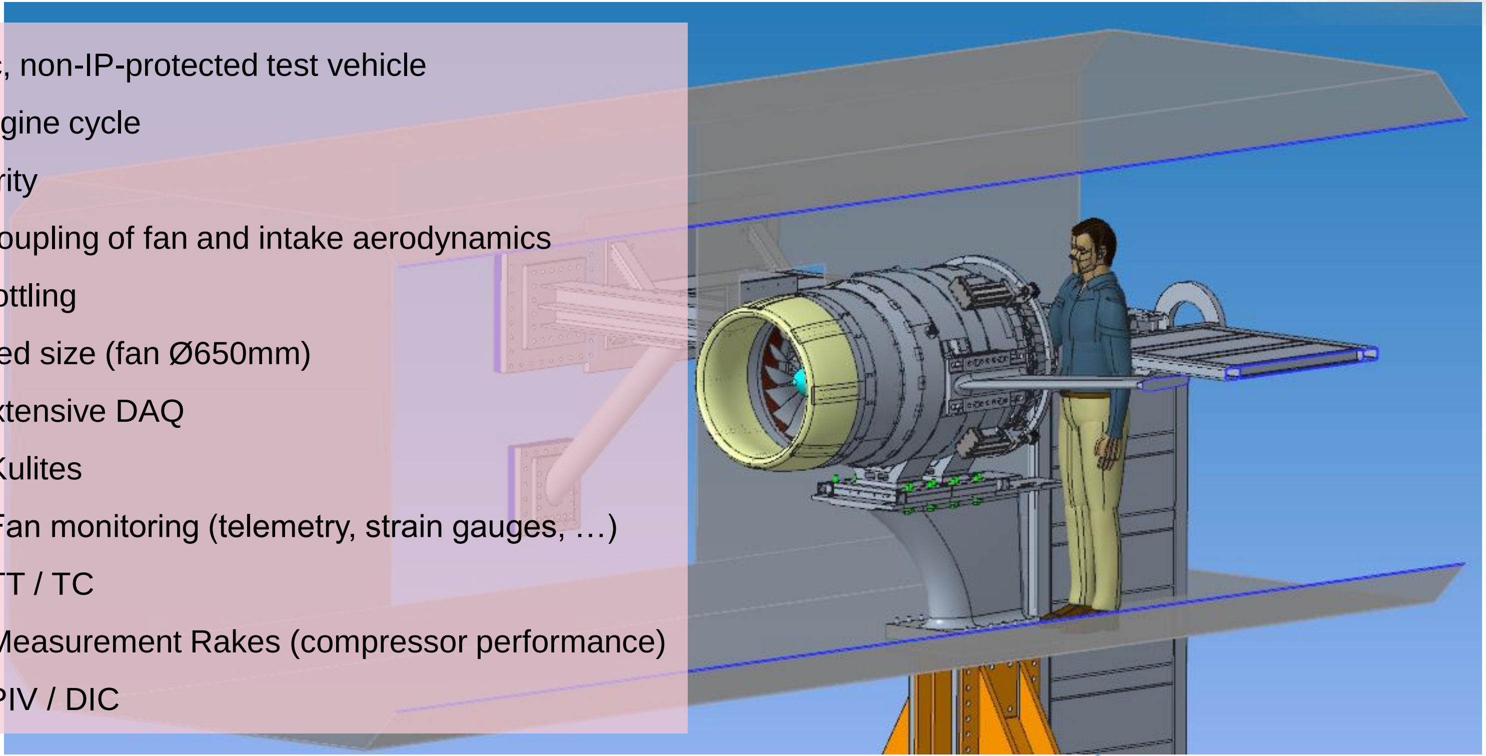


Fig. 13: INFRa Rig in test tunnel (CAD)

INFRa – Rig: Modules

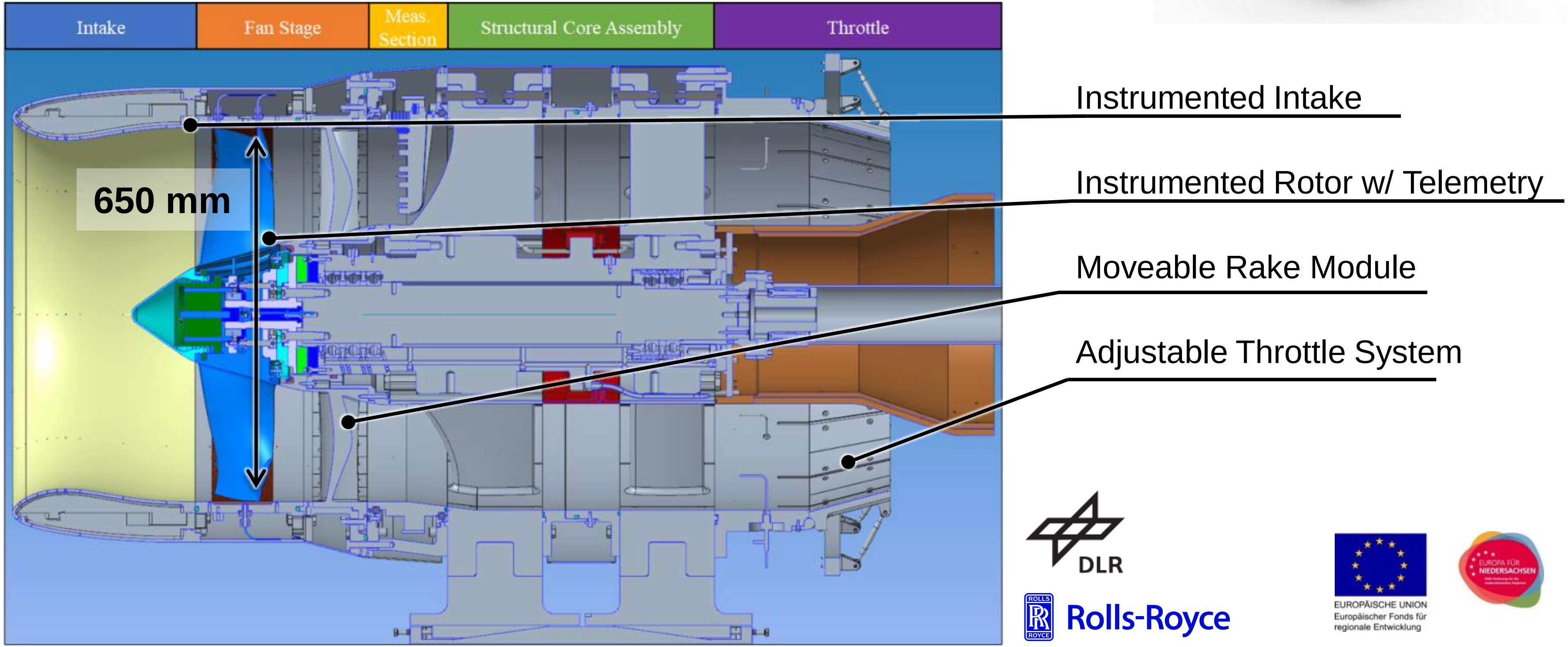


Fig. 14: Cross section of INFRa-Rig

INFRa – Rig: Fan Design

E-Machine:
- Max. power of 2 MW @ 8.000 rpm

Fan-Parameter:

• FPR:	1,32 (1,37@cruise)
• Tip speed:	< 275 m/s
• Ø:	650 mm
• HTTR:	0,26
• Rotor blades:	18
• Stator blades:	40
• Tip gap:	0,5 mm

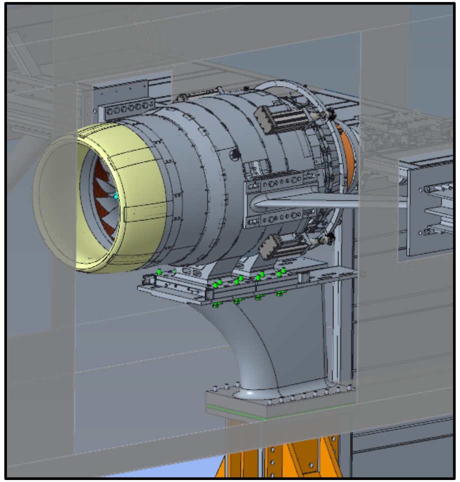


Fig. 15: INFRa-Rig in test tunnel

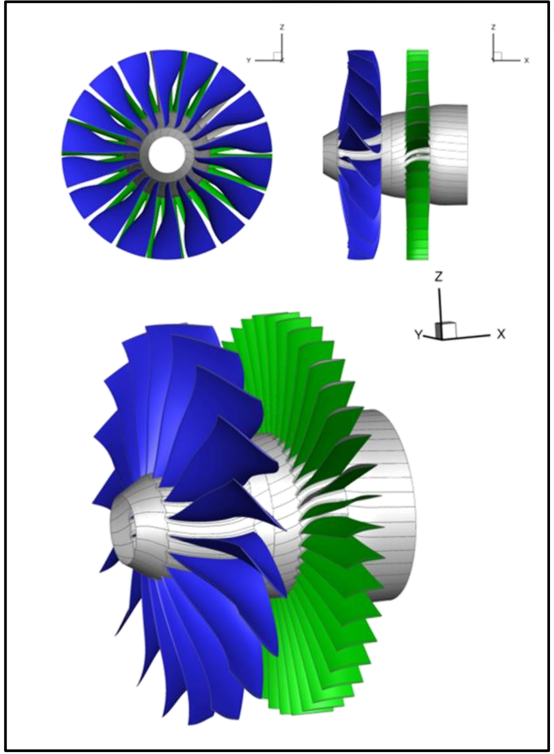


Fig. 16: INFRa fan design

→ CA³ViAR fan replaces INFRa fan

Motivation / Introduction

PTF Layout and Specs

INFRa Rig

Measurement Technology

Status Quo

INFRa – Rig: Instrumentation

Instrumentation consists of:

- Highly instrumentated intake section
- Fan section monitored by BTT and BTC, strain gauges on blades and unsteady pressure transducers
- Stage performance evaluated by 4 rakes
- Mass flow measurement by correlation with bellmouth intake and throttle
- Telemetry to transmit data from the rotating system
- Vibration and temperature sensors for operational monitoring of the rig
- PIV and DIC

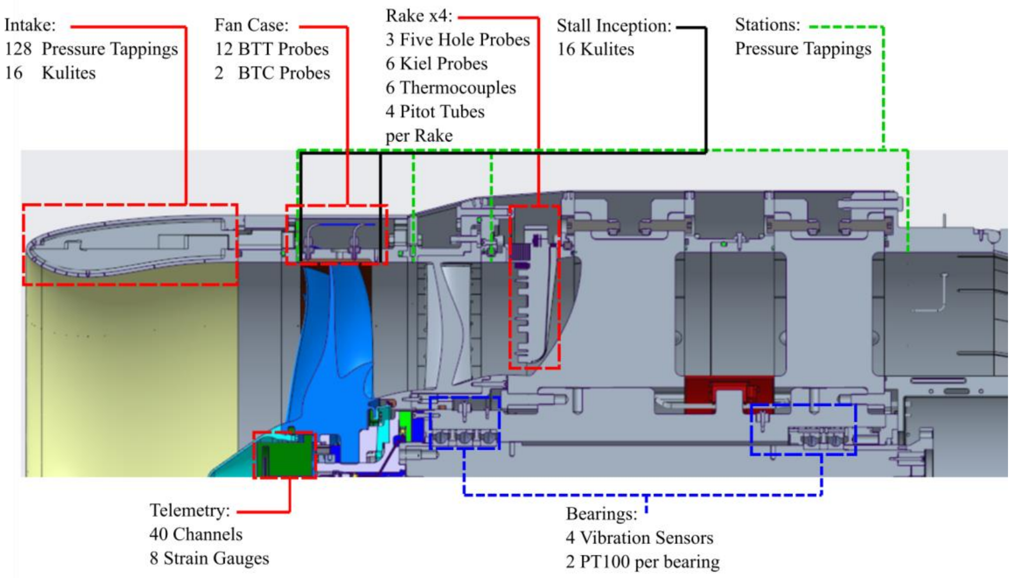


Fig. 17: Overview INFRa Rig instrumentation

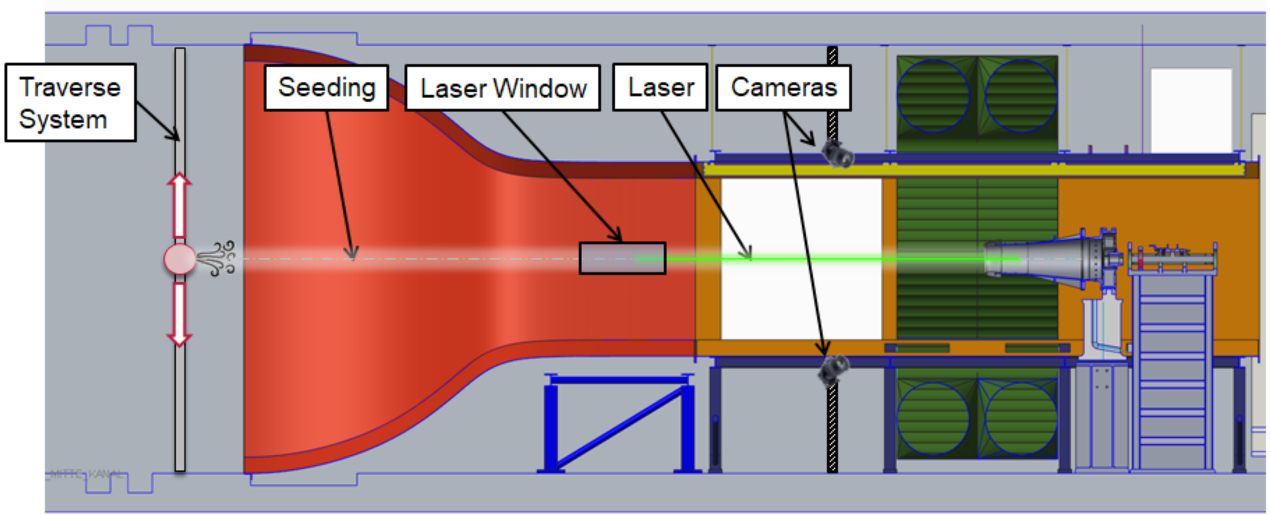
Particle Image Velocimetry (PIV) Test Setup

Principle of PIV:

- Optical measurement technique to measure flow behavior
- Seeding the flow and capturing the particles passing a laser plane in two timesteps

Challenges / Setup

- PIV in horizontal plane
- Laser access via transparent door/window
- Seeding necessary only in a linear array



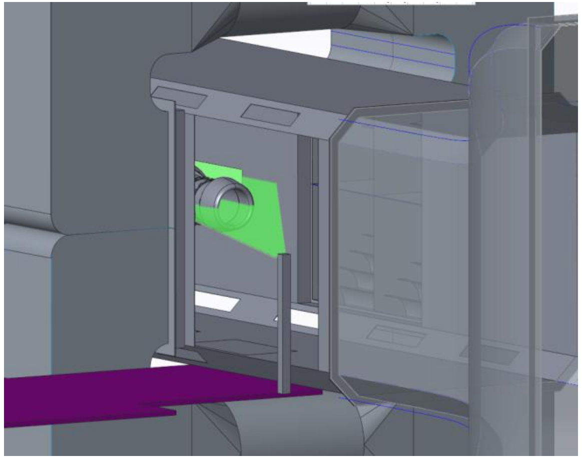


Fig. 18: PIV setup in PTF test tunnel

Digital Image Correlation (DIC) – Pre-Test

Principle of DIC:

- Optical measurement technique to measure surface deformations
- Corresponding points on the surface are detected via image correlation
- Calibration of two cameras required

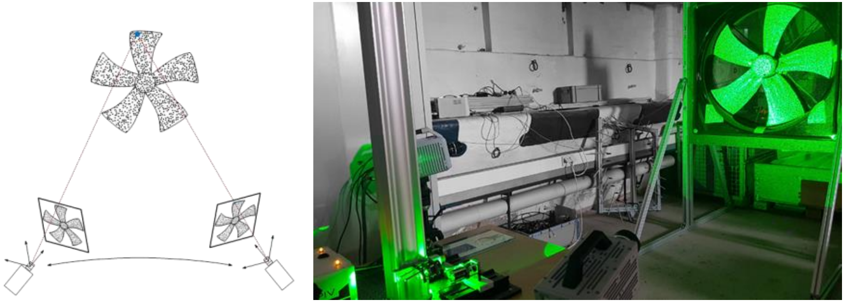


Fig. 19: DIC Scheme and Pre-Test Setup

Challenges in *CA³ViAR*:

- High sampling rates ($f_s > 1000$ Hz) due to blade eigenfrequencies & rotational speed
- Short exposure times ($t_{exp} < 1.78$ µs) to eliminate motion blur

➢ A new **high-speed DIC setup** had to be arranged and tested

➢ Successfully measured deformation and vibration on rotating industrial fan

➢ Next Step: Implementation inside PTF

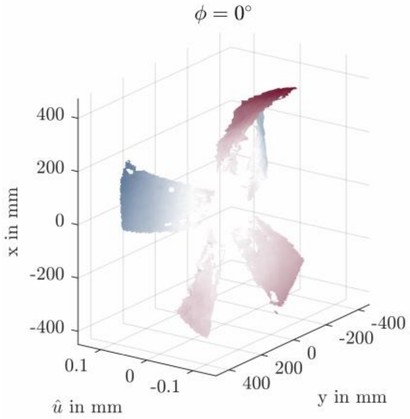
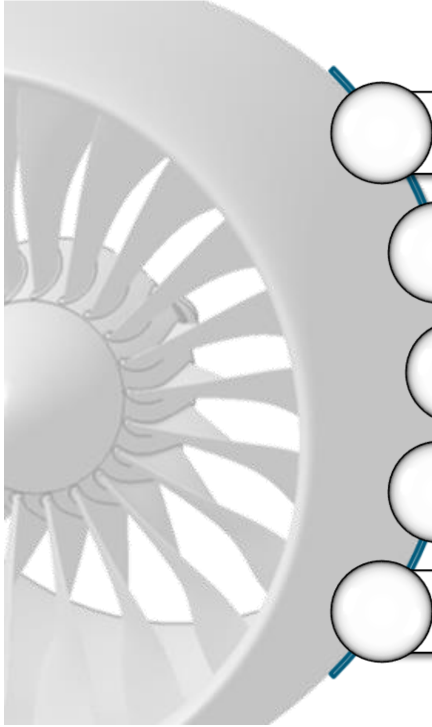


Fig. 20: Vibration pattern of first bending mode at 32 Hz [3]



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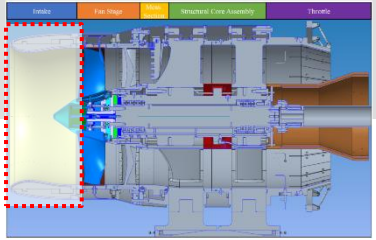
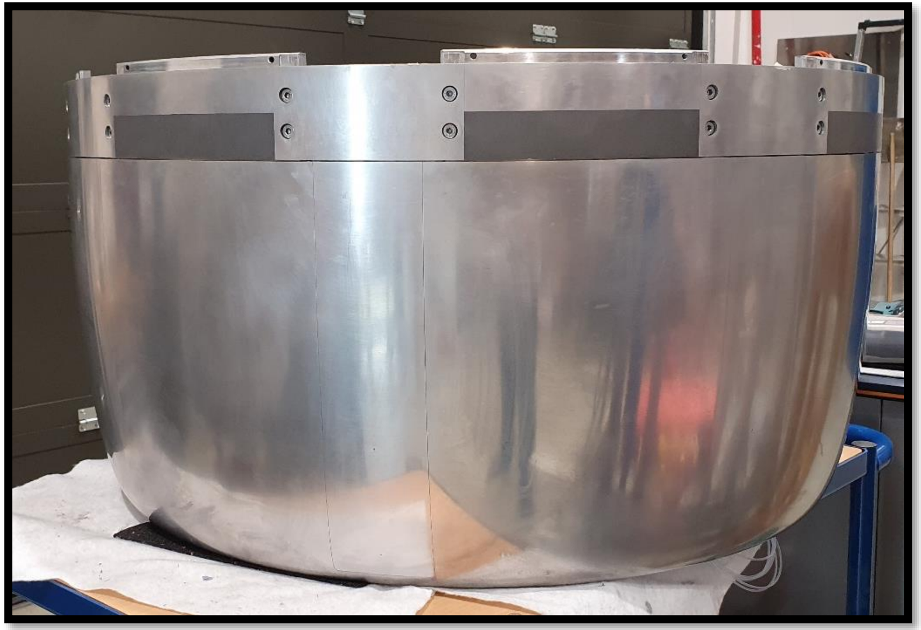
- **Status Quo**

Status Quo: Intake (long)





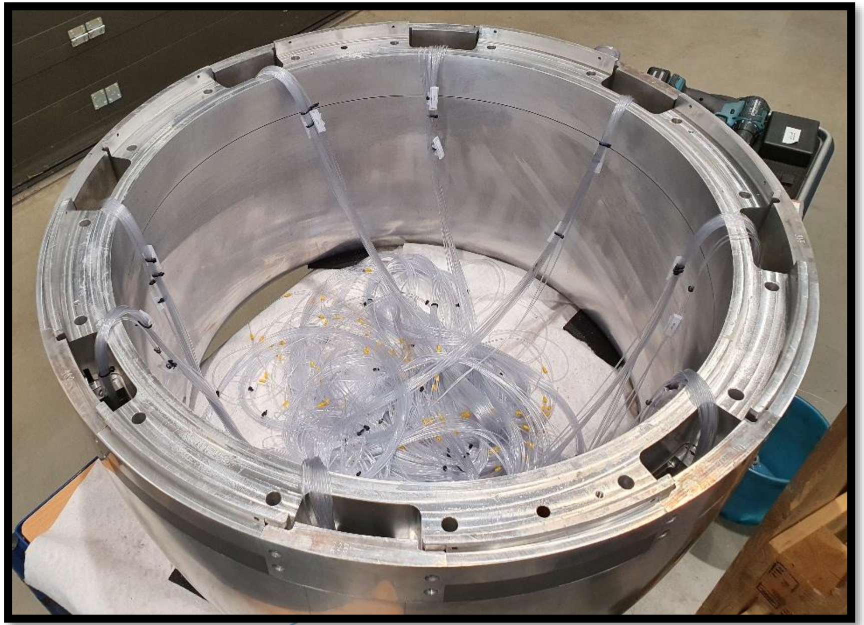


Fig. 20: Photos of long intake

Status Quo: Blisk

Fig. 21: Photos of INFRa Blisk

Status Quo: OGV

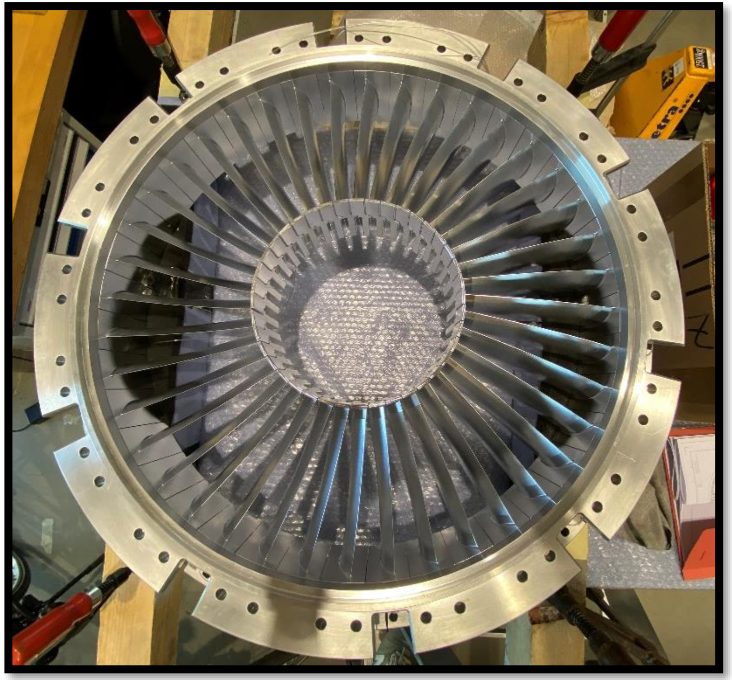
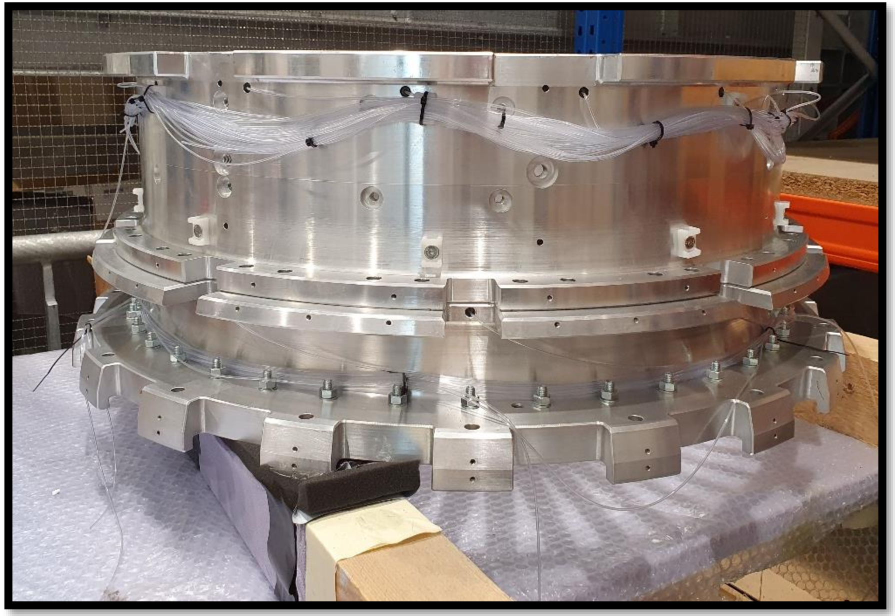
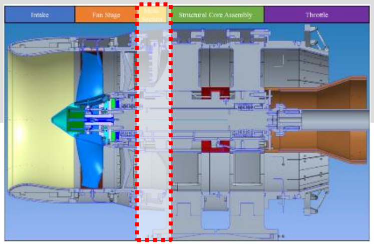


Fig. 22: Photo OGV section and fan case



Status Quo: Measurement Section



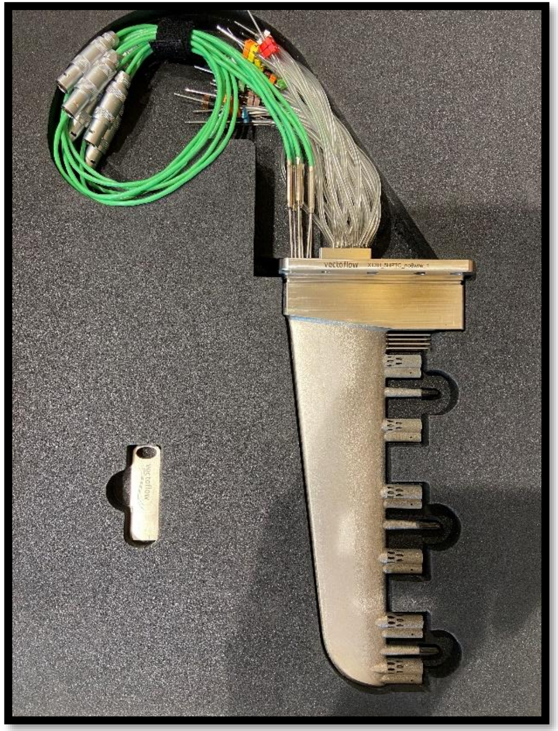
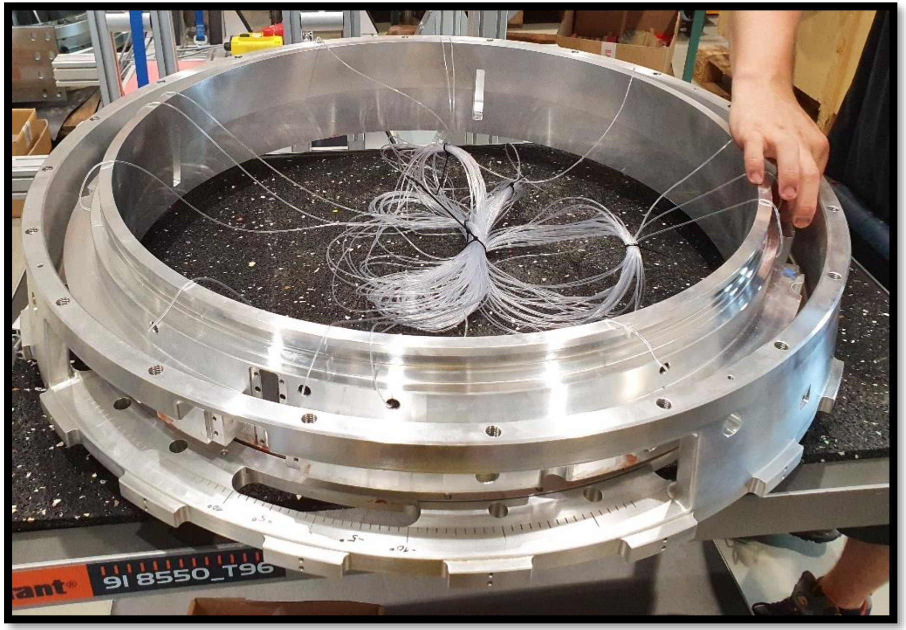


Fig. 23: Photo of rake and measurement section



Status Quo: Spindle / Strut Case

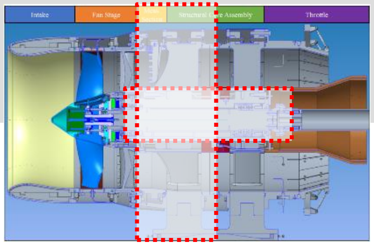
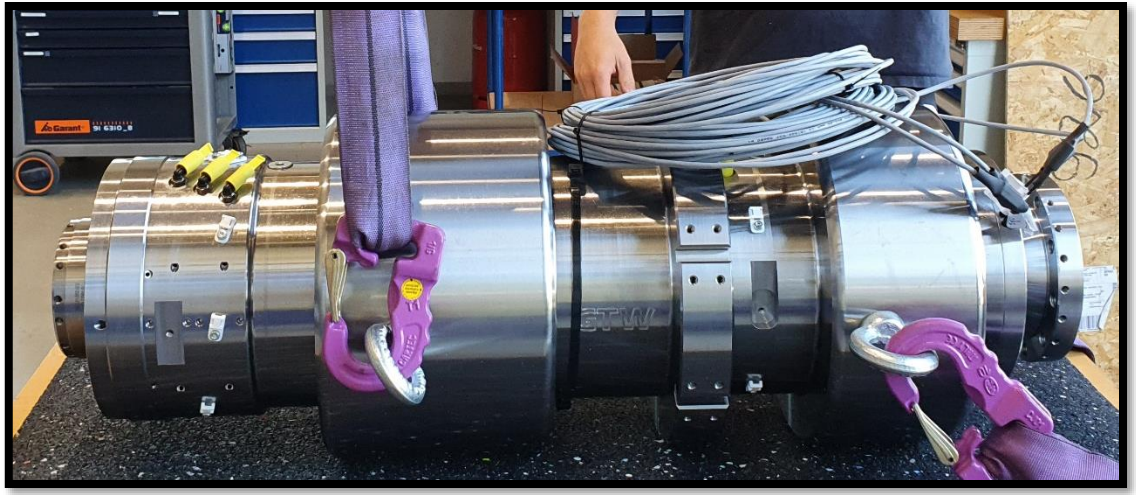


Fig. 24: Photos of strut assembly and spindle



Status Quo: Main Structure

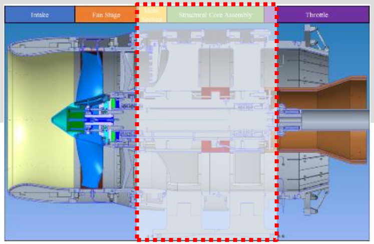
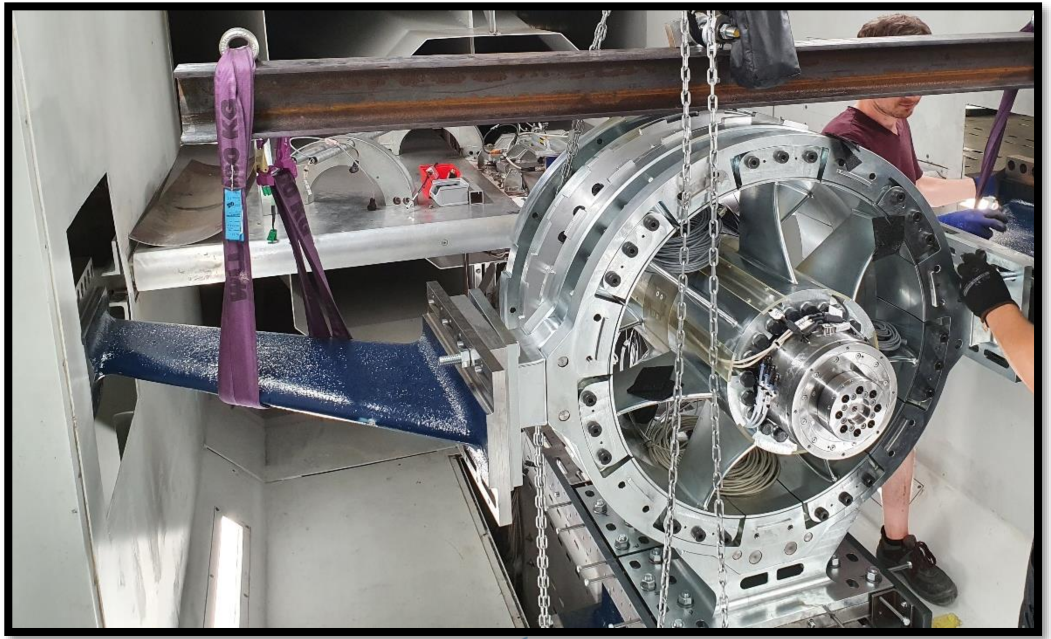
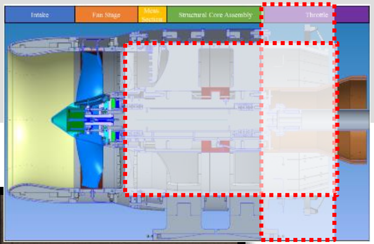


Fig. 25: Photos of strut assembly inside the test tunnel



Status Quo: Throttle



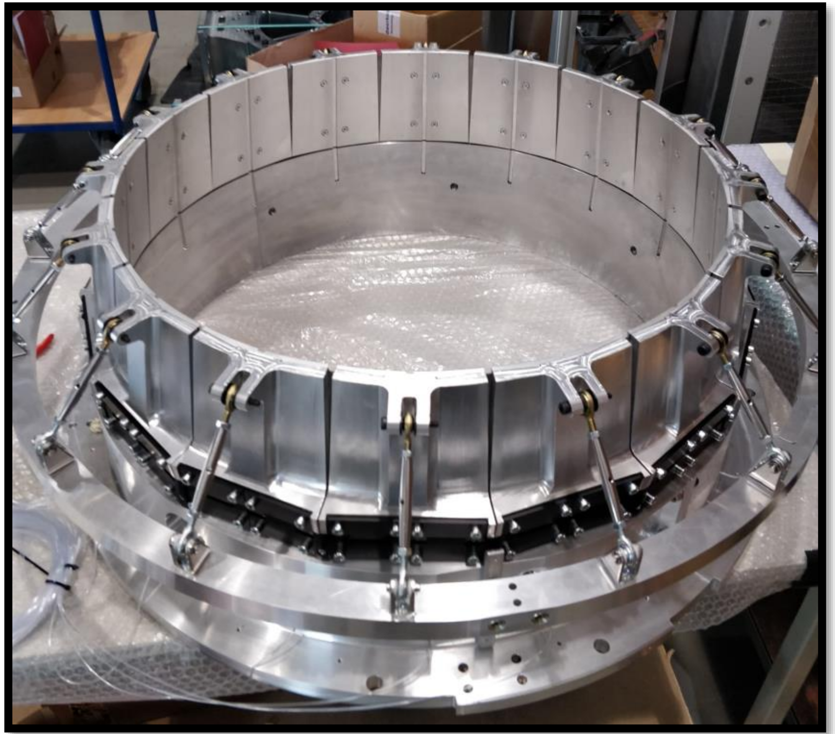
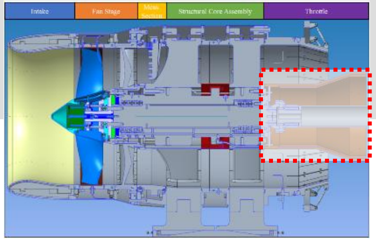


Fig. 26: Photos of throttle assembly (solo and attached)

Status Quo: Inner Contur



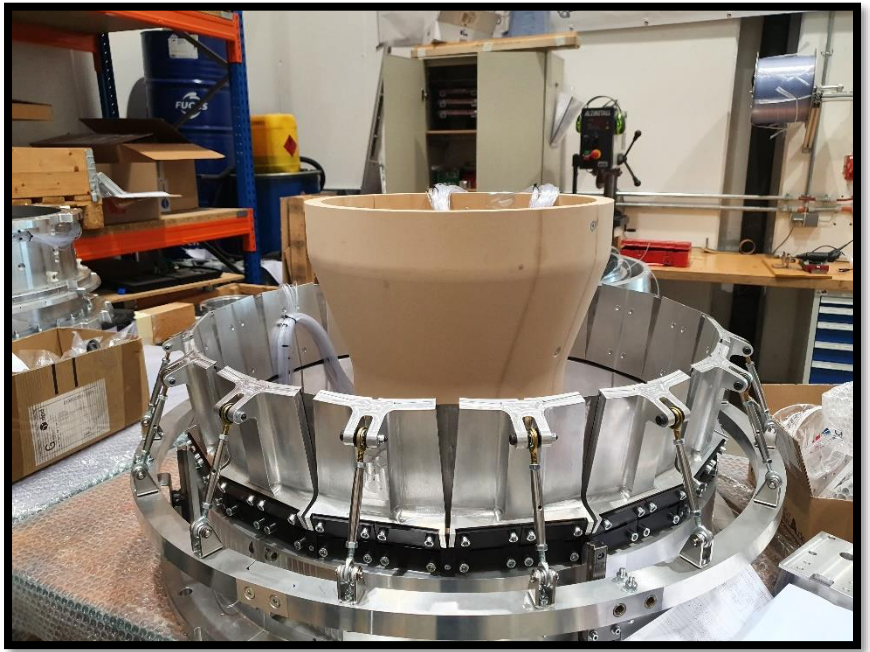


Fig. 27: Photos of inner contour (solo and with throttle)

Status Quo: Support Structure

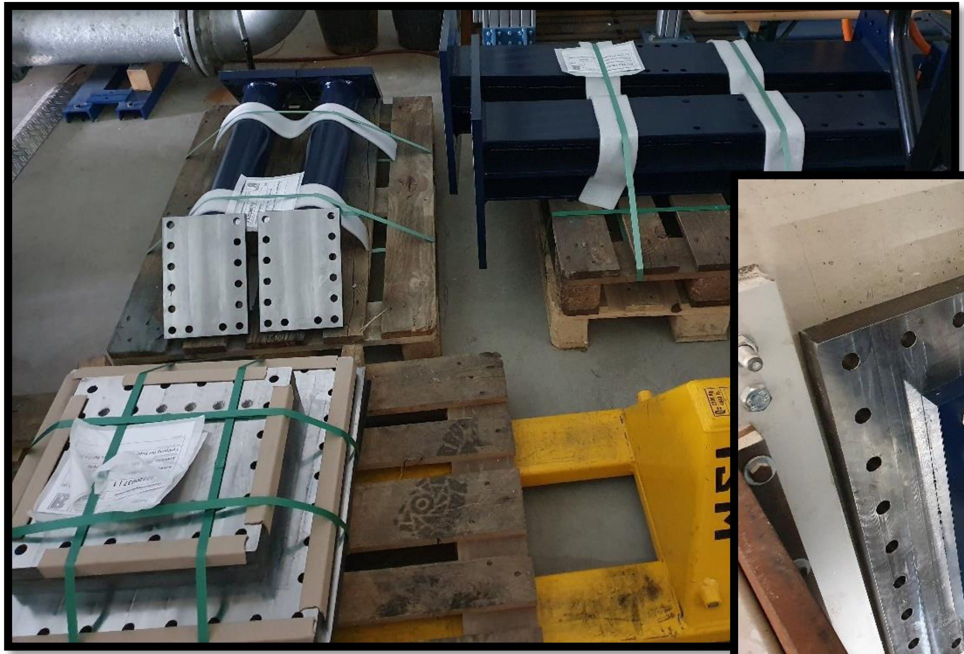


Fig. 28: Photos of support structure

Next steps

- Concrete filling @supports
- Installation of adapter shafts
- Balancing

- Throttle actuation
- Actuated measurement section

Summary / Outlook

- Facility / test vehicle / DAQ overview

- Facility commisioned via successful aspirated intake campaigns
- INFRa installation ongoing → Commissioning end of 2022

Sources:
(1) www.rolls-royce.com
(2) ONERA F1 Windtunnel, South France
(3) DLR UHBR Test Rig for Compressor Test Rig M2VP, Cologne
(4) LU Hannover, J. Gößling

Thank you for your attention!

Questions?

Acknowledgements

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