Institute for
Thermal Turbomaschinery
and Machine Dynamics

Graz University of Technology
Erzherzog-Johann-University

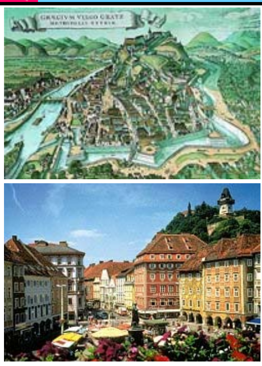
Aeroengine Research in European Cooperation at Graz University of Technology

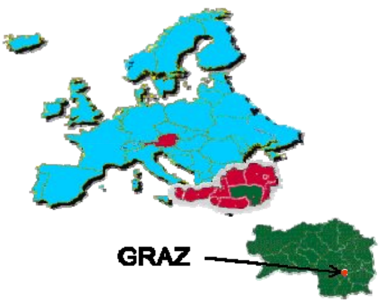
Seminar at the
Department of Aerospace Engineering
Middle East Technical University
Ankara, April 2008

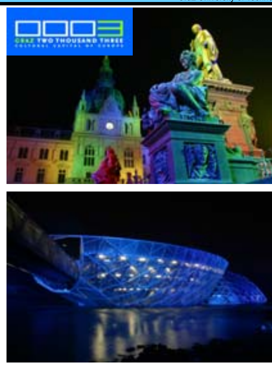
Wolfgang Sanz
Institute for Thermal Turbomachinery and Machine Dynamics
Graz University of Technology
Austria

>> MIDDLE EAST TECHNICAL UNIVERSITY

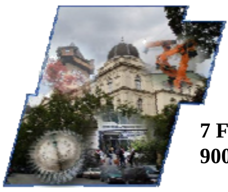
Graz



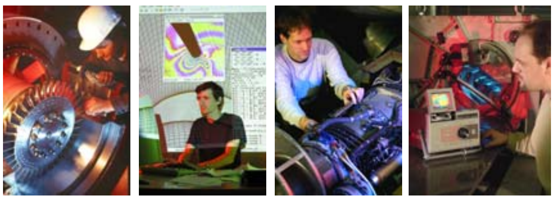




City: 240.000 inhabitants
City+Suburbs: 370.000 inhabitants
4 Universities with 50.000 students



7 Faculties
9000 students



TUG Graz University of Technology

Institute for Thermal Turbomachinery and Machine Dynamics

Graz University of Technology

Students total		**9 200**
of which women	20 %	
of which foreigners	14 %	
(30 students from Turkey)		
Beginners		**1 400**
Graduates		**1 019**
Master degrees	590	
Doctoral degrees	148	
Staff total		**1 610**
Academic Staff	980	
Non-academic Staff	630	

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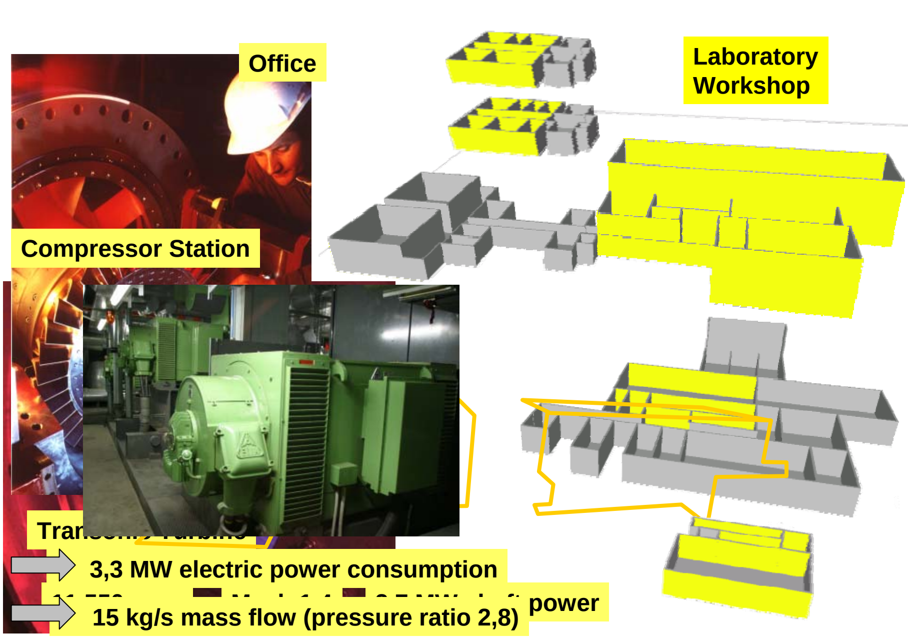
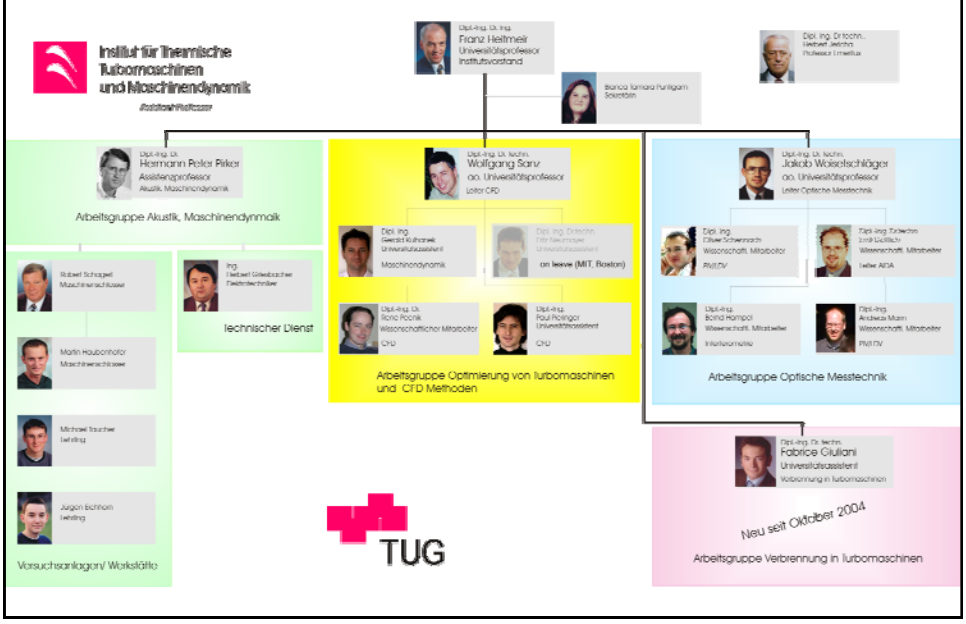
Insitute f. Thermal Turbomachinery & Machine Dynamics

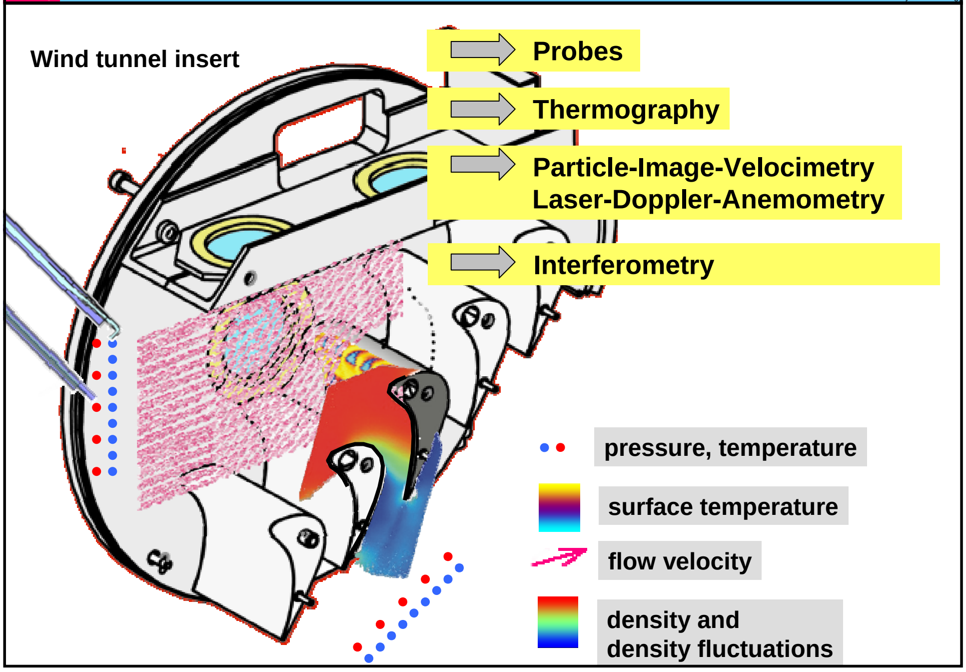


- 3,3 MW electric power consumption
- 15 kg/s mass flow (pressure ratio 2,8)

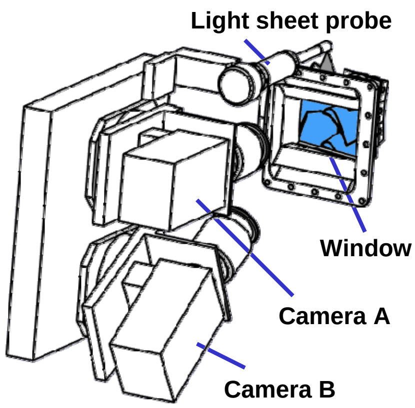
Organisational structure



Metrology used



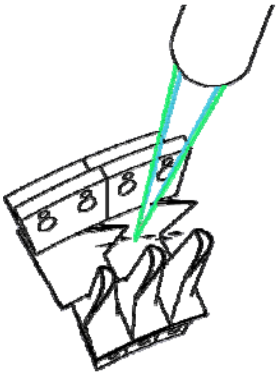
Stereo-PIV



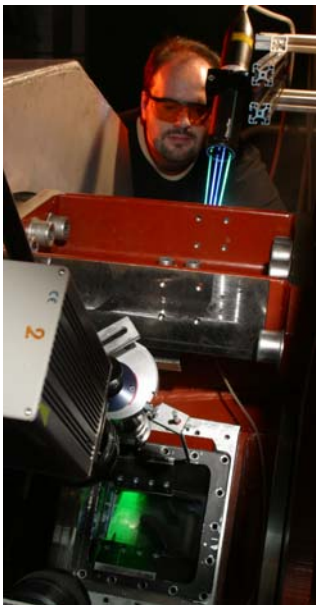
Nd:YAG Laser:
New Wave GEMINI PIV
120 mJ, double cavity
Pulse duration: 3-5 ns
Time between pulses: 0.7 – 1 µs

Cameras:
DANTEC HiSense 80C60
1280 x 1024 pixel size
Min. inter-frame period: 0.2 µs
AF Micro NIKKOR 60/2.8

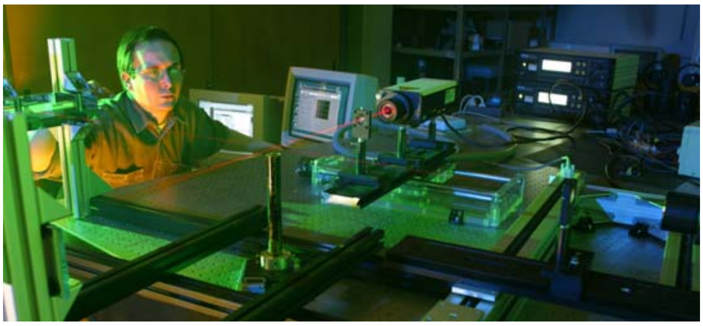
Laser - Doppler - Anemometer

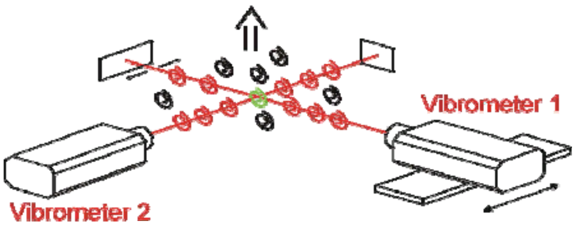


DANTEC Fiber-Flow
Ar+ laser and Burst Spectrum Analyser processor units used to record 2 velocity components



Laser Interferometer





Polytec OVD 353

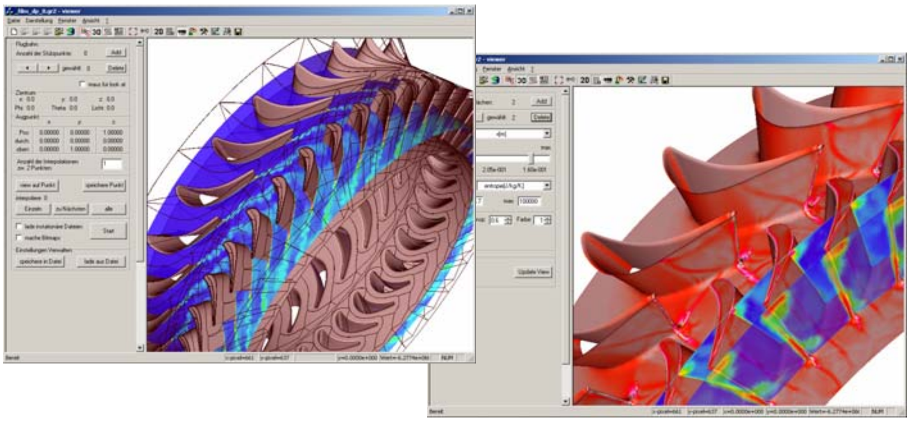
He-Ne laser with OVD 02 velocity decoder used to record integral and local frequency spectra of density fluctuations

Computational Fluid Dynamics

Pre-processors → **Mesh generation, ...**

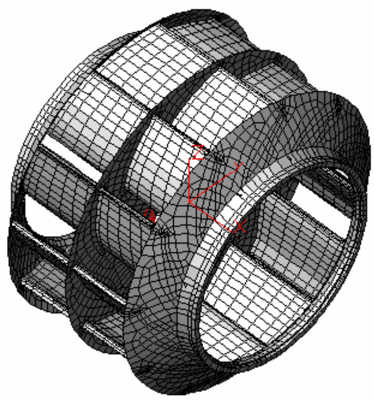
Navier-Stokes solver → **Roe-solver, characteristic solver, solver for LES, ...**

Post-processors → **Visualization, evaluation, ...**

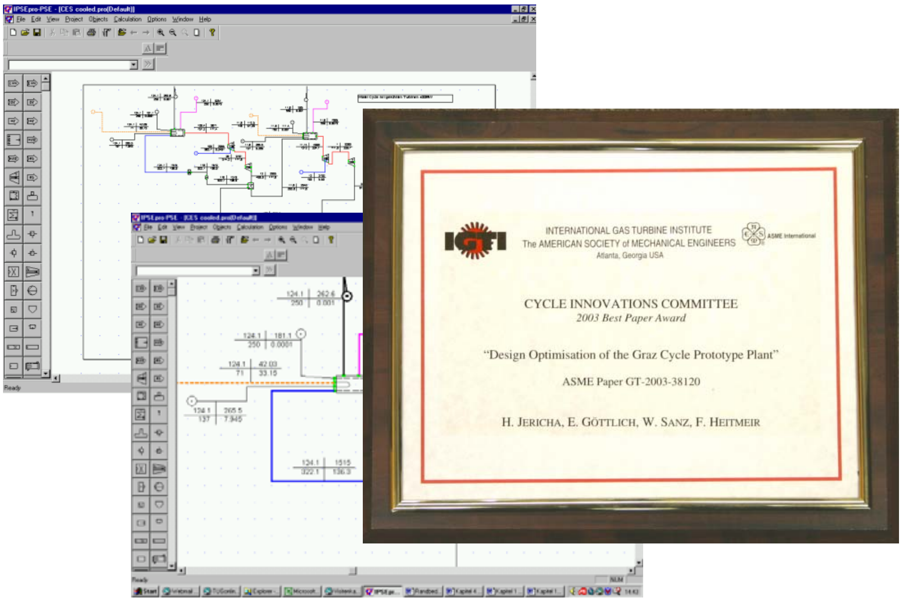


Vibration and Stress Analysis

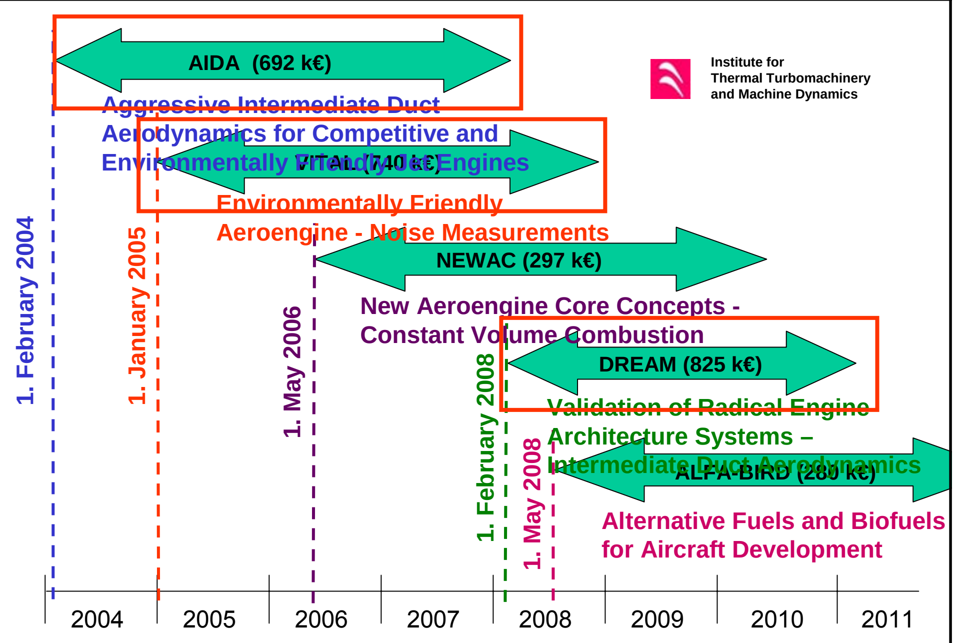
- **Objective: Failure analysis of a ventilator wheel of 1.5 m diameter**



Graz - Cycle



TTM Participation in EU Projects



Introduction

Sixth Framework Programme
Priority 4 Aeronautics & Space
Specific Targeted REsearch Project
AST3-CT-2003-502836
AIDA
Aggressive Intermediate Duct Aerodynamics for Competitive & Environmentally Friendly Jet Engines

- Increasing problem of enviromental pollution
- Increasing fuel costs
- Running out of fossil fuels
  - •
  - •
  - •

→**Reduce fuel consumption**

Increasing efficiency

Introduction

- Aero engines with a further increased bypass ratio
  - ➔**LP turbines of lower speed and larger diameters**
  - ➔**typical S-shaped duct**
- The flow from the HP turbine has to be guided to a LP entry at a larger diameter
  - ➔**without any separation**
- This intermediate turbine duct (ITD) has to be as short as possible
  - ➔**less weight and costs**
- A detailed test arrangement under engine representative conditions is necessary
  - ➔**investigation of the flow through such an aggressive (highly diffusing) duct**

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Introduction

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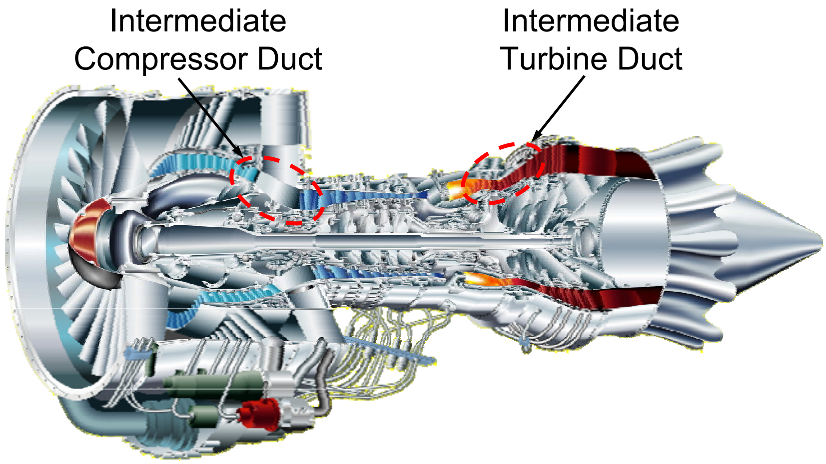

Guides the flow from the LP to the HP compressor

Guides the flow from the HP to the LP turbine

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Introduction

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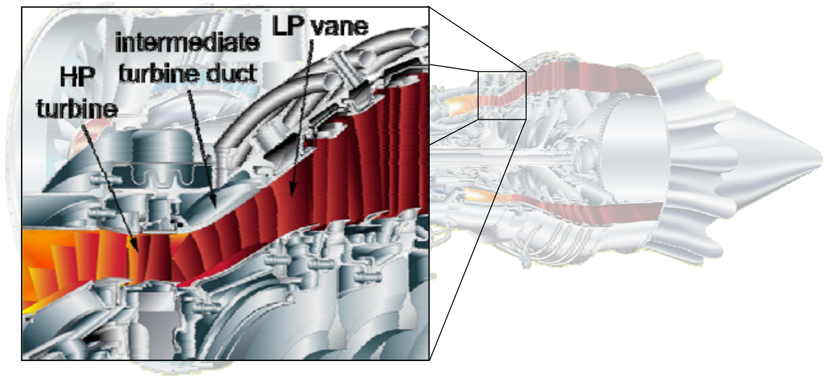
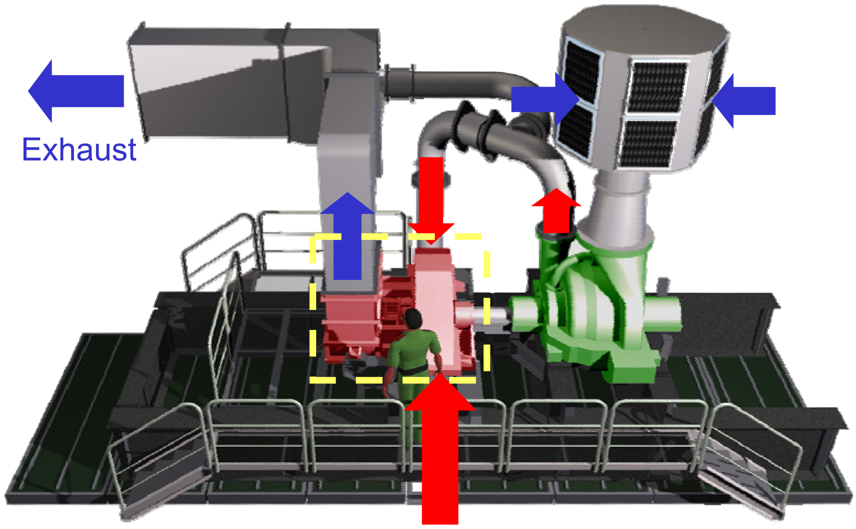
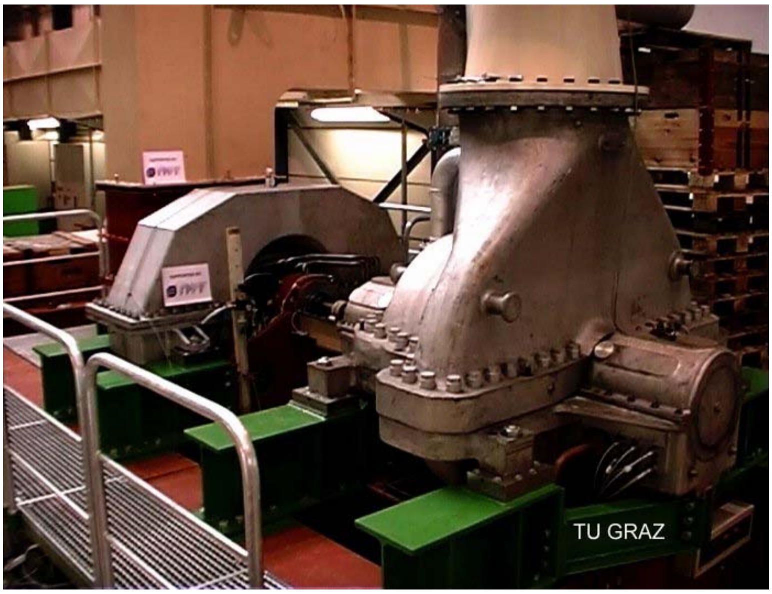


AIDA Transonic Test Turbine Facility



AIDA Transonic Test Turbine Facility



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Transonic Test Turbine Facility

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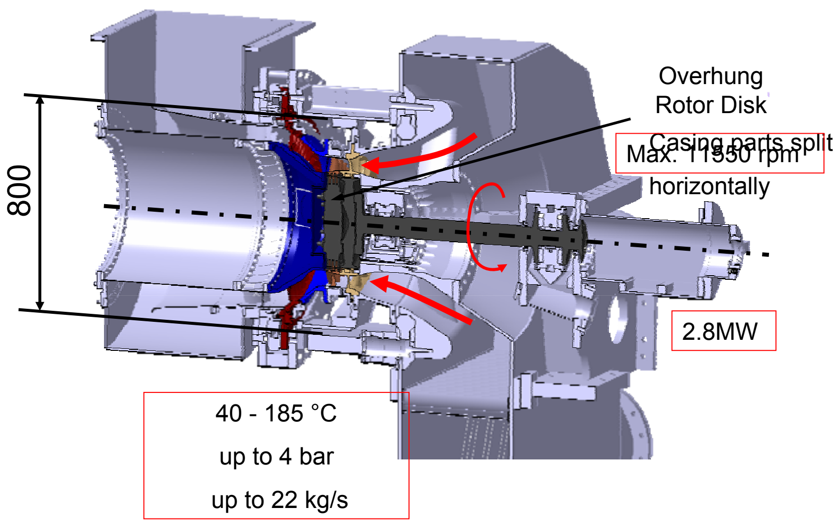

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Test Rig General Arrangement

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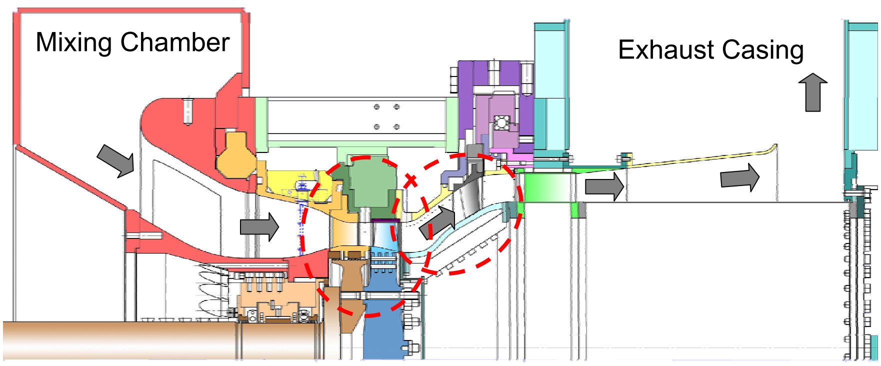
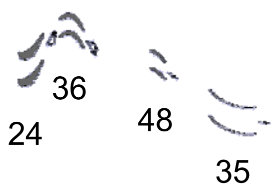


Stage ADP:

1. **Pressure Ratio Π: 3.1**
2. **Rotational Speed: 11000 rpm**
3. **Power: 1590 kW**
4. **Swirl Angle at Blade Exit: ~ -15 deg**



1. **Mach Number at Blade Exit: ~ 0.65**
2. **Blade Tip Gaps: 1.5% and 2.4% span**

Duct:

1. **A2/A1: ~1. 5**
2. **Length/Height: ~2**

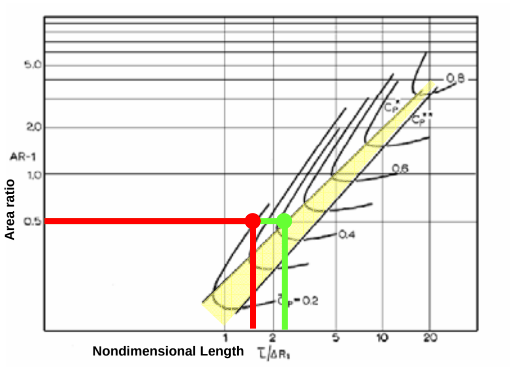
AIDA Duct Classification and Test Objectives

- Understanding of the duct flow near separation → aggressive
- Understanding of the duct flow with significant separation

  Reduction of duct length by 20%

  → super-aggressive
- Suppress separation by means of vortex generators

  Shape and position suggested/tested by the technical universities Genova and Chalmers



AR: ~1. 5, Length/Height: ~2

Performance of straight-walled annular-diffuser for inlet boundary layer blockage of approximately 2 %.
Cp* and Cp** are the limits for optimum pressure recovery coefficient for a given diffuser
L … average wall length, ΔR1 … inlet height
From Sovran and Klomp (1967).

AIDA Overview of the Investigations

- 3 Configurations C3, C4 and C5

C3	represents an integrated concept
C4	duct flow near separation
C5	separated flow

  → Should provide the following rotor with the correct inflow

- C5 with Vortex Generators (low profile)

  Vortex generator height appr. 20% of boundary layer thickness

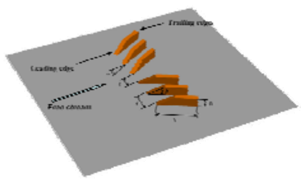
  Geometry and arrangement proposed

  by the Univ. of Genova

  Axial pos. depends on the position of separation

  Proposal of position by Chalmers

  → Cascade Testing necessary!

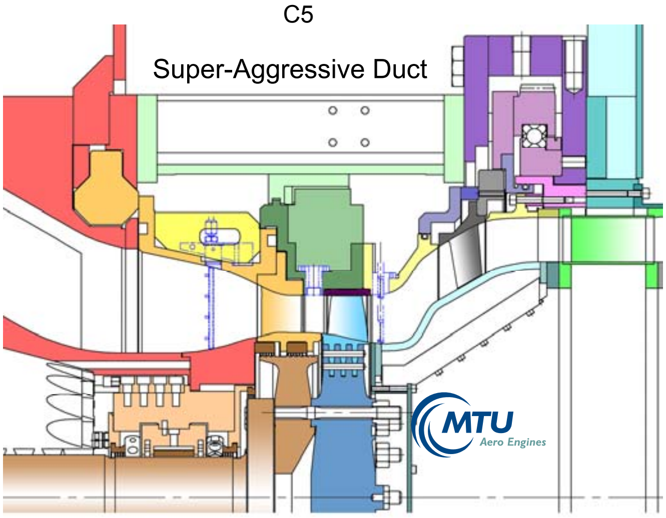


- Two different Aero design points (ADP's)
- For each ADP two different rotor tip clearances

AIDA Test Setups

C5

Super-Aggressive Duct



AIDA - Results

Priority 4 Aeronautics & Space
Specific Targeted REsearch Project
AST3-CT-2003-502836

Aggressive Intermediate Duct Aerodynamics for Competitive & Environmentally Friendly Jet Engines

The Influence of Blade Tip Gap Variation on the Flow Through an Aggressive S-Shaped Intermediate Turbine Duct Downstream a Transonic Turbine Stage

Presentations held by
Andreas Marn and **Emil Göttlich**
at the ASME IGTI Conference in Montreal
May 2007

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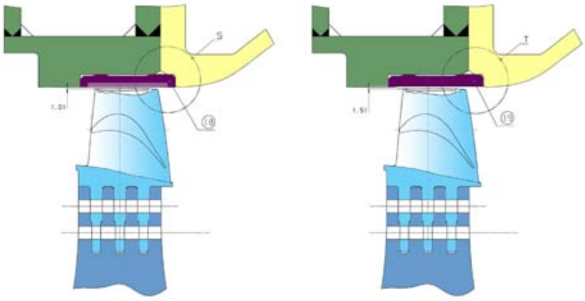
Test Rig-Tip Clearance



1.5% span   2.4% span

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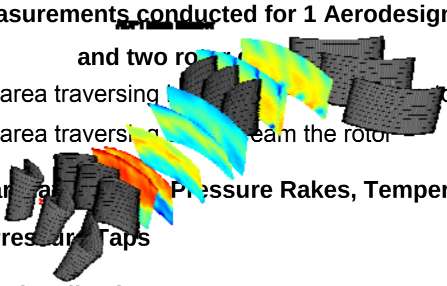
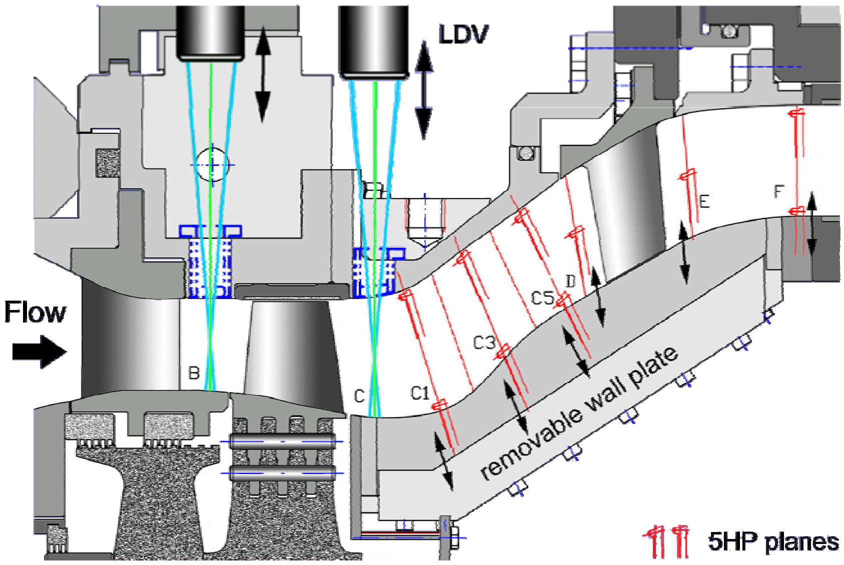
Measurement Techniques

- **Five-hole-probe measurements conducted for 2 Aerodesign Points and two rotor gaps**
  - Full area traversing in 2,5,6 planes between rotor and LP Vane
  - Full area traversing in 2 planes downstream the LP Vane
- **LDV measurements conducted for 1 Aerodesign Point and two ro**
  - Full area traversing   or
  - Full area traversi   eam the rotor

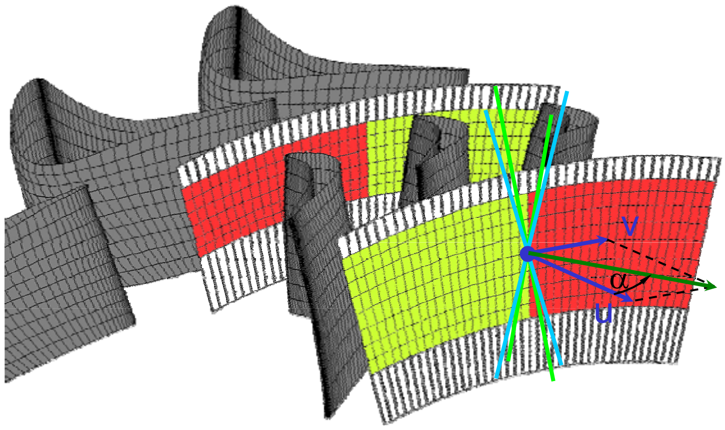


- **Boundar   a   Pressure Rakes, Temperature Rakes**
- **Static Pres   r   Taps**
- **Oil flow visualisation**

Instrumentation



LDV Measurement Grid

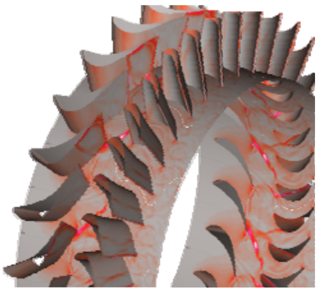


AIDA **Numerical Results - Flow Solver LINARS** TU Graz Graz University of Technology

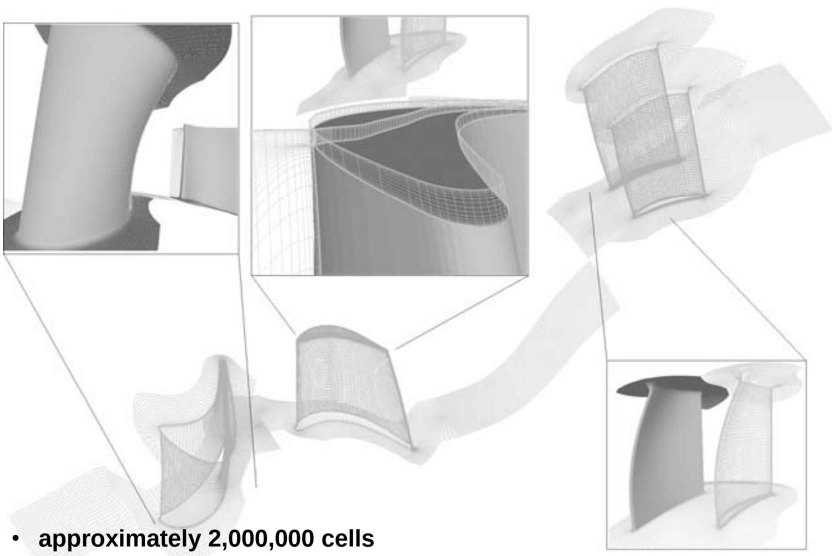
In-house code (LINARS) developed at Institute for Thermal Turbomachinery, Graz

Code specifics:

- finite volume spatially third order TVD upwind scheme
- fully implicit treatment of the equation system (ADI)
- second order accurate in time
- pressure gradient sensitive wall functions
- phase-lagged boundary conditions
- Spalart and Allmaras turbulence model

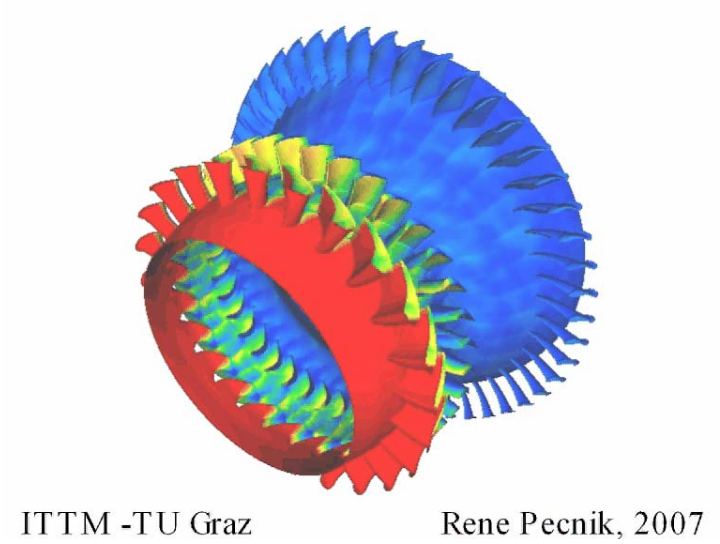


AIDA **Calculation Specifics** TU Graz Graz University of Technology

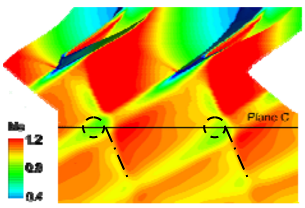


- **approximately 2,000,000 cells**
- **fillets and the clearances were modeled**

AIDA — Unsteady Flow Through ITD

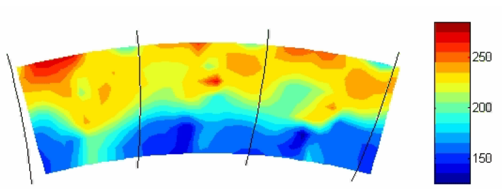


AIDA — LDV Measurements at Duct Inlet

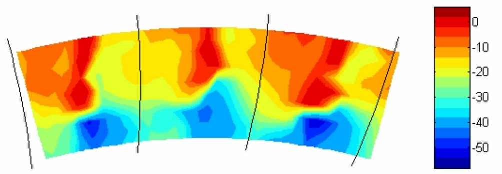


Mach Number

Velocity [m/s]



Yaw Angle [deg]



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Turbulent Kinetic Energy

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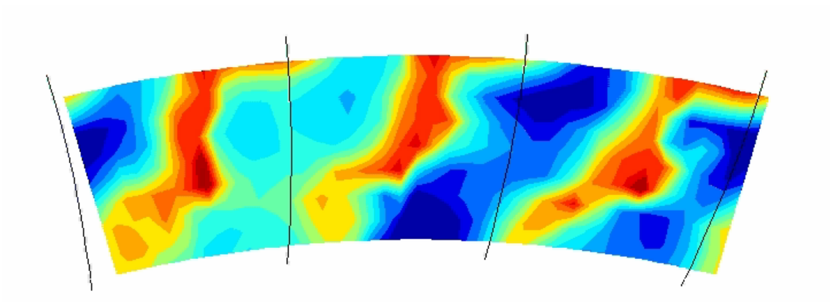

$$k = \tfrac{3}{4} \cdot \left(\overline{u'^2} + \overline{v'^2} \right) \quad \text{with} \quad \overline{w'^2} = \tfrac{1}{2} \cdot \left(\overline{u'^2} + \overline{v'^2} \right)$$

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Rotor Wakes (TKE)

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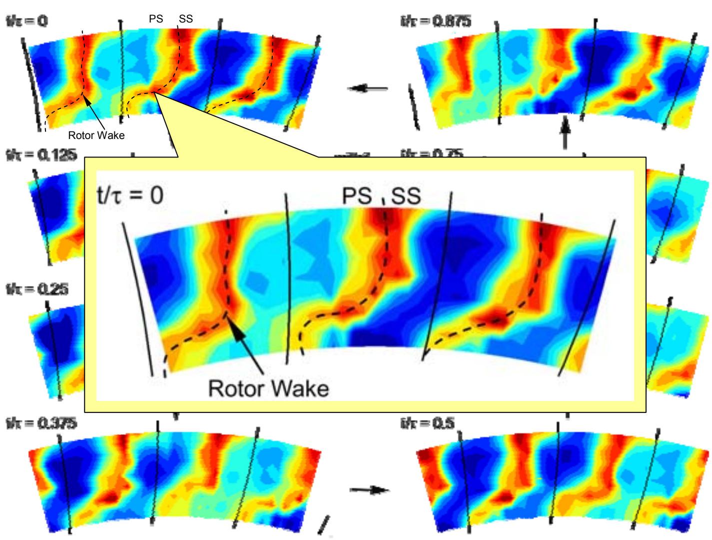

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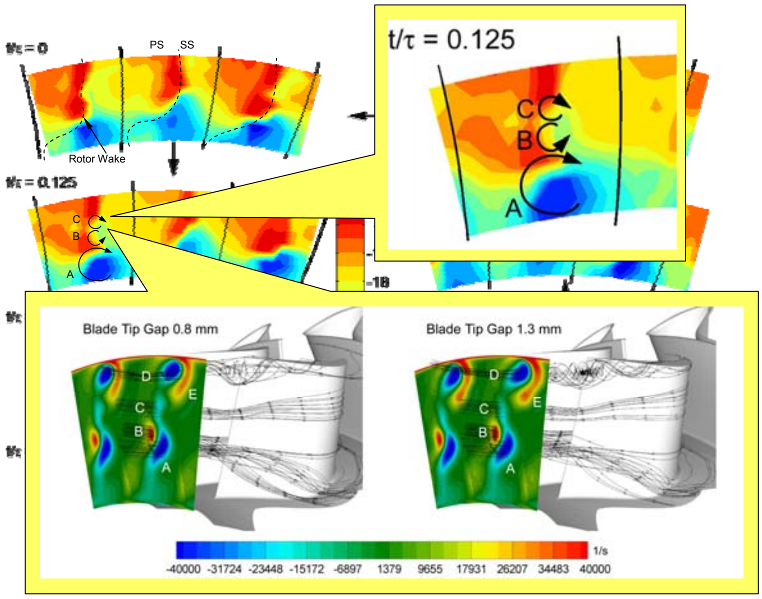
Vortical Structures



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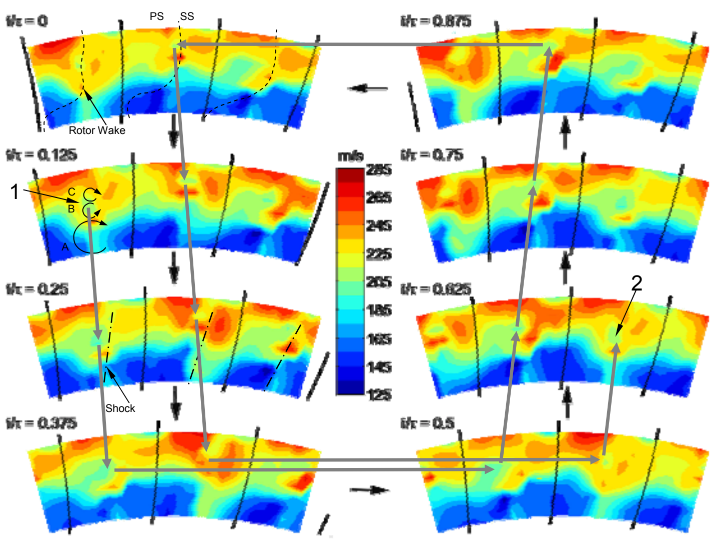
Velocity Distribution



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Tip Leakage Flow

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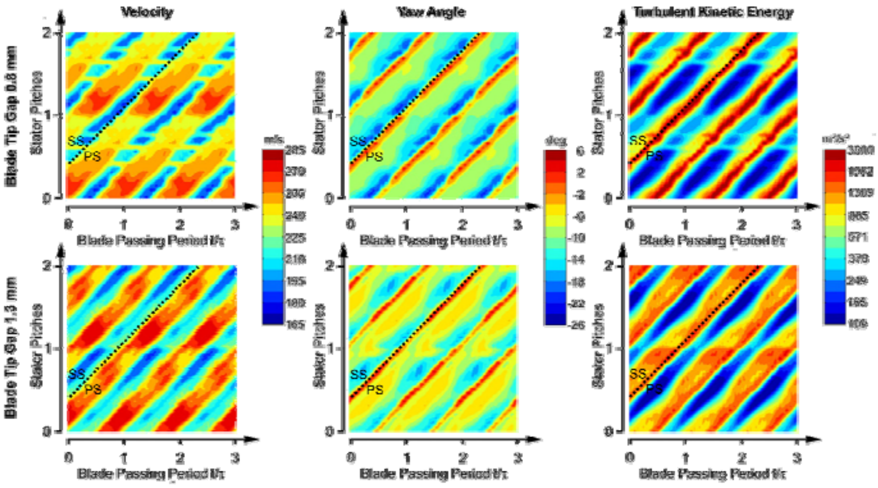
Time-space plots at 88 % span



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Instrumentation – Five-Hole-Probe

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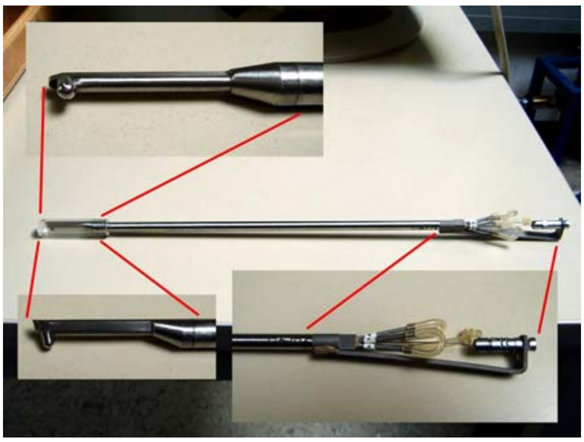


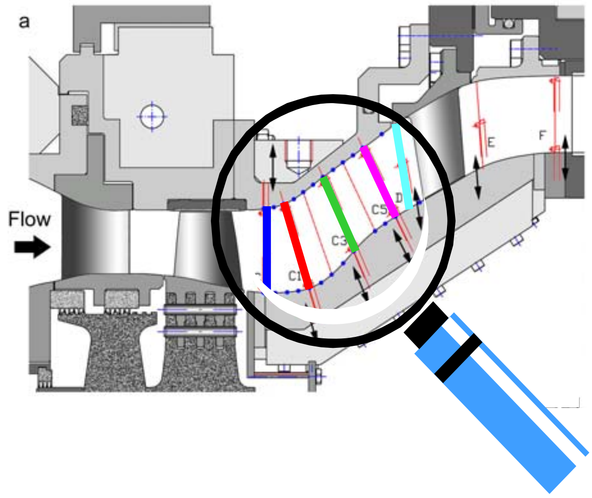
Calibration Range

0.2 < Ma < 0.8

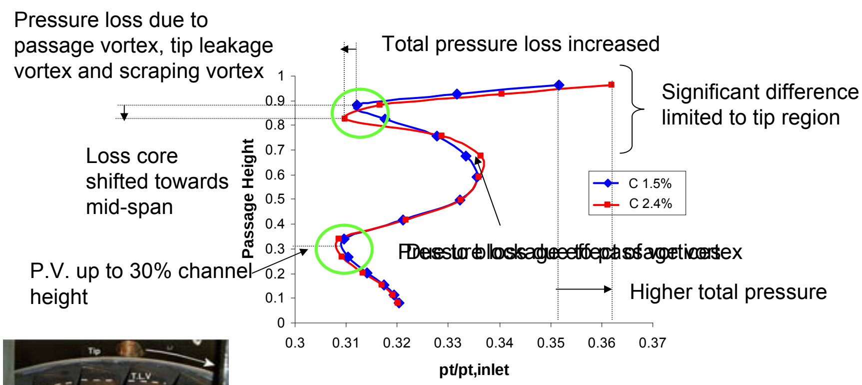
-20 < a +20

-16 < g +20

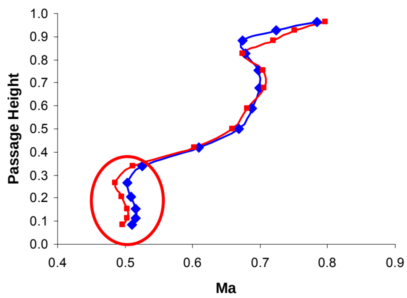
Probe from RWTH Aachen (IST)

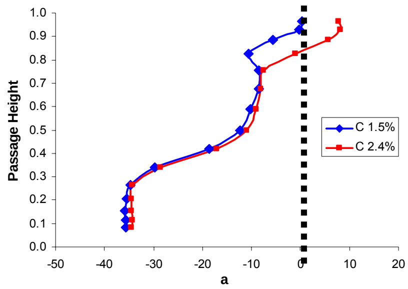


Duct Inlet-Total Pressure



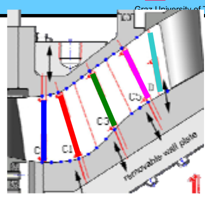
Duct Inlet Mach Number and Yaw Angle





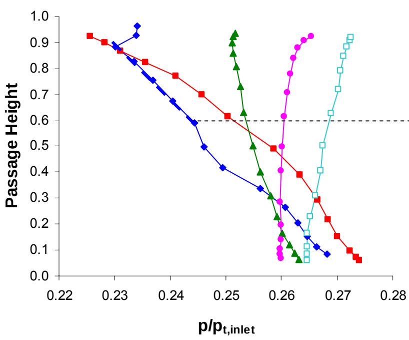
Lower Ma for 2.4% span case

Static Pressure

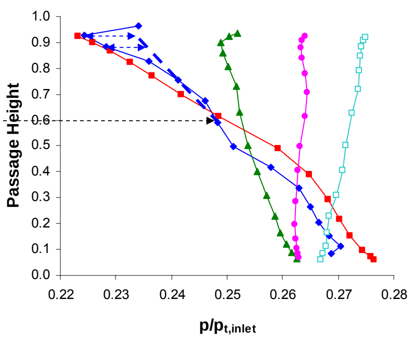


Rotor Tip Gap size

1.5% span



2.4% span



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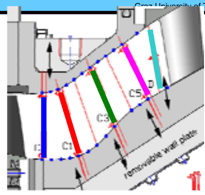
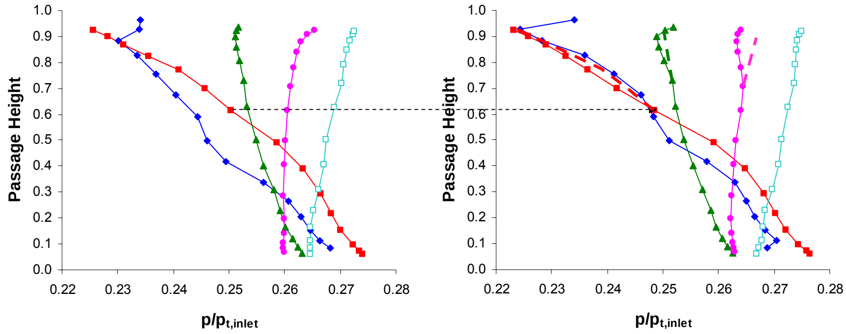
Static Pressure



Rotor Tip Gap size

1.5% span 2.4% span



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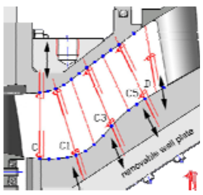
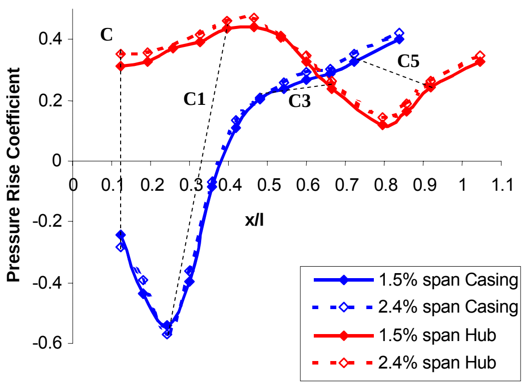
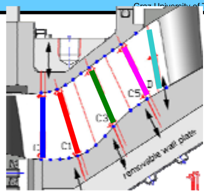
Pressure Rise



$$C_p = \frac{(p_n - p_C)}{(p_{t,C} - p_C)}$$



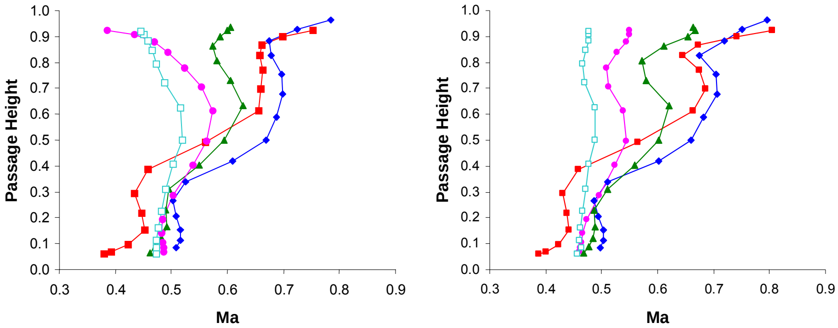
AIDA — Mach Number



Rotor Tip Gap size

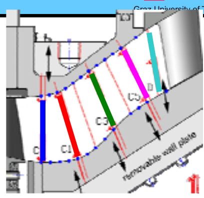
1.5% span — 2.4% span

Ma number minimum can be seen in every plane



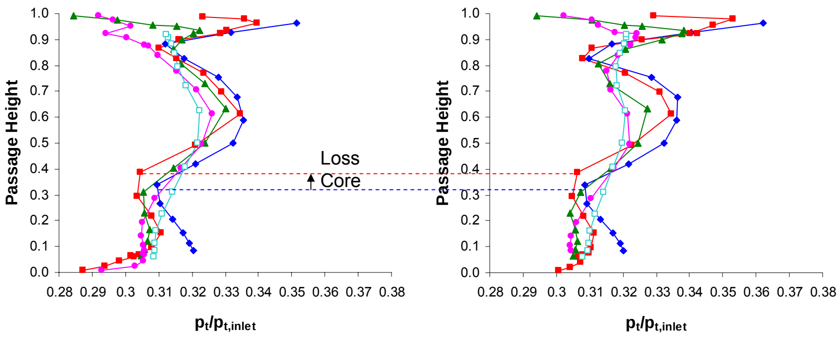
Downstream C1 no distinct Ma minimum can be seen at the hub / Ma peak at mid span flattens

AIDA — Total Pressure



Rotor Tip Gap size

1.5% span — 2.4% span

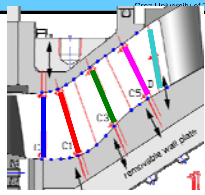


Downstream C1 no distinct minimum at the hub in pt can be seen / Pt peak at mid span flattens

AIDA

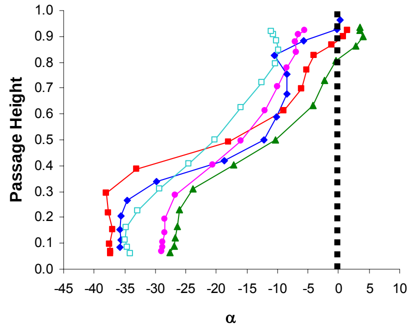
Yaw Angle

TU Graz

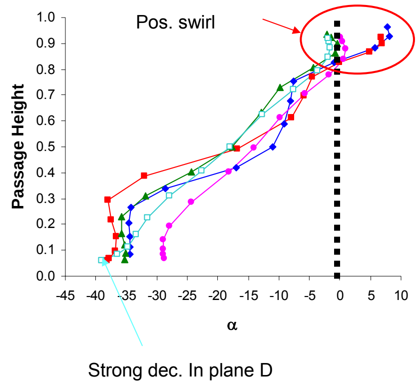


Rotor Tip Gap size

1.5% span



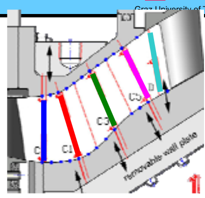
2.4% span



AIDA

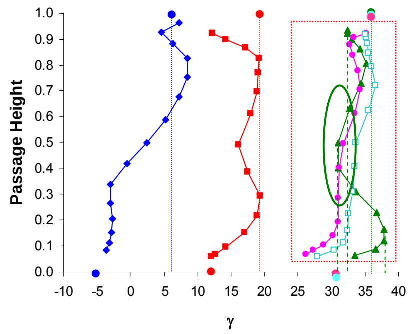
Pitch Angle

TU Graz

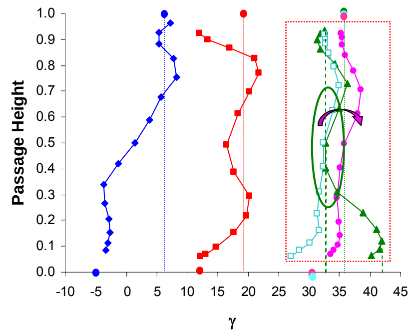


Rotor Tip Gap size

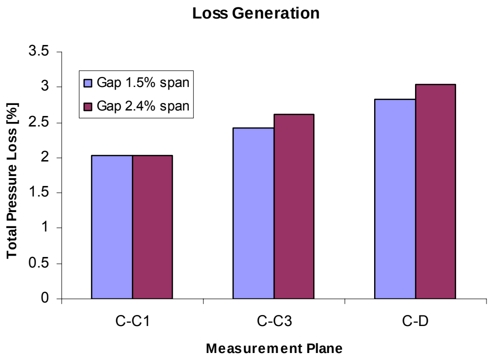
1.5% span



2.4% span



Estimation of Duct Loss

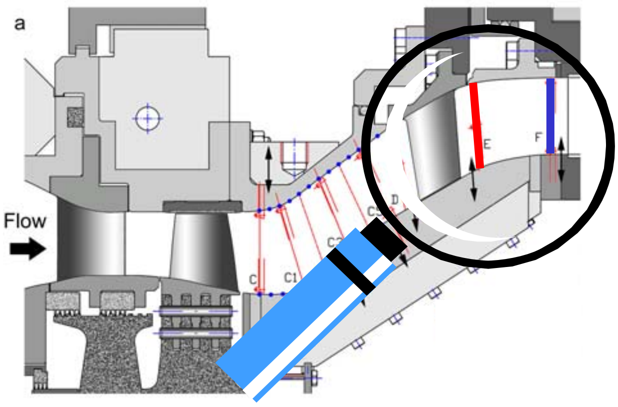


$$\Delta p_t = \frac{p_{t,C} - p_{t,local\ plane}}{p_{t,C}} \times 100$$

→ main portion of the loss generated between plane C and C1

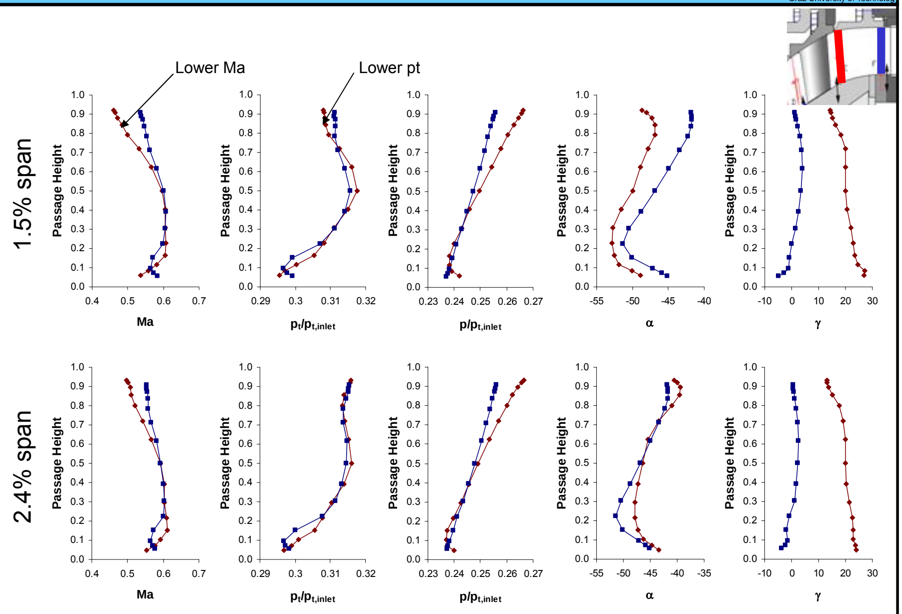
→ mixing losses take effect in planes downstream of C1

Measurements Downstream the LP Vane



AIDA

Downstream the LP-Vane



AIDA

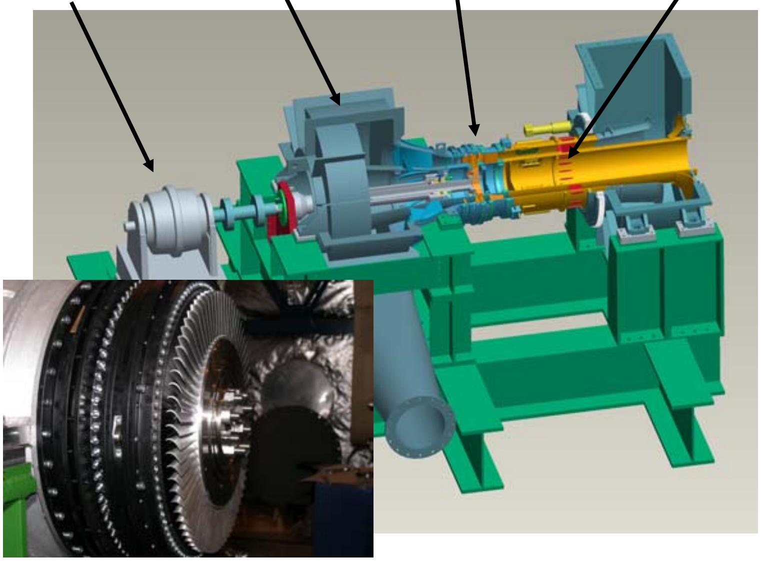
Conclusions

- This investigation was conducted to show the influence of the tip gap size on the flow through an aggressive ITD close to separation.
- LDV as well as pressure probes were applied
- In plane C the upper 20% of the passage height is affected
- The small changes in the duct inflow are responsible for a different behavior over a large spanwise area further downstream.
- The comparison with the steady CFD simulation shows that the effects of the tip clearance variation were captured precisely.
- The project goal was to create a unique database for flows within high diffusing S-shaped ducts to get more insight to their flow physics and for CFD verification.

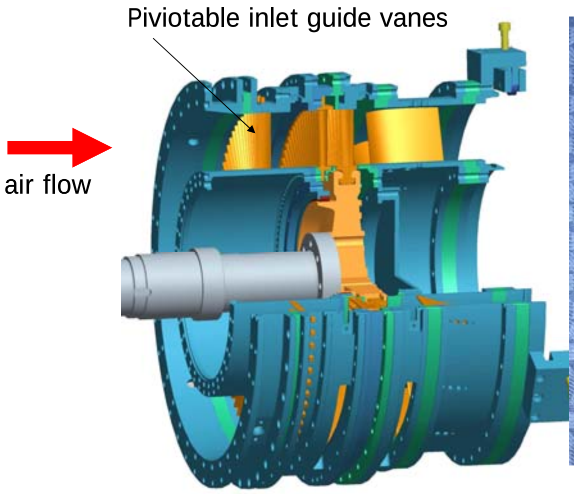
VITAL

- VITAL … Environmentally Friendly Aero Engine
- Integrated Project within FP 6
- Subtask at Graz University of Technology:
- Building of a test rig for acoustic measurements behind a turbine stage
- Acoustic measurements together with DLR, Germany

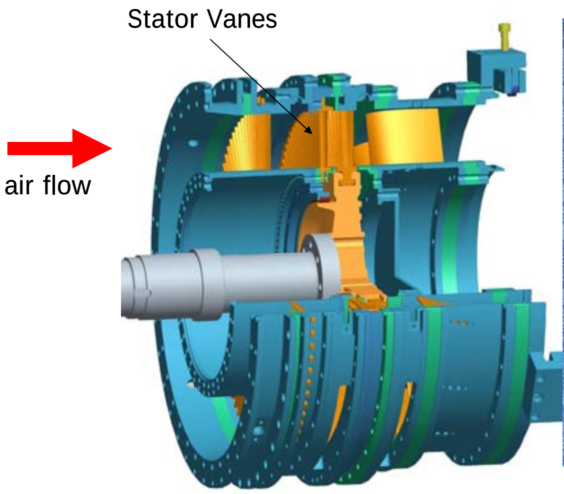
Test Facility



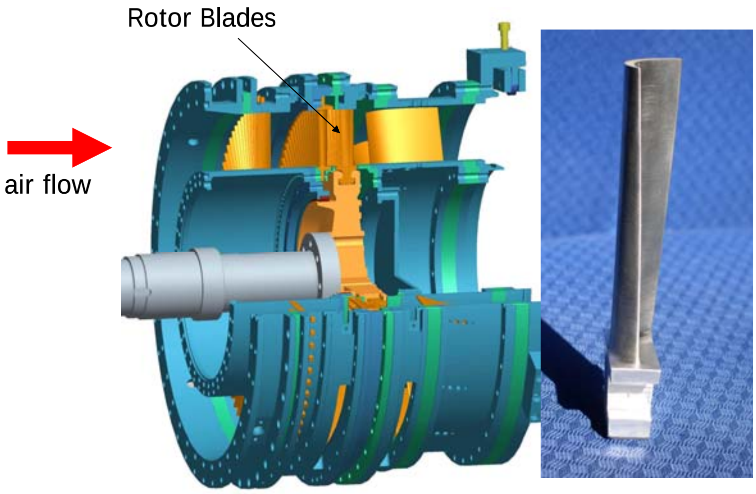
Turbine Stage



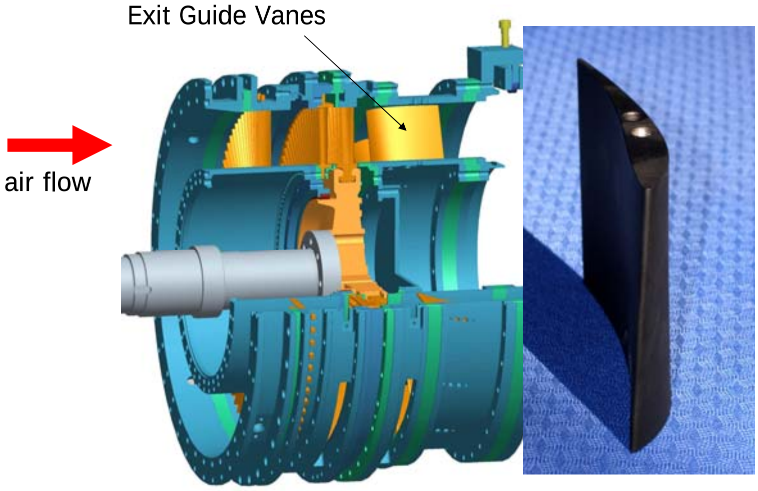
Turbine Stage



Turbine Stage

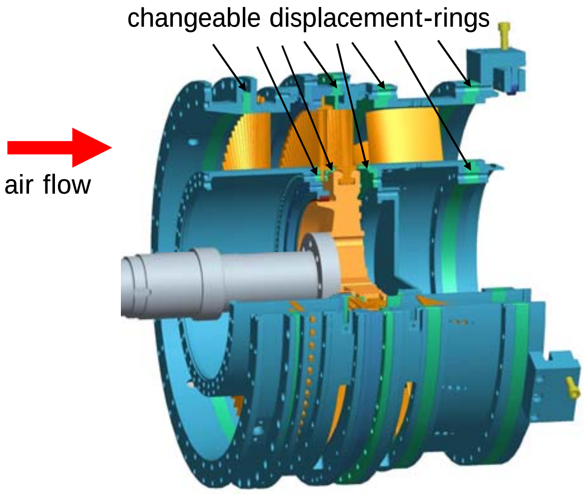


Turbine Stage



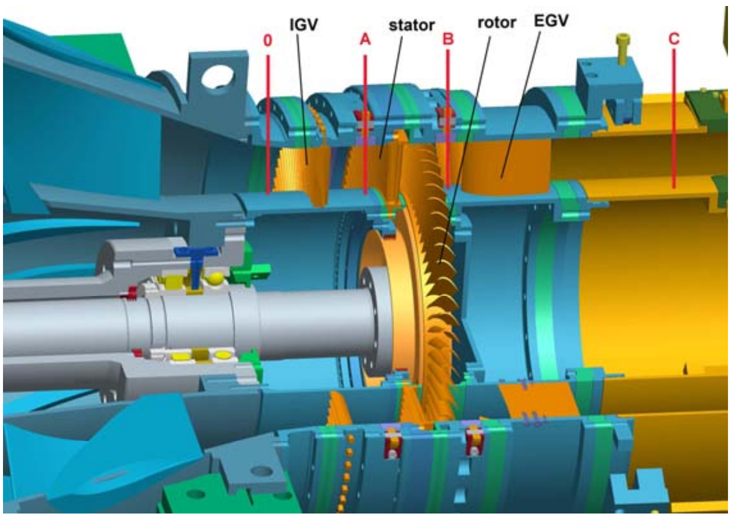
Turbine Stage

Test rig - blade rows distance modification



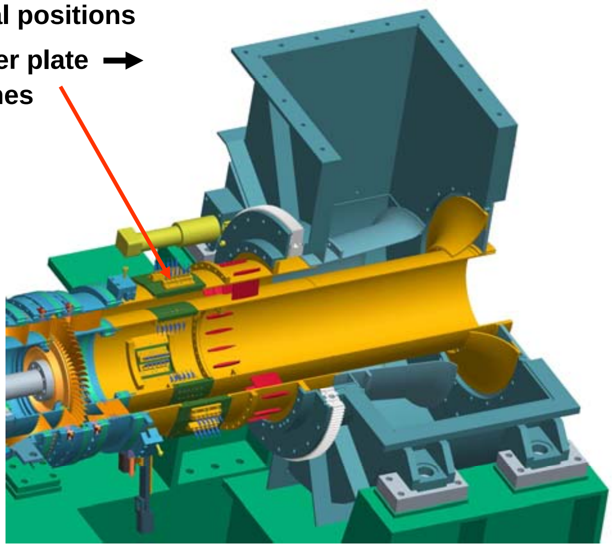
Probe Measurements

A, B, C … Measurement planes for Five-Hole Probe



Acoustic Measurements

- Rotatable cylindrical exit duct
- 3 microphone plates at inner and outer duct wall at 3 circumferential positions
- 12 microphones per plate ➞ total 72 microphones



DREAM

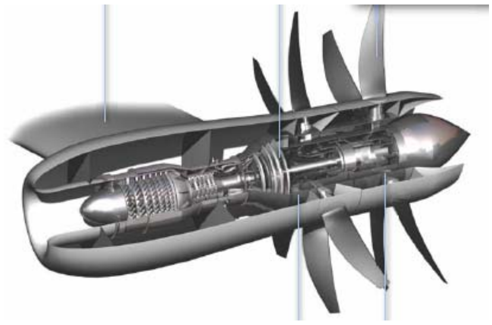
Research objectives:

- Open rotor contra-rotating engines: more efficient than traditional high bypass ratio turbofans (better propulsion efficiency), but are noisier
- Novel architectures and structures (e.g. mid-frame structures)
- Active and passive engine systems to reduce vibrations and study active turbine control.
- Alternative fuels

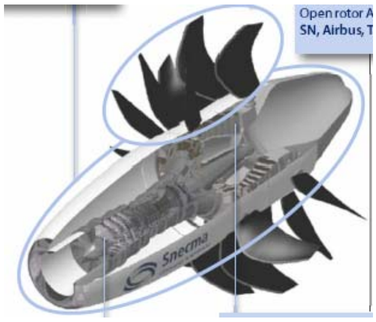
Open Rotor

- Open Rotor Architecture needs a mid-frame structure for mounting to aircraft
- Mid-frame structure is based on an intermediate duct with massive struts ⟶ influence on duct and turbine aerodynamics
- TU Graz: duct aerodynamics between two full turbine stages

Geared Open Rotor



Direct Drive Open Rotor



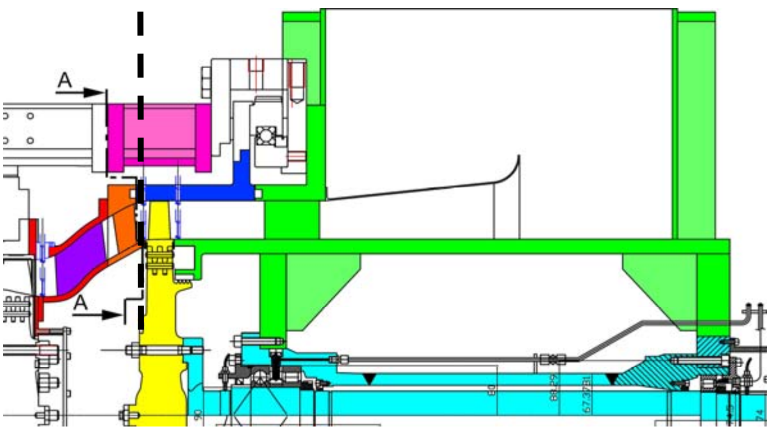
Source: DREAM

DREAM

- Adaptation of existing AIDA configuration with 1 ½ stage to a 2-stage test rig with duct between a HP and a LP turbine stage
- Combination of AIDA and VITAL test rigs

AIDA rig

DREAM rig



To water break →

TU Graz
Graz University of Technology

Thank you
for your attention!