Aerothermal Research for Turbine Components – An overview of the European AITEB-2 Project

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AEROTHERMAL INVESTIGATIONS ON TURBINE ENDOFFWALLS AND BLADES

17 Partners
and
2 sub-contractors
from
7 countries
within Europe

Duration:
03/2005 – 08/2009

Budget:
7,3 Mio € with 5 Mio €
EC contribution
### Consortium

**AEROHERMAL INVESTIGATIONS ON TURBINE ENDWALLS AND BLADES**

**Industry & Research Institutes**

- RRD (1)
- Alstom (2)
- Avio (3)
- SIEM (4)
- MTU (5)
- Snecma (6)
- Turbomeca (7)
- Volvo (8)

- DLR Göttingen (9)
- VKI (10)

**Universities & Research Institutes**

- Imppan (12)
- Uni. Cambridge (13)
- ITS Karlsruhe (14)
- Uni. Florence (15)
- Uni. Chalmers (16)
- UniBw Munich (17)

**Sub-Contractors**

- Uni. Cranfield
- Uni. Genova
Motivation of AITEB-2

Aero-Engine Market Demands

- reduced cost and weight → reduced part counts
- higher by-pass ratios → increased fan power,
  smaller core engines,
  increased inlet temp‘s

Consequences for High Pressure Turbine Component

- highly loaded one or two stage HP turbines
- higher, flatter inlet temperature traverses
- „aggressive interducts“ to LP turbines
Scope of AITEB-2

Aerothermal Investigations on Turbine Endwalls and Blades

HPT LPT

passive flow control

advanced cooling concepts

high-lift technology for 2-stage HPT
supersonic aerodynamics for 1-stage HPT
Work Package Structure

WP1: Film-Cooling and Heat Transfer in Separated Flow (MTU)
WP2: Advanced Trailing Edge Cooling Concepts (ITS)
WP3: Flow and Heat Transfer on Turbine Endwalls (Avio)
WP4: Advanced Rotor Tip Cooling Concepts (Alstom)
WP5: Heat Transfer in Turbine Interducts (Volvo)
WP6: Enhancement of the CFD-Process (RRD)
WP7: Project Management (RRD)
Work Package Structure

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Isentropic Mach number
@ Design boundary conditions

**Steady State**

**Transient Results**

T120D Blade Cascade

EXP $M_a=0.67$ $Re=390000$ $Pr=1.09$
DEF $M_a=0.67$ $Re=390000$ $Pr=1.09$
PRD $M_a=0.67$ $Re=390000$ $Pr=1.09$
TM $M_a=0.67$ $Re=390000$ $Pr=1.09$

$X/Cax$ vs. Isoen. Mach Number
WP1: Film-Cooling & Heat Transfer in Sep. Flow

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T120D with LES (TM) …

and with URANS / TRAF (DEF)
Heat transfer coefficient @ Design Boundary Conditions

**Steady State** vs. **Transient Results**

**Heat transfer coefficient**

\[ HTC = \frac{\dot{q}}{T_w - T_{t1}} \]

Unsteady CFD does not really improve agreement with experimental data
Film cooling effectiveness @ Design boundary conditions

Steady State vs. Transient Results

Only more appropriate CFD modelling (LES) improves agreement!
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1. Validate CFD for current industrial standard rim seal configurations

2. Relate **steady low-speed** data with **unsteady high-speed full-stage** calculations

3. Complement and extend test matrix with parametric studies
   => **derive design guidelines**

**etc.**
WP3: Flow and Heat Transfer on Turbine Endwalls

Improvement in $\Delta \eta \approx +0.2\%$
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Further improvements of shroud design and cooling methods require the knowledge of the local heat transfer coefficients $h$ and local flow structures.
PIV in 1st shroud cavity: R-X plane

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PIV in 1st shroud cavity: R-X plane
PIV in 1st shroud cavity: R-X plane

Aerothermal Investigations on Turbine Endwalls and Blades

Talk 6C  6th European Aerodays 2011, Madrid Spain, 31.03.2011
PIV in 1st shroud cavity: R-X plane

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Talk 6C    6th European Aerodays 2011, Madrid Spain, 31.03.2011
CFD flow vector animation: inlet & 1st cavity

Shroud gaps open
Heat transfer on shroud top (Experiment)

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Fin1

Fin2

Swirling cavity flow

Fin3

Nu

1200
1000
800
600
400
200

rotation

SS

PS

TE
WP4: Advanced Rotor Tip Cooling Concepts

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1.50% coolant

Experiment

CFD

eta-cool: 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35

Talk 6C

6th European Aerodays 2011, Madrid Spain, 31.03.2011
Squealer Geometries.

Concepts

- **TG-1** - full squealer geometry. (2006)
- **TG-3** - partial double sided squealer. (2009)
- **TG-4** - “at worn condition” geometry. (2009)

Cooling

- Pressure side film cooling.
  - TG-1 & TG-4 positioning.
  - TG-2 & TG-3 positioning.
- Dust holes.
\textit{“worn” geometry TG4}

Separation  \hspace{1cm} Reattachment
Downstream Loss Carpet Plots - HRHM, no cooling

TG-1 : $\zeta_c$ (11.8%)

TG-2 : $\zeta_c$ (15.3%)

TG-3 : $\zeta_c$ (12.9%)

TG-4 : $\zeta_c$ (12.9%)
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WP6: Enhancement of the CFD-Process (RRD)
WP7: Project Management (RRD)
Basic CFD Process

CAD import/repair/modification

Meshing

MeshTools

BoXeR

Solver

Postprocessing / Obj. Function

feature definition (.xml)

.stp, .wrl

b.c.'s (.xml)

.cgns

.cgns
WP6: Enhancement of the CFD-Process

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GIF ANIMATION view in slideshow mode

Fixed Topology Optimisation using MeshTools
WP6: Enhancement of the CFD-Process

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Topology independent Optimisation using Boxer

Rapid meshing of complex geometries is no problem
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DoE results – Adiabatic Surface Temperature

4 holes

7 holes

10 holes

Squealer 3.2mm  Squealer 4.1mm  Squealer 5.0mm
Overall combined metric: \( G(\eta, \varepsilon) = 0.5 \* \eta + 0.5 \* \varepsilon \)
Conclusions (1)

- Within the AITEB-2 project, a wide variety of CFD applications was applied ... RANS, URANS, LES, particle separation, approaches using Conjugate Heat Transfer methods (CHT).
- Meshing of complex geometries and handle meshes with ~10 Mio cells has become standard, an efficient CFD process from CAD – Solve was shown.
- CFD predicts flow separation well, but has significant difficulties with predicting re-attachment locations in complex flows.
- The inclusion of transition models – as available in commercial CFD codes and as developed at Univ. Florence – improved agreement with exp. data.
- Focus on unsteady CFD for unsteady problems vs. iterating various turbulence models.
- Even unsteady CFD with transition (URANS) do not fully accurately capture experimental data for film-cooling effectiveness and heat transfer coefficient.
- CFD captures trends, but is still off quantitatively for complex flows.
Conclusions (2)

- We still need experiments and will continue to do so!
- Increasing CFD capabilities require more detailed boundary conditions (not just flow, but more turbulence quantities)
- Comments to CFD vendors and academic CFD partners:
  - Mesh quality control essential for controlling standards of flow results; in particular during CFD based optimisation
  - Need for readily available higher level CFD methods for assessment of detailed flow features (e.g. trailing edge cooling)
  - Need for readily applicable conjugate CFD methods for very complex geometries with related requirements for meshing tools
  - Need for dedicated turbulence model development for Turbo-machinery capable of coping with very strong streamline curvature
Thank you very much!

www.aiteb-2.eu