Active Core
(An Overview)

Wolfgang Sturm, MTU Aero Engines

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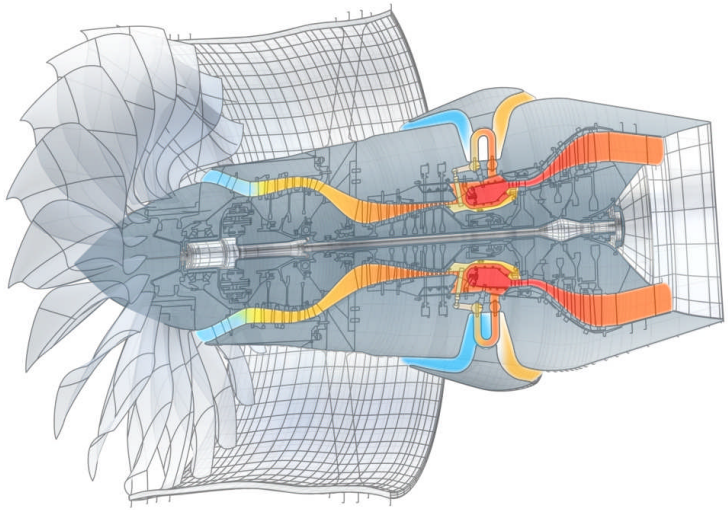
Why have we been working on active systems?

- **Active systems …**
  - … can be adapted to the very different operating conditions of a flight mission,
  - … open up additional degrees of freedom in the design,
  - … can compensate efficiency and safety penalties due to deterioration.

- The **high level objectives** have been …
  - … a SFC reduction of 4%,
  - … a weight reduction of 1% for the propulsion system,
  - … no increase in NO_x production



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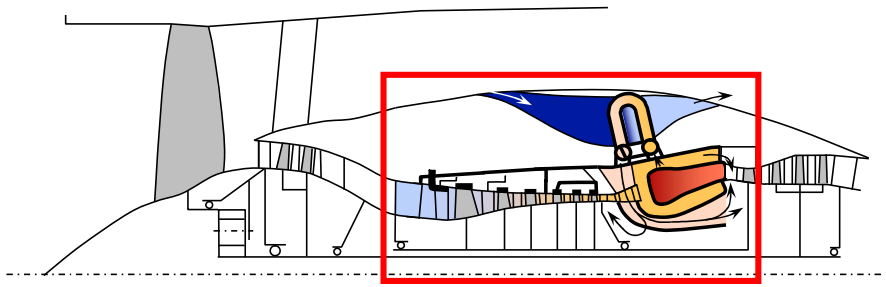
Which NEWAC partners have been part of the team?



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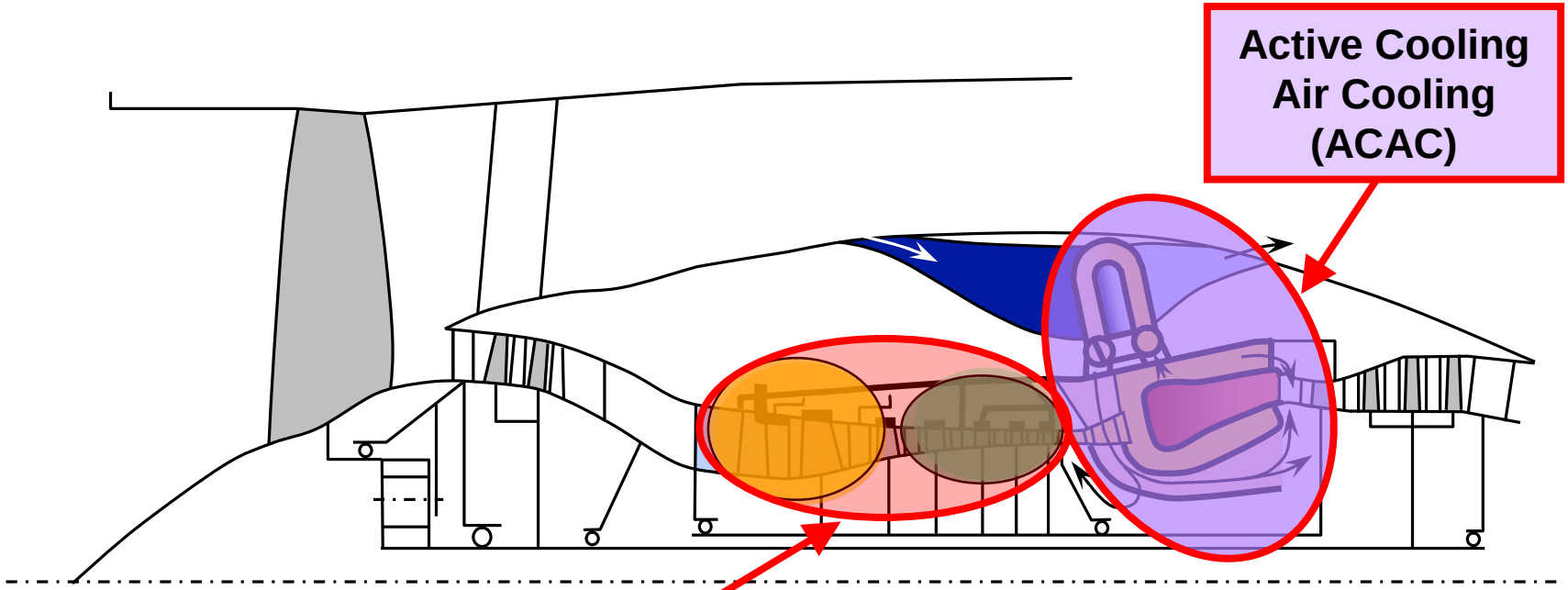
What have been the basic concepts investigated?



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Active Cooling Air Cooling

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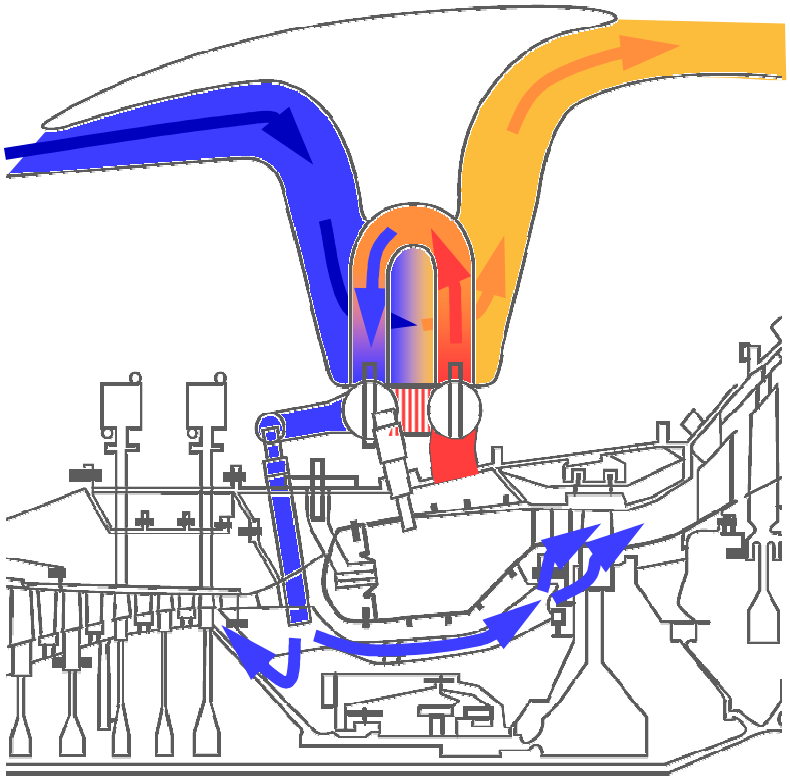
Why is Active Cooling Air Cooling attractive?

- Roughly 25% of HPC exit air used for cooling purposes
- Trend to increasing OPRs leads to high HPC exit temperatures resulting in …
  - … increasing demand for cooling air,
  - … expensive rear cone materials (e.g. powder metal).
- Active Cooling Air Cooling (ACAC) …
  - … lowers the temperature of the cooling air,
  - … modulates cooling air temperature,
  - … allows for new design approaches (thickness, material & manufacturing).



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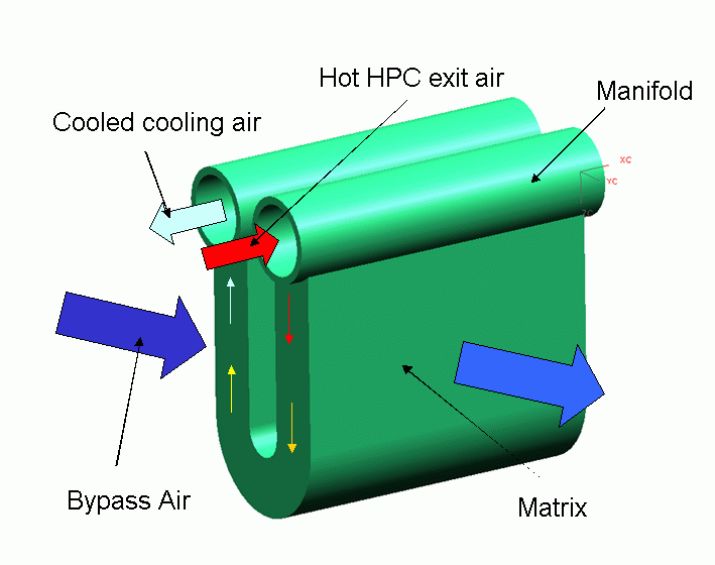
What was the scope of work on Active Cooling Air Cooling (1/3)

- General concept study (MTU Aero Engines)
  - Exemplary general arrangement developed
  - Appropriate secondary air system worked out (input for evaluation of heat pick-up and design tasks)
  - MTU cross counter flow heat exchanger chosen for HEX investigations
  - Different control system configurations evaluated with respect to projected reliability
  - Potential of HPC Rear Cone Cooling and reduction of cooling air mass flow in HPT airfoils investigated
  - For details refer to presentation on "*Concept Study on an Advanced Cooling Air Cooling System*" during this workshop



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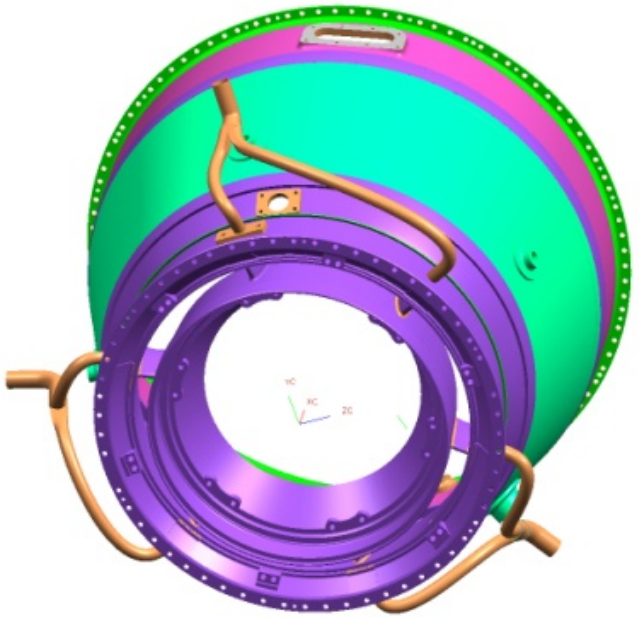
What was the scope of work on Active Cooling Air Cooling (2/3)

- Design and manufacturing trials for a ACAC combustor case (Volvo Aero)
  - Study performed on feeding the cooled air from the heat exchanger to the HPT (min. pressure losses & heat pick-up)
  - Tube solution selected but modifications to the combustor case necessary to accommodate the tubing
  - Bosses added by Laser Metal Deposition as a cost effective method
  - Heat transfer testing performed at Lund University to verify the analytical results
  - For details refer to presentation on "*Design and Manufacturing Trials for a Combustor Case with Active Cooling Air Cooling*" during this workshop



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What was the scope of work on Active Cooling Air Cooling (3/3)

- Investigation of supporting aspects
  - Adding heat exchangers and tubings results in a weight penalty
  - Weight offset activities performed by WSK (for details refer to presentation on "*Weight Offset with Titanium Aluminides*" during this workshop)
  - Investigation of new manufacturing methods for thin walled HPC rear cones performed by Sonats and Steigerwald Strahltechnik (for details refer to presentation on "*Development of a High-speed Beam Deflection System for Quality Improvement of Electron Beam Welds*" during this workshop)

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Smart HPC Technologies

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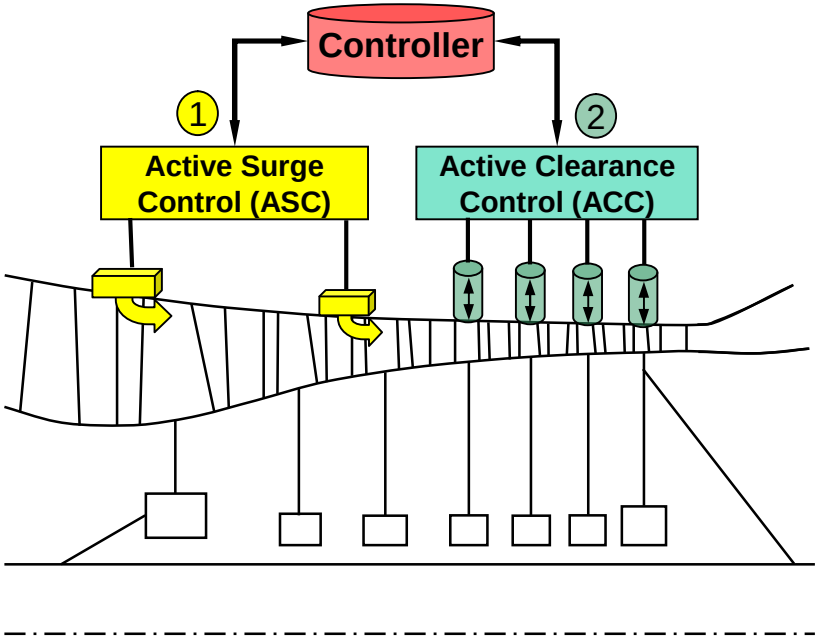
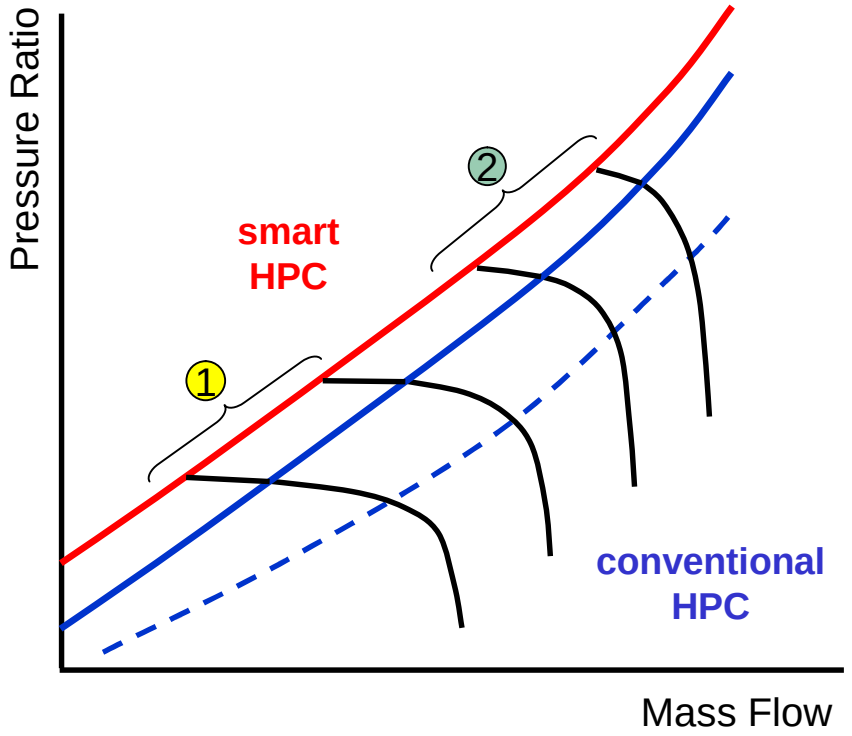
Why are Smart HPC Technologies attractive? (1/2)





- ASC in HPC front block generates increased part load stability
- ACC in HPC rear block generates increased stability in upper speed range

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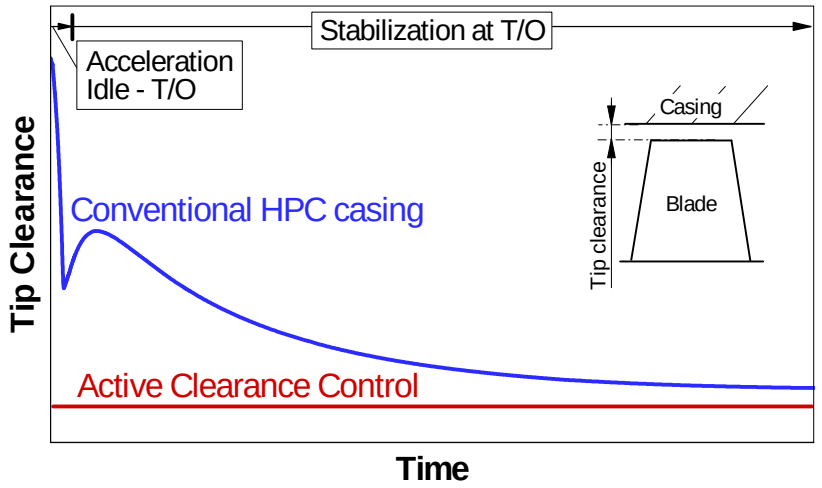
Why are Smart HPC Technologies attractive? (2/2)

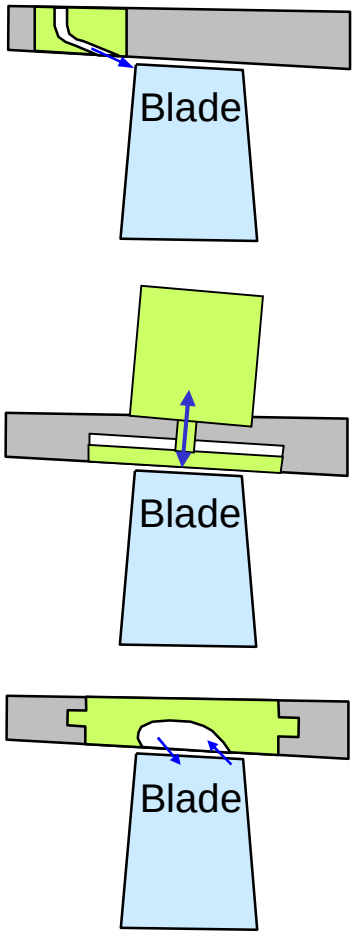
- Potential due to increased stability margin
  - higher operating line → efficiency benefit
  - reduced number of stages → length and weight benefit
  - reduced blade count → efficiency and weight benefit

- Additional potential of an ACC system
  - small tip clearances over whole mission even during transients (e.g. takeoff)
  - compensation of casing deflections due to manoeuvre loads



What have been the key elements?

- Active Surge Control (ASC) for HPC front block
  - Design/manufacture of a tip injection system
  - Development of a surge detection sensor
  - Test in full speed rig
- Active Clearance Control (ACC) for HPC rear block
  - Design/manufacture of a system based on mechanical actuators
  - Development of tip clearance sensors
  - Test in a proof-of-concept rig
- Comparison to the semi-active alternative of multi-stage Casing Treatment (CT)
  - Design of a sophisticated CT system
  - Test in compressor rig at RWTH Aachen



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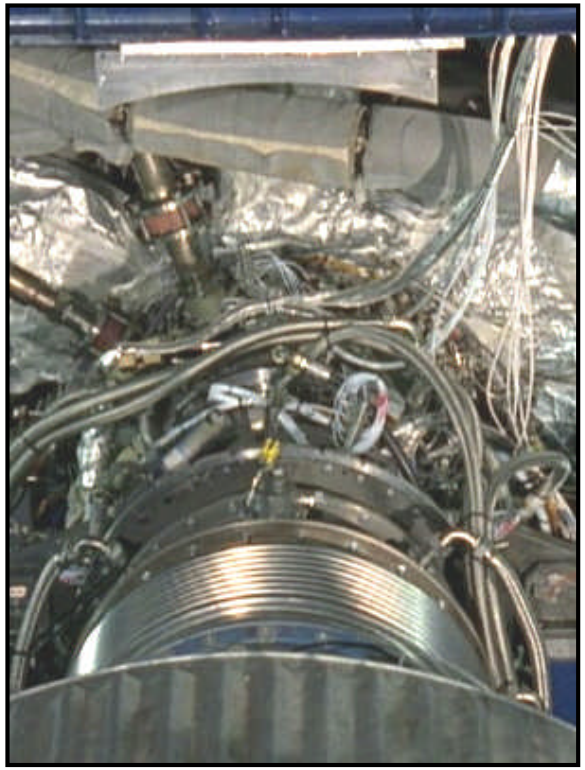
What was the scope of ASC rig testing?

- First test campaign in September 2008
- Second test campaign finalized end of June 2010 with 44 test days and 215 test hours accumulated
- Variation of injection liners as well as mass flow and temperature of injected air
- Measurement of overall and stage characteristics
- Interaction between injection jet and main flow investigated by means of probe traverses (5-hole probe & FRAP) and Particle Image Velocimetry (PIV)



ASC rig on MTU compressor test bed

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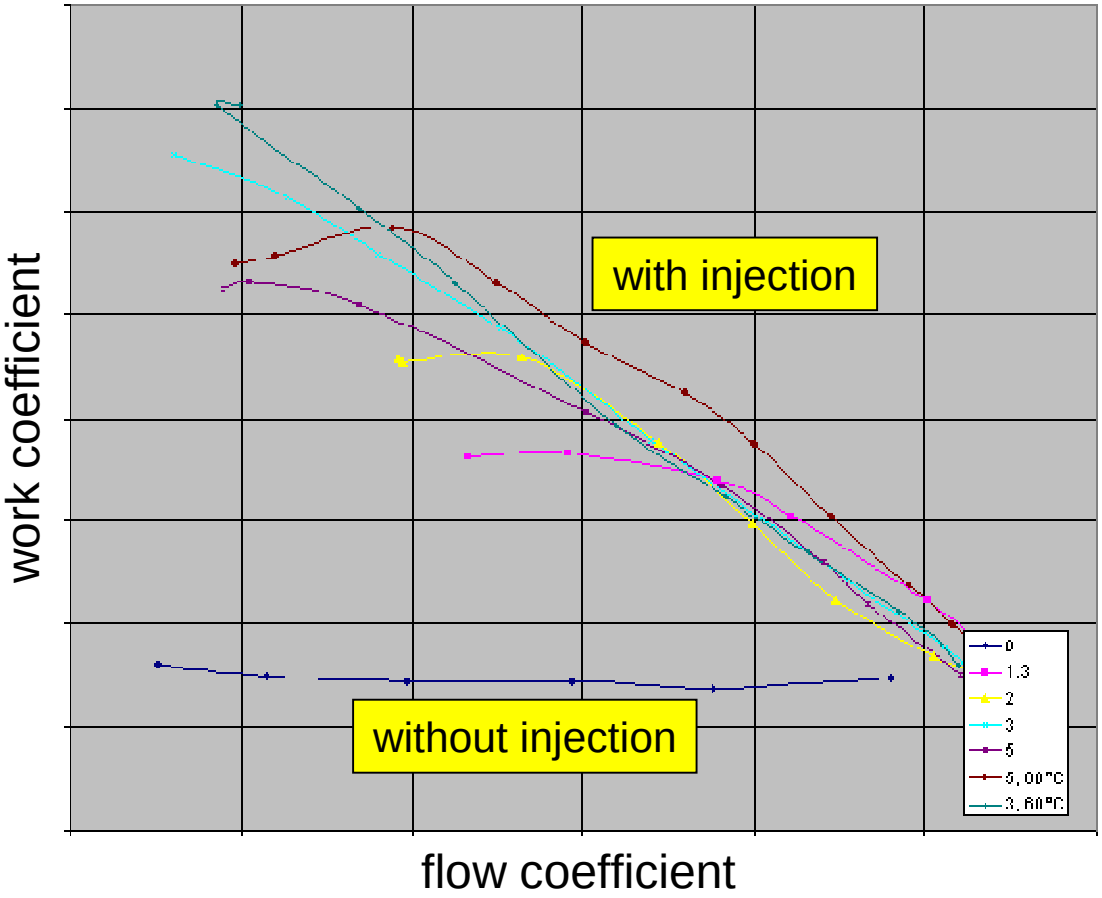
What was a typical result of ASC rig testing?

- Tip injection in the front stage led to a significantly higher work coefficient for that stage
- Overall benefit depending on surge triggering stage
- For details refer to presentation on "*Active Surge Control by Tip Injection*" during this workshop



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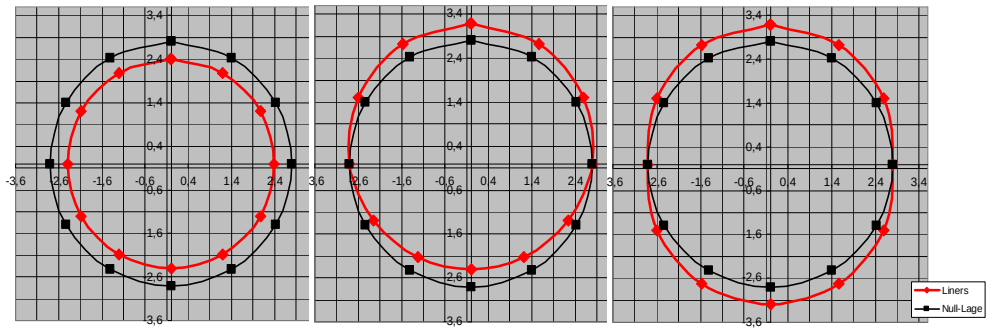
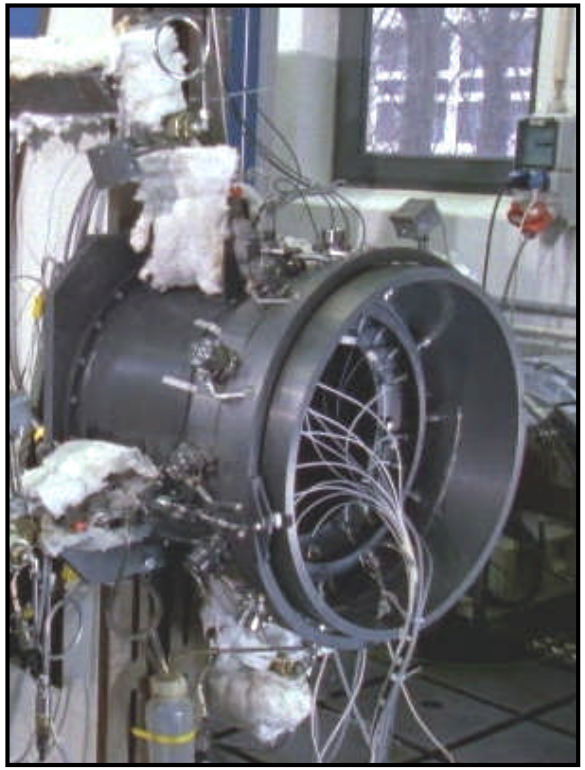
What was the scope of ACC rig testing?

- Test campaign finalized end of May 2010 with 31 test days and 134 test hours accumulated
- Adjustment of various centric, eccentric and oval tip clearance distributions at various speeds of actuating system



centric eccentric oval



ACC rig on MTU test stand

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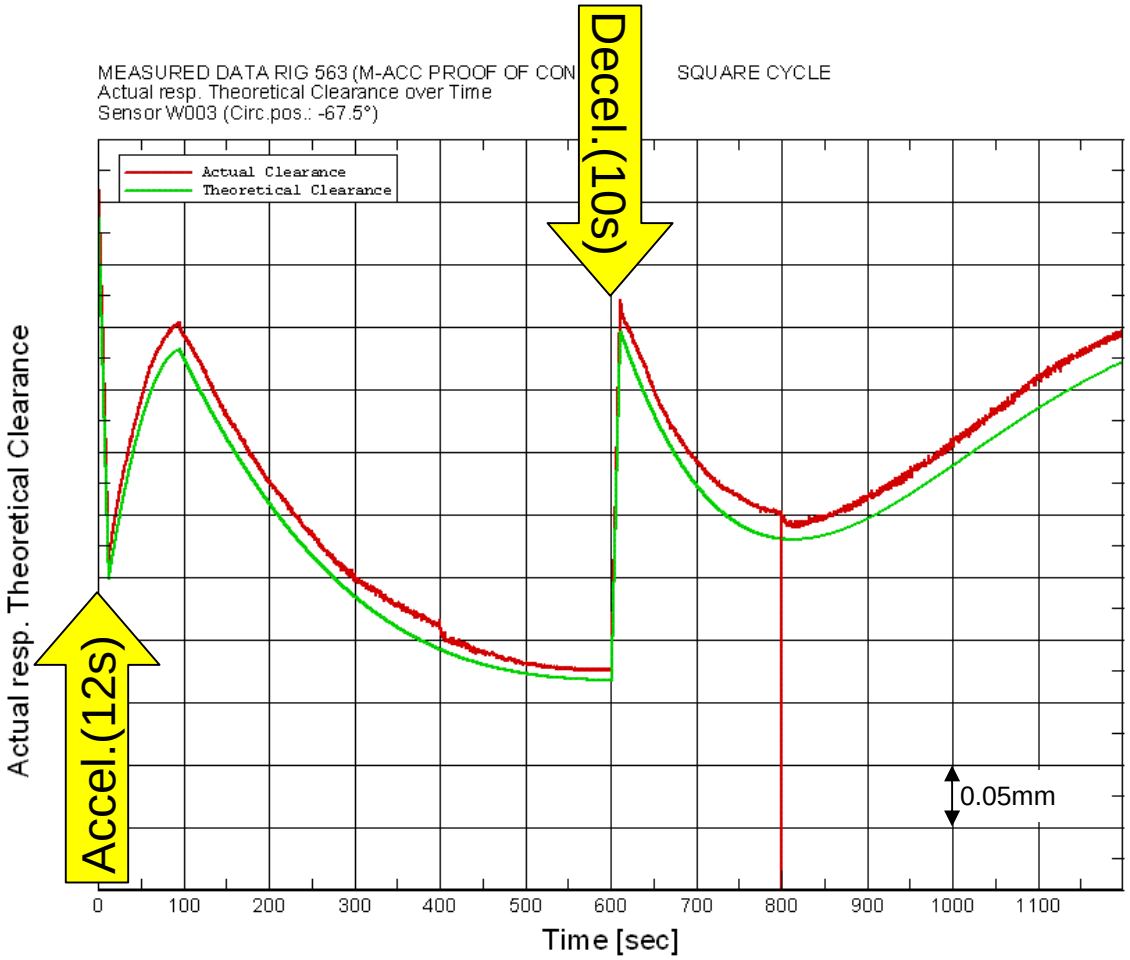
What was a typical result of ACC rig testing?

- Adjustment of centric transient tip clearances during a typical square cycle with a max. deviation of 0.03mm
- For details refer to presentation on "*Proof of Concept of a Mechanical Active Clearance Control System*" during this workshop



What was the motivation of sensor development?

- The application of Smart HPC Technologies in future production engines requires reliable controller input signals on …
  - … surge detection/precursor for Active Surge Control,
  - … tip clearance distributions for Active Clearance Control.
- The related sensors/electronics will have to withstand the harsh engine environment at least for the time on wing.
- The systems currently in use for development testing have significant constraints in terms of …
  - … robustness against temperature and vibrations,
  - … size (sensor & signal conditioning unit),
  - … lifetime.

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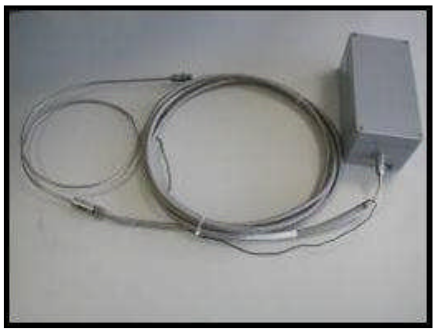
What was the scope of sensor development?

- Vibro Meter developed and delivered …
  - … a fast pressure sensor for the front stage,
  - … two different types of tip clearance sensors (eddy current & microwave) for the rear part of an HPC.
- These sensors were tested in a high speed HPC rig at MTU Aero Engines.
- For details refer to presentation on "*Fast Pressure Sensor and Tip Clearance Sensors for Smart HPC Technologies*" during this workshop

Fast pressure sensor



Eddy current sensor

Microwave sensor

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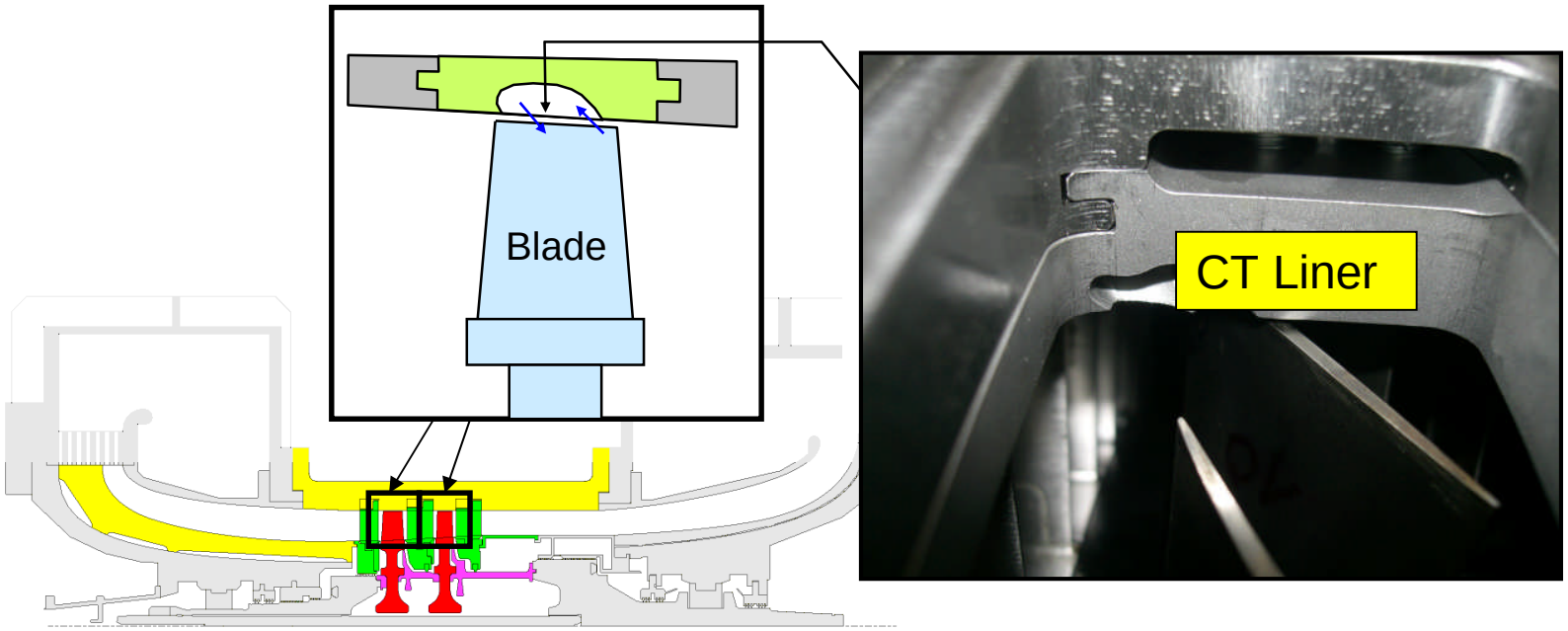
What was the motivation of multi-stage CT rig testing?

- Although ASC and ACC are considered to have a significant potential to increase the HPC stability both at part load and in the upper speed range, multi-stage CT could be an attractive alternative
- This should be checked in a related test campaign at RWTH Aachen



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What was the scope of multi-stage CT rig testing?

- Test campaign with multi-stage Casing Treatment (CT) is due to be finalized in July 2010
- Measurement of overall and stage characteristics
- Flow field measurement by 5-hole probe traverses
- Test results will be shown in presentation on "*Multistage Casing Treatment at High Pressure Compressor Rear Stages*" during this workshop

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Summary

- Work on active core within NEWAC provided a multitude of concepts, studies, designs and tests to verify predicted improvements towards overall goals.
- Rig tests on Smart HPC Technologies showed encouraging results.
- Manufacturing and sensor technology development contributed vital input for use of active elements in future engine programs.
- Cooperation of partners from engine industry, suppliers and university has proven to be an effective way forward.

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Thank you for your attention!

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