Project AST5-CT-2006-030874

PUBLISHABLE

Main Annulus Gas Path Interactions - MAGPI

Publishable Final Activity Report

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SUMMARY:

This document provides an overview of the activities carried out within the MAGPI project during the project duration from 01. Sep. 2006 to 31. Aug. 2011 (60 months).

It summarises the project activities and results over the full duration.

This report is intended for publication by the European Commission.

CIRCULATION: to EC and all Partners of the MAGPI-Consortium via

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1 List of Content

2 Abbreviations

CFD Computational Fluid Dynamics
FE Finite Element
WP Work Package

3 Partners

Partners:

1 Rolls-Royce Deutschland Ltd & Co KG
2 SNECMA
3 Rolls-Royce plc
4 Avio S p A
5 Siemens Industrial Turbomachinery Ltd
6 Alstom Ltd
7 ITP S.A.
8 MTU Aero Engines GmbH
9 Turbomeca
10 University of Surrey
11 University of Sussex
12 University of Karlsruhe / now: Karlsruhe Institute of Technology
13 University of Darmstadt
14 University of Florence
15 University of Madrid (UPM)

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4 Project Execution

4.1 General Description

The project MAGPI addresses interactions between main gas path and secondary flow systems in commercial gas turbines for improving engine thermal efficiency and reducing secondary air losses. This is a novel approach as these systems have hitherto only been considered separately.

In a modern aero engine, up to 20% of the main annulus flow is bled off to perform cooling and sealing functions. The vicinity of these bleed ports and flow sinks is characterized by complex unsteady swirling flows which are not fully understood. Even the most up-to-date numerical tools have difficulties predicting the behavior of the secondary flow system when interacting with the main annulus. The project addresses interactions between main gas path and secondary flow systems in commercial gas turbines in response to Research Activity AERO-2005-1.3.1.2a “Concepts and technologies for improving engine thermal efficiency and reducing secondary air losses.”

Within MAGPI, experiments have been conducted on turbine disc rim and compressor manifold cavity heat transfer, hot gas ingestion, and spoiling effects of cooling air flow and their impact on turbine and compressor performance, as well as on reduction of secondary air losses.
These experimental data, obtained at four rigs, are used for better understanding of the complex flow phenomena and improvements of platform and cavity design.
Furthermore, the industrial partners validate their design tools with these test data and improve their prediction capability of secondary flow systems when interacting with the main gas path.

Obtained technical results are:

- Improved knowledge of the interaction phenomena and its effect on cavity heat transfer, spoiling and performance,

· - Experimental results for validation of improved numerical tools for secondary flow systems,
· - Optimized design methods and CFD best practice guidelines.

Main improvements include:

- Experiments provided reliable rig test data to validate improved CFD/FE methods,
- Effective coupled CFD/FE convective heat transfer method demonstrated – this method will be applied as design tool,
- Alternative cooling flow configuration shows potential to improve rim seal cooling effectiveness
- Effect of different rim seal geometries on hot gas ingestion and pressure loss.

The targeted outcome will contribute to the ACARE goals to improve the environment and strengthen the competitiveness of European gas turbine manufacturers:

- Reduced CO2 emissions via reduced fuel burn (reduced cooling air flow, increase of turbine and compressor efficiency)
- weight decrease (turbine disc and compressor casing)
- increase of critical parts life
- improved reliability
- reduced development time (better methods for design of cooling system and off-takes)

4.2 Project Structure

There are four technical work packages:

WP1: Effects of Cooling System/Main Annulus Gas Interactions – Rotor Heat Transfer
– RR lead – Turbine Stator Well rig at Univ Sussex

WP2: Spoiling Effects of Sealing Flows on Turbine Performance
-- ITP lead – Large Scale Turbine Rig at Univ Darmstadt

WP3: Fundamental Studies on Heat Transfer and Aerodynamic Spoiling
-- MTU lead -- Linear Cascade rig at Univ Karlsruhe

WP4: Compressor Bleed
-- SN lead -- Outer bleed off-take rig at Univ Karlsruhe.

4.3 Summary of WP1 on Rotor Heat Transfer

Rotor heat transfer (Fig. 1) has been investigated experimentally on a two stage turbine stator rig at University of Sussex. A comprehensive set of test data has been produced for a range of geometries and flow conditions.
A coupled CFD/FE modelling capability has been established for convective heat transfer in the complex flow fields of turbine stator wells, Fig. 2. This methodology has been adequately validated for a representative geometry and selected flow cases. Moving mesh capability was developed to include transient deflections for better simulation of engine acceleration, Fig. 3.
The technologies demonstrated are expected to deliver the benefits of reduced fuel consumption and emissions that go with the improvements to the engine performance resulting from reduced cooling air consumption.

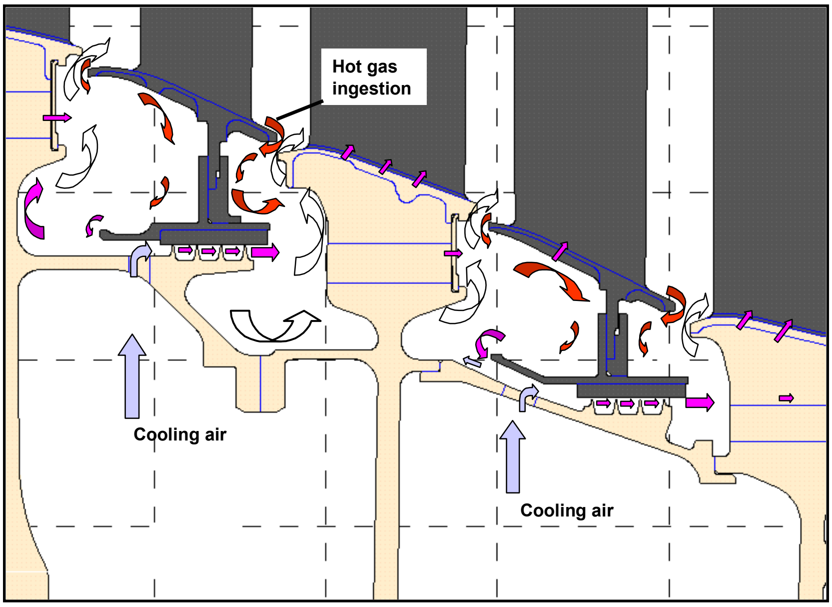

Fig. 1: Heat Transfer in Typical Turbine Stator Well

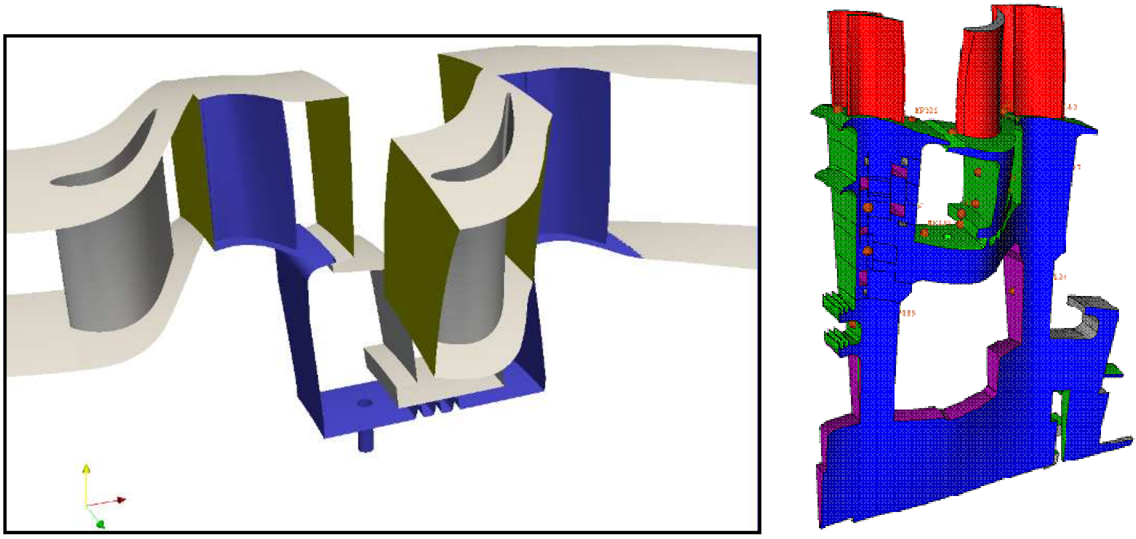

Fig. 2: CFD used for gas flow analysis (left), FE used for metal temperatures (right)

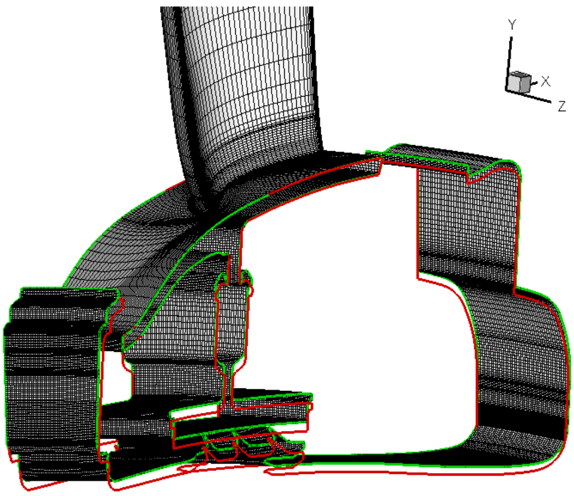

Fig. 3: Deformed mesh capability for coupled CFD/FE approach

4.4 Summary of WP2 on Spoiling Effects on Turbine Performance

A good quality and flexible rig has been built and allows to measure accurately all phenomena related to cooling flow-mainflow interaction, Fig. 4.
Significant amount of useful experimental data were obtained and compared to pre-test CFD predictions, Fig. 5, which showed good agreement.

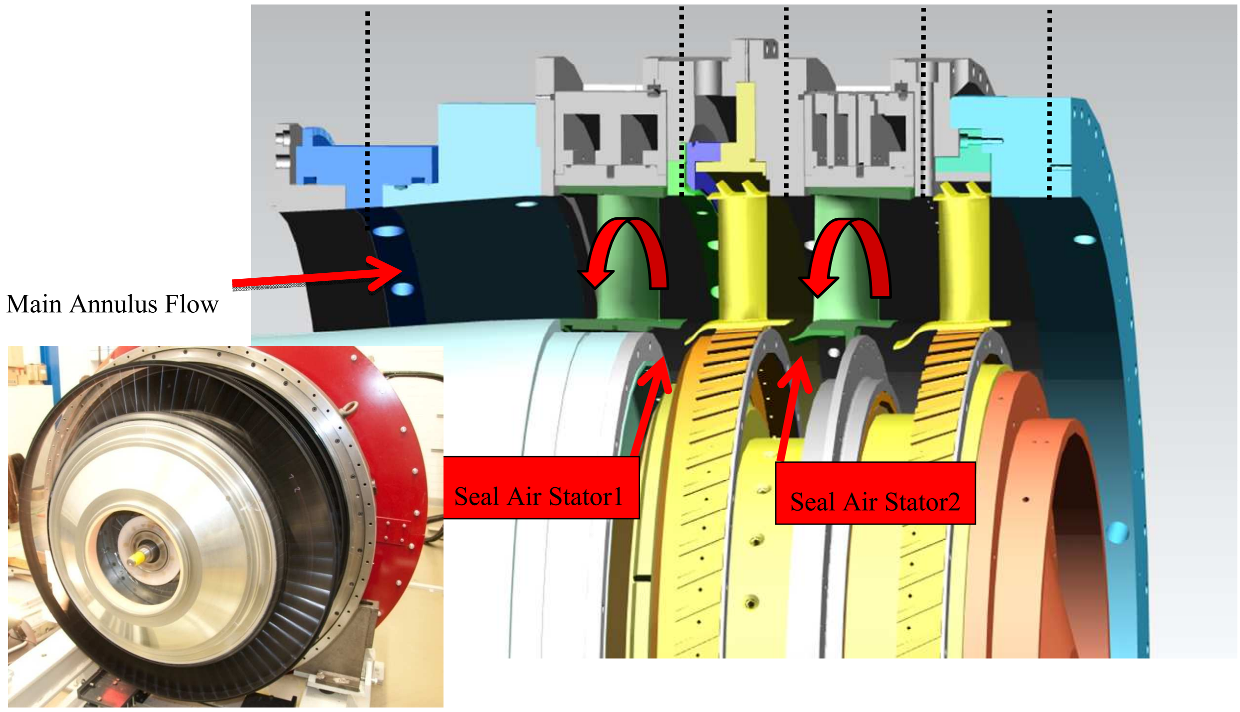

Fig. 4: Large Scale Turbine Rig

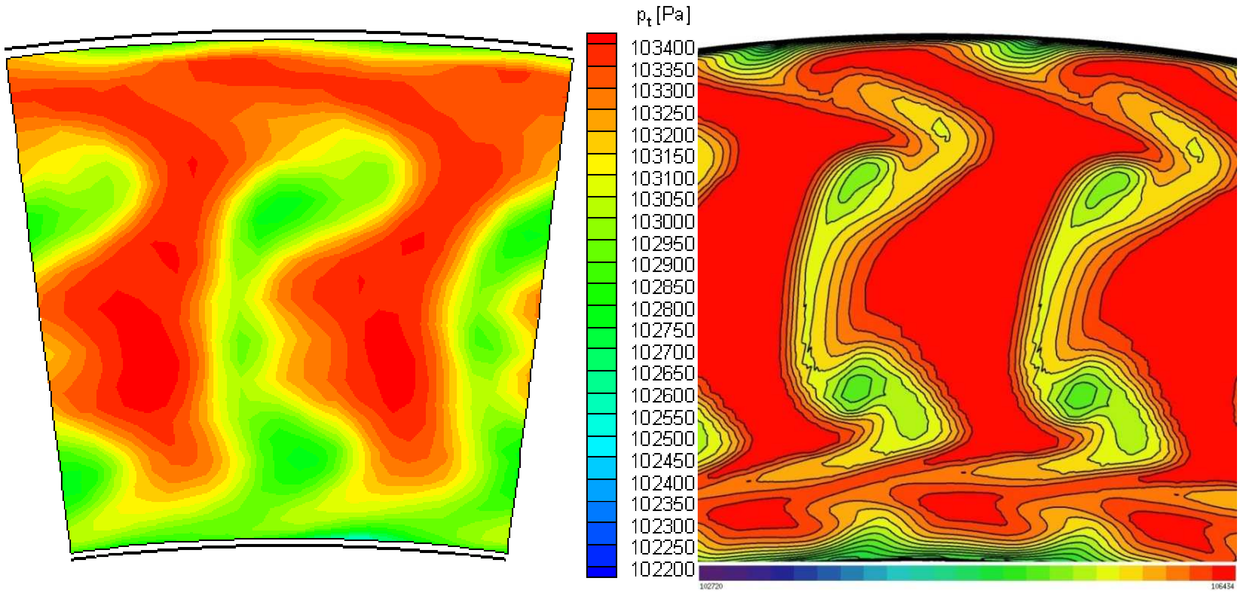

Fig. 5: Comparison of Pressure Field between CFD predictions (left) and 5-hole probe measurements (right)

4.5 Summary of WP3 on Fundamental Studies

A cascade rig with inflow of rim sealing air has been built at University of Karlsruhe, Fig. 6. Three seal configurations (axial gap, shingled and compound seal) were investigated in detail. Measurements of total pressure loss, blade loading, velocity (LDV and PIV) and temperature distribution on the end wall have been conducted for different sealing mass flow rates, Fig. 7. A data base with good quality experimental data was established in this WP and helped in combination with the validated CFD analysis to improve the physical understanding of the interactions between the cooling flow and the main gas flow.

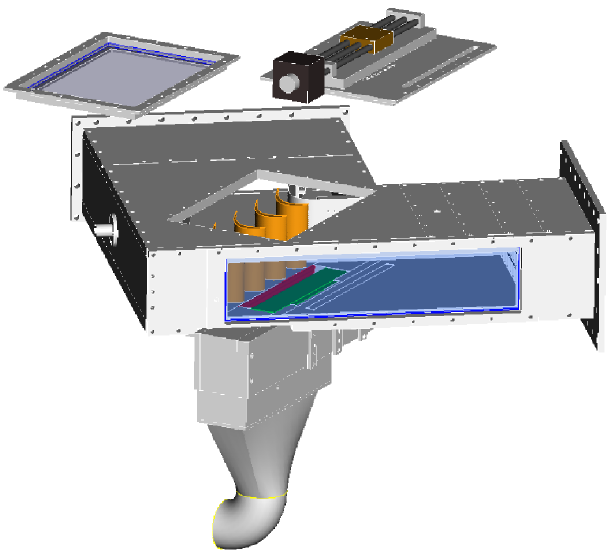

Fig. 6: Cascade Rig

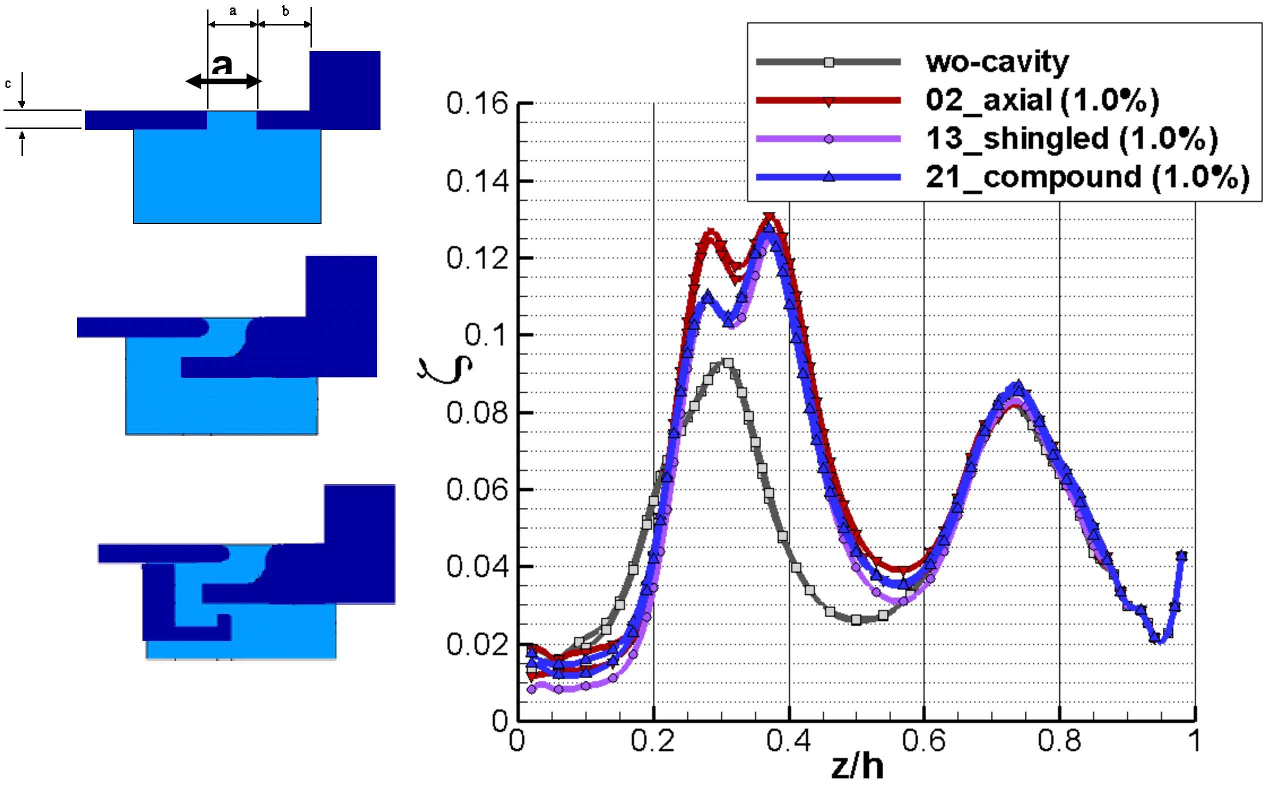

Fig. 7: Effect of Seal Geometry on Pressure Loss Coefficient vs Blade Height

4.6 Summary of WP4 on Bleed Air Off-Takes

Interactions between bleed off-take and main gas path have been studied on a full 360 degree rig for various geometries and flows, Fig. 8. The experimental database allowed CFD validation in terms of pressure loss as well as flow distortion in the manifold.
The number of off-take positions has a significant impact on the flow distortion, Fig. 9. More off-takes are clearly beneficial to reduce pressure losses.

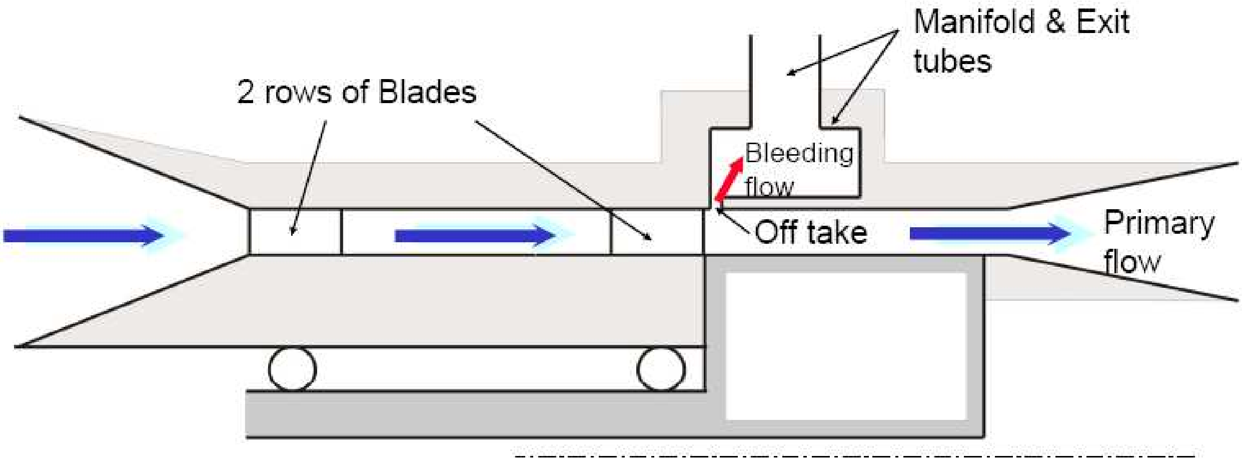

Fig. 8: Bleed Off-take Rig

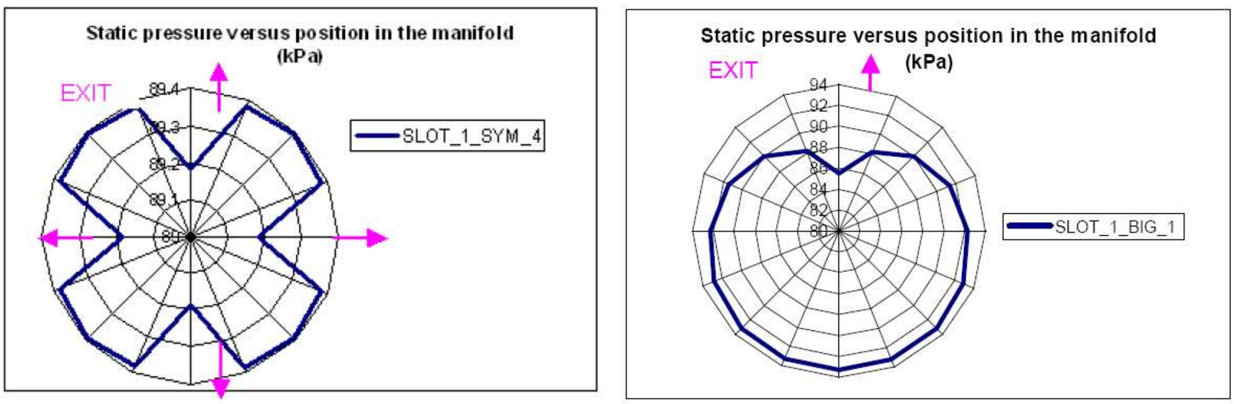

Fig. 9: Pressure Distribution in Manifold for one Large and four Small Exit Tubes

5 Dissemination and Use of the Knowledge

5.1 Dissemination

Several papers have been published to disseminate the results. A list of published and proposed conference and journal papers is given below in chronological order:

TURBINE STATOR WELL CFD STUDIES: EFFECTS OF CAVITY COOLING AIR FLOW, A. Andreini, R. Da Soghe, B. Facchini (UFI), S. Zecchi (AVIO), GT2008-51067, ASME Conference Berlin, June 2008.

TURBINE STATORWELL CFD STUDIES: EFFECTS OF COOLANT SUPPLY GEOMETRY ON CAVITY SEALING PERFORMANCE, A. Andreini, R. Da Soghe, B. Facchini (UFI), presented on ETC conference in Graz, March 2009.

TURBINE STATORWELL CFD STUDIES: EFFECTS OF COOLANT SUPPLY GEOMETRY ON CAVITY SEALING PERFORMANCE, A. Andreini, R. Da Soghe, B. Facchini (UFI), ASME Conference Orlando, Florida, June 2009. GT2009-59186
Transaction of this paper was also published in ASME Journal of Turbomachinery vol. 133

HEAT TRANSFER IN TURBINE HUB CAVITIES ADJACENT TO THE MAIN GAS PATH J. Dixon, A. Guijarro, A. Bauknecht, D. Coren (RR & USUS), ASME Conference Glasgow, June 2010. This paper has been chosen for a Best Paper Award by the Heat Transfer Committee.

THE INFLUENCE OF DIFFERENT RIM SEAL GEOMETRIES ON HOT-GAS INGESTION AND TOTAL PRESSURE LOSS IN A LOW-PRESSURE TURBINE, P. Schuler, W. Kurz, K. Dullenkopf, H-J. Bauer (UKA), ASME Conference, Glasgow, June 2010

AN EXTENSION OF FEA/CFD COUPLING TO INCLUDE THERMO-MECHANICAL DISTORTION, D. Amirante, N. Hills, C. Barnes (USUR&RR), ASME Conference, Glasgow, June 2010

AN ADVANCED MULTI-CONFIGURATION STATOR WELL COOLING TEST FACILITY, D. Coren et al., (USUS & RR, WP1), ASME Conference, Glasgow, June 2010

MAIN ANNULUS GAS PATH INTERACTIONS IN GAS TURBINES, by M. Klingsporn (coordinator representing the consortium), Aerodays Conference 2011, Madrid (30.3.-1.4.2011), see www.aerodays2011.org session 2C.

HEAT TRANSFER IN TUBINE HUB CAVITIES ADJACENT TO THE MAIN GAS PATH INCLUDING FE/CFD COUPLED THERMAL ANALYSIS, A. Guijarro et al. (RR & USUS), GT2011-45695, ASME Conference, Vancouver, June 2011

EXPERIMENTAL INVESTIGATION OF TURBINE STATOR WELL RIM SEAL, REINGESTION AND INTERSTAGE SEAL FLOWS USING GAS CONCENTRATION TECHNIQUES AND DISPLACEMENT MEASUREMENTS, D. Eastwood et al. (USUS & RR), GT2011-45874, ASME Conference, Vancouver, June 2011

THE EFFECT OF STATOR WELL COOLING FLOW RATE AND PASSAGE CONFIGURATION ON COOLING EFFECTIVENESS, D. Coren et al. (USUS & RR), GT2011-46448, ASME Conference, Vancouver, June 2011

VALIDATION OF A COUPLED FLUID/SOLID HEAT TRANSFER METHOD, J. Chaquet et al. (UPM & ITP), GT2011-45951, ASME Conference, Vancouver, June 2011

INVESTIGATION OF THE INFLUENCE OF DIFFERENT RIM SEAL GEOMETRIES IN A LOW-PRESSURE TURBINE, P. Schuler, K. Dullenkopf, H-J Bauer (UKA), GT2011-45682, ASME Conference, Vancouver, June 2011

MEASUREMENTS OF RIM SEAL MIXING PROCESSES IN AN AXIAL TWO STAGE TURBINE, S.Schrewe, C. Linker, A. Krichbaum, H.-P. Schiffer (UDA), ISABE-2011-2720, ISABE Conference Gothenburg, September 2012 (planned)

EXPERIMENTAL ANALYSIS OF THE INTERACTION BETWEEN RIM SEAL AND MAIN ANNULUS FLOW IN A LOW PRESSURE TWO STAGE AXIAL TURBINE, S.Schrewe, H.Werschnik, H.-P. Schiffer (UDA), GT2012-68292, Proposed for ASME Conference, Copenhagen, June 2012 (planned)

5.2 Use of the knowledge

The knowledge obtained within the MAGPI project is classified as non-publishable. It will be used by the industrial partners for improvement of internal methods and design guidelines. Relevant products are gas turbines for aero engines and helicopters as well as for power plants.

University partners will use the results in lectures for teaching and further cooperation with industrial partners, e.g. make use of gained knowledge on experimental and numerical methods.

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