Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdańsk

The Szewalski Institute of Fluid Flow Machinery
Polish Academy of Sciences

Department of Transonic Flows and Numerical Methods

Transonic Flows Dept. research tools

General research directions

Participation in European research projects

5FP
AITEB

6FP
AITEB-2
FLIRET
TLC

Coordination - UFAST
7FP
ERICKA
FACTOR
Department of transonic flows and numerical methods

CFD tools:

In-house code **SPARC** - parallel aerodynamic research code, obtained from Karlsruhe University (dr. Magagnato)

**Fine-Turbo** of Numeca from Brussels (prof. Ch. Hirsch)

**FLUENT**

**FLOWer** – aerodynamic code from DLR (German Aerospace Establishment) in Germany, Chimera meshing

Hardware:

Academic Computer Centre in Gdansk TASK, INTEL tests HPC clusters in Swindon, UK
Experimental tools

Test Section: 1800mm × 350mm × 100mm
Vacuum Tanks: 120 m³
Pump Unit: 2300 + 700 m³/h
Evacuation time: 5, 20, 35 min
Blow down time (100mm × 100mm throat:) ~20 sec.
Drying Unit: silica gel, layer of 1 m height 2.5 m diameter; 70 kW heating system (end temp. 150°C).

Measurement Equipment:

Pressure: -digital barometer DRUCK,
-pressure transducers KULITE and DRUCK
-intelligent pressure scanners PSI System 9010, 4 × 16 channels,
-computer controlled pneumatic probe
-PSP Pressure Sensitive Paint

Optics: -Schlieren system, SPECLE method
-Mach-Zehnder interferometer,
-CCD technology for picture registration
-PIV system of DANTEC.
Experimental tools

Methods under current implementation:

- Quantitative schlieren system – **SPECLE** method precise digital photography and post processing system – cooperation with prof. N. Fomin from Minsk

- Post-processing of the **interferograms** – elimination of optical errors in finite fringe mode – cooperation with prof. H. Babinsky in Cambridge University

- Pressure Sensitive Paint (**PSP**) – purchase of light source (ultra-violet) and CCD camera (16-bit light intensity), paint formula – cooperation with ONERA in Paris Yves Le’Sant and Marie-Claire Merienne
General research directions

1) Shock wave – boundary layer interaction
2) Shock wave induced separation
3) Flow control methods counteracting separation \textbf{EUROSHOCK I / II}
4) Shock waves interaction (triple point)
5) Formation of asymmetric shock system in a nozzle
6) Secondary flows and vortical structures analysis
7) Air humidity effects on shock wave induced incipient separation
8) Condensation process – phenomenological models comparison with Molecular Dynamics, effect of inert gases presence
9) Lift enhancement methods \textbf{HELIX subcontractor}
10) Cooling of gas turbine blades and end walls \textbf{AITEB, AITEB-2}
11) Supports interference with model measurements in transonic wind tunnels \textbf{FLIRET}
12) Aerodynamic study of modern lean combustors \textbf{TLC}
13) Induction of asymmetric flow field by steam extraction in a turbine
14) Unsteady effects in shock wave induced separation \textbf{UFAST}
15) New projects in 7th FP \textbf{ERICKA and FACTOR}
4th FP 1994 – 1999 EUROSHOCK I and II (in Karlsruhe)

Local supersonic area

Shock wave

Boundary layer

Perforated plate application

$M_w = 1.30$

Shock position

Porous plate $p_{corr} = 4.9\%$

Passive cavity

Suction cavity

$X = 0 \quad 50 \quad 100$
5th FP subcontract

Lift enhancement methods

LET = Lift-Enhancing Tab

EU project HELIX
Lift enhancement methods

no LET

with LET

with LET

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Cooling of gas turbines blades and end walls

Aerothermal Investigations on Turbine Endwalls and Blades (AITEB)
Co-ordinator: Frank Haselbach, Rolls-Royce-Deutschland

WP 1
- improved cooling methods
- num. aerothermal design tools for 3D-Turbine Components

WP 2

WP 3

WP 4

WP 5

WP 6

CFD-Process

Mesh
Model
Evaluation

5th FP partner

12 May 2011, Gdańsk

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### AITEB-2 Partners

<table>
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<th>Company Name</th>
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Cooling of gas turbines blades and end walls

AITEB-2
WP3 Effusive cooling

Micro-holes d=0.05 mm

- Is micro-flow modelling important?
- Transpiration flow model
- Holes stopping problem?
- Experiment

Test section proposed for the basic study

Air jets

Coolant supply

WP-1

AITEB-2

IMP contribution
Piotr Doerffer

Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdańsk

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reference

\( \phi = 0.5 \text{ mm} \)

\( \phi = 1 \text{ mm} \)
# Flight Reynolds Number Testing

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<td>Univ. Stuttgart -IAG</td>
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Supports interference with model measurements in transonic wind tunnels

WP 1 is dedicated to supports for complete wind tunnel models (high speed).

WP 2 considers the main unsteady effects which play a major role in cryogenic testing: buffet onset and model vibrations (high speed).

WP 3 deals with half models for high lift configurations (low speed).

WP 4 provides the integration which is split into CFD, models, testing and recommendations for the future.
IMP PAN contribution

BLADE STING
Rear end measurements
MODEL I

CFD analysis:
FLOWer code from DLR
Chimera mesh techniques

experiment, DNW full-span model
experiment, NWB half-model

$C_\alpha$

$\alpha$

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Flow conditions:
1) $Ma = 0.85$ and $Ma = 0.87$
2) $Re = 27 \times 10^6$
3) $\alpha = -1^0, 0^0, 1^0$

**REMFI full-span model with blade sting**

**free-flight chimera mesh:**
REMFI 57 blocks, 8.7 millions
STING 16 blocks, 1.9 millions
BLADE 24 blocks, 1.5 millions

------------------------------------------
TOTAL 97 blocks, 11.1 millions
The subject of TLC focuses on low-emission combustion of liquid fuel in aircraft engine combustors.

Many specific difficulties have to be solved from the physical point of view (auto-ignition, flashback, instabilities, lean extinction limit).

**Trapped Vortex Combustor**

**TVC concept (from the paper NASA/TM-2004-212507)**
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Contribution of IMP PAN

Geometry of LPP duct and combustion chamber
Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdańsk

Unsteady effects in shock wave induced separation **UFAST**

Coordination by **IMP PAN**

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<td>Queens University Belfast, School of Aero. Eng.</td>
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<td>Russian Academy of Science, Siberian Branch, Novosibirsk, Inst. of Theor. App. Mech.</td>
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Industry Observer Group:
- RRD,
- Ansys Group
- Alenia
- Dassault aviation

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Objectives of UFAST:

The first objective of the UFAST project is to provide a comprehensive experimental data base.

Experiments of “basic” interaction (WP-2)

and with flow “control devices” (WP-3) e.g. perforated walls, sublayer vortex generators, stream-wise vortex generators, synthetic jets, electro-hydrodynamic actuators EHD/MHD

The second objective - application of recent developments in numerical simulations:

RANS/URANS (WP-4),

hybrid RANS-LES and LES (WP-5).

“best-practice guidelines”

The third objective, improvement in physical understanding of unsteady effects in shock induced separation.

Interaction types considered in UFAST:

- Transonic interaction
- Nozzle flow
- Oblique shock reflection
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<table>
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<tr>
<th>UFAST</th>
<th>Transonic interaction</th>
<th>Channel flow</th>
<th>Shock reflection</th>
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<tbody>
<tr>
<td>WP -2</td>
<td>A) QUB – wall bump B) INCAS – biconvex aerofoil C) ILOT – NACA0012 with aileron</td>
<td>2) ONERA (DAFE) – nozzle, forced shock oscillation B) CUED – nozzle, forced shock oscillation C) IMP – nozzle, curved channel</td>
<td>3) A) TUD – M=1.6 B) ITAM – M=2.0 C) IUSTI – M=2.25</td>
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Piotr Doerffer 22
Application of the Passive Control of Shock Wave to the Reduction of High-Speed Impulsive Noise
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Model helicopter rotor in hover (F. X. Caradonna and C. Tung, NASA 1981)

2-bladed NACA0012 rotor in high-speed hover (AR=6)

Perforation charact.: outer 20% of the span, 10%c - 65%c, porosity 5%

experimental set-up

tip Ma: 0.88, Re: 4 \cdot 10^6
AoA \alpha: 8^o

single blade grid topology (80 blocks)

perforation location

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High velocity flight – $M = 0.22$

Blade tip velocity $M = 0.66$

FLOWER (DLR)

$k$-$\omega$ (Linear Explicit Algebraic stress mod.)

No blade elastic deformation but full articulation included
ERICKA - **Engine Representative Internal Cooling Knowledge and Applications**

FACTOR - **Full Aero-thermal Combustor – Turbine interactiOn Research**

Follow-up project of UFAST – Effect of transition location on the shock wave induced separation – external and internal aerodynamics

**THE PEOPLE PROGRAMME – Marie-Curie**
Industry-Academia Partnerships and Pathways

**STA-DY-WI-CO** (LMS Belgium - IMP PAN Poland)

STAtic and DYnamic piezo-driven StreamWIse vortex generators for active flow Control

**Initial Training Networks**

**IMESCON**
Innovative MEthods of Separated Flow CONtrol in Aeronautics
Thank you for your attention