Aeroengine Research in European Cooperation at Graz University of Technology

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

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Graz

City: 240,000 inhabitants
City+Suburbs: 370,000 inhabitants
4 Universities with 50,000 students

7 Faculties
9000 students

Institute for Thermal Turbomachinery and Machine Dynamics
Graz University of Technology
Graz University of Technology

Students total: 9,200
  - of which women: 20%
  - of which foreigners: 14%
    (30 students from Turkey)

Beginners: 1,400

Graduates:
  - Master degrees: 590
  - Doctoral degrees: 148

Staff total: 1,610
  - Academic Staff: 980
  - Non-academic Staff: 630

Institute for Thermal Turbomachinery and Machine Dynamics
Insitute f. Thermal Turbomachinery & Machine Dynamics

Turbine Blade Test Rig

Transonic Turbine

Office

Laboratory

Workshop

Compressor Station

→ 3.3 MW electric power consumption

→ 15 kg/s mass flow (pressure ratio 2.8)

2.7 MW shaft power

3.3 MW electric power consumption

11.550 rpm

Organisational structure
Metrology used

Wind tunnel insert

- Probes
- Thermography
- Particle-Image-Velocimetry
- Laser-Doppler-Anemometry
- Interferometry

- pressure, temperature
- surface temperature
- flow velocity
- density and density fluctuations

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

1. February 2004
AIDA (692 k€)
Aggressive Intermediate Duct
Aerodynamics for Competitive and
Environmentally Friendly Jet Engines

1. January 2005
VITAL (740 k€)
Environmentally Friendly
Aeroengine - Noise Measurements

1. February 2008
DREAM (825 k€)
New Aeroengine Core Concepts -
Constant Volume Combustion

1. May 2008
ALFA-BIRD (280 k€)
Validation of Radical Engine
Architecture Systems –
Intermediate Duct Aerodynamics

1. May 2009
NEWAC (237 k€)
Alternative Fuels and Biofuels
for Aircraft Development
Introduction

- Increasing problem of environmental pollution
- Increasing fuel costs
- Running out of fossil fuels

→ Reduce fuel consumption

Increasing efficiency

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

Aggressive Intermediate Duct Aerodynamics for Competitive & Environmentally Friendly Jet Engines

- 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
**Intermediate Compressor Duct**
Guides the flow from the LP to the HP compressor

**Intermediate Turbine Duct**
Guides the flow from the HP to the LP turbine
Transonic Test Turbine Facility

Exhaust

Air from 3 MW Compressor Station
Transonic Test Turbine Facility

Overhung Rotor Disk

40 - 185 °C
up to 4 bar
up to 22 kg/s

Test Rig General Arrangement

Stage ADP:
1. Pressure Ratio $\Pi$: 3.1
2. Rotational Speed: 11000 rpm
3. Power: 1590 kW

Mach Number at Blade Exit: ~ 0.65
Blade Tip Gaps: 1.5% and 2.4% span

Duct:
1. A2/A1: ~ 1.5
2. Length/Height: ~ 2
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.

\[ L \ldots \text{average wall length}, \; R1 \ldots \text{inlet height} \]

From Sovran and Klomp (1967).

Overview of the Investigations

- **3 Configurations C3, C4 and C5**
  - C3 represents an integrated concept
  - C4 duct flow near separation
  - C5 separated flow

  ➜ **Cascade Testing necessary!**

- **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

- **Two different Aero design points (ADP’s)**
- **For each ADP two different rotor tip clearances**
**Wide Chord Vanes (Strut)**

**Aggressive Duct**

**AIDA Test Setups**

C5 Super-Aggressive Duct

**AIDA - Results**

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
Test Rig-Tip Clearance

1.5% span

2.4% span

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 rotor gaps
  - Full area traversing between LP Vane and rotor
  - Full area traversing downstream the rotor

- Boundary layer rakes, Pressure Rakes, Temperature Rakes

- Static pressure taps

- Oil flow visualisation
Instrumentation

LDV Measurement Grid
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

**Numerical Results - Flow Solver LINARS**

- Calculation Specifics
  - approximately 2,000,000 cells
  - fillets and the clearances were modeled
Unsteady Flow Through ITD

ITTM - TU Graz
Rene Pecnik, 2007

LDV Measurements at Duct Inlet

Mach Number

Velocity [m/s]

Yaw Angle [deg]
Turbulent Kinetic Energy

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

Rotor Wakes (TKE)
Tip Leakage Flow

Time-space plots at 88 % span

Instrumentation – Five-Hole-Probe

Calibration Range

- $0.2 < Ma < 0.8$
- $-20 < a +20$
- $-16 < g +20$

Probe from RWTH Aachen (IST)
Duct Inlet-Total Pressure

Pressure loss due to passage vortex, tip leakage vortex and scraping vortex

Loss core shifted towards mid-span

P.V. up to 30% channel height

Total pressure loss increased

Significant difference limited to tip region

Higher 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
Static Pressure

Rotor Tip Gap size

1.5% span

2.4% span

Pressure Rise

\[ C_p = \frac{(p_x - p_C)}{(p_{t,C} - p_C)} \]
**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 number minimum can be seen at the hub.

**Total Pressure**

**Rotor Tip Gap size**

1.5% span  
2.4% span

Loss Core

Downstream C1 no distinct minimum at the hub in pt can be seen.
**AIDA**

**Yaw Angle**

**Rotor Tip Gap size**

1.5% span  
2.4% span

![Graph showing yaw angle](image)

- **Passage Height**
- **α**
- **Strong dec. In plane D**

**Pitch Angle**

**Rotor Tip Gap size**

1.5% span  
2.4% span

![Graph showing pitch angle](image)

- **Passage Height**
- **γ**
- **Pos. swirl**
Estimation of Duct Loss

Loss Generation

Δp_i = \frac{p_{i,C} - p_{i,local\ plane}}{p_{i,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
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

Water brake
Scroll and Inlet Casing
Turbine stage
Exit duct with microphones
Pivotable inlet guide vanes

Stator Vanes

air flow
Rotor Blades

air flow

Exit Guide Vanes

air flow
Test rig - blade rows distance modification

changeable displacement-rings

air flow

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 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

Source: DREAM

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• 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

Source: DREAM
Thank you for your attention!