Gas Turbines and Aerospace Propulsion

Technische Universität Darmstadt

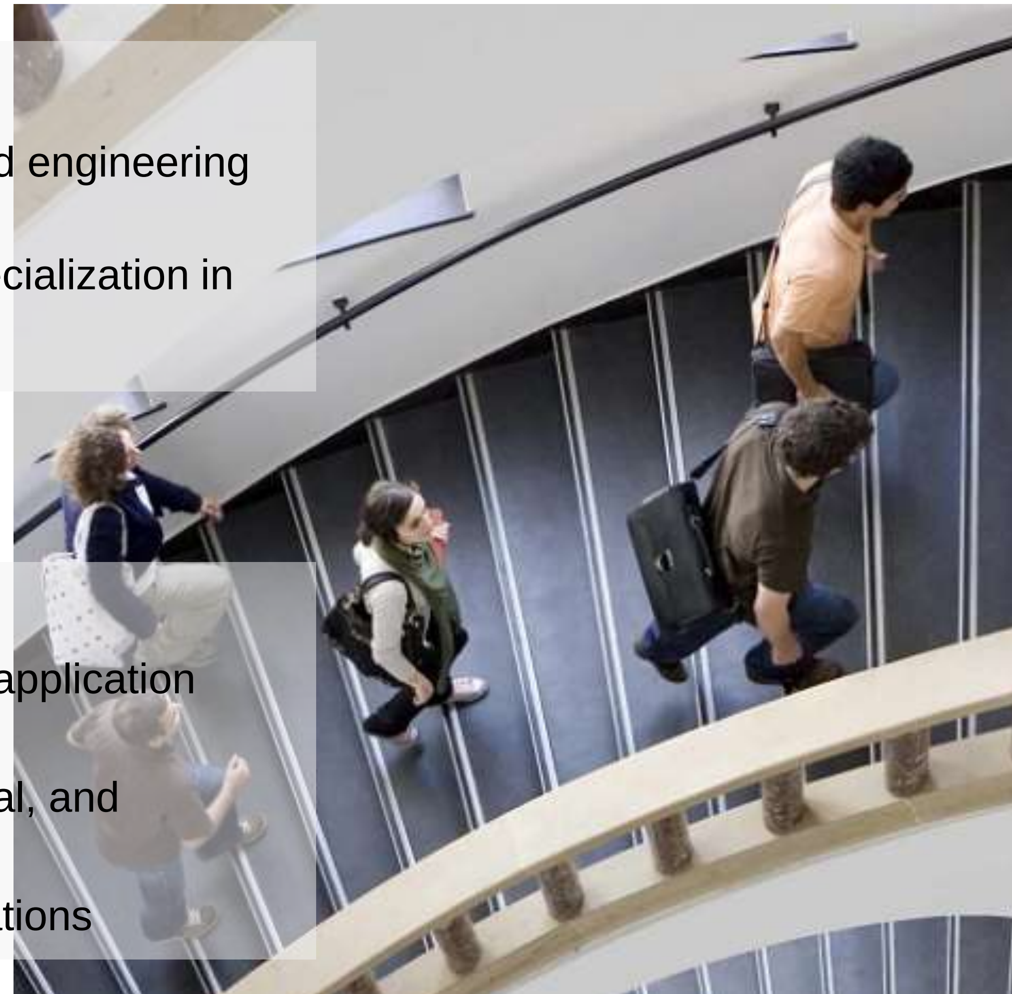
Department of Mechanical Engineering

Institutes

TECHNISCHE UNIVERSITÄT DARMSTADT

29	professors
27	institutes
3650	students
250	M.Sc. leaving each year
475	researchers
80	PhD each year
200	administrative and technical staff
370	student co-workers

Teaching and Research



Teaching

Excellent basic education in natural and engineering sciences for all students

Subsequent further deepening and specialization in promising future high-tech branches

Research

Balanced portfolio of fundamental and application oriented research

Combination of experimental, theoretical, and numerical research methods

Initiation of transfer to industrial applications

Established Research Highlights

Application Oriented Research

Fundamental Research

Production-Engineering/ Automation

Aeronautical Engineering

Paper Technology & Printing Machines

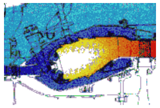
Automotive Engineering

Component Strength/ System Reliability

Mechatronics

Product Development

Fluid Mechanics and Combustion

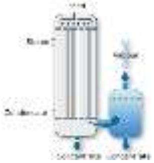


Structural Dynamics

Computational Engineering

Material Science

Process Engineering



External Research Funding

In 2013: 41.4 Mio € for research
(approx. 1.4 Mio € / professor)

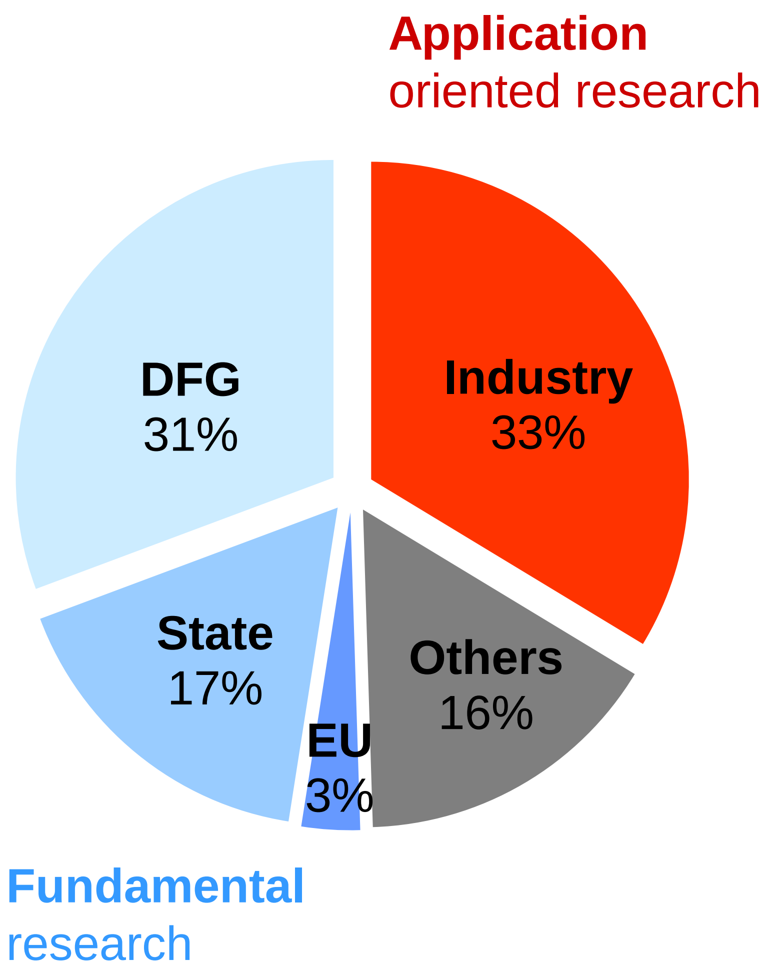
Excellent balance between application orientation and fundamentals

Transparent Distribution within the department

- state funding in 2014: 19.4 Mio €
- deduction for expenditures from 2013: 1.9 Mio €

Budget of each institute consists of

- basic budget (fixed)
- teaching budget (variable)
- research budget (variable)



Joint Research Programmes

SPP 1207
Nature Inspired Fluid Mechanics

LOEWE Center
Adaptronics

SFB 568
Flow and Combustion in Future Gas Turbine Combustors

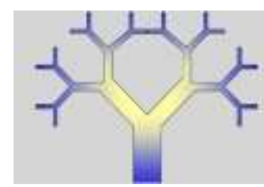
GRK 1344
Unsteady System Modelling of Aircraft Engines

Graduate School
Computational Engineering

SPP 1369
Polymer-Solid Contacts: Interface and Interphase

DFG research group
Combustion Noise Initiative

University Technology Centre
Combustion Turbine Interaction



SFB 666
Integral Sheet Metal Design with Higher-Order Bifurcations

SFB 805
Control of Insecurity in Loaded Systems

GRK 1114
Optical Techniques for Interfacial Transport Processes

Gas Turbines and Aerospace Propulsion

Who We Are

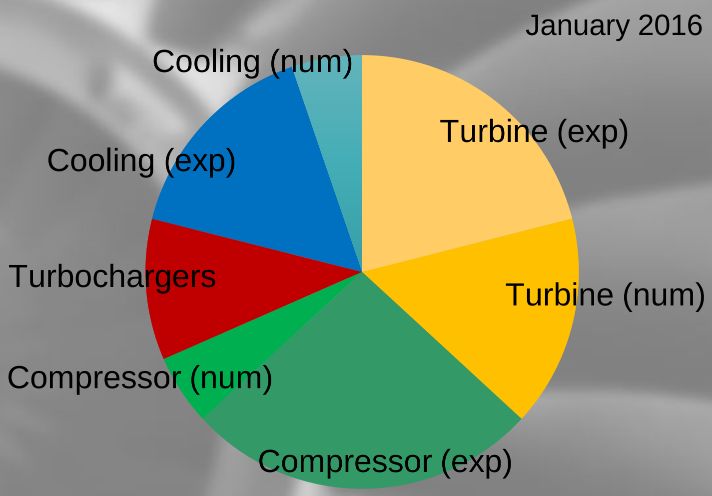
Head Prof. Dr.-Ing. H.-P. Schiffer

Secretary Mrs. B. Löhr

Assistants 19 research associates

Workshop 1 foreman, 1 technician, 5 mechanics

Workgroups compressors (6 researchers)
turbines (7)
turbochargers (2)
novel technologies & blade cooling (4)



Students 24 Bachelor‘s theses p.a. (2015) 213 total (since 2004)
18 Master‘s theses p.a. (2015) 136 total (since 2004)
25 student research assistants

Our Industrial Partners

TECHNISCHE UNIVERSITÄT DARMSTADT

Long Term Partners

Rolls-Royce

SIEMENS

MTU Aero Engines

BorgWarner Turbo Systems

Project Partners

Avio propulsione aerospaziale

Snecma Groupe SAFRAN

VOLVO AERO

MAN

ITP Grupo Industria de Turbo Propulsores, S.A.

Turbomeca Groupe SAFRAN

ALSTOM

ebmpapst

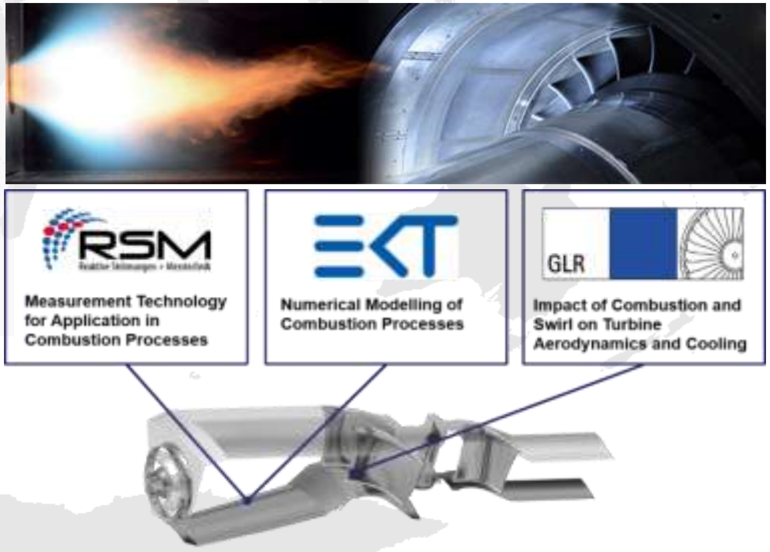
Rolls-Royce University Technology Centre

UTC Combustor and Turbine Interaction

Intensified Co-operation between TU Darmstadt and Rolls-Royce Deutschland since 2006

Technical focus is the reduction of engine fuel consumption and emissions by understanding the interaction between combustor and turbine

31 research associates at 3 institutes are currently involved at TU Darmstadt



Institutes involved in the Darmstadt UTC

TurboScience GmbH - A GLR Spin-Off

TECHNISCHE UNIVERSITÄT DARMSTADT

TurboScience is a start-up company founded in 2013 by Dr. Leichtfuß, a GLR graduate, and Prof. Schiffer.

Today 5 engineers are permanently employed.

The company is closely linked to GLR and enables the acquisition of subcontract work.

The opportunities: continuous, long-term cooperation with industrial partners and short-term work prospects for graduates.

Mission Statements

TECHNISCHE UNIVERSITÄT DARMSTADT

To become a widely recognized **turbomachinery laboratory** - continuously strengthening our reputation in this field

To achieve the best possible insight into the aerodynamics and heat transfer in the field of turbomachinary investigations by combining **experimental and numerical approaches**

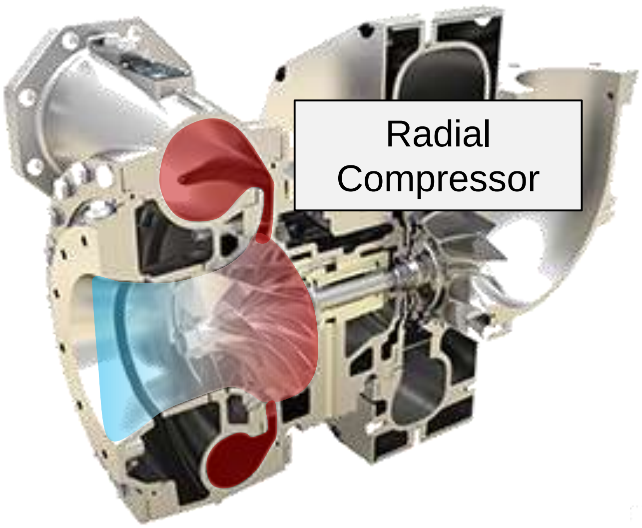
To stay focused and distinct by keeping our work group at a **limited staff size**

Prof. Dr.-Ing. H.-P. Schiffer

Gas Turbines and Aerospace Propulsion

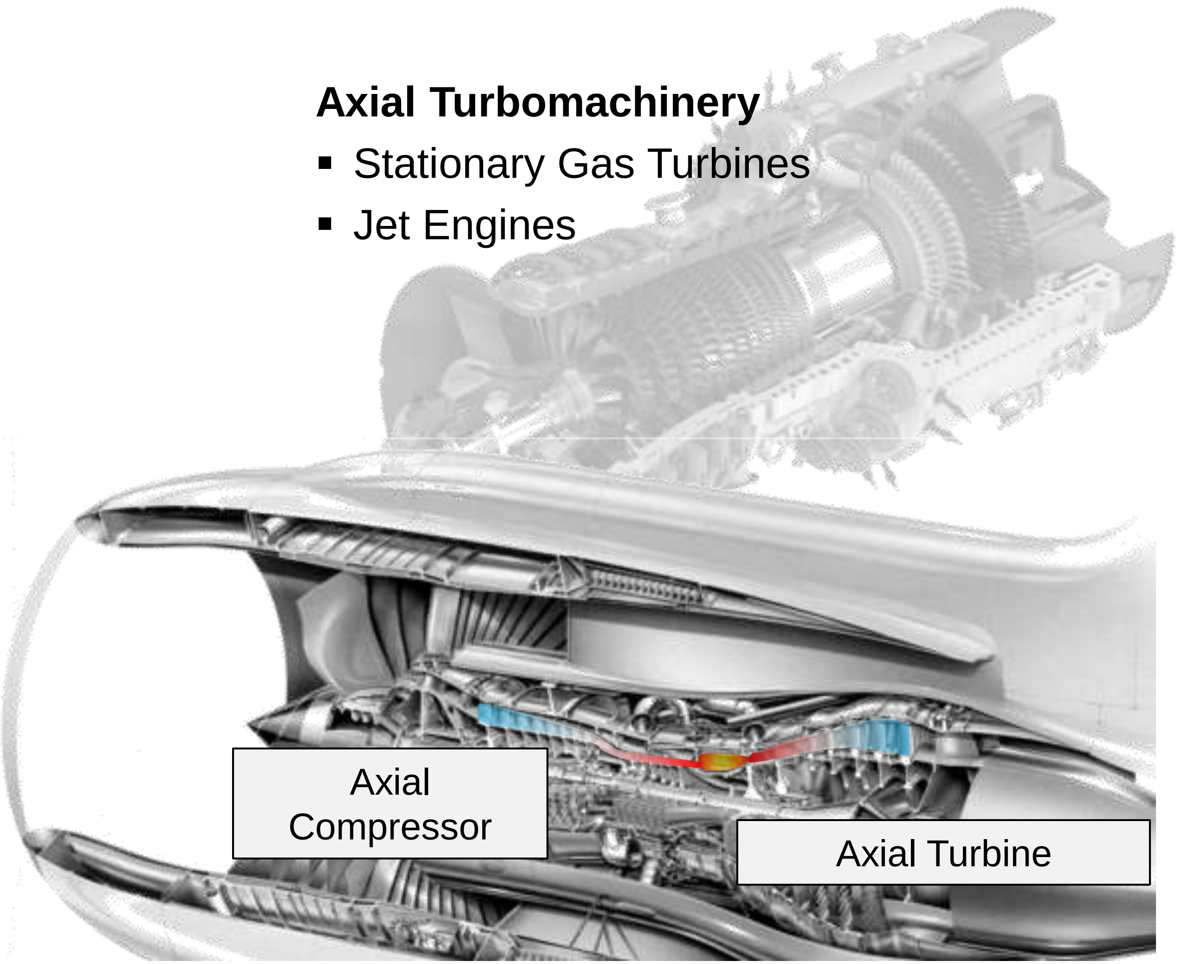
Research Areas

Applications of our Research



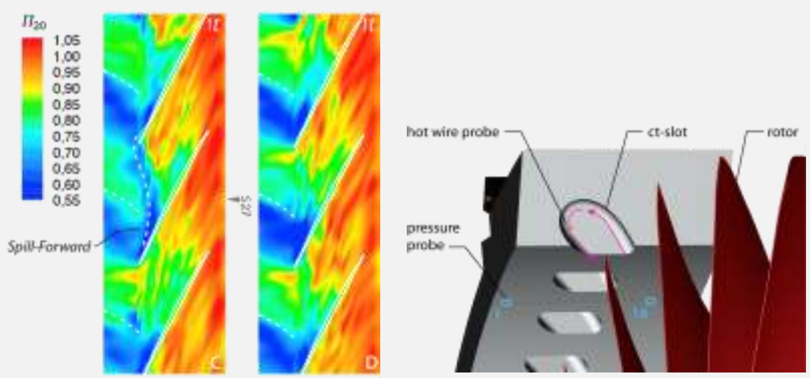
Radial Turbomachinery
- Automotive Turbochargers
- Marine Turbochargers

Axial Turbomachinery
- Stationary Gas Turbines
- Jet Engines

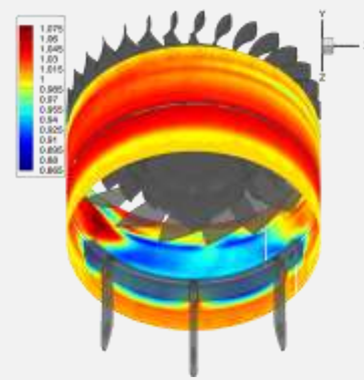


AXIAL COMPRESSORS

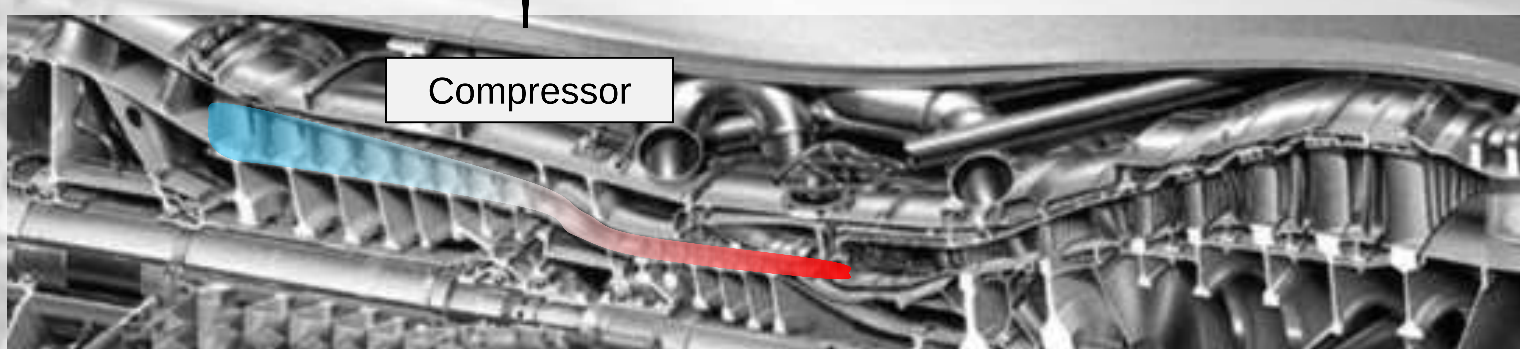
> Compressor Aerodynamics, Stall Inception and Stability



> Compressor Inlet Distortions

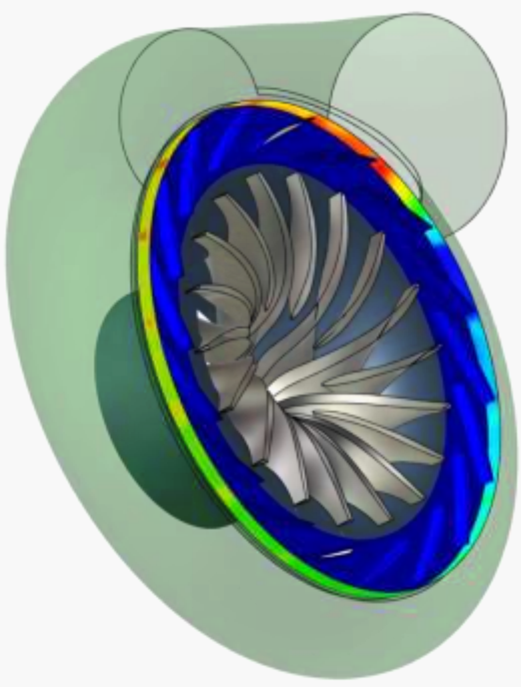


> Compressor Aeroelasticity

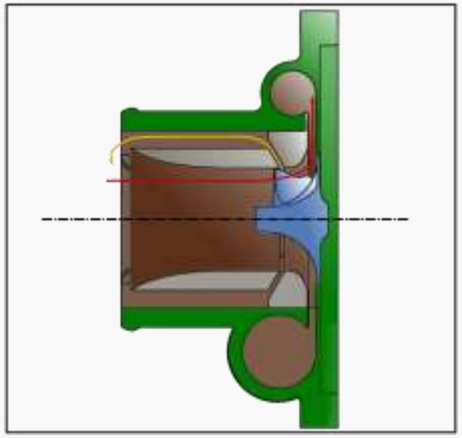


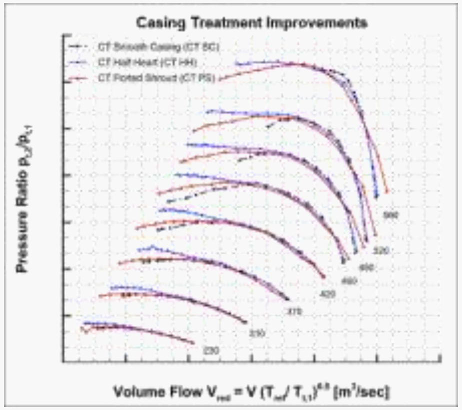
RADIAL COMPRESSORS - TURBOCHARGER

> Diffuser and Volute Optimization

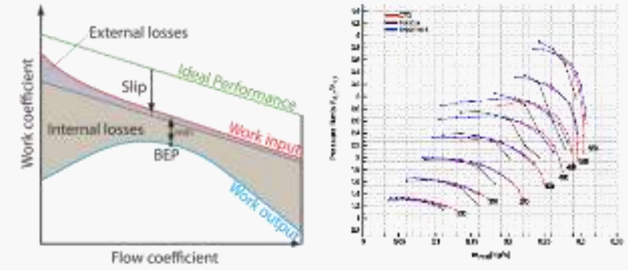


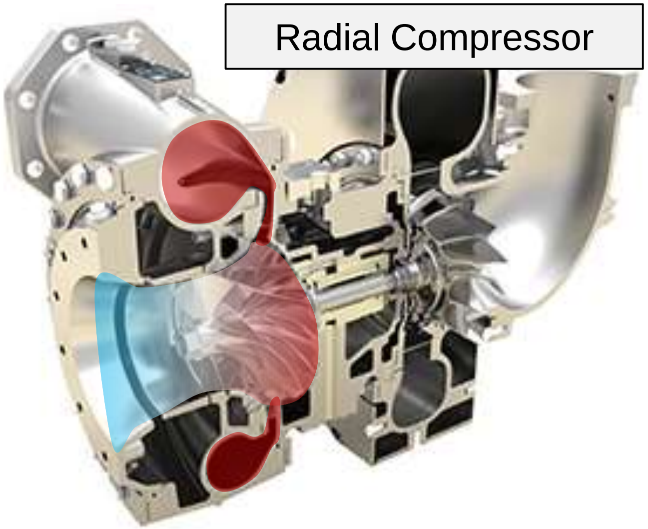
> Casing Treatments





> Compressor Performance Prediction and Loss Modelling





Radial Compressor

COMBUSTOR TURBINE INTERACTION

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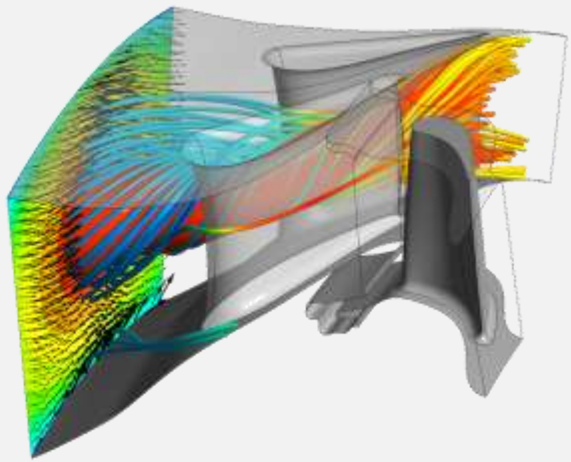
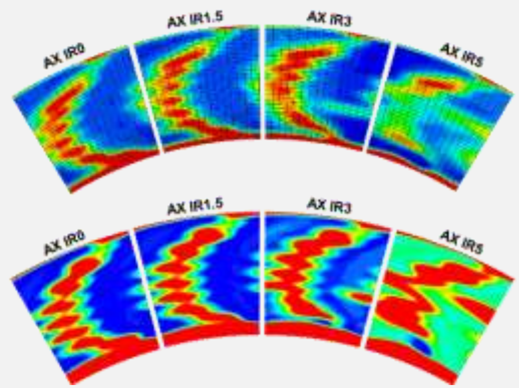
> Effect of Turbine Inlet Swirl, Temperature and Turbulence

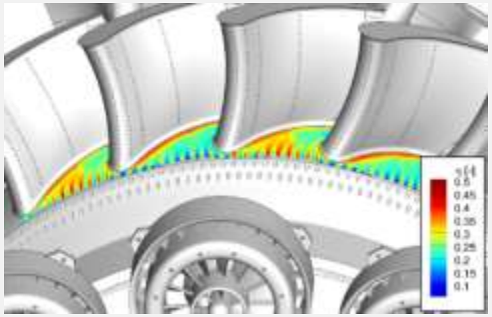


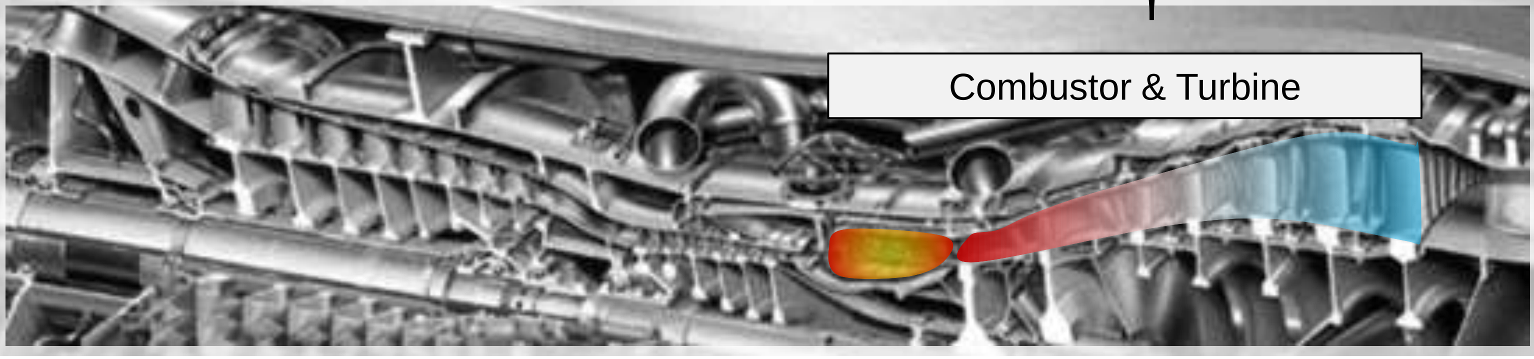
> Turbine Efficiency, Aerodynamics and Heat Transfer with Inlet Swirl



> Rotor Endwall & Tip Cooling

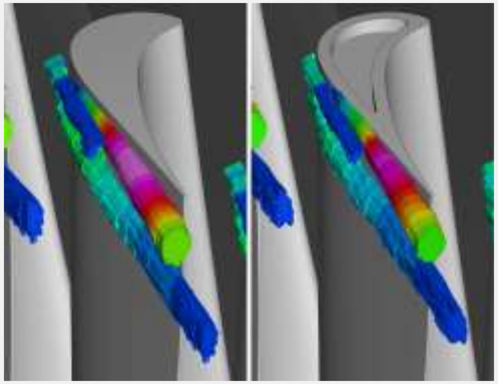
> NGV Endwall Cooling, e.g. by RIDN Flow



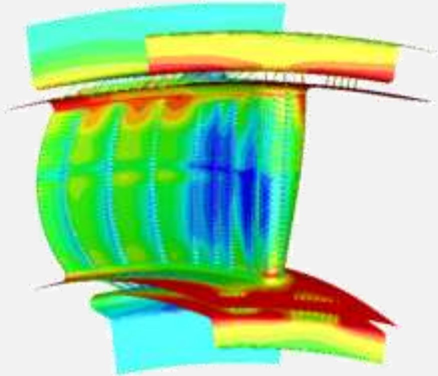


TURBINE AERODYNAMICS & COOLING

> Secondary Flows and Loss Mechanisms

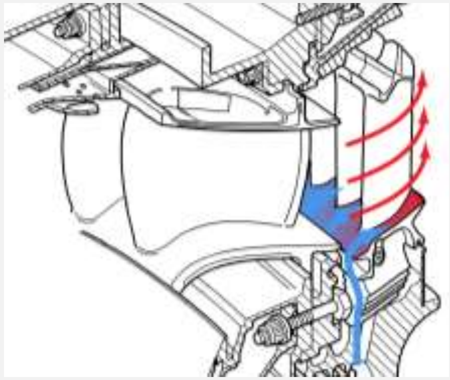


> Conjugate Thermal Analysis of Turbine Blading



© Ni et al., 2013

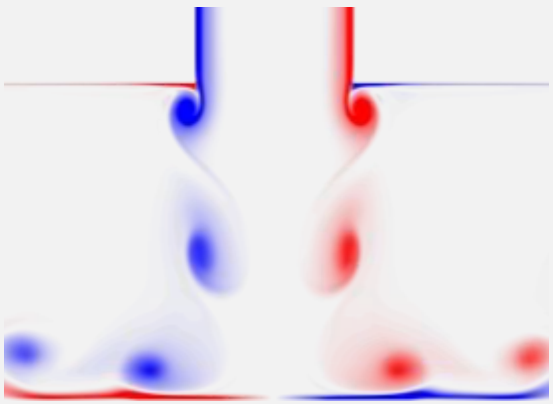
> Rotor Endwall & Tip Cooling



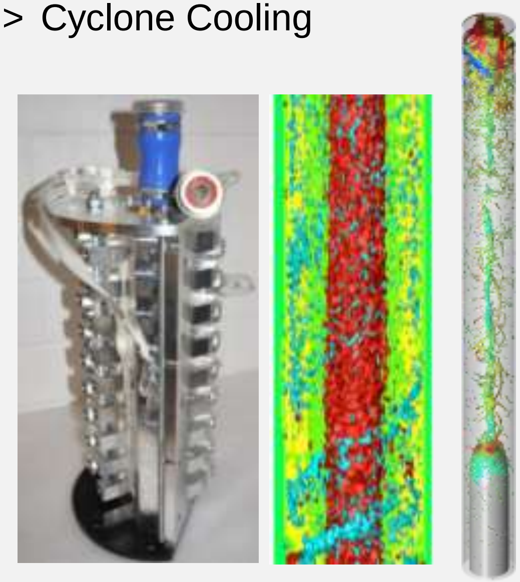
© The Jet Engine

NOVEL TECHNOLOGIES & COOLING

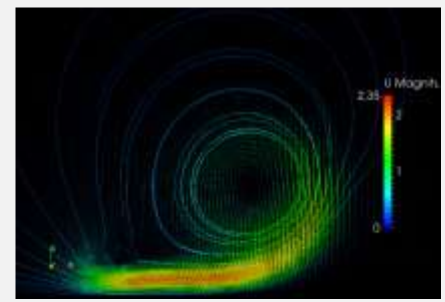
> Impingement Cooling



> Cyclone Cooling

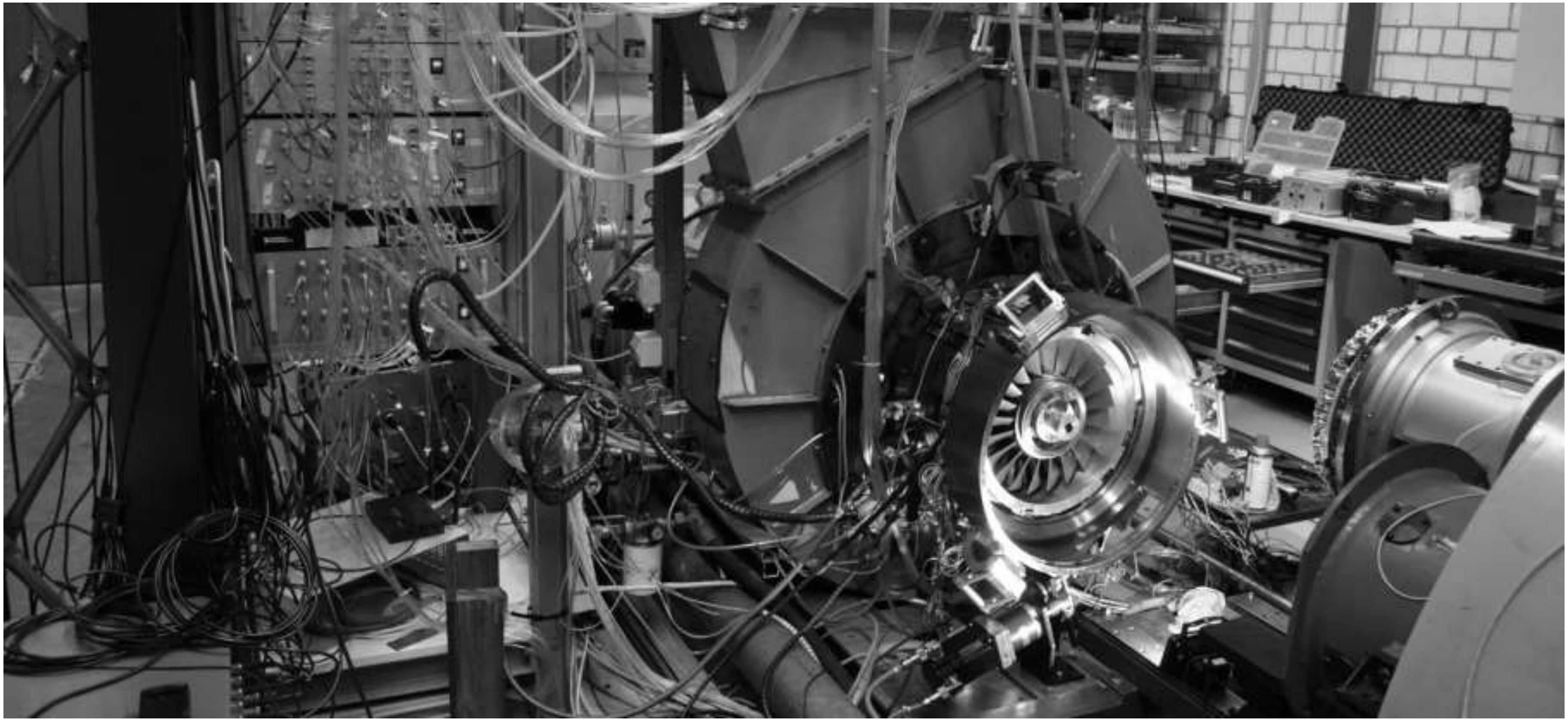


> Plasma Actuators



Gas Turbines and Aerospace Propulsion

Test Rigs



Overview of Test Rigs

Compressor Rigs

- 1,5-Stage Transonic Axial Compressor Test Rig
  1st generation
- 1,5-Stage Transonic Axial Compressor Test Rig
  2nd generation - Commissioning in 2016
- Turbocharger Test Rig

Turbine/CTI Rigs

- 2-Stage Large Scale Turbine Rig
- 1,5-Stage Turbine Rig
- Turbine Cascade Test Rig & Combustor Module

Technology Focused Rigs

- Rotational Test Rig
- Cyclone Film Cooling Test Rig
- Plasma-Actuator Test Rig

History of Turbomachinery Test Rigs at GLR

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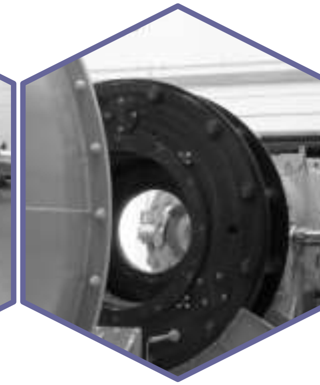
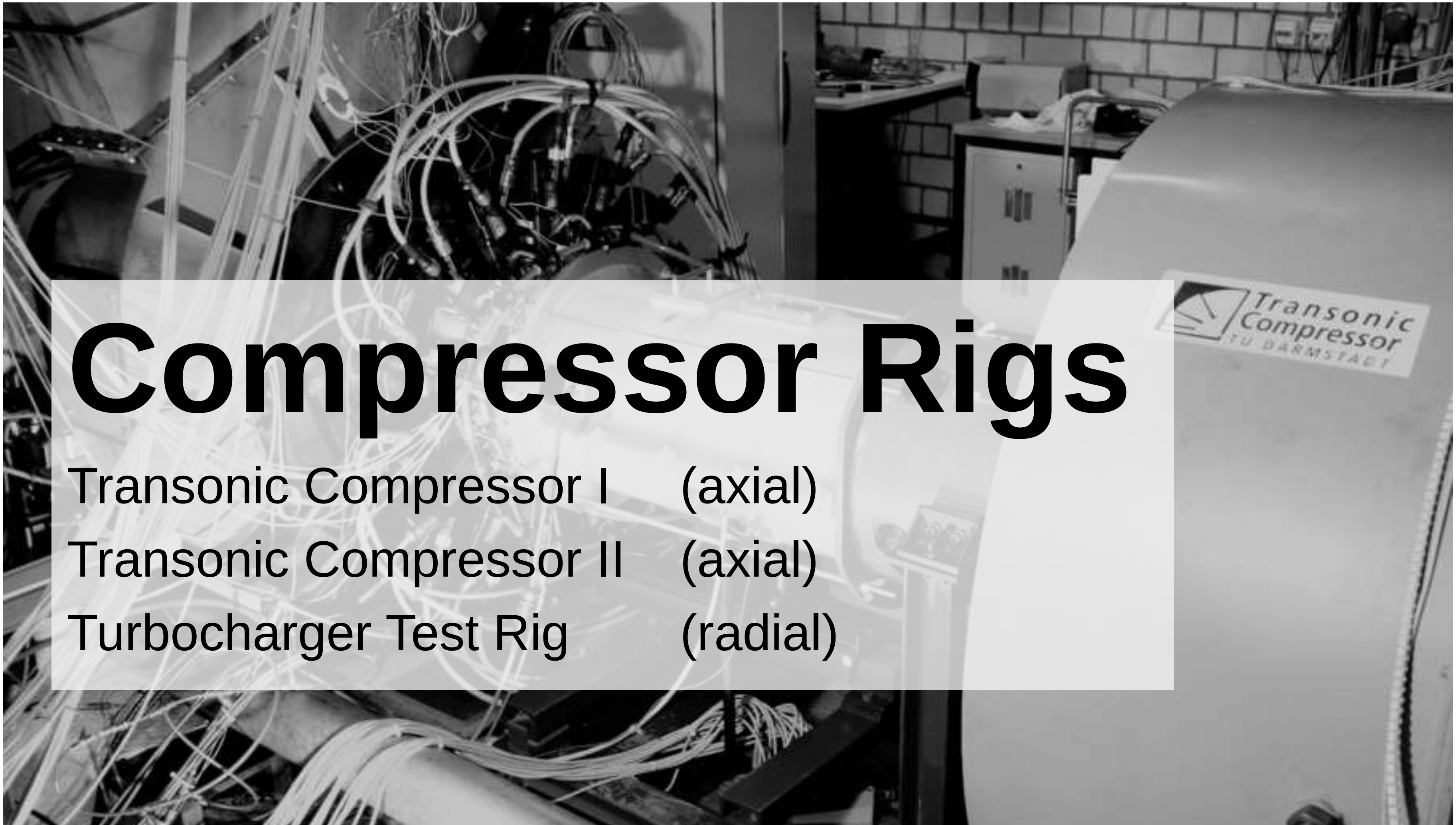


	Transonic Compressor Test Rig TSV1	Large Scale Turbine Rig	High Reynolds-Number Turbine Test Rig	Turbocharger Laboratory	Transonic Compressor Test Rig TSV2
Commis-sioning	1994	2009	2012	2014	2016
TRL	**5**	4	4	6	**5**
	• Focus on Aero- Engine Compressors	• Advanced Turbine Blading • Aerodynamic & Thermal Investigations • Combustor-Turbine Interaction	• Advanced Turbine Blading • Aerodynamic Investigations • Qualification of new Measurement Techniques	• Radial Compressor Aerodynamics • Stationary & Pulsed Inlet-Conditions	• High Flexibility: Gas Turbine Compressors + Aero Engine Compressors



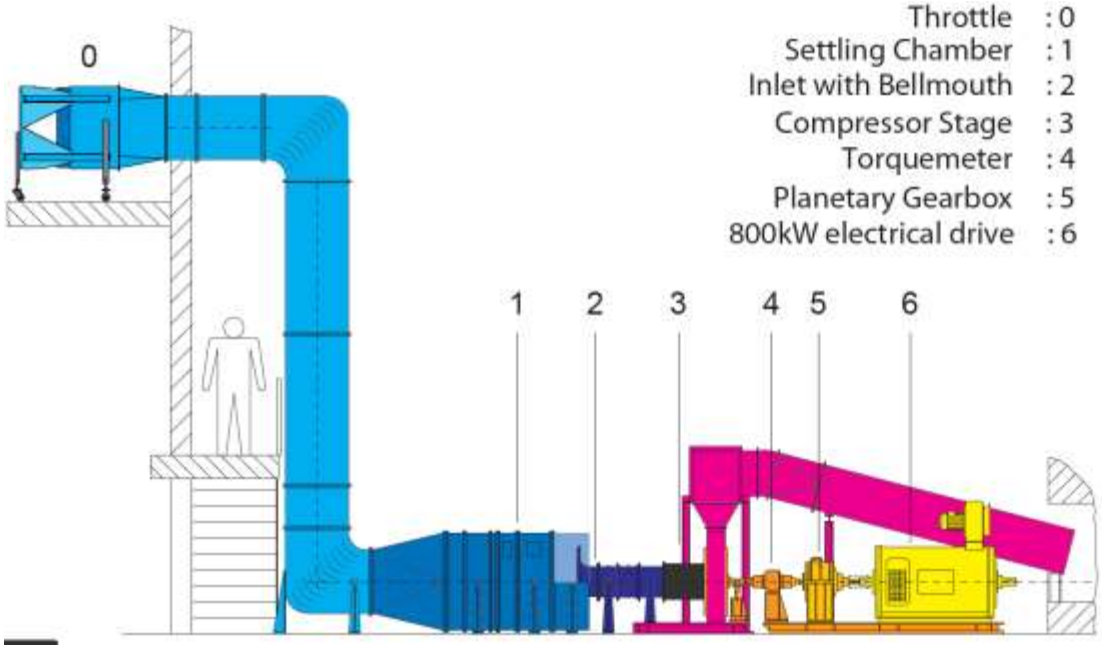
Compressor Rigs

Transonic Compressor I (axial)
Transonic Compressor II (axial)
Turbocharger Test Rig (radial)

TRANSONIC COMPRESSOR (TSV)

Introduction

- Traversable stator
- Traversable VIGV
- Exchangeable rotor casing
- Variation of inflow boundary layer by mesh inserts
- Inlet pressure variation with inlet throttle
- 6 blisk rotors + 2 CRP rotors
- 4 stators
- 2 VIGVs



Transonic Compressor Rig Schematic

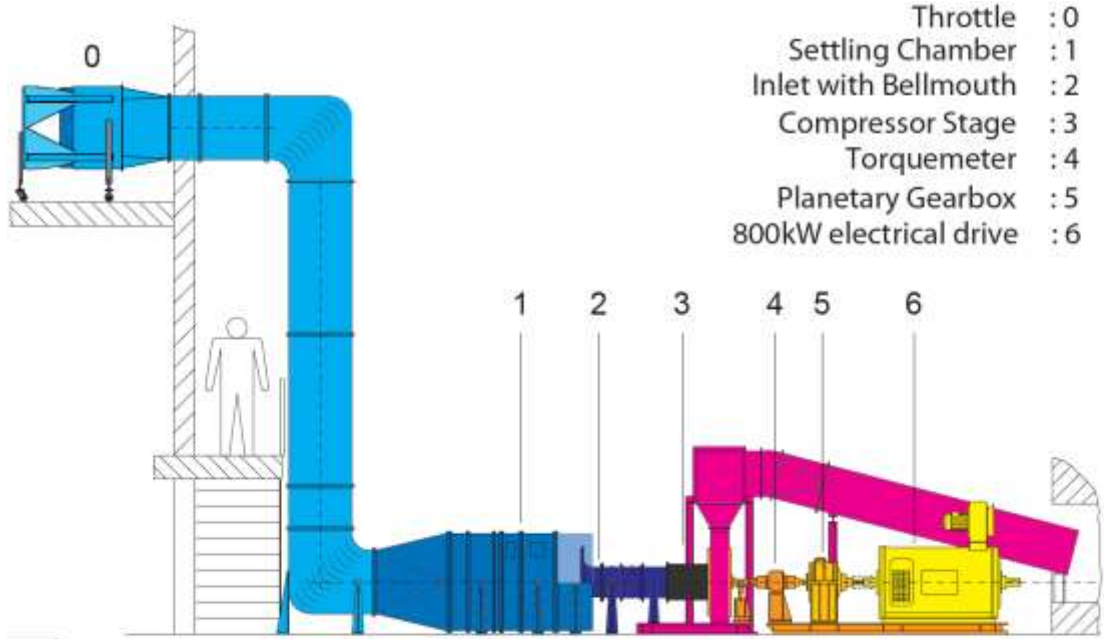
Transonic Compressor Test Rig (TSV)

Specifications

Drive Power:	800 kW
Revolutions:	20,000 rpm
Hub-Tip-Ratio:	0.51
Mass Flow:	16 kg/s
Pressure Ratio:	1.5

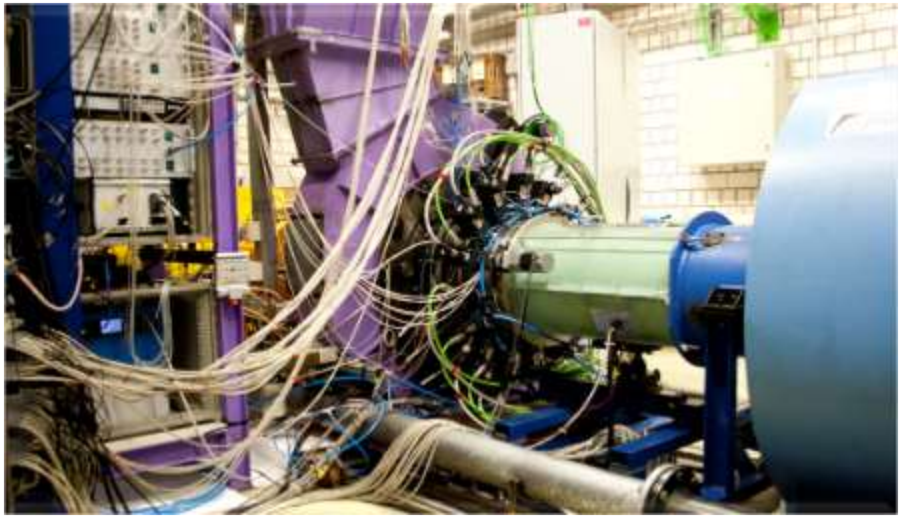
Measurement Techniques

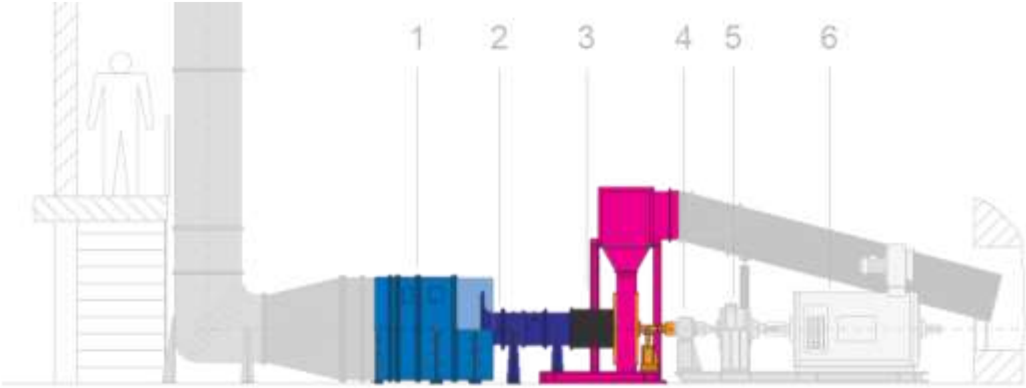
- Total Pressure and Total Temperature Rakes
- Wall Pressure Taps
- 5-hole probes
- Kulites
- Torquemeter
- Laser-2-Focus Velocimetry
- PIV (Particle Image Velocimetry
- Tip Clearance & Tip Timing (FOGALE)
- Strain gauges (telemetry system)



Transonic Compressor Rig Schematic

Transonic Compressor Test Rig (TSV)





TSV - Instrumentation

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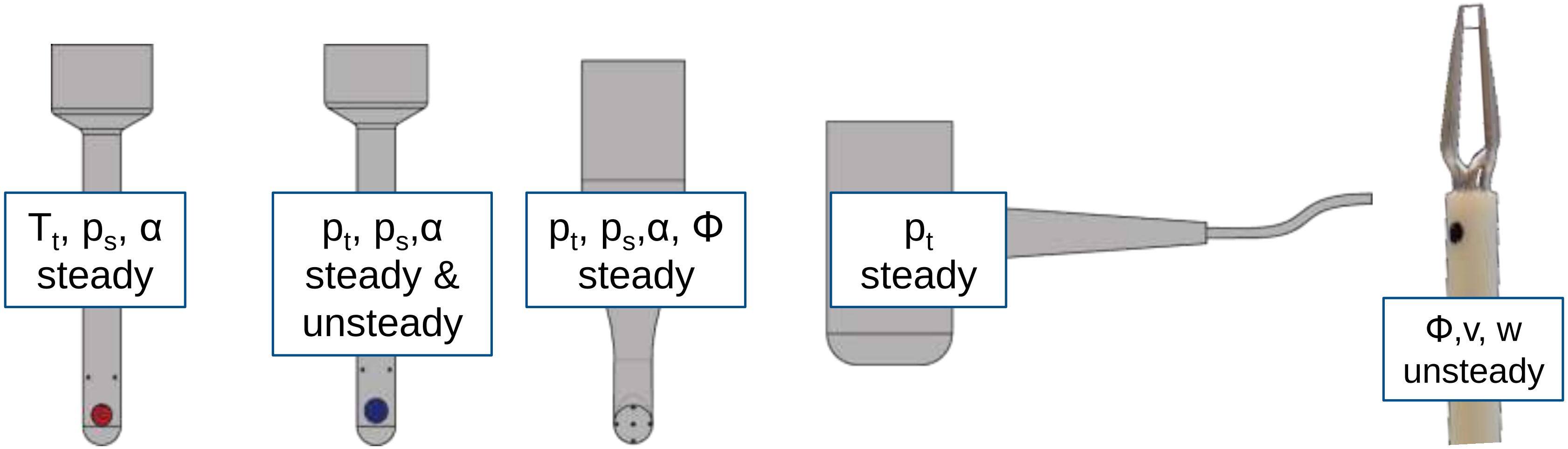
Instrumentation

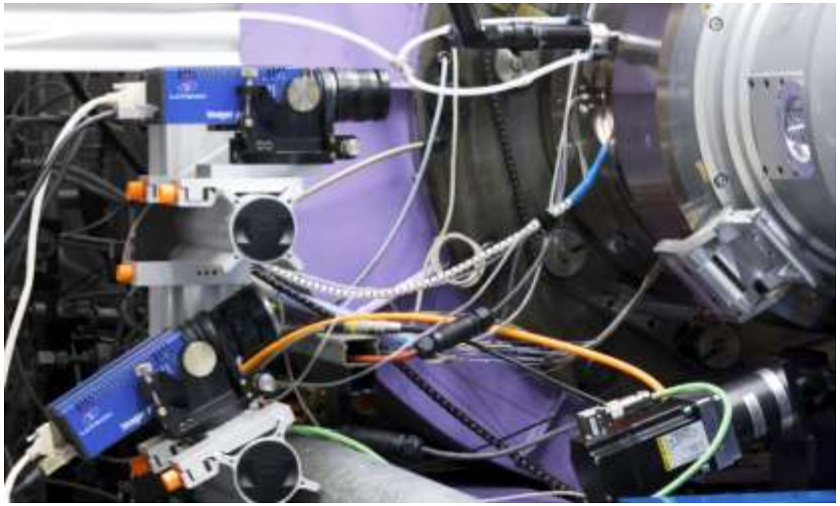
- In-house designed and assembled probes
- In-house
    - steady pressure
    - dynamic (shock tube)
    - free stream channel



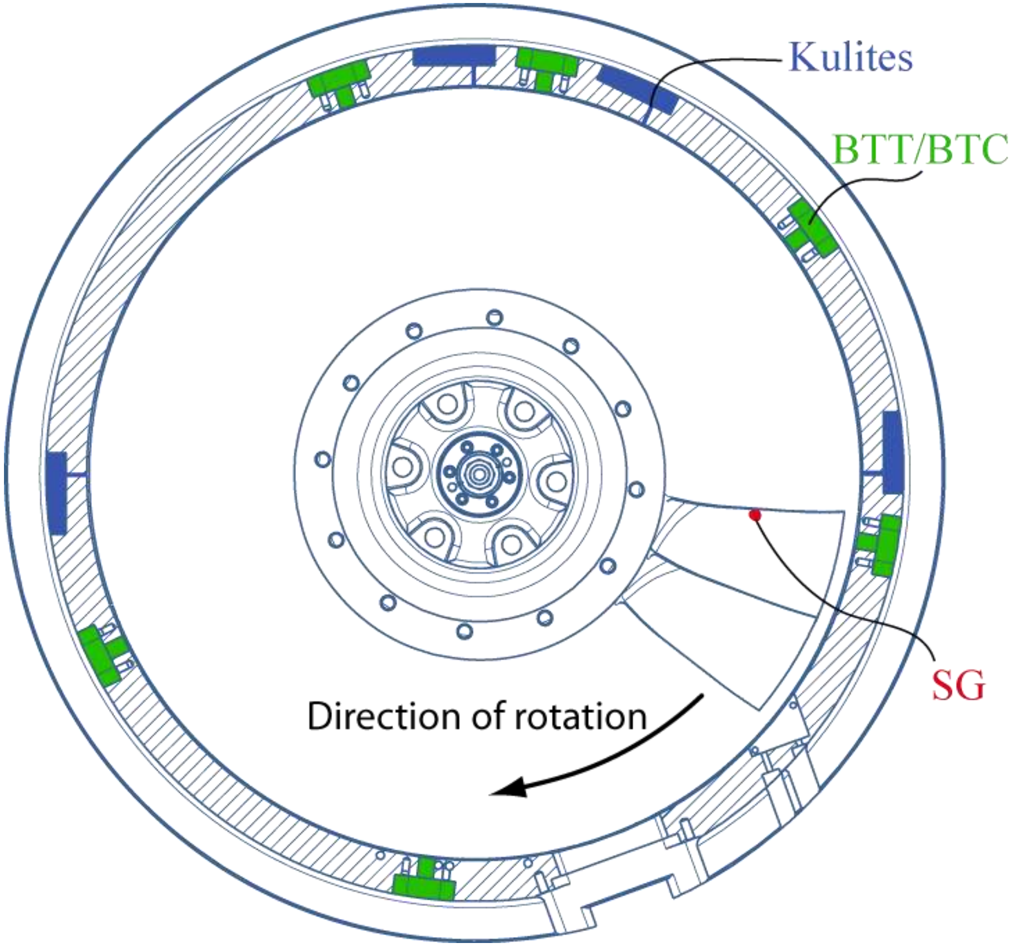
TSV – PIV Instrumentation

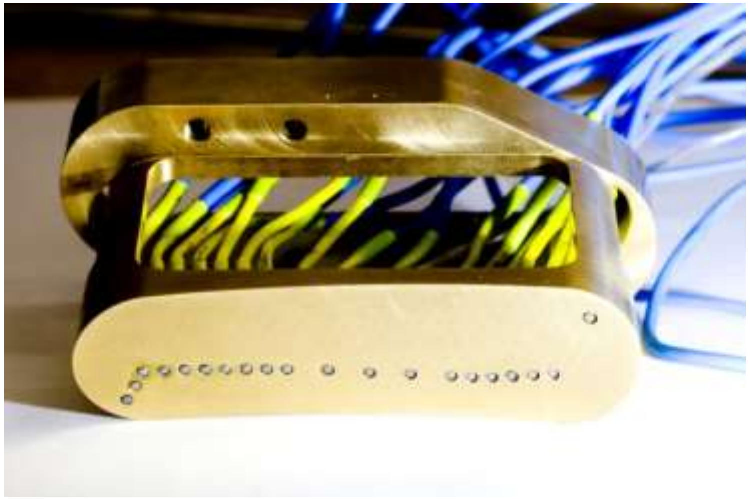
PIV Instrumentation

- In-house designed light sheet probes
- Tip gap measurements with casing treatments
- Stereo PIV



TSV – Tip Timing and Tip Clearance

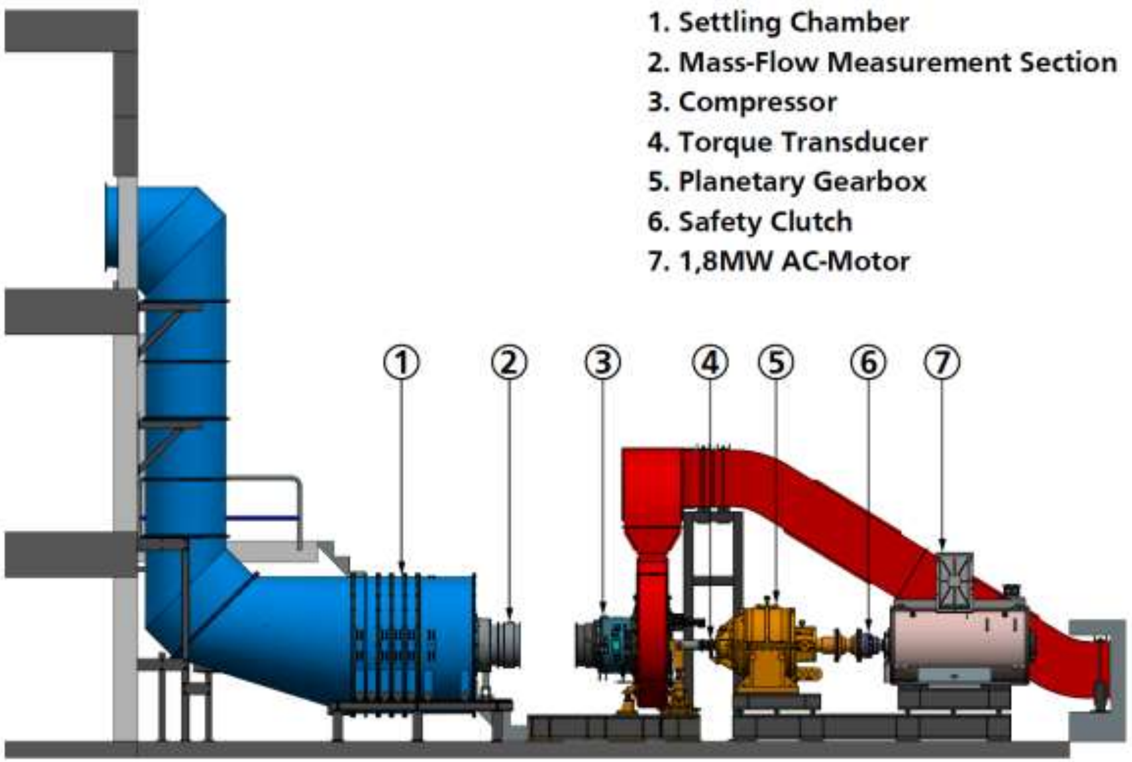




TRANSONIC COMPRESSOR II

Introduction

- Based on knowledge gained at Transonic Compressor Test Rig TSV1
- Fully variable guide vanes
  - area traversable
- Design optimized for short turn-around times
- Compared to TSV I:
  - Improved geometrical flexibilty (e.g. hub to tip ratio, blade aspect ratio, blade gapping)
  - Exchange of full compressor module
  - Increased pressure ratios and/or two stage configuration



Transonic Compressor Rig II Schematic

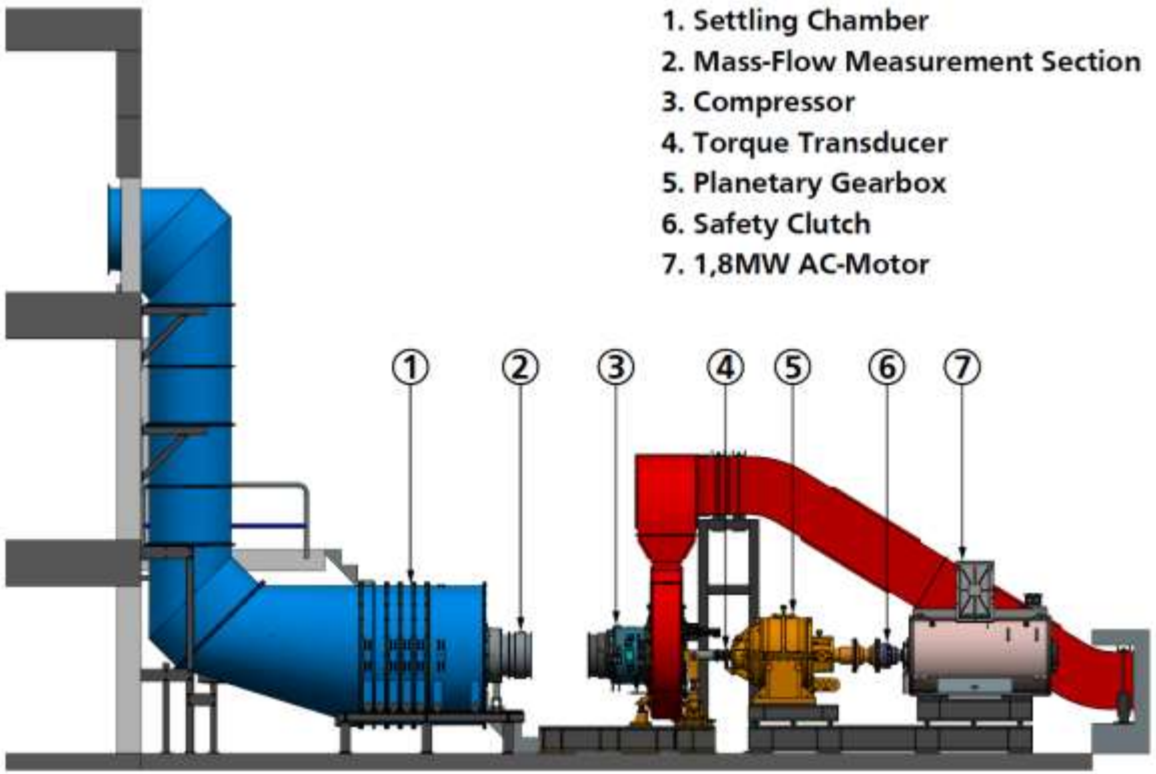
Transonic Compressor Test Rig II

Specifications

Drive Power:	2000 kW
Revolutions:	20,000 rpm
Mass Flow:	27 kg/s
Pressure Ratio:	> 1.6

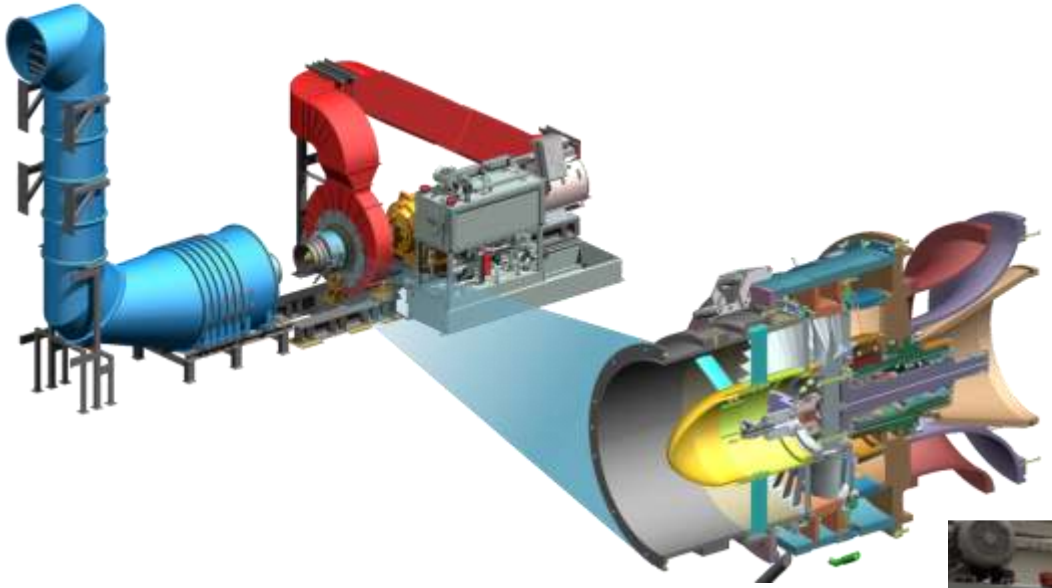
Measurement Techniques

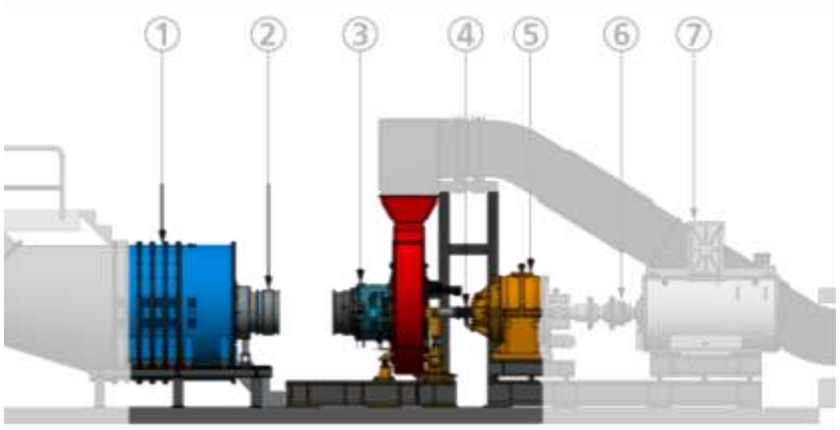
- Total Pressure and Total Temperature Rakes
- Wall Pressure Taps
- 5-hole probes
- Kulites
- Torquemeter
- PIV

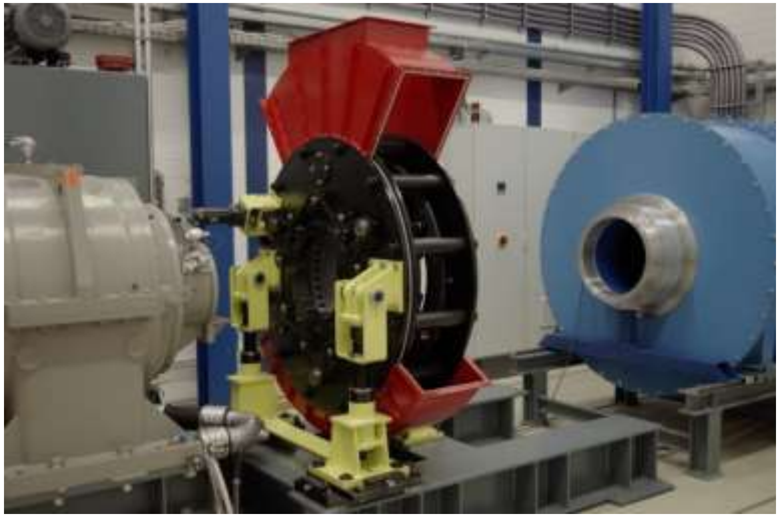


Transonic Compressor Rig II Schematic

Transonic Compressor Test Rig II







TURBOCHARGER LABORATORY (TCL)

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Specifications

Max. Mass Flow: 0.8 kg/s

Max. Pressure: 4.5 bar abs

Outlet/Inlet Throttle

Pressure Pulsation Unit at Compressor Outlet

Measurement Techniques

- Stationary Wall Pressure Taps
- Shaft Speed
- Thermocouples/Pt100
- Dynamic Pressure Sensors
- Traverse System (Total Pressure, Velocity, Turbulence)

TCL - Additional Units

Pressure Pulsation Unit

- Investigation of interaction between piston engine and turbocharger
- Adaption of 1-4 cylinder piston engines
- Crank shaft speed: up to 6000U/min
- Bypass circuit
- Low degree of abstraction

Traverse Unit

- Direct measurement of total pressure distribution at outlet by 4-Hole Pressure Probe

Turbine & CTI Rigs

Large Scale Turbine Rig (LSTR)

High Reynolds Number Turbine (HiReNT)

Turbine Cascade Rig

LARGE SCALE TURBINE RIG (LSTR)

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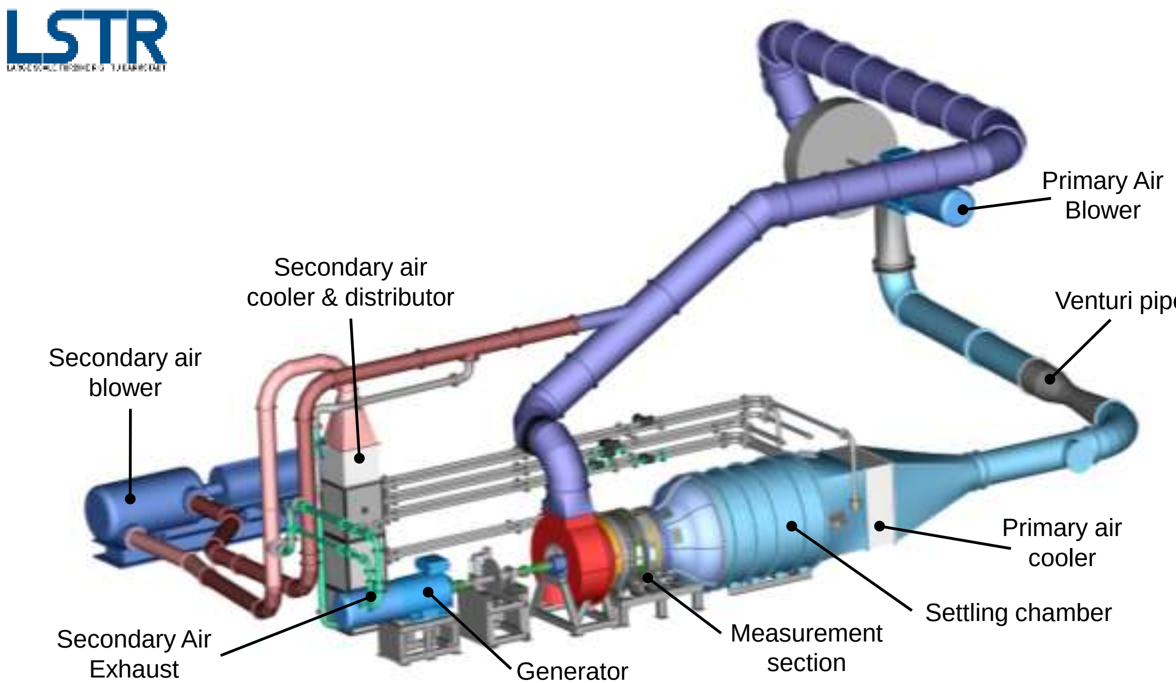
Specifications

Mass flow (MF):	14.5 kg/s
Pressure ratio:	1.15
Rotational speed:	1,000 rpm
Number of blades:	24-36-34
Swirler-NGV-count:	1:2
Span height:	130 mm
Annulus diameter:	1136 mm
Coolant mass flow:	20% MF
Nominal power:	2 MW

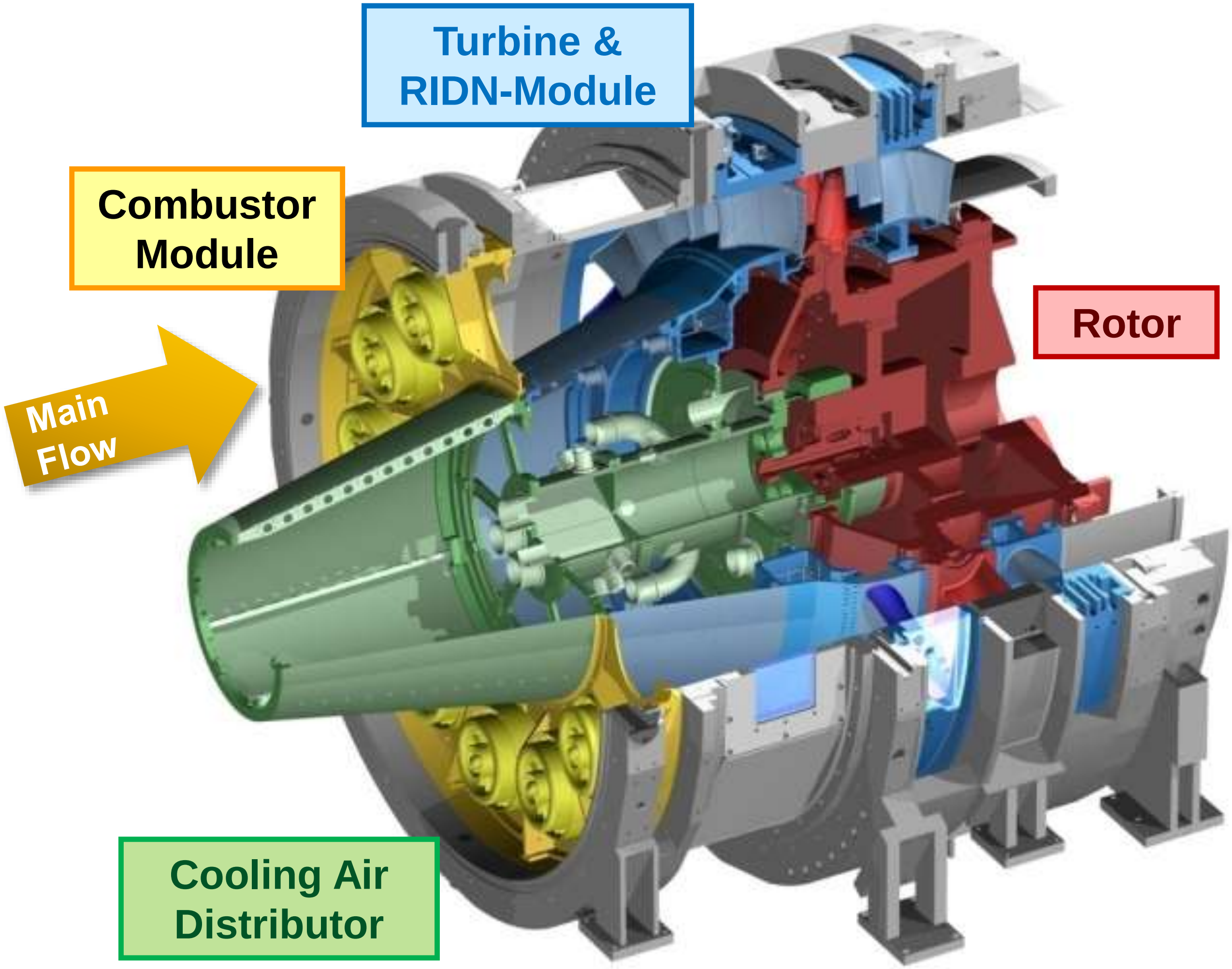
Measurement Techniques

- Wall Pressure Taps
- 5-hole probes
- Hot Wire
- PIV
- IR-Thermography
- CO2 Tracing

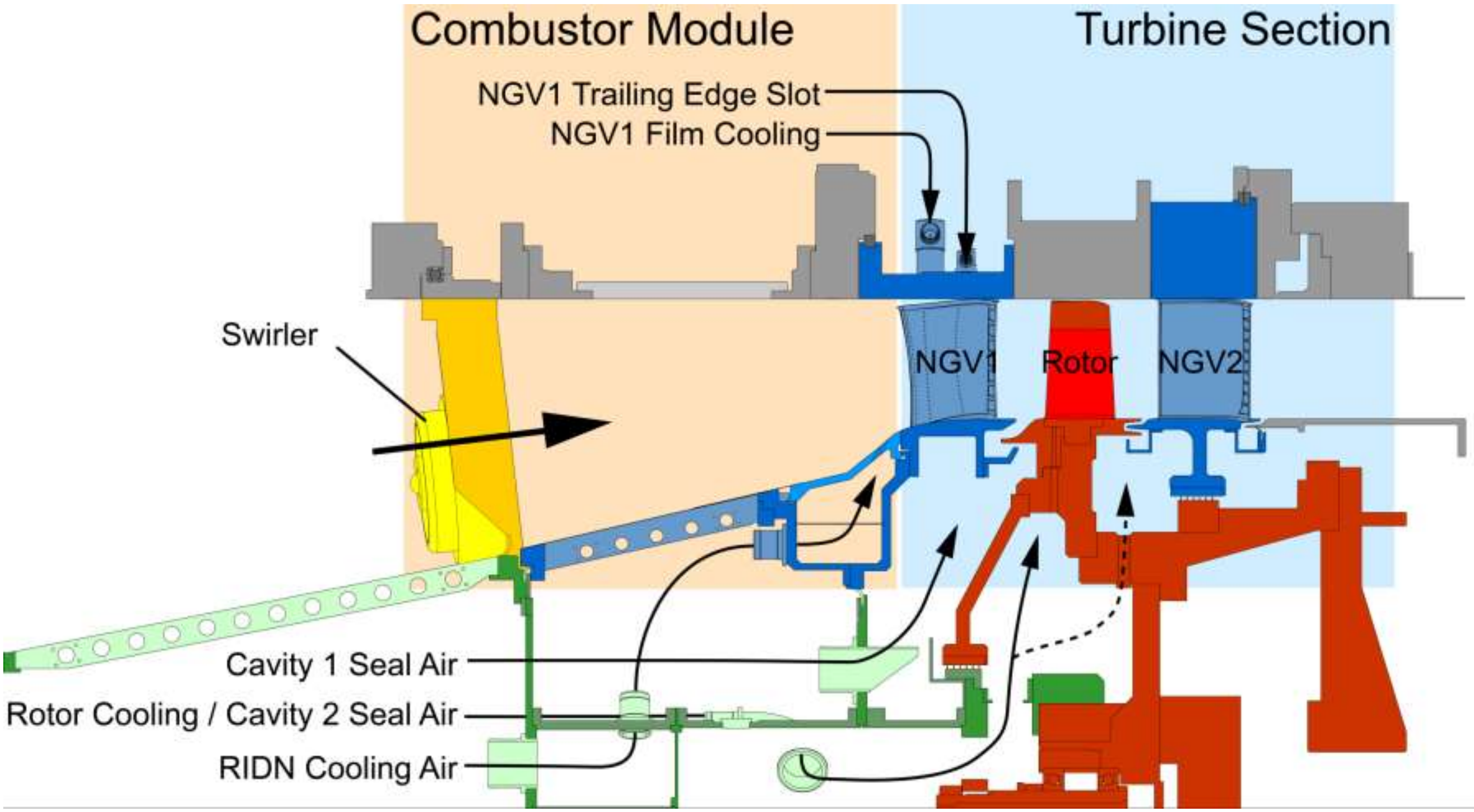


LSTR Rig Schematic

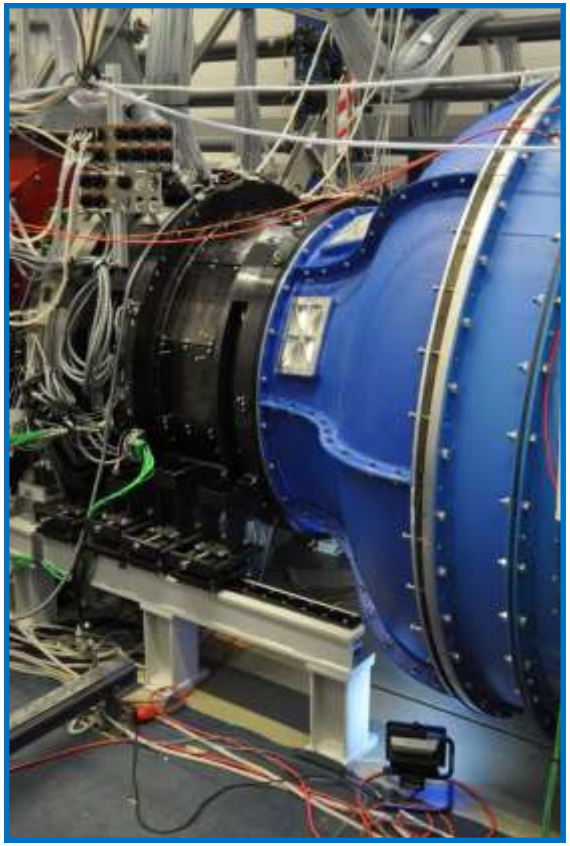
LSTR - Measurement Section

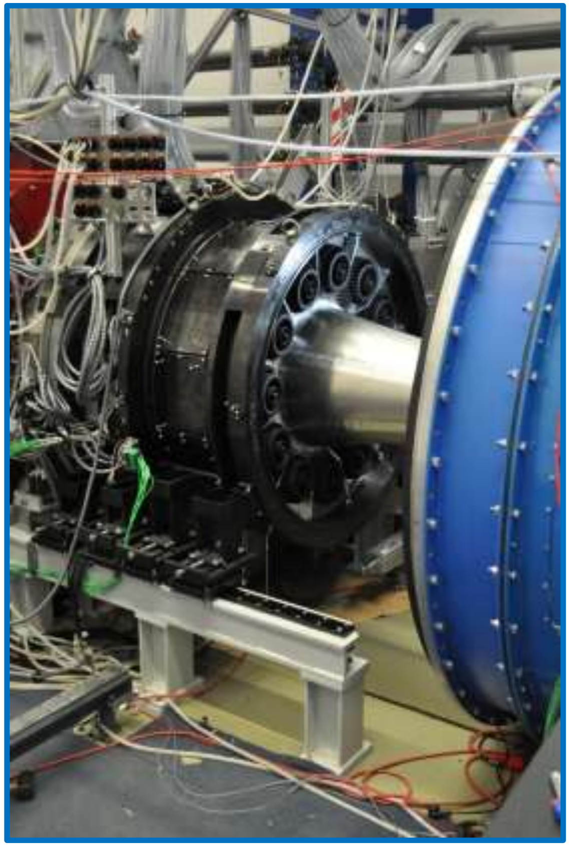


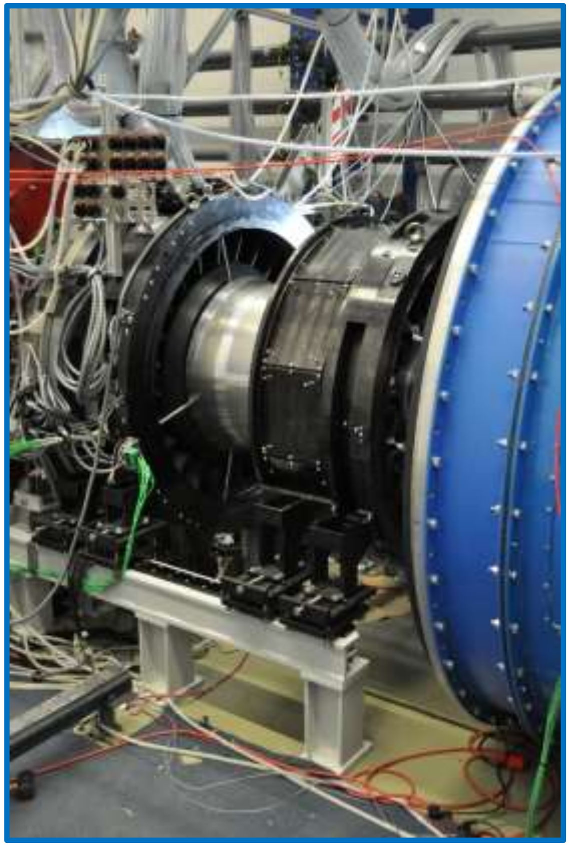
LSTR - Measurement Section



LSTR - Access Times



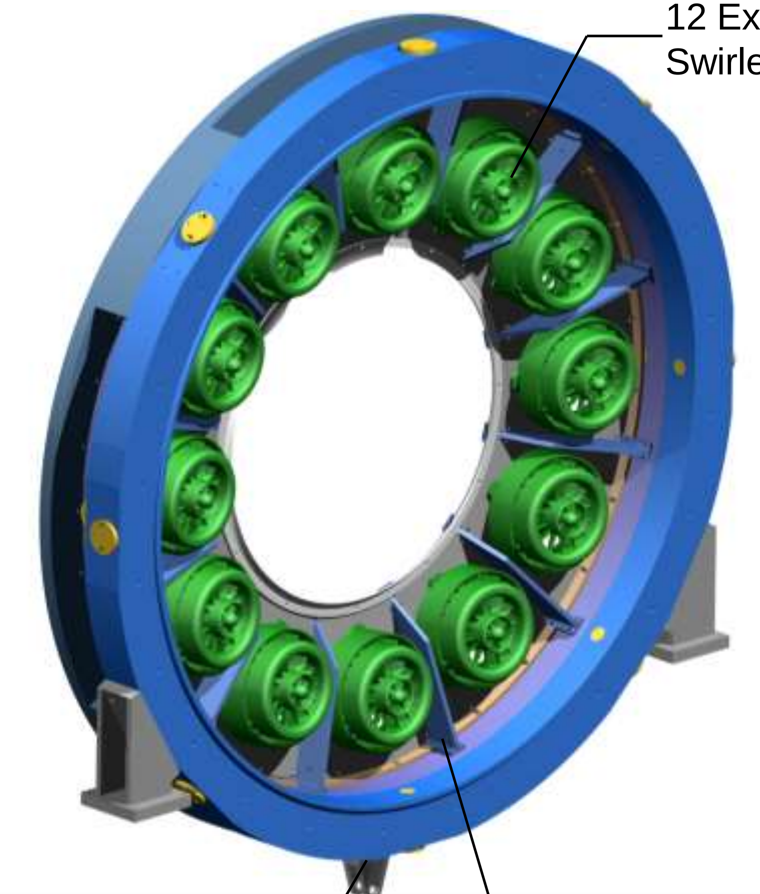


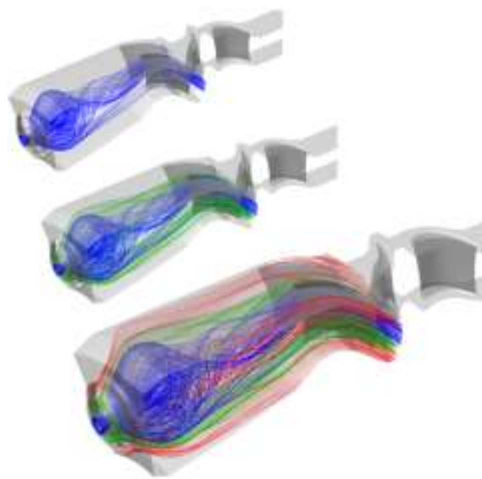


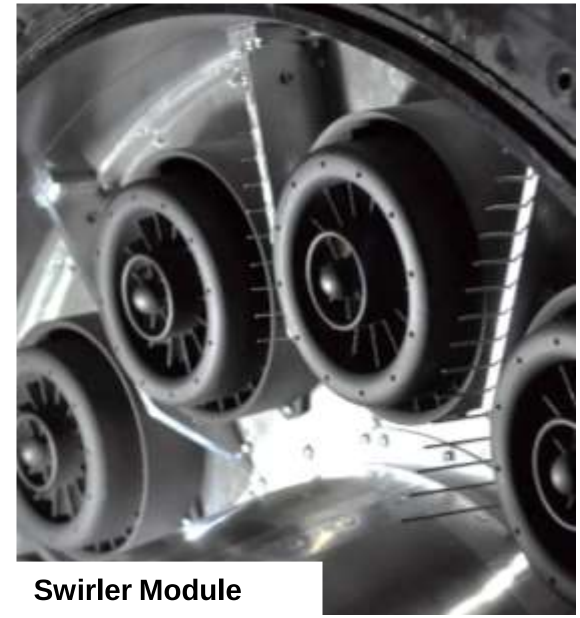
Closed Rig ⟷ Combustor Access ⟷ NGV / RIDN Access

2 hrs — 15 min

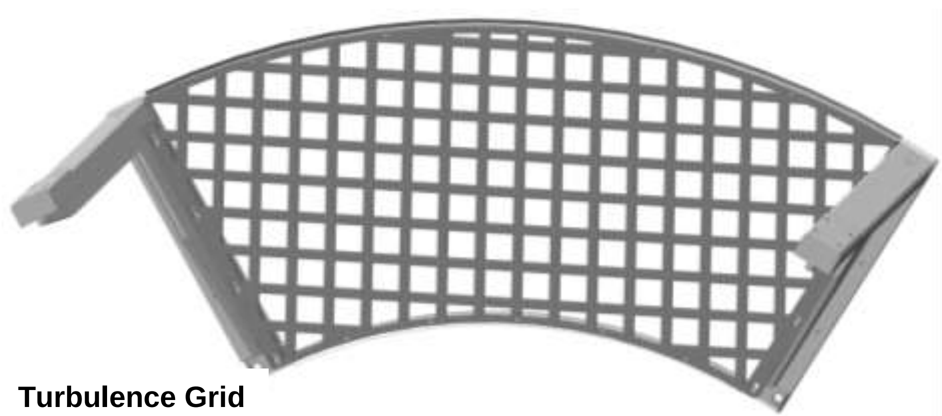
LSTR - Combustor Simulator Module





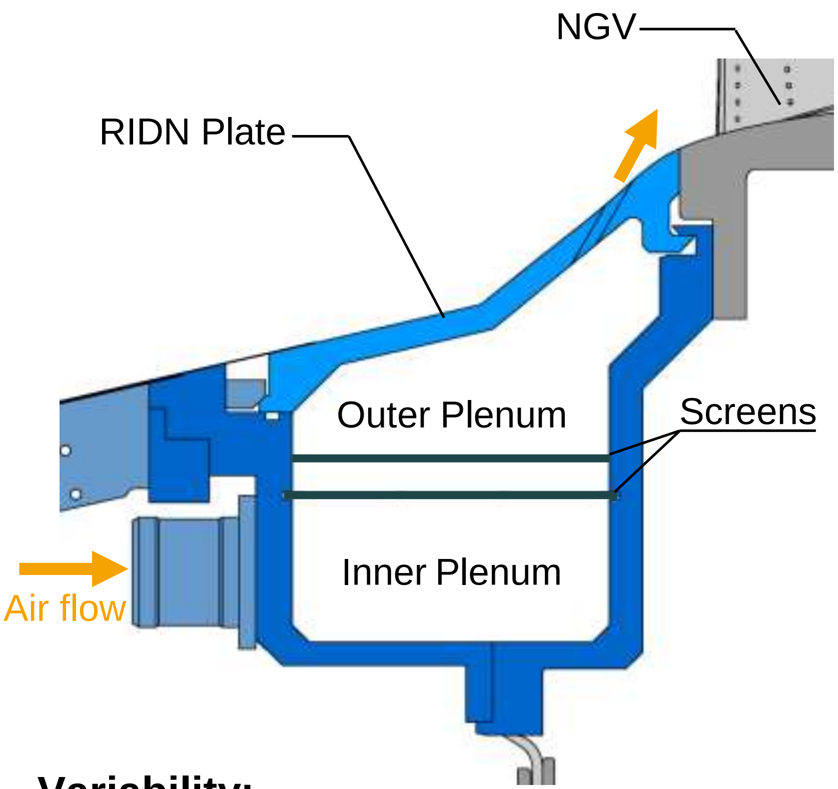


Swirler Module

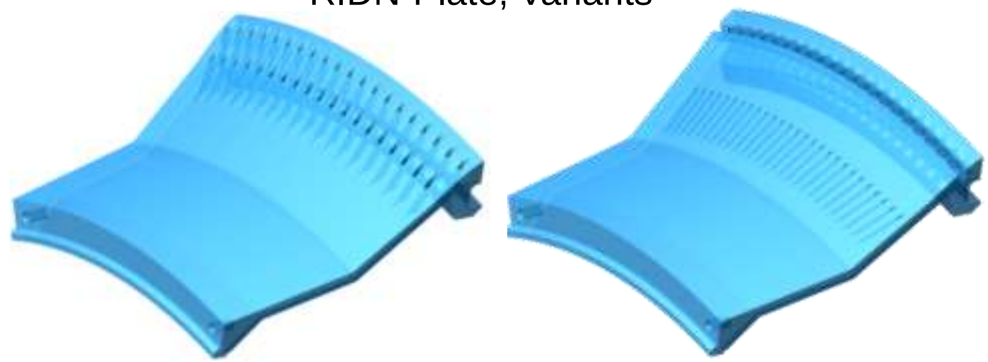


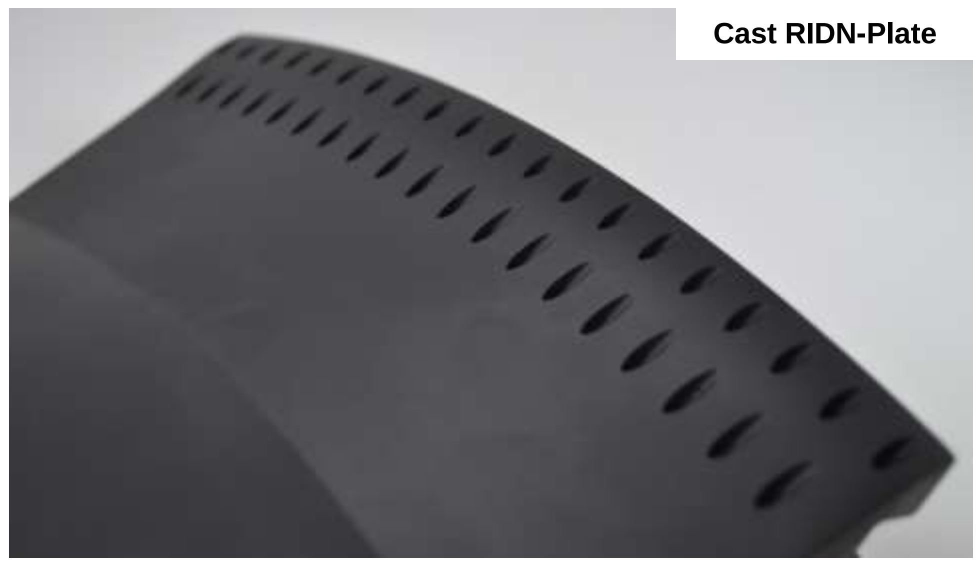
Turbulence Grid

LSTR - RIDN / Hub Side Coolant Injection



RIDN-Plate, Variants



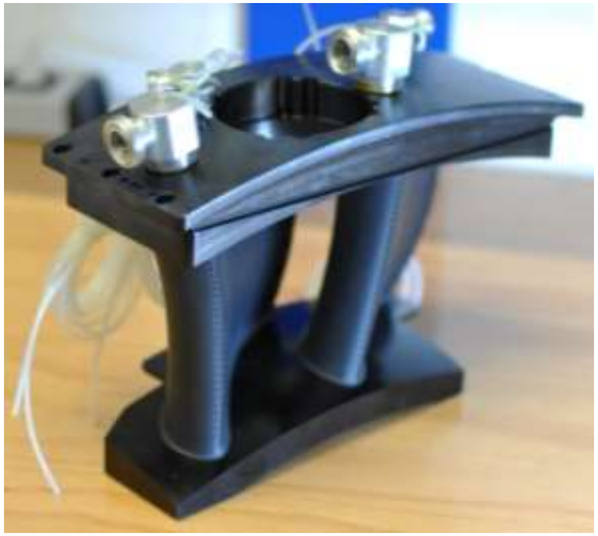


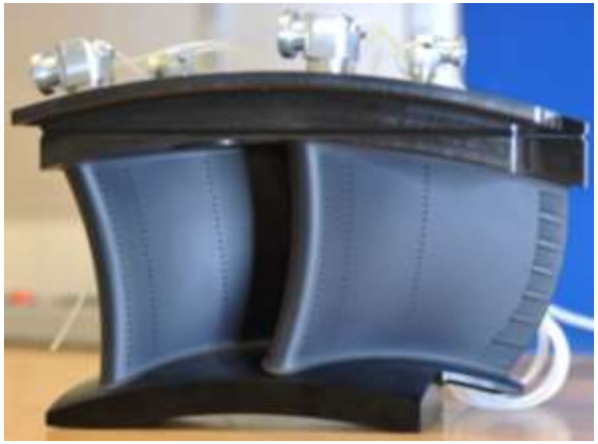
Cast RIDN-Plate

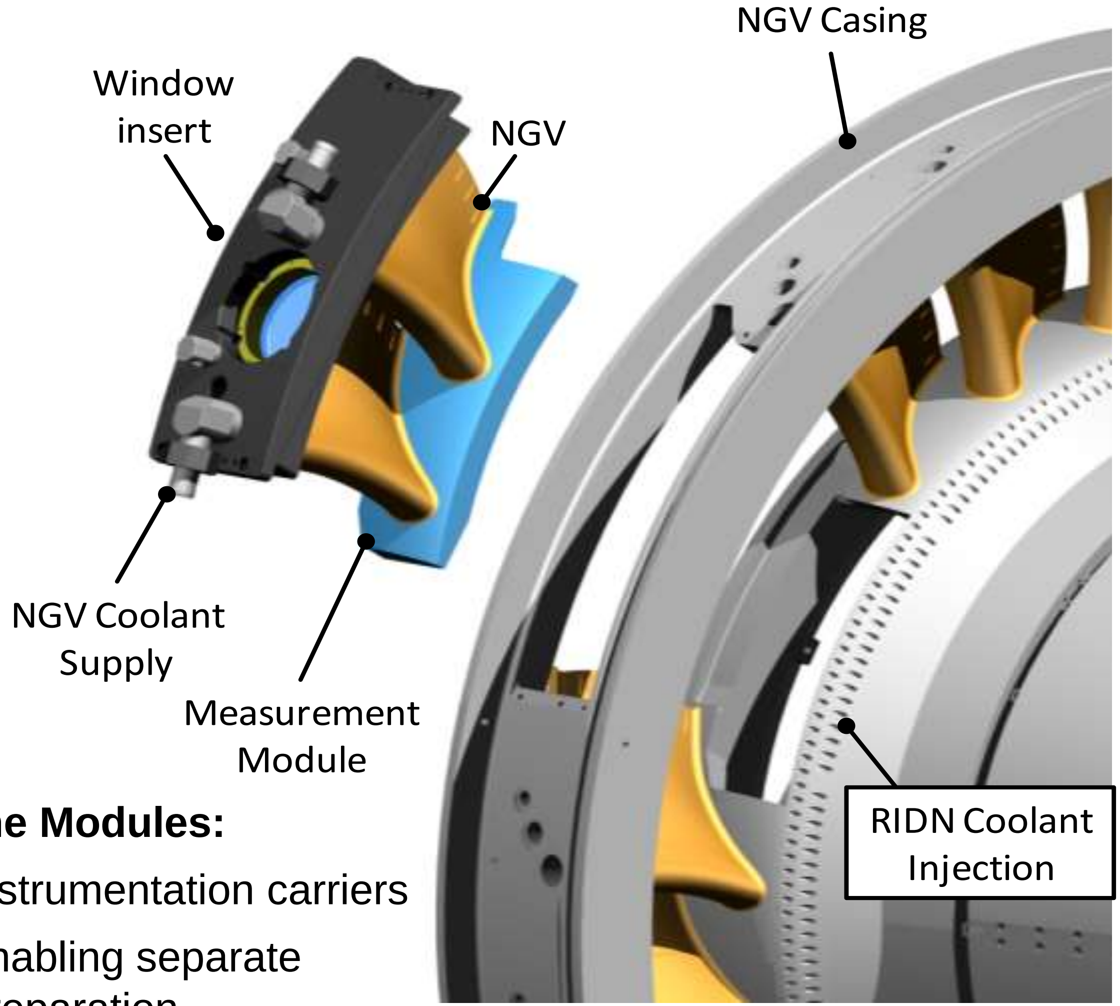
Variability:

- Blowing Ratio
- Injection geometry
- Seeding options (Gas Tracing, PIV)

LSTR - Measurement Vane Modules







Vane Modules:

- instrumentation carriers
- enabling separate preparation

LSTR - Rotor Section

- 36 exchangeable blades
- Fast access through casing window
- Blades and/or tips used as instrumentation carrier
- Blade cooling available
- Enabling separate pre-test preparation

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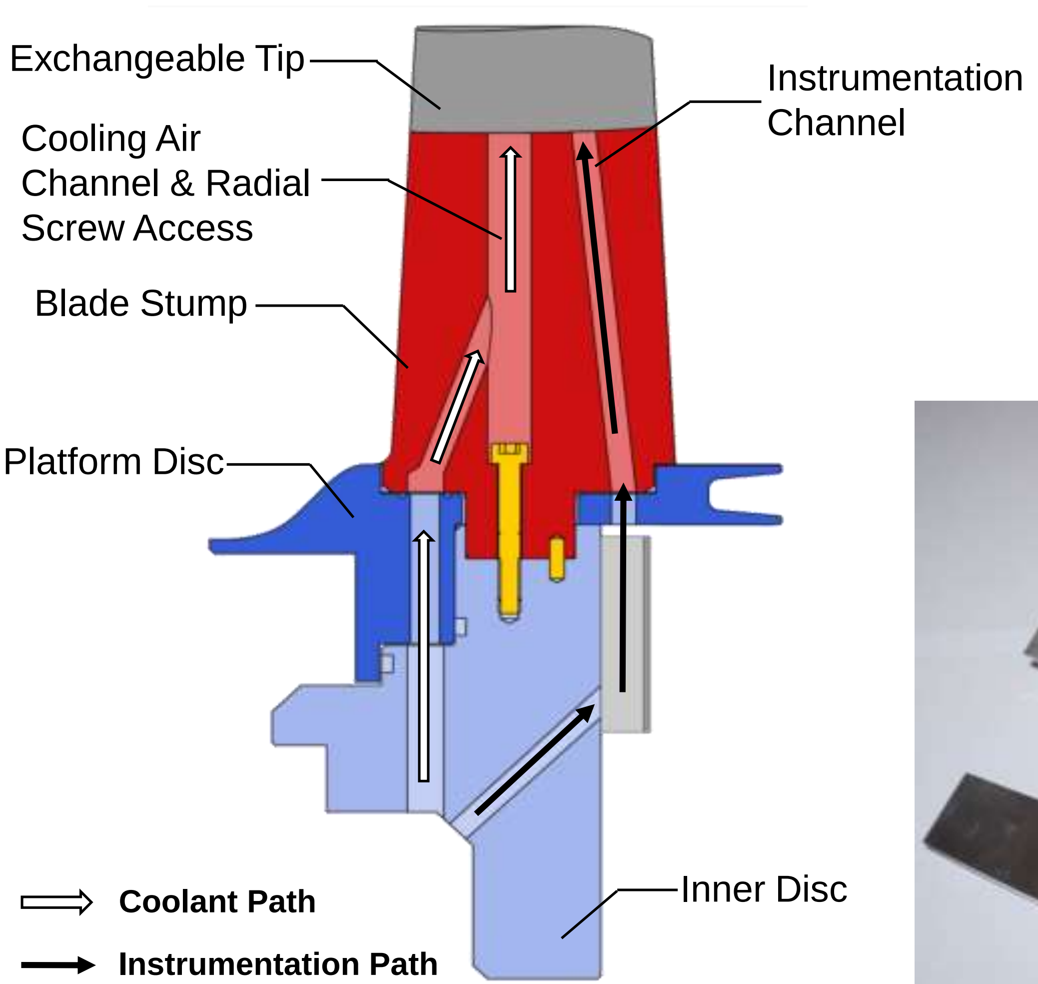
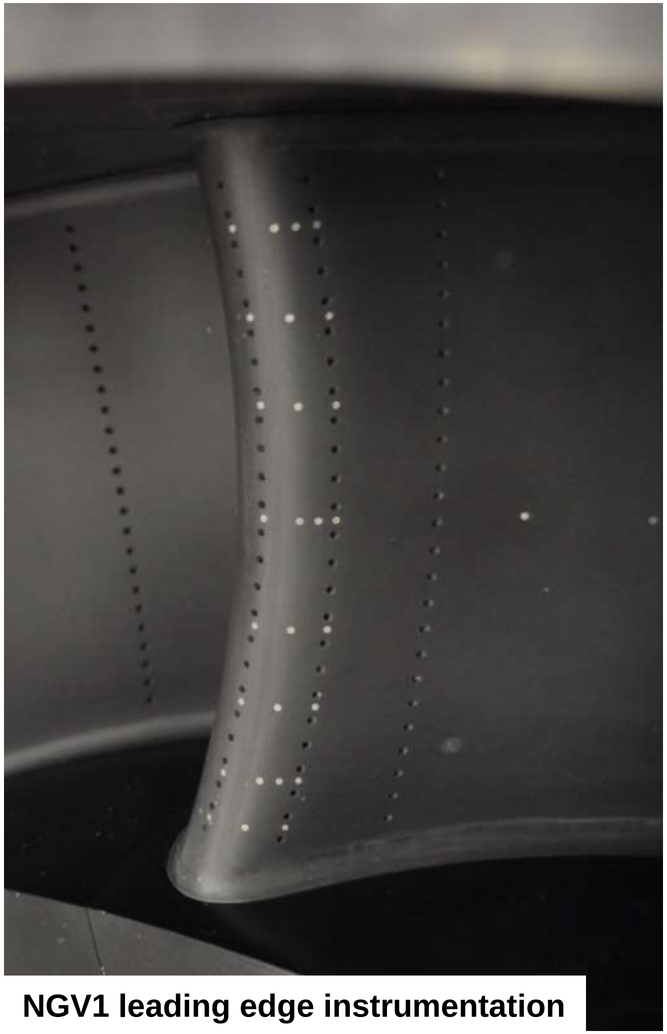
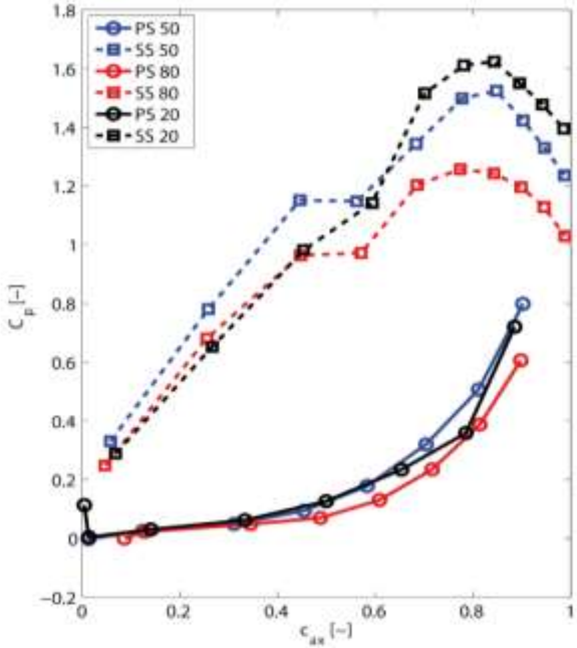
LSTR - Rotor Details



LSTR - NGV1 Static Pressure Taps



NGV1 leading edge instrumentation



- Leading edge instrumentation (5 parallel rows)
- Profile pressure taps SS+PS at 20 / 50 / 80% SH
- 8 instrumented vanes distributed over annulus

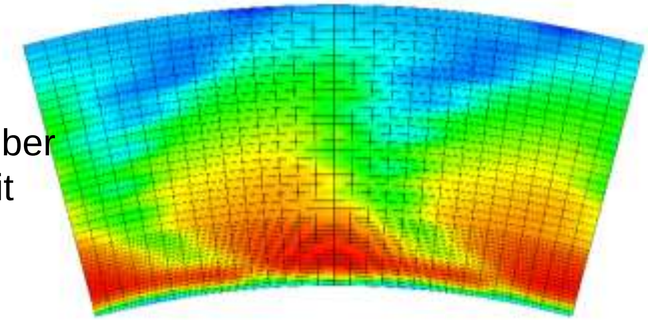
LSTR - 5-Hole-Probes

- Measurement of steady 3D flow field
- Tip Diameter: 1.5 mm

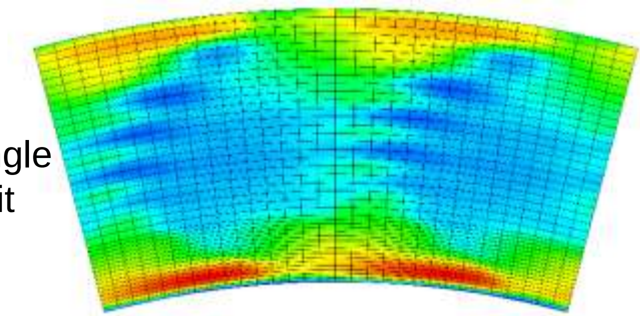
Traversing Unit:

- radial translation
- yaw angle variation
- pitch angle adjustment by clocking of stators / swirler

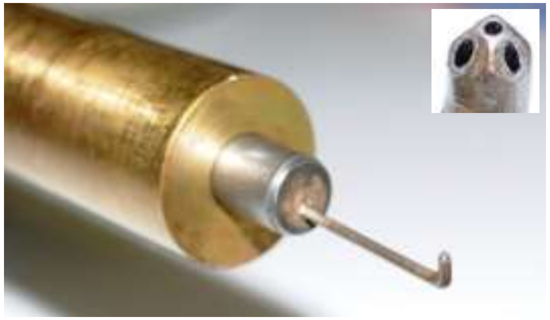
Ma-number NGV-exit



Whirl angle NGV-exit



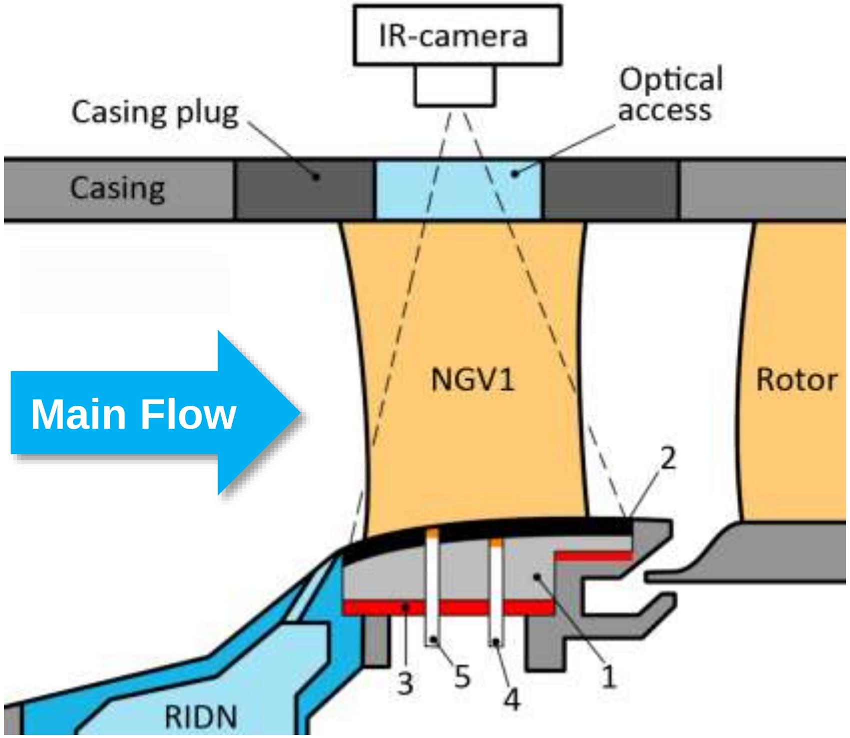
2-axis probe traversing unit



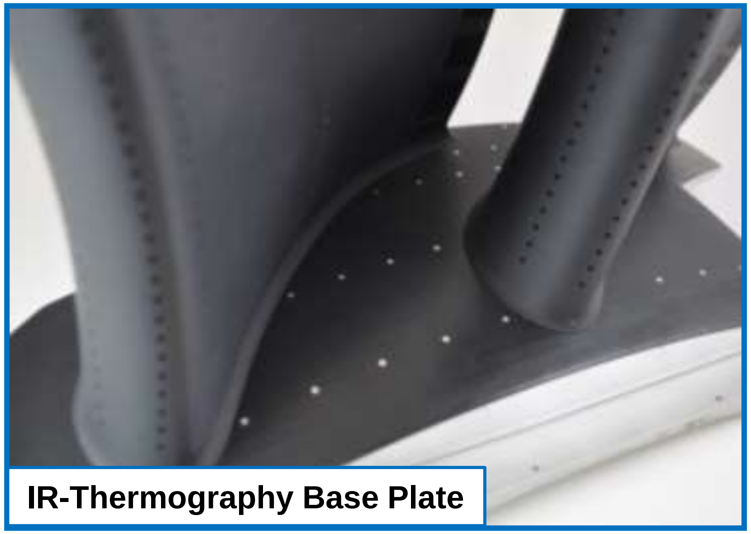
5-Hole-Probe

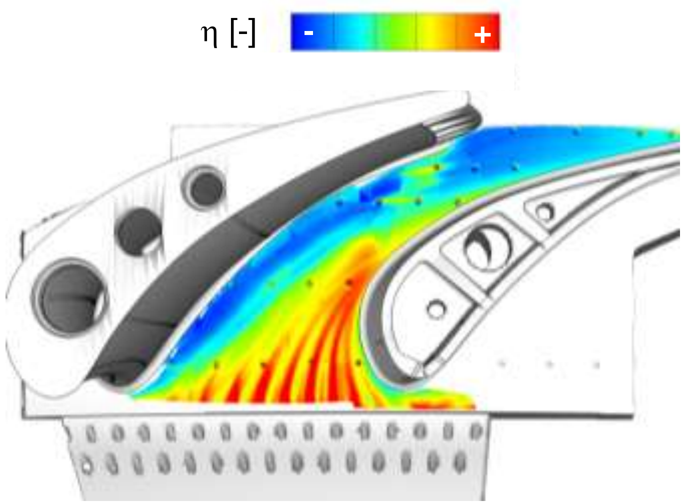
LSTR - IR Thermography

Auxiliary Wall Method → HTC + FCE

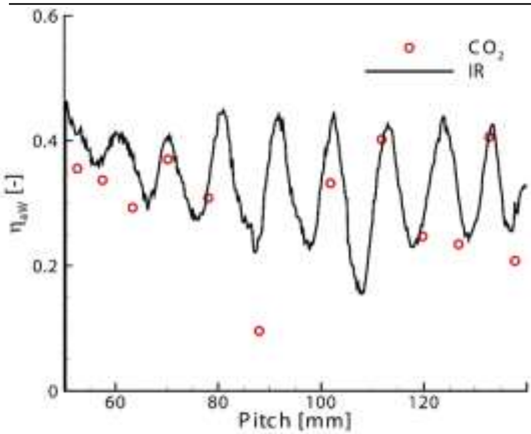


1 - Aluminium Base Plate
2 - Auxiliary Wall (ETFE)
3 - Heater Foils
4 - Base Temperature TC
5 - Reference TC

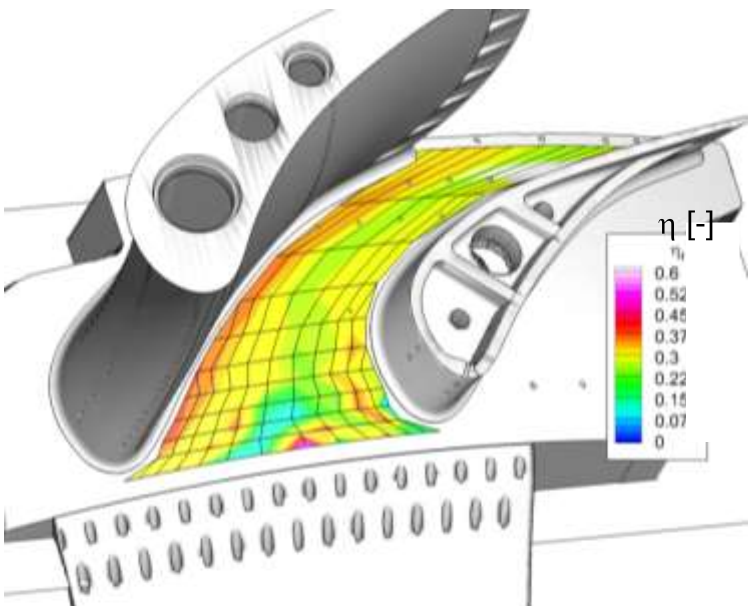

IR-Thermography Base Plate



LSTR - CO_2 Tracing



Base Plate with static pressure taps / FCE Base Plate



- Seeding of individual cooling air flows with foreign gas (CO_2)
- Use of static pressure taps for gas sampling
- Film cooling effectiveness as function of foreign gas concentration

$$\eta_{aW} = \frac{c_{meas} - c_{main}}{c_{sec} - c_{main}}$$

- LSTR operated in partly open configuration

HIGH REYNOLDS NUMBER TURBINE (HiReNT)

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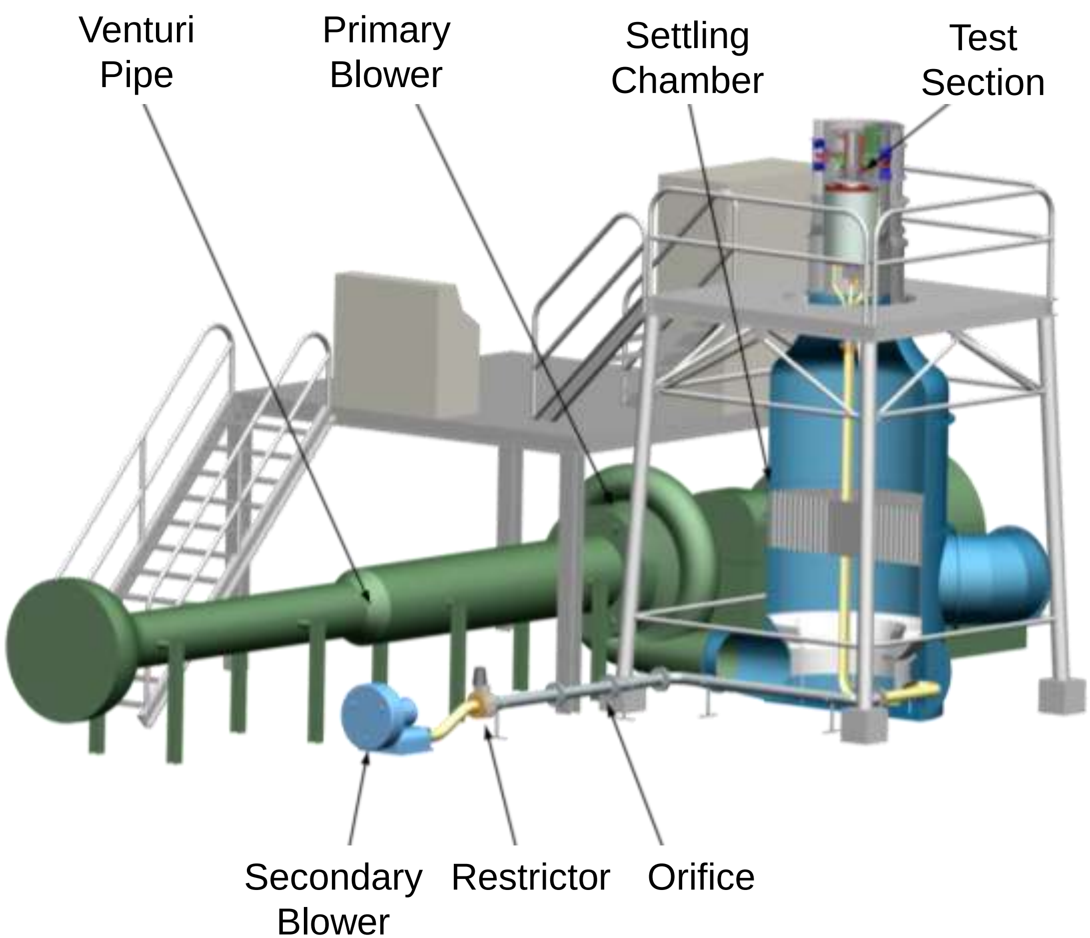
Specifications

Mass Flow:	8.06 kg/s
Pressure Ratio:	1.09
Turbine Revolutions:	1,600 rpm
Primary Blower Power:	57.03 kW

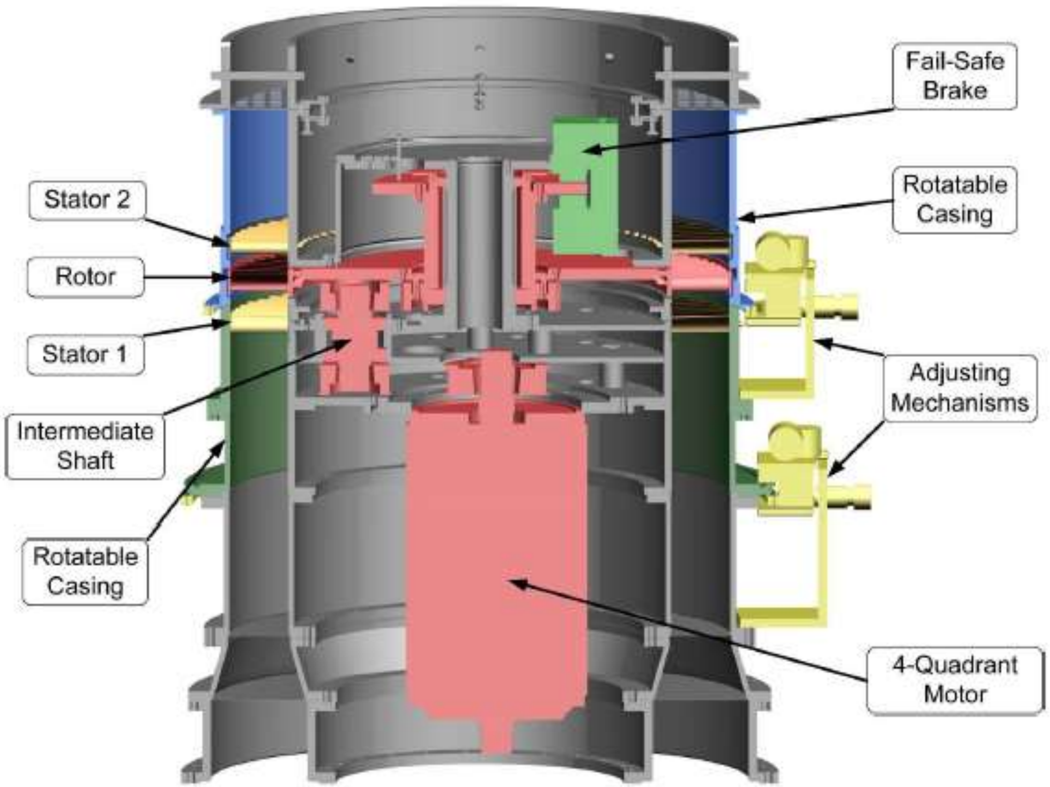
Measurement Techniques

- Total Pressure and Total Temperature Rakes
- Stationary Wall Pressure Taps
- 5-Hole-Probes
- Hot Wire Anemometry
- PIV (Particle Image Velocimetry)
- Kulites (up to 500 kHz)



High Reynolds Number Turbine Schematic

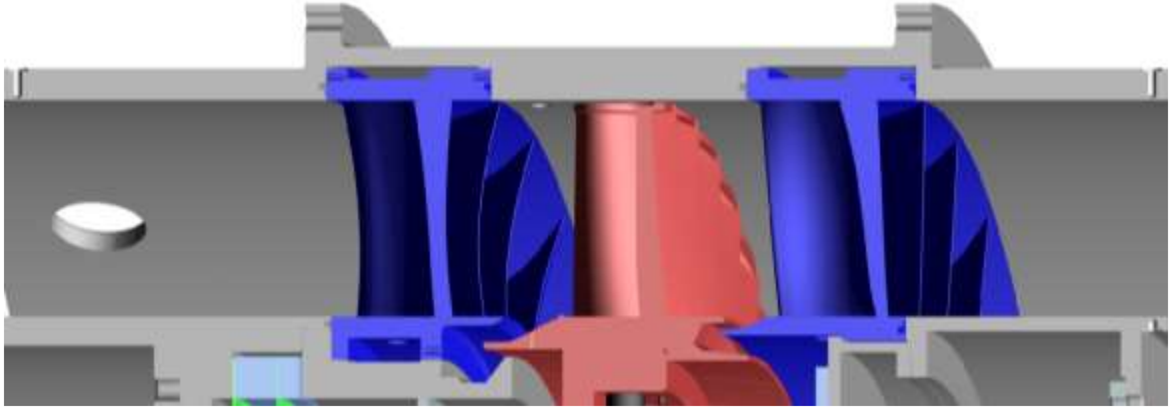
HiReNT – Measurement Section



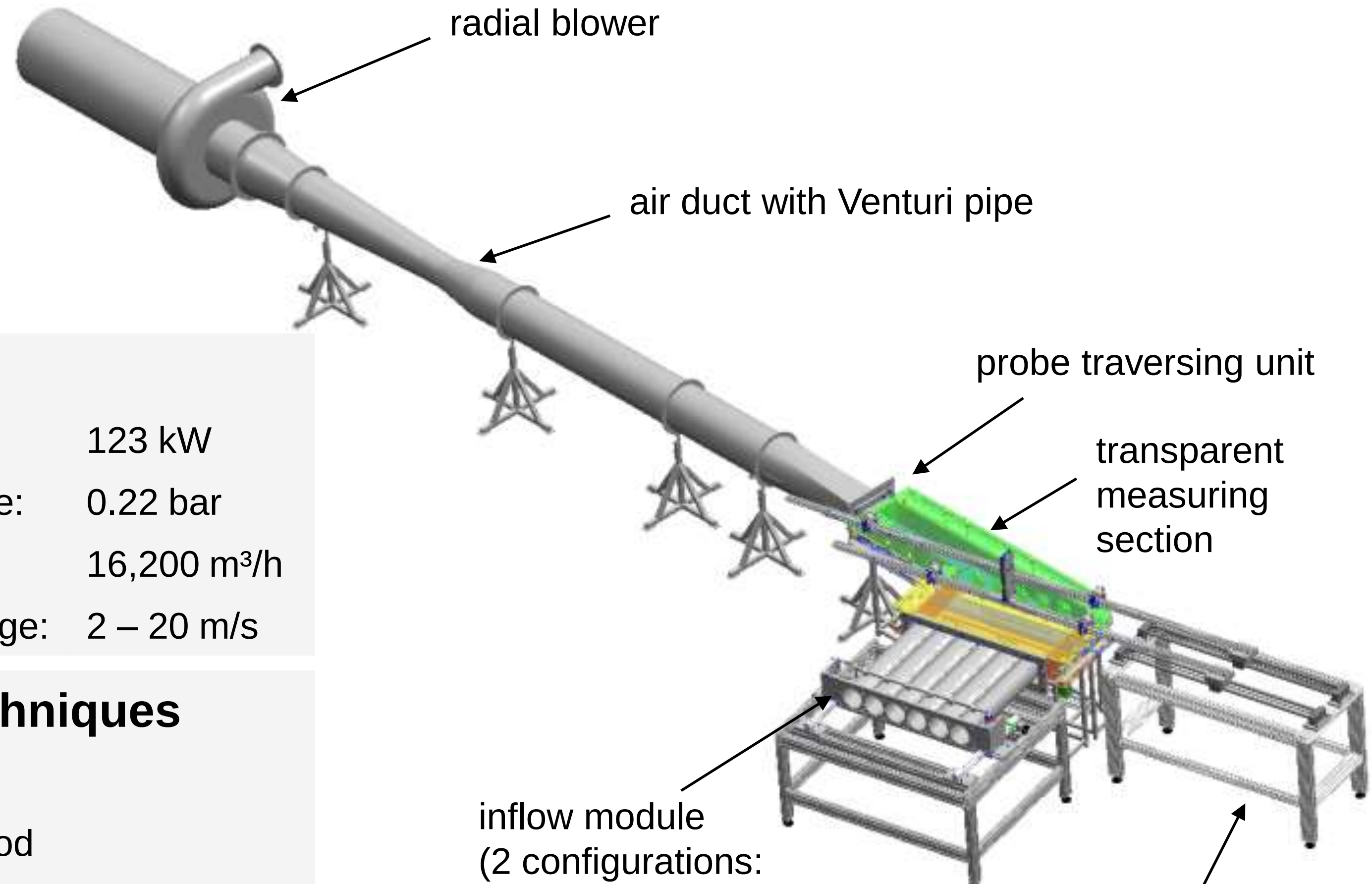
HiReNT – Rotor Blades

Investigated Configurations

- NGV1: 30 Blades
- Rotor: 45 Blades
- NGV2: 30 Blades
- Endwall contouring
- Blade tip designs



TURBINE CASCADE



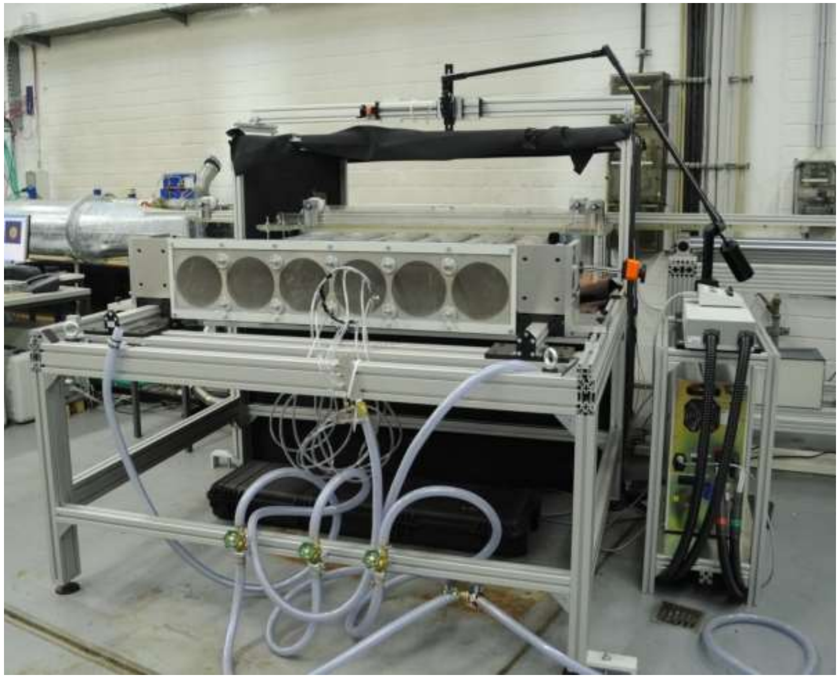
Specifications

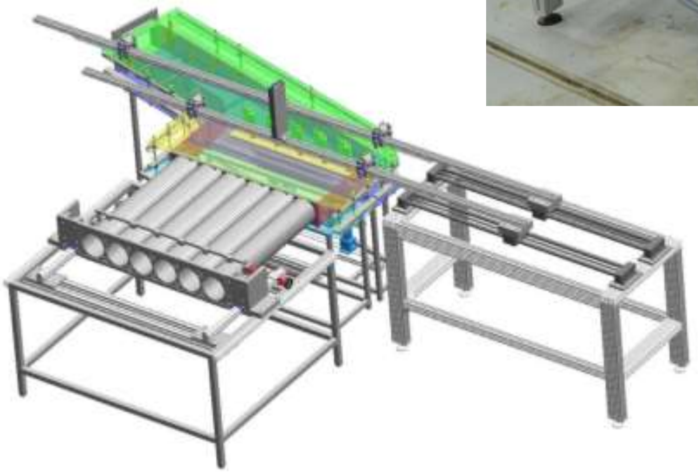
Blower Power:	123 kW
max. Pressure Difference:	0.22 bar
max. Volume Flow:	16,200 m³/h
Wind Tunnel Speed Range:	2 – 20 m/s

Measurement Techniques

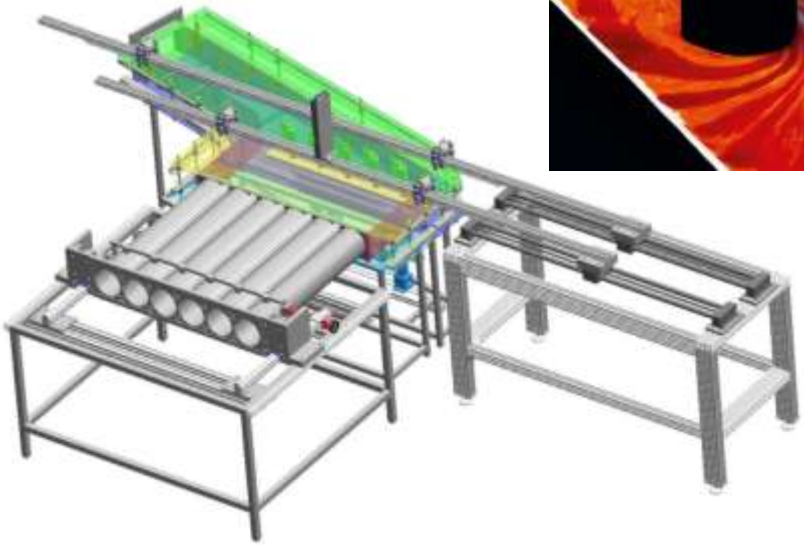
- 5-hole probe
- Ammonia-Diazo Method
- PIV (Particle Image Velocimetry)
- Stationary Wall Pressure Taps

Turbine Cascade





Turbine Cascade



Paint flow visualization

Combusor Simulator Test Section Schematic

Other Rigs

Rotating Rig

Plasma Actuator Rig

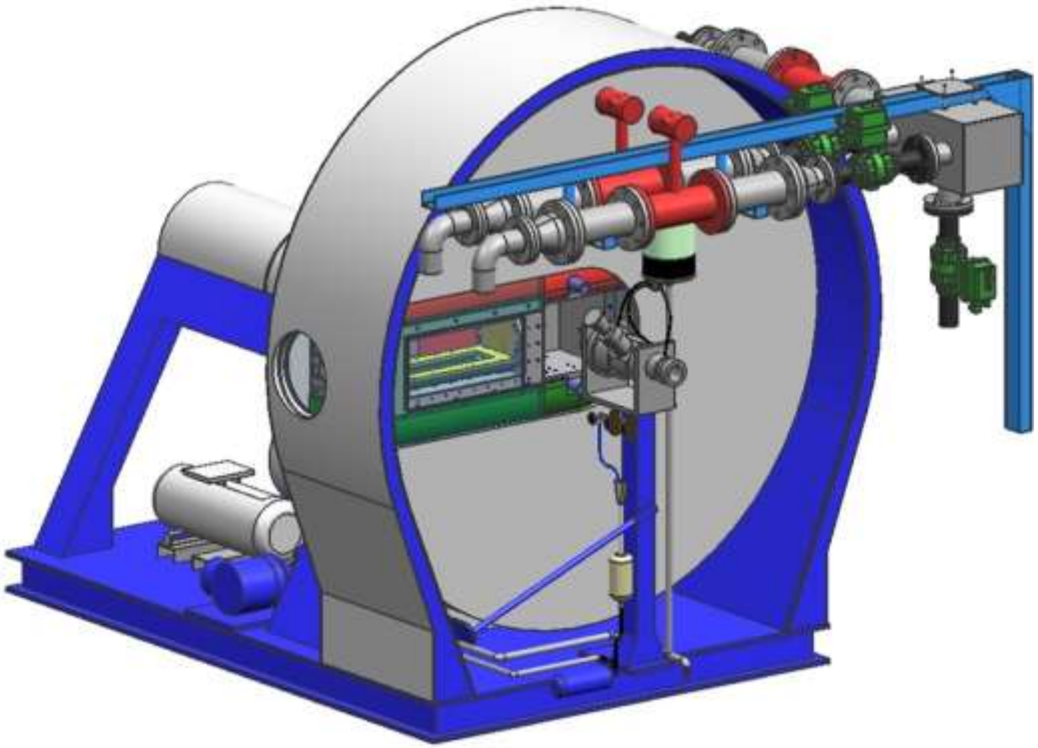
ROTATING TEST RIG

Specifications

Drive Power:	111 kW
max. Revolutions:	900 rpm
Blower Power:	22 kW
max. Volume Flow:	550 m^3/h
max. Pressure Loss:	45 kPa
Inner Radius Meas. Section:	300 mm

Measurement Techniques

- Naphtaline Sublimation Method with Optical Sampling (laser triangulation) – mass transfer measurement
- PIV (Particle Image Velocimetry)
- 32 pressure taps (via telemetry)
- 32 temperature gauges (via telemetry)
- In preparation: liquid crystal measurement technique - heat transfer measurement



Rotating Test Rig Schematic

Rotating Test Rig

Test Section

PLASMA ACTUATORS – TURNING DUCT

Specifications

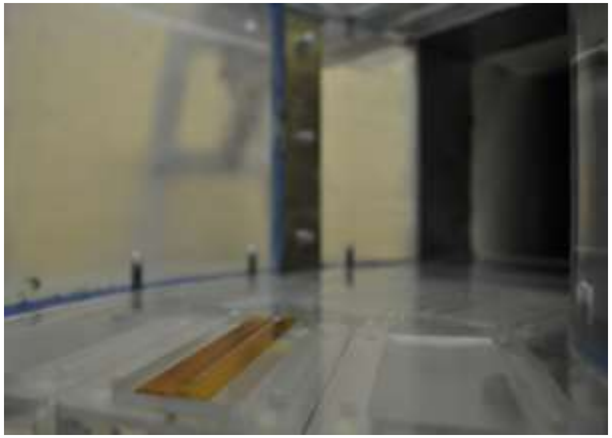
max. Pressure Difference:	0.15 bar
Range of Volume Flow:	400 – 5,000 m³/h
Reynolds Number:	125,000
Wind Tunnel Speed Range:	2 – 20 m/s

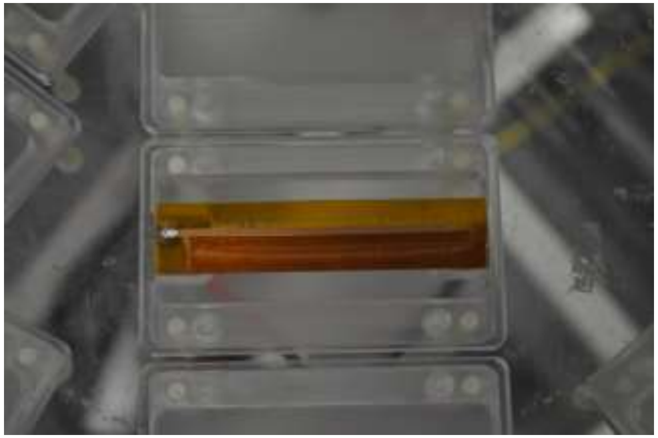
Measurement Techniques

- 5-Hole Probe
- PIV (Particle Image Velocimetry)
- Stationary Wall Pressure Taps

Plasma-Actuator Rig Schematic

Plasma-Actuator - Turning Duct

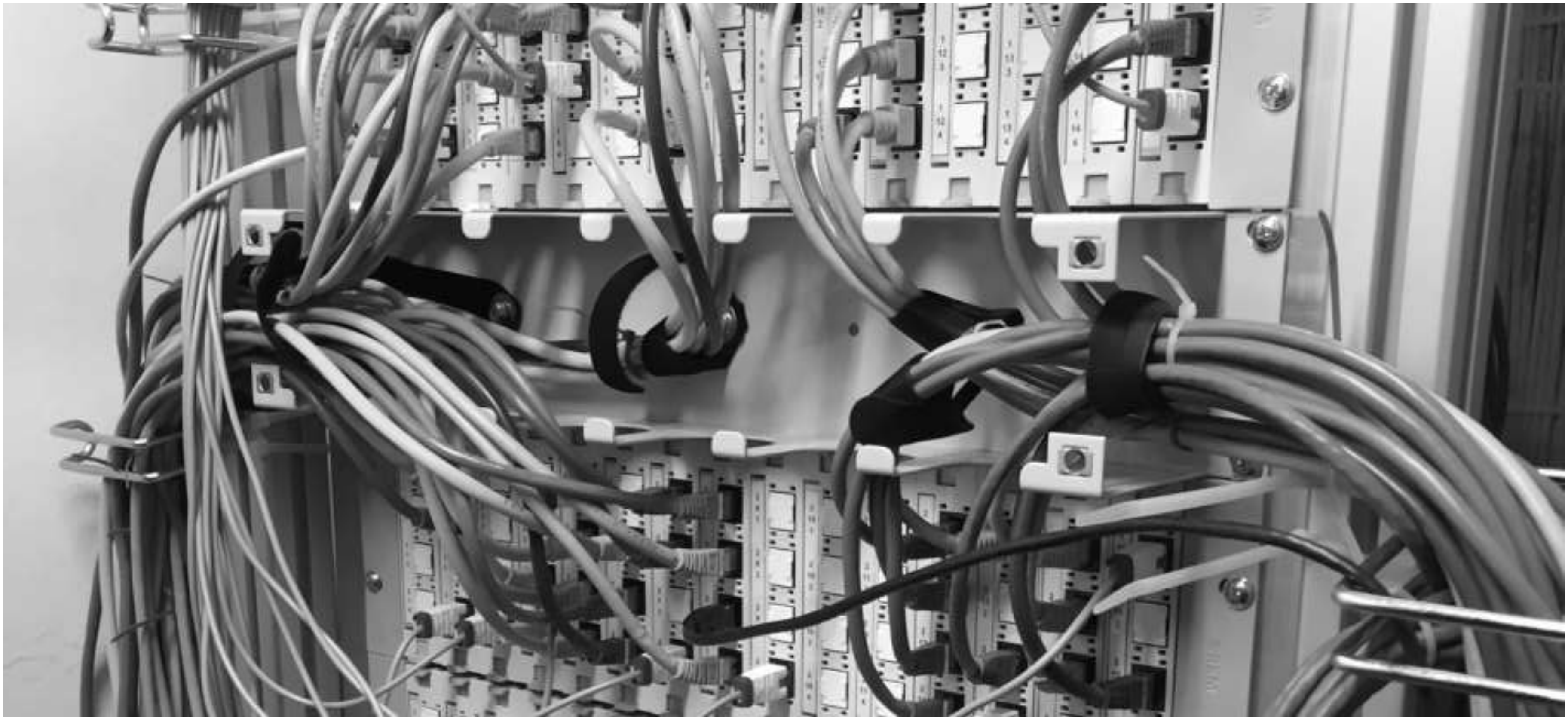




Plasma actuators in turning duct

Gas Turbines and Aerospace Propulsion

Numerical Simulations



Numerical Tools and Methods

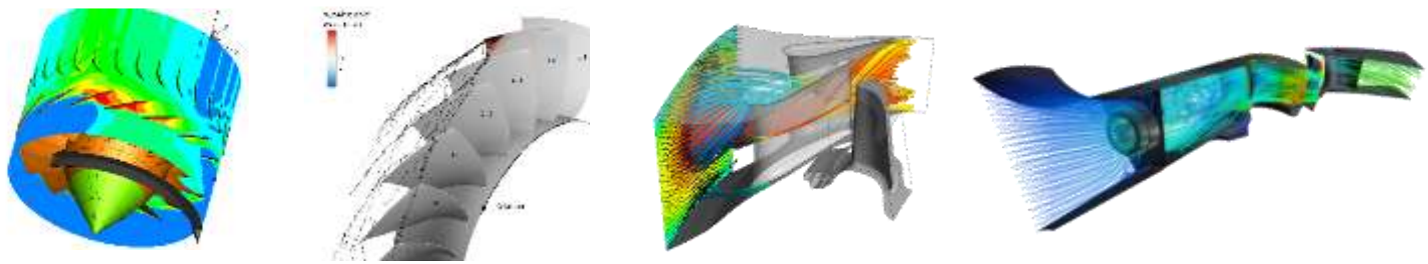
Software Expertise

Commerical CFD, FEM and Meshing Tools

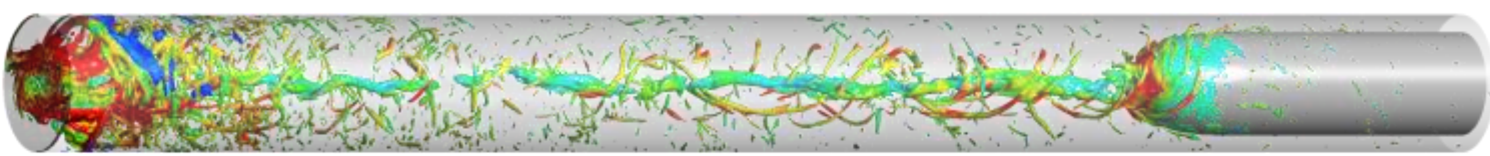
- ANSYS
- TRACE by DLR
- NUMECA

Different Rolls-Royce inhouse codes

> RANS



> LES



Hardware available at GLR/TU Darmstadt

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Local Cluster at GLR

Self-administered LINUX cluster

Suitable for small and medium-sized projects using confidential data and software

Hardware:

- 356 Cores
- 1,472 GB RAM

Lichtenberg High Performance Cluster (HHLR)

IBM/Lenovo research cluster, administered by TU Darmstadt

Listed among 500 fastest super computers worldwide

Hardware:

- 27,500 Cores
- 1 Pflop/s