

# Sub – Project 4 Active Core

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## SP4 – Active Core – Technical Approach

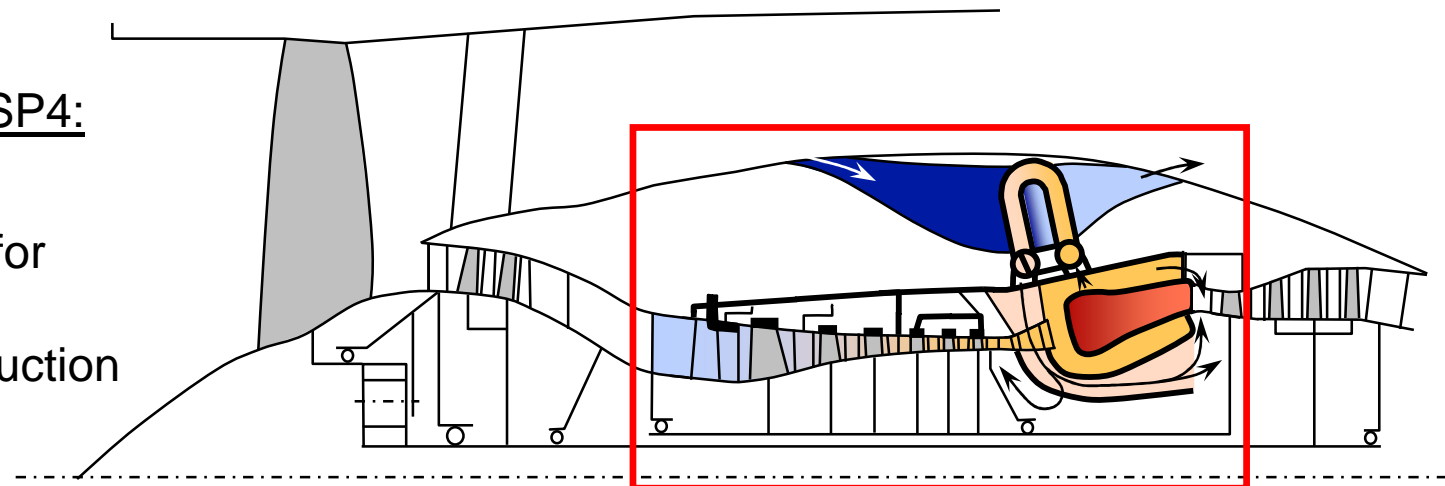
Active systems open up a new area of technological opportunities

- Adaptation to various operating conditions
- Additional freedom for design – no “worst case design” necessary
- Compensation of deterioration

In SP4 different active systems for core engine applications will be investigated and the most promising will be validated in a series of full scale rig tests.

### High level objectives of SP4:

- SFC reduction by 4%
- Weight reduction by 1% for propulsion system
- No increase in NO<sub>x</sub> production



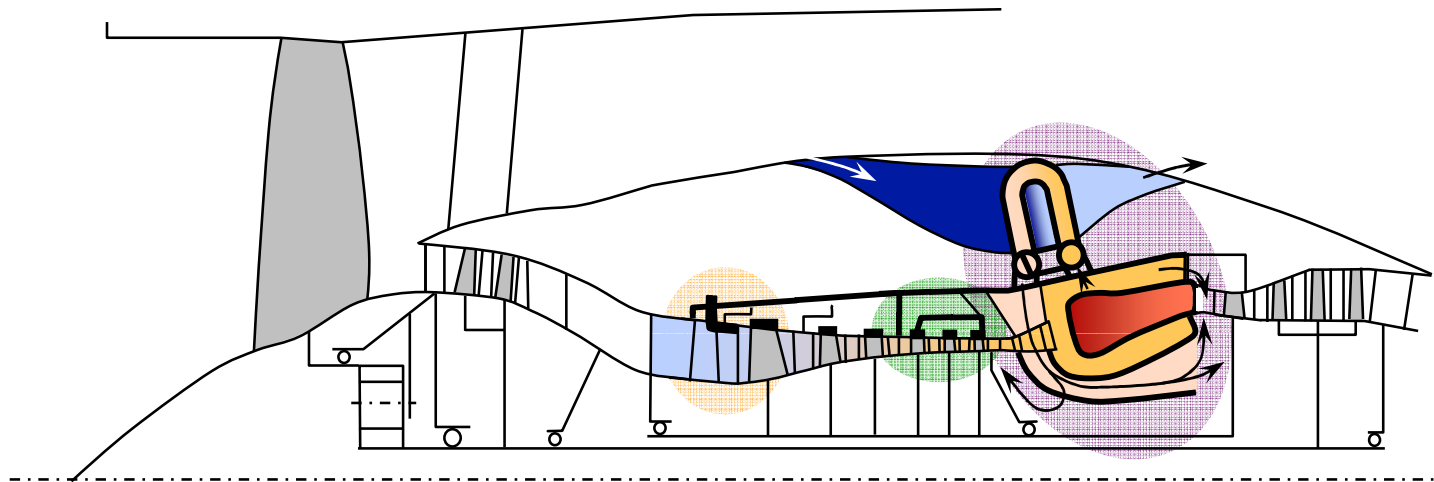
## SP4 – Active Core – Technical Approach

### Active surge control (ASC) with air injection

- Potential of injection for compressor front stages compared to the passive alternative of multi stage casing treatment
- Active surge control validation

### Active clearance control (ACC) system

- Improved tip clearance with active clearance control system (thermal or mechanical)
- Comparison with alternative technologies for tip clearance improvement



Links to:

SP2, SP3, SP5

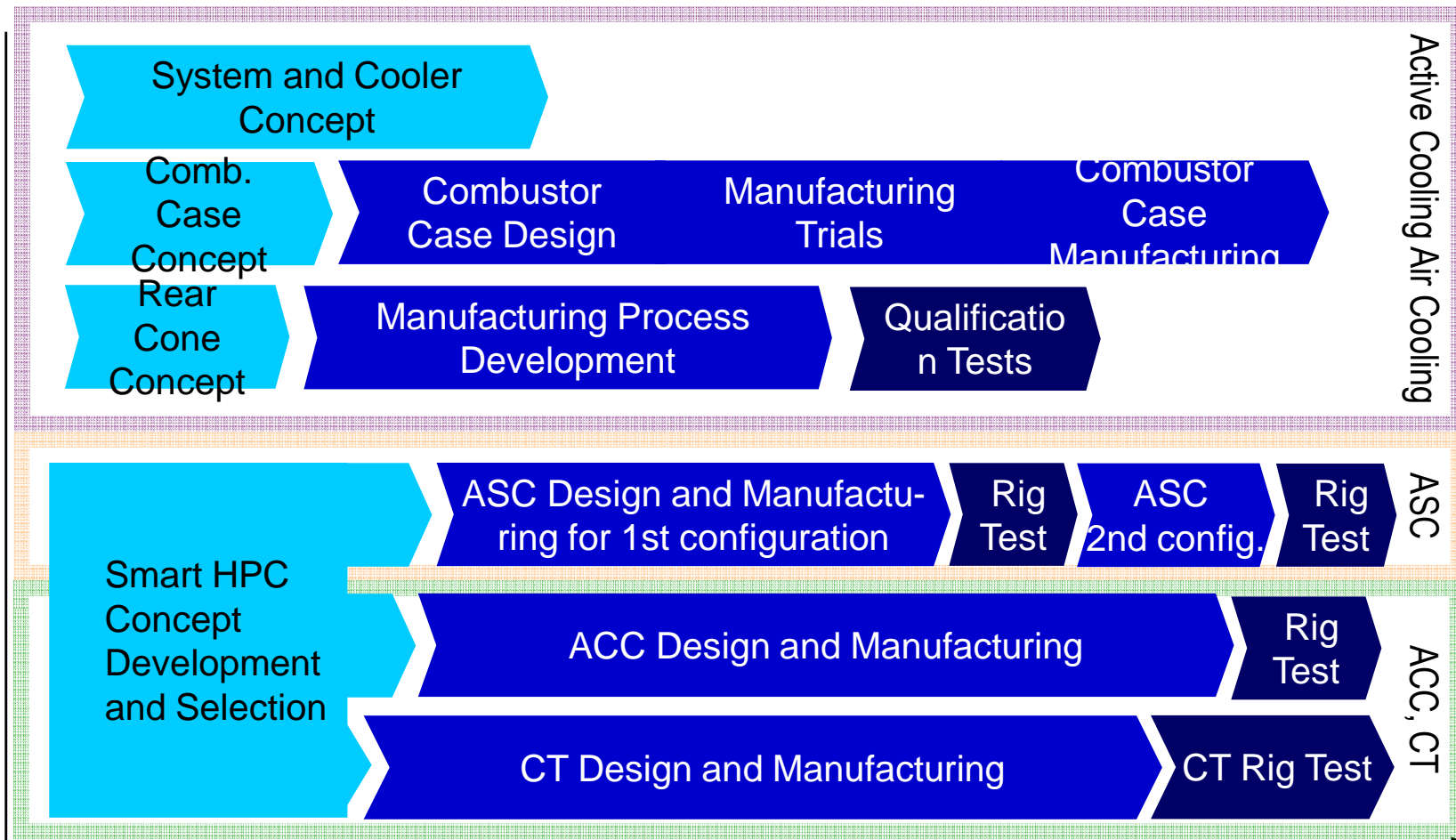
SP2, SP3, SP6

### Active cooling air cooling (ACAC)

- General concept
- Air cooler and control system
- Combustor case cooling air flow path
- HPC rear cone cooling

## SP4 – Active Core – Roadmap

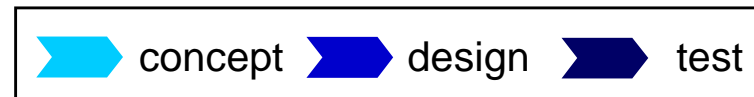
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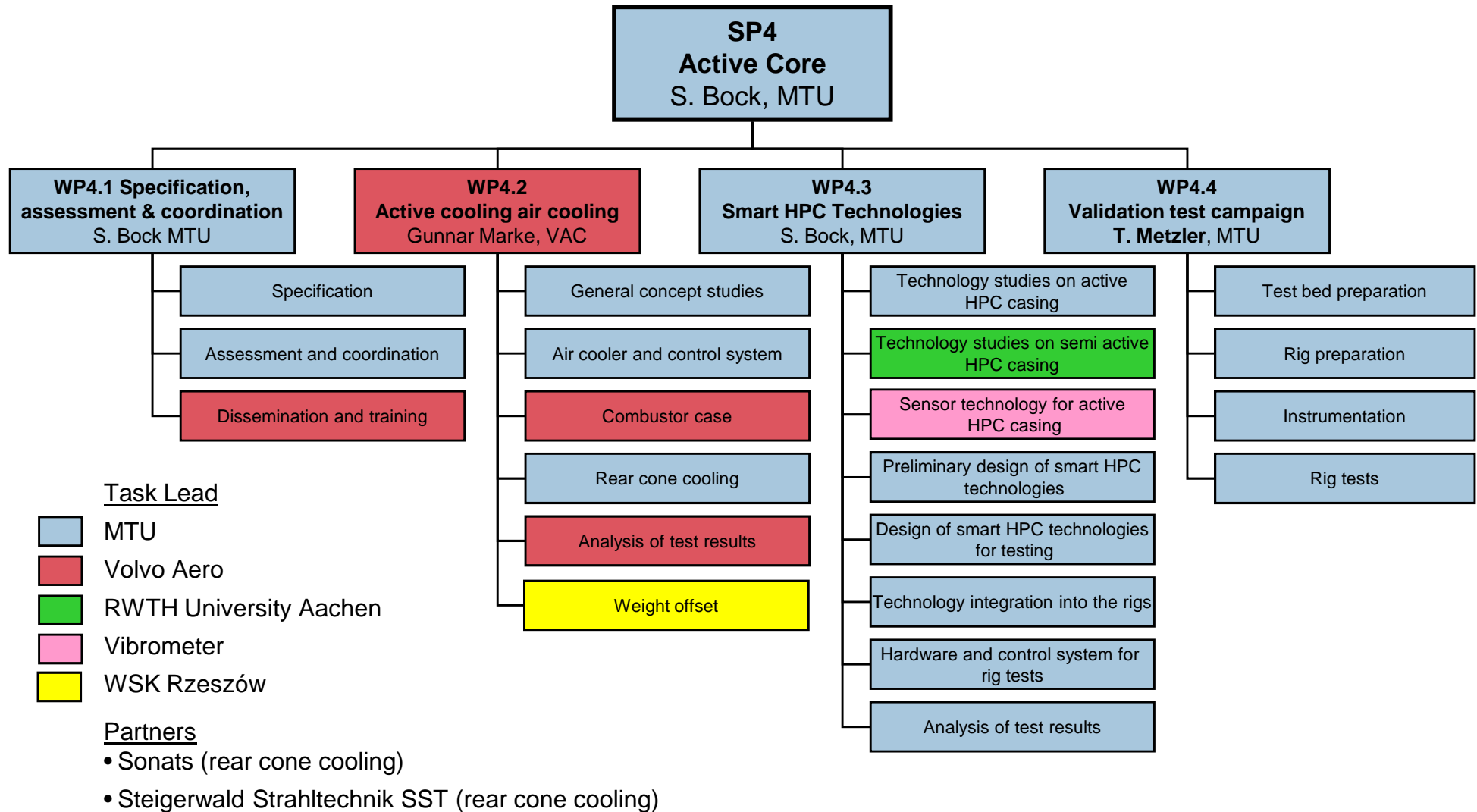
M1

M30

M48



## SP4 Active Core - Organisation



## SP4 Active Core – Concept Parameters

### Basic parameters for cooling air cooling

NEWAC objectives:

- 35% cooling air mass flow
- + 1% HPT efficiency



	Take-off*	Cruise*
HPC exit temperature	958 K	797 K
Reduction cooling air temperature	200 K	0 K
Pressure loss cooling air	5 %	3 %

### Basic parameters for smart HP compressor technologies

NEWAC objectives:

- + 1,5% efficiency (pol.)\*\*
- + 15% surge margin\*\*\*



	Take-off*	Cruise*
HPC pressure ratio	16,3	15,7
HPC inlet temperature	425 K	350 K
HPC inlet pressure	302 kPa	111 kPa

### → Core engine

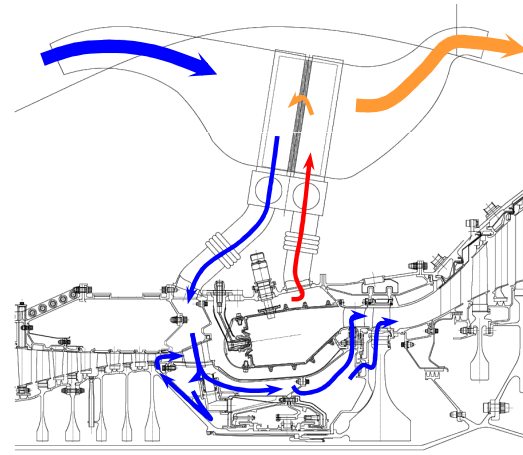
NEWAC objectives:

- 4% SFC
- 1% weight

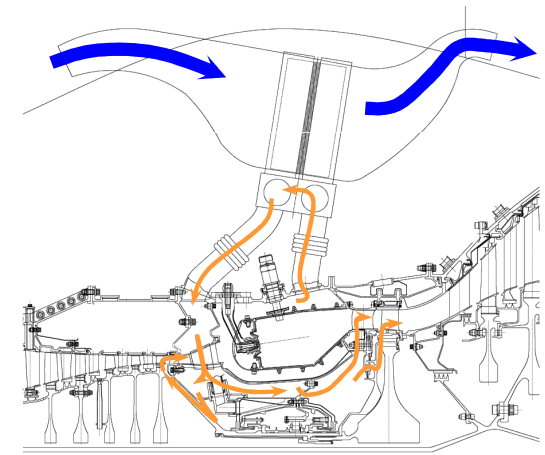
\* AC-GTF long range  
 \*\* including compensation of tip clearance deterioration  
 \*\*\* used for lift of operating line

## WP4.2 Active Cooling Air Cooling – Concept Study

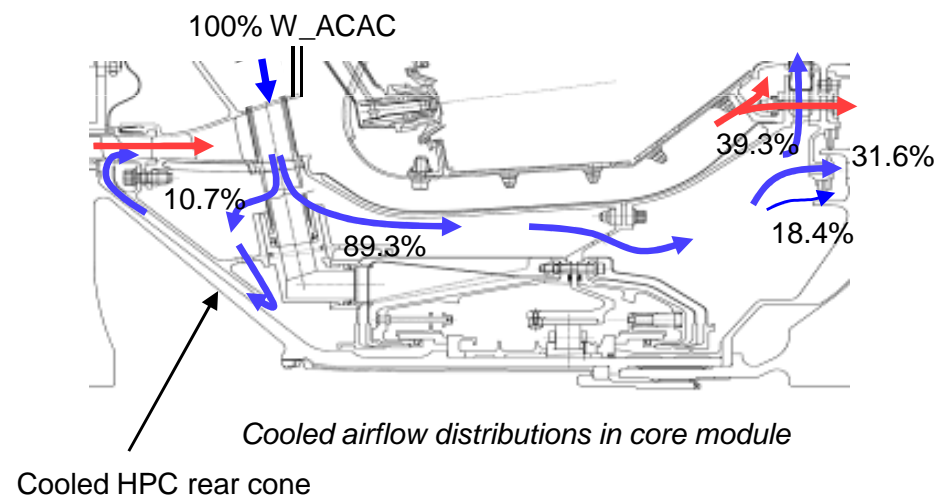
- HPT and HPC rear cone cooled with reduced temperature cooling air during T/O and cruise
- Bypass of cooler during cruise to avoid efficiency penalty
- Concept study with  $\Delta T$  cooler = 200°C showed SFC benefit >1.5% driven by cooling air mass flow reduction of >20%
- Weight and reliability study showed feasibility of concept
- Problems are possibly increased oxidation and creep due to hotter metal temperatures at cruise



Active Cooling Air Cooling switched on during take-off and climb



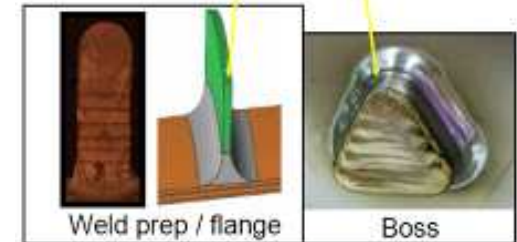
Heat exchanger bypassed during cruise



## WP4.2 Active Cooling Air Cooling – Manufacturing Technology

- Development of new metal deposition processes to build necessary features for active cooling air cooling (e.g. bosses and flanges) in a cost effective way.

**VOLVO  
AERO**



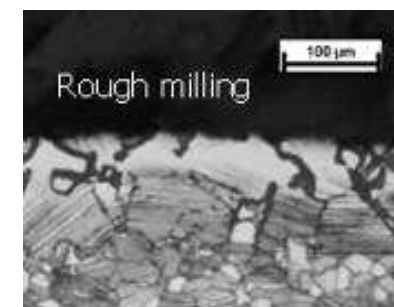
*Metal deposition trials for cost effective manufacturing of relevant features for active cooling air cooling on a combustor case*

- Investigation of new manufacturing methods for thin walled rear HPC cone. Ultrasonic shot peening and multi-beam electron beam welding for distortion free machining and improved material properties.

**SONATS**

**SST**  
STEIGERWALD STRAHLTECHNIK GMI. H

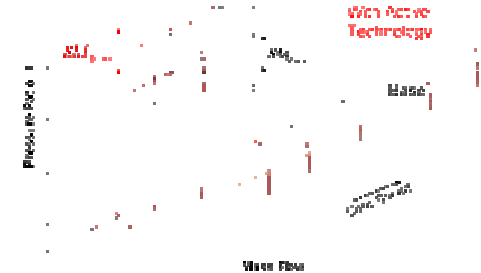
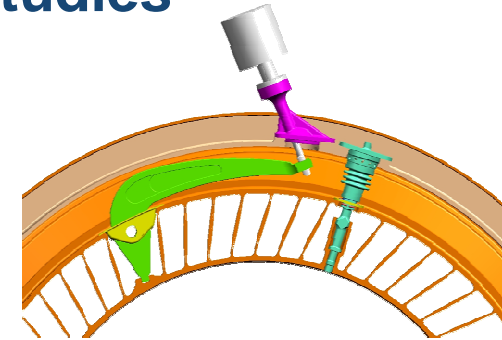
- Manufacturing technology development for Ti-Al usage in compressor components.



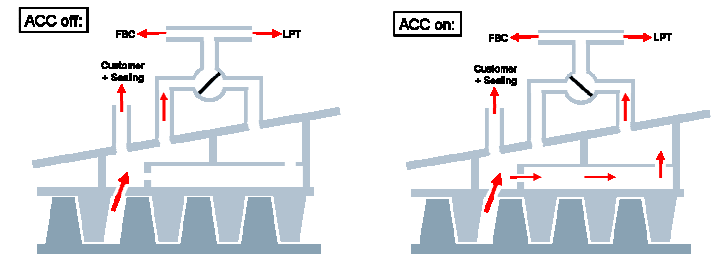
*Metallurgical examination of a milled Ti-Al surface*

## WP4.3 Smart HPC Technologies – Technology Studies

- Studies on active and „semi-active“ HPC technologies
  - Thermal active clearance control (TACC)
  - Mechanical active clearance control (MACC)
  - Active surge control (ASC) through injection of air into rotor tip gaps
  - Comparison to various casing treatment options
- Studies lead to further investigation of MACC, ASC and advanced casing treatment
- Definition of relevant rig tests to verify technology



Concept of a mechanical active clearance control system (top) and potential benefit in surge margin displayed in compressor map (bottom)



Schematic depiction of an active thermal clearance control system in “off” and “on” position

## WP4.3 Smart HPC technologies – Sensor Technology

Active Core needs fast, reliable sensors

- Fast pressure transducer for monitoring and detection of stall precursors
  - Extremely fast reaction time (ms)
  - Very high sensitivity
  - Robust against vibration, pollution etc.
- Tip clearance sensor for control of active clearance control system
  - Microwave and Eddy Current systems investigated
  - Very high sensitivity (1/100mm)
  - High temperature capability  $>800^{\circ}\text{C}$  for rear HPC stages
  - Extremely high reliability



*Two different prototype versions of fast pressure transducer to be used in NEWAC HPC rig test*

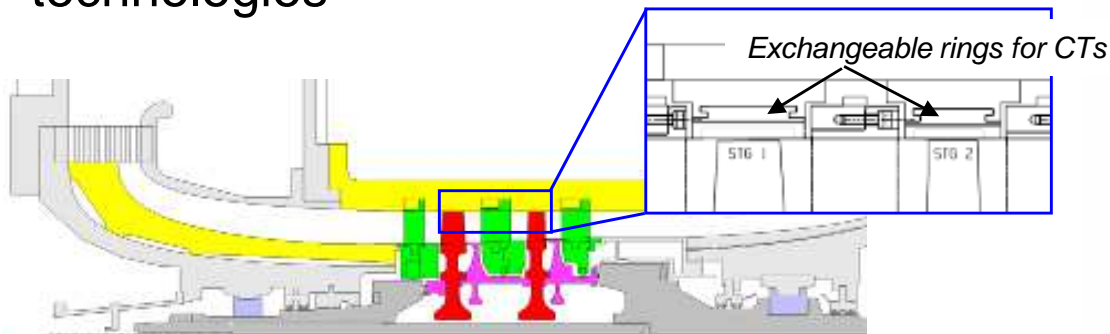


*CAD model of eddy current sensor used for NEWAC HPC rig tests.*

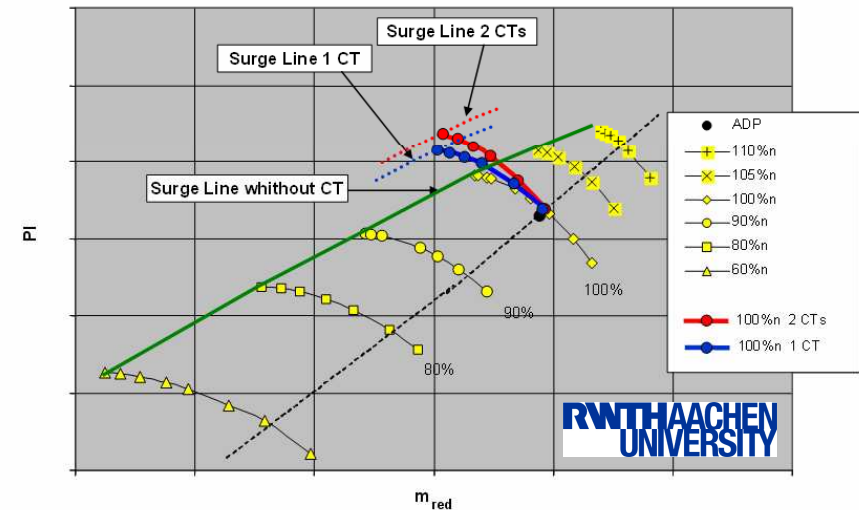
## WP4.3 Smart HPC technologies – RWTH Aachen University Rig

### Active Core benchmark – advanced CT

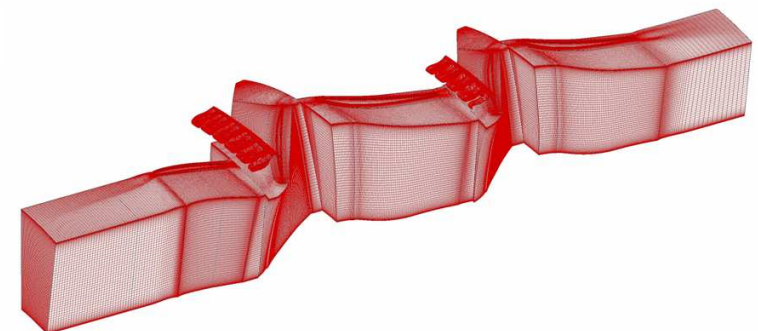
- New casing treatment was designed for rear HPC stages in cooperation between RWTH Aachen and MTU
- Hardware manufactured and ready
- Design to be validated by dedicated rig tests on RWTH Aachen HPC rig starting fall 2009
- Results are compared to active control technologies



Cross section of RWTH Aachen compressor rig



Compressor map showing effect of two successive casing treatments. Surge line is lifted considerably when compared to surge line without CTs.

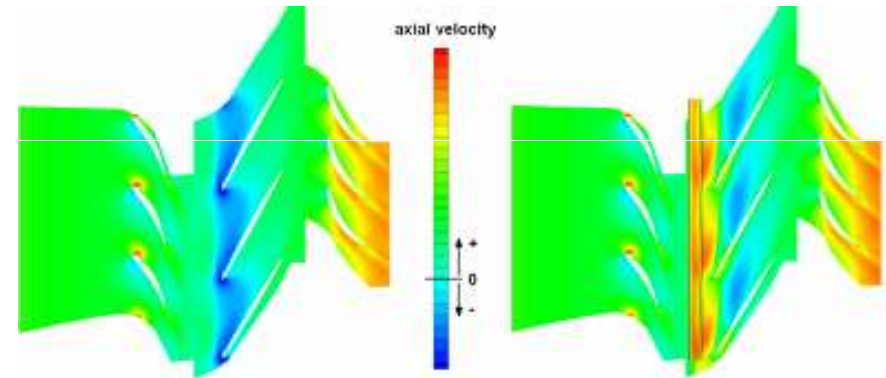


Computational grid for CFD calculations of two CTs with 6 million grid cells

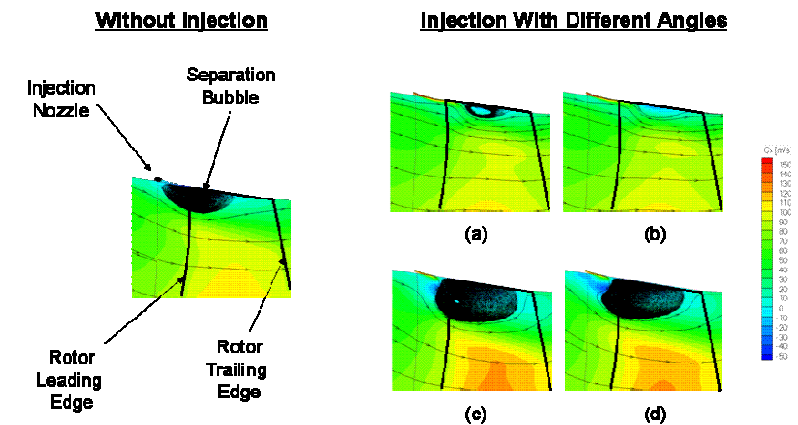
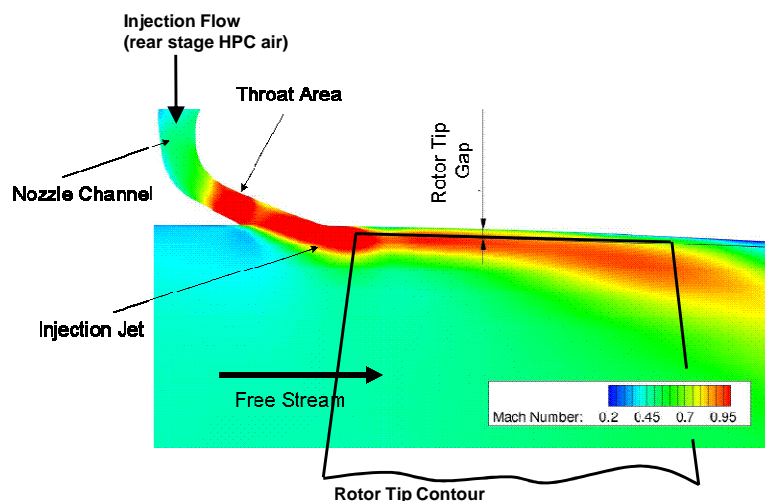
## WP4.3 Smart HPC technologies – Active Surge Control

### Active Surge Control by tip injection

- Injection of high momentum fluid through nozzles at the outer case
- Tangential injection into rotor tip used to influence development of tip vortex
- System activated when rotor nears stall conditions



CFD simulation of section near outer case. Left picture shows flow near stall point with large areas of reversed flow (blue). Same situation with tip injection shows improvement (right).

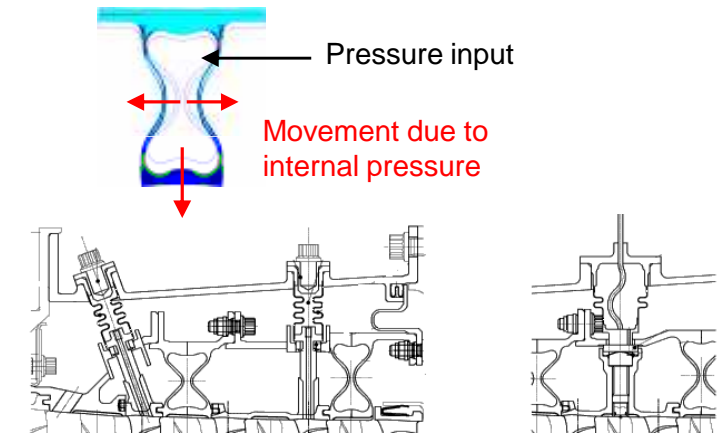


Results of a parameter study with varying injection angle. Best reduction in separation bubble achieved for case b)

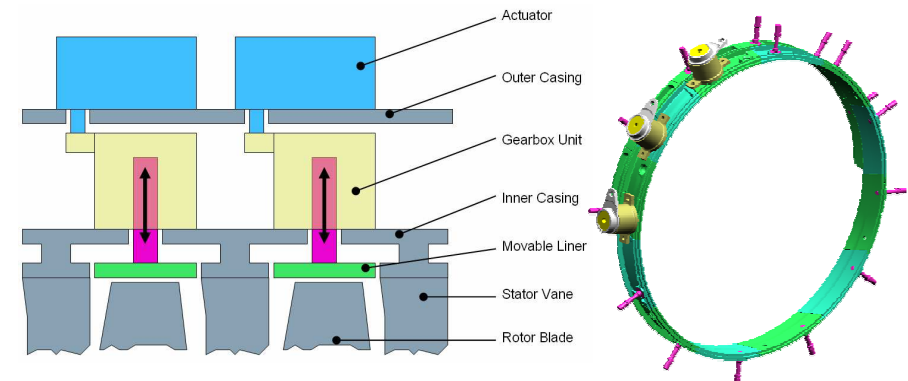
## WP4.3 Smart HPC technologies – Active Clearance Control

### Mechanical Active Clearance Control

- Fast reaction needed to account for transients and maneuvers (<0.5s). Therefore, thermal system excluded after initial concept study
- Different mechanical approaches investigated with two systems in final consideration
  - Pressurized “bellow” system with hourglass shape
  - System with hydraulic actuators and gearboxes working on segments
- Proof-of-concept rig with one stage being built to investigate feasibility of second concept (kinematics, reaction times, accuracy)

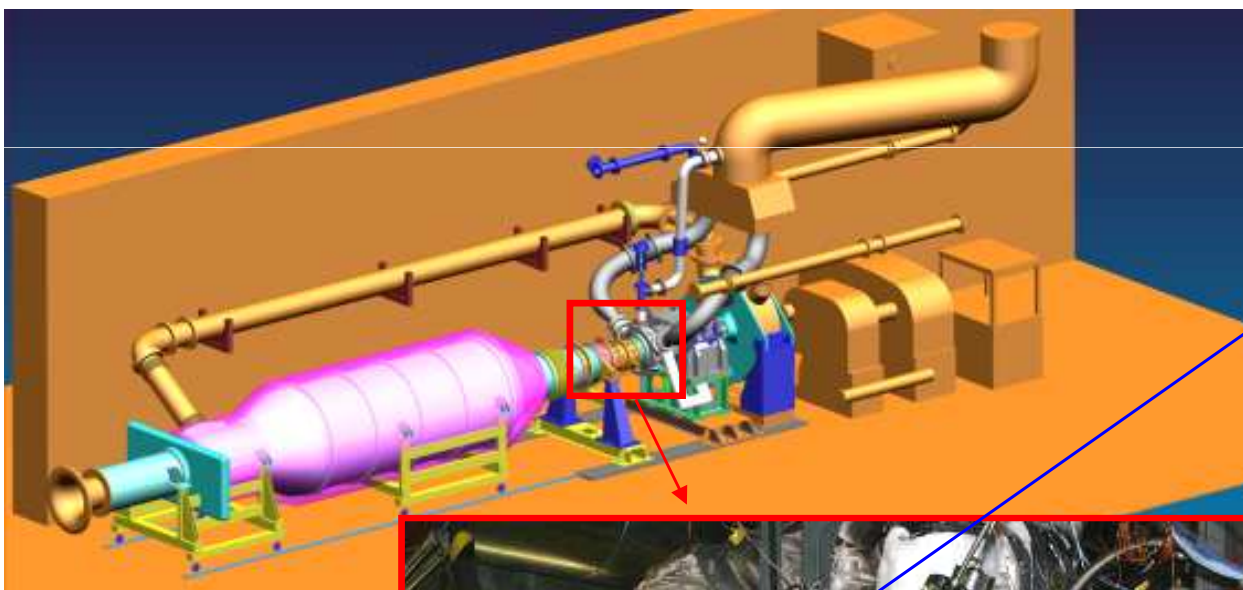


*Pressurized rings with hourglass cross section investigated for mechanical active clearance control (top) and study for borescope and sensor integration*



*ACC system with actuators and gearboxes to move segments of the annulus contour.*

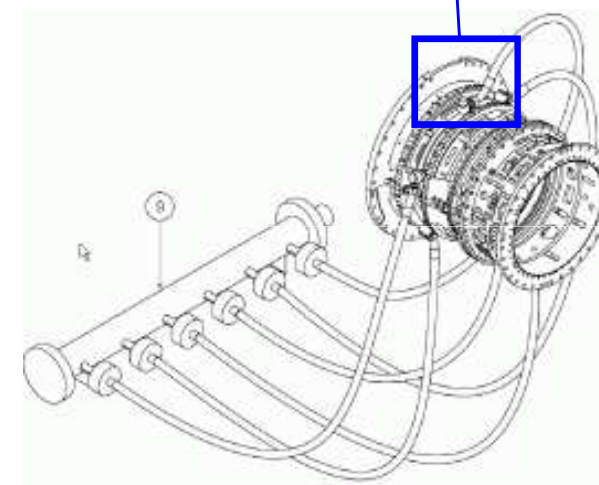
## WP4.4 Technology Validation Test Campaign – ASC rig



MTU HPC test facility



Close-up of air injection port



NEWAC ASC test setup

## WP4.4 Technology Validation Test Campaign – ASC rig

MTU test bed preparation for HPC tests

- Introduction of shop air supply
- Installation of electric heater for simulation of rear stage bleed air for tip injection
- Installation of distribution manifold, piping and metering section at test bed



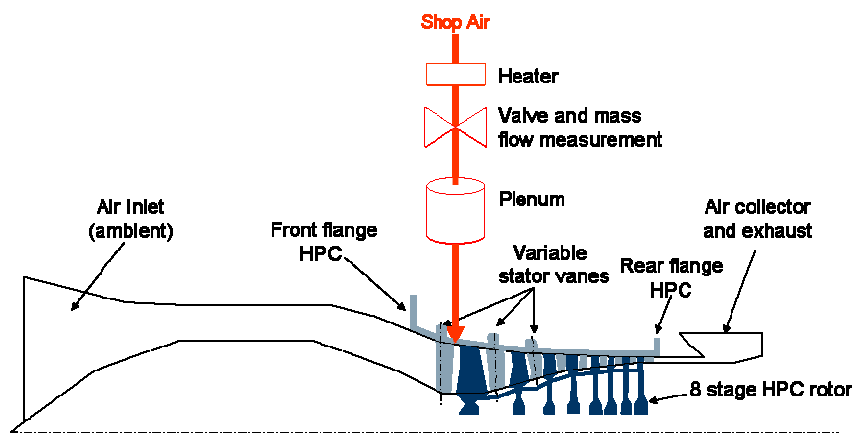
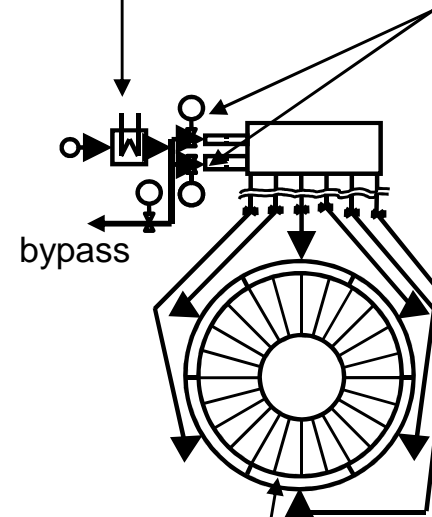
Electric heater



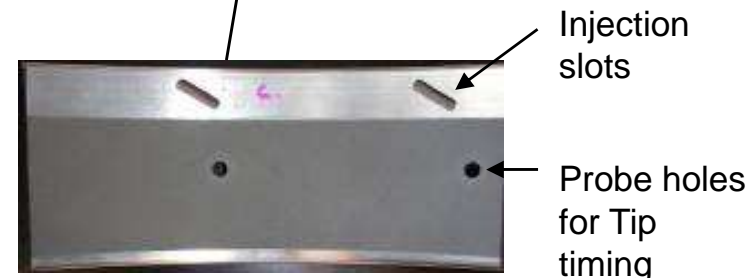
Valves + metering sections



Manifold



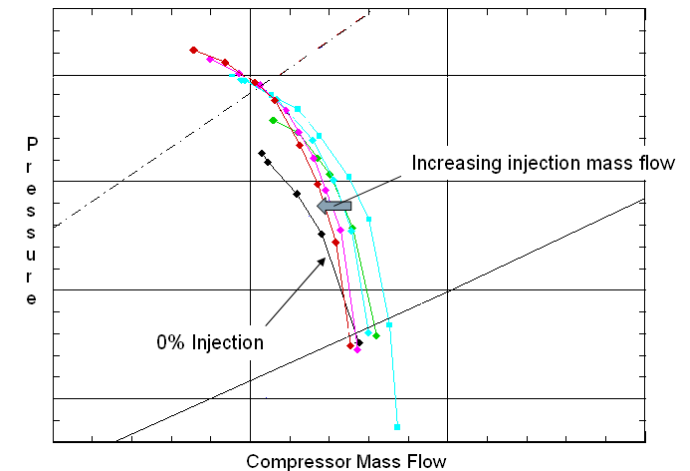
Schematic setup of 8 stage MTU HPC test rig for tip injection



Annulus Liner Segment (view radially outward)

## WP4.3 Technology Validation Test Campaign – ASC rig

- Successful first rig test campaign in September 08
- Variations in injection mass flow and temperature, number of injector ports, variable stator vane (VSV) schedules, HPC speed and mass flow



*Measured increase of surge margin with injection*

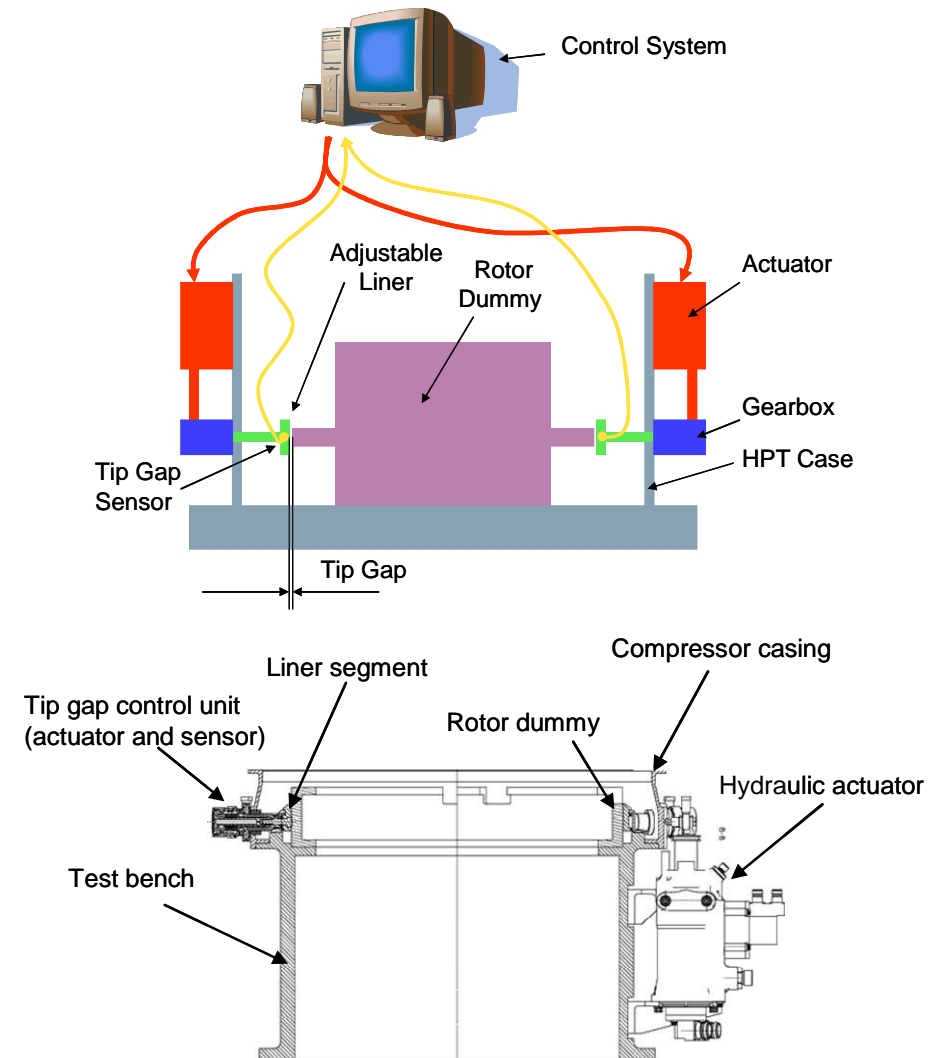


*Rig on test stand with injection hoses and probes*

- Results show encouraging extension of surge margin and other beneficial effects on HPC behavior
- Very good database for second ASC rig in 2009

## WP4.4 Technology Validation Test Campaign – ACC rig

- Proof-of-concept rig
  - No rotating parts to reduce risk of damage in case of failure
  - Tip gap modification simulated with control system
  - System reaction to simulated tip gap changes monitored
  - Information about kinematics, speed, accuracy and proof of control loop



Schematic (top) and cross section (bottom) through ACC proof-of-concept rig

## Summary

- NEWAC SP4 „Active Core“ provides multitude of concepts, studies, designs and tests to verify predicted improvements towards overall goals
- First tests show encouraging results for Active Surge Control (ASC)
- Further testing during 2009/2010 will improve the technology development for all pursued SP4 technologies
- Manufacturing and sensor technology development contributes vital input for use of active elements in future engine programs
- Combination of OEMs, suppliers and academia has proven to be an effective way to strengthen the European aviation research.

**Thank you for your attention.**