Compressor Rig Testing at MTU Aero Engines: Testbed / Instrumentation / Data Acquisition

Ingolf Krenz, Aerospace Testing Expo, 19 May 2010

Agenda

- Introduction
- MTU Test Facility for Compressor Rigs
- Data Acquisition and Reduction
- Online Visualization and Testing
- Controller
- Heated Inlet
- Summary

Chapter Break

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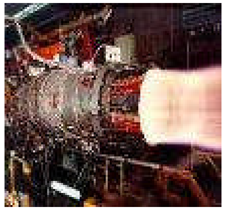
MTU Development Testbed Overview

Engine Testbeds

MTU I

PW6000
PW300/500
EJ200

MTU II



EJ200
RB199
PW300/500

MTU III

V2500
PW2000
GP7000

MTU VI

MTR390

ATF-Stuttgart

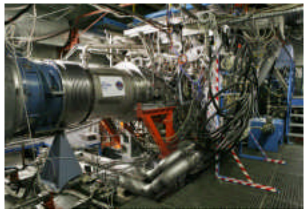
EJ200
RB199
PW300/500

Ludwigsfelde

TP400

Rig Testbeds

Compressor I



HPC, IPC
RB199, EJ200
PW6000
ATFI, NGSA

Compressor II

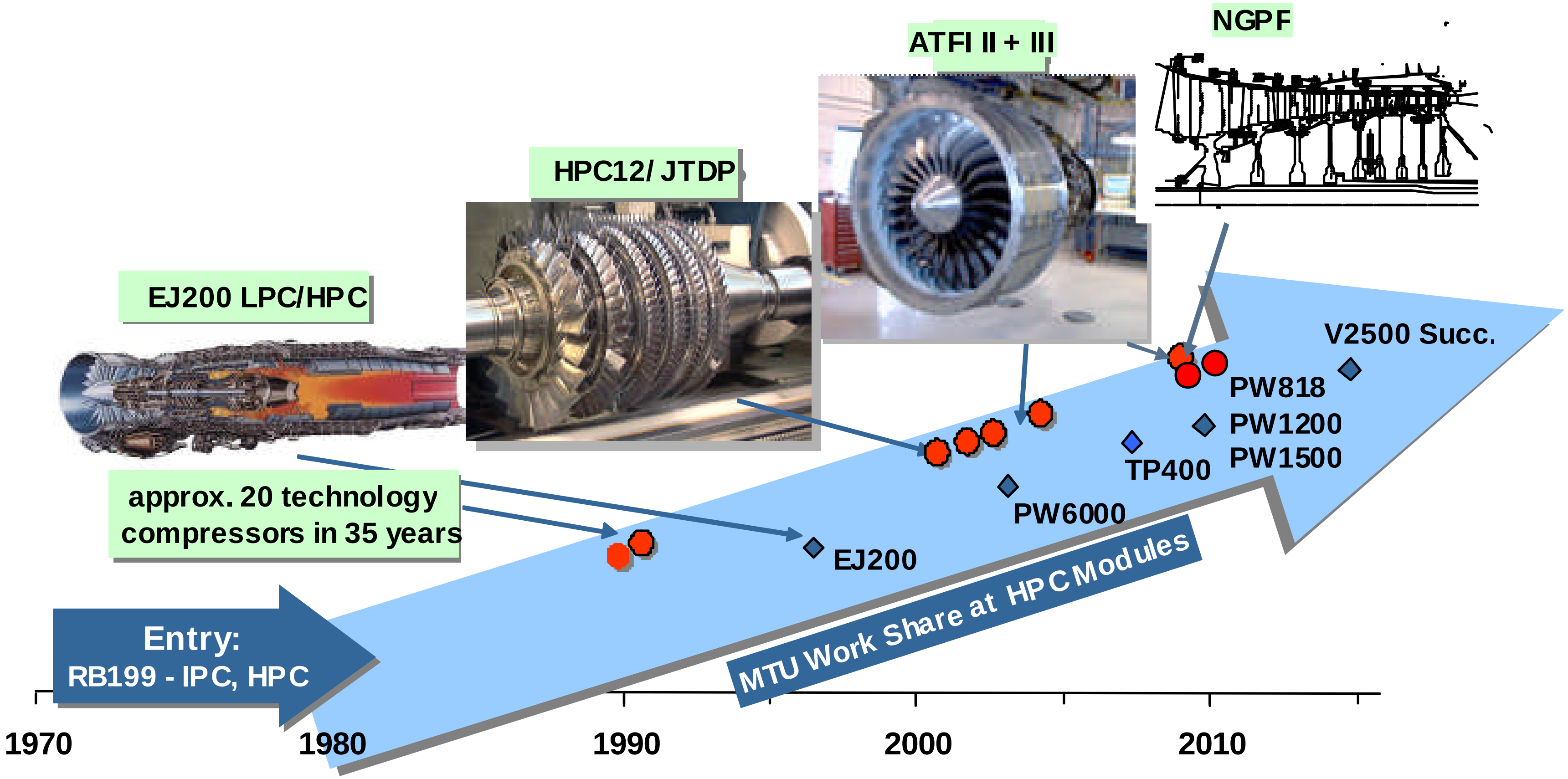
LPC, IPC, HPC
RB199, EJ200
PW300, TP400

Turbine at ATF Stuttgart

LPT, HPT
V2500, PW300, PW2037
PW6000, PW4084, GP7000

MTU Compressor Rig Testing

with respect to engine application



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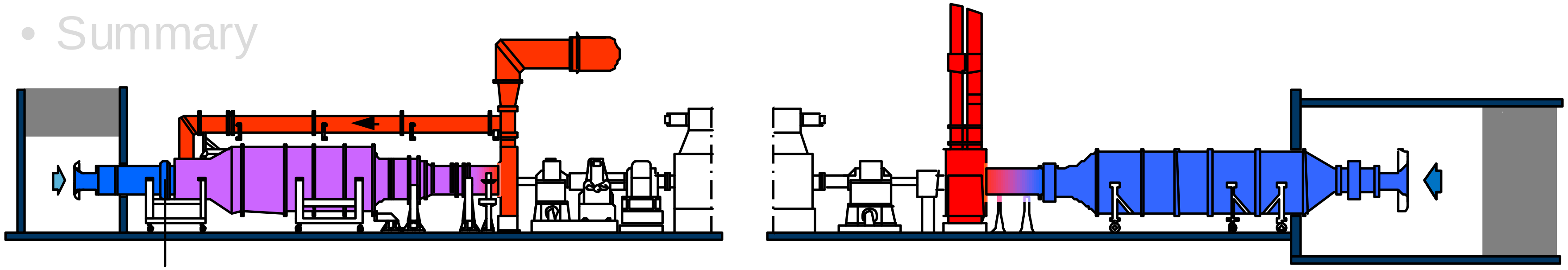
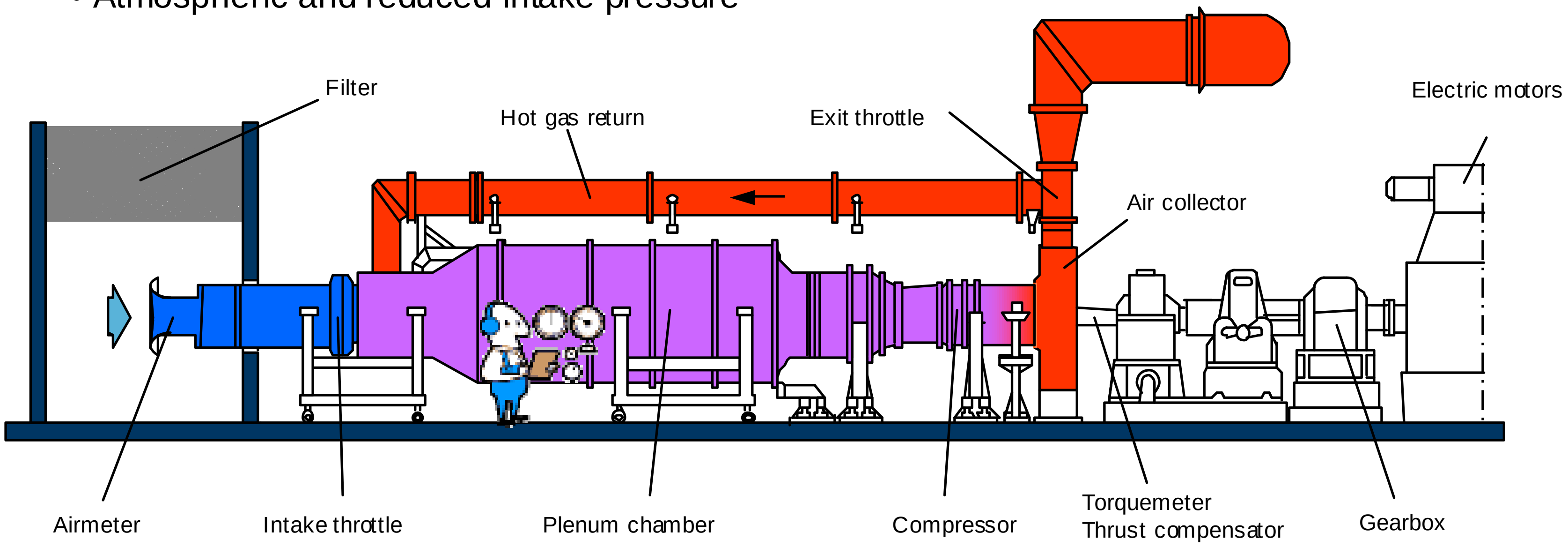


MTU Test Facility for High Pressure Compressor Rigs

- Aerodynamic testing (ambient intake temperature)
- Aeromechanical tests with hot intake air
- Atmospheric and reduced intake pressure

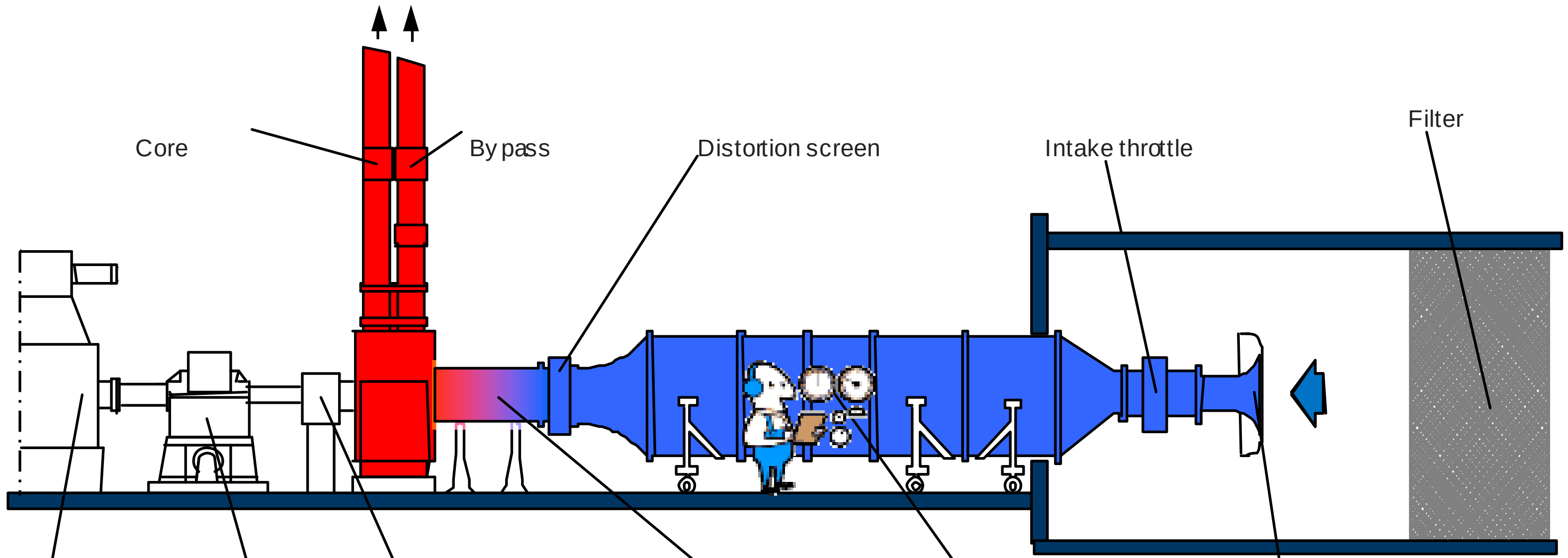


Max. power:	16 MW
Max. compressor speed:	21,000 rpm basis 28,000 rpm TPV14 add. gear unit 60,000 rpm TG16 add. gear unit
Max. air mass flow:	80 kg/s
Intake pressure:	0.2 bar up to atmospheric pressure
Max. intake temperature:	480 K

Max. exit pressure:	16 bar
Max. exit temperature:	923 K
Special features:	axial thrust compensation, hot gas return, torque measurement
Data acquisition:	1650 parameters special measurement techniques available

MTU Test Facility for Low Pressure Compressor Rigs

- Variable bypass ratio
- Atmospheric and reduced intake pressure



Max. power:	16 MW	Max. exit temperature:	773 K
Max. compressor speed:	14,380 rpm	Special features:	axial thrust compensation, variable bypass ratio, torque measurement
Max. air mass flow:	140 kg/s		
Intake pressure:	0.2 bar up to atmospheric pressure	Data acquisition:	1500 parameters
Max. exit pressure:	11 bar		special measurement techniques available

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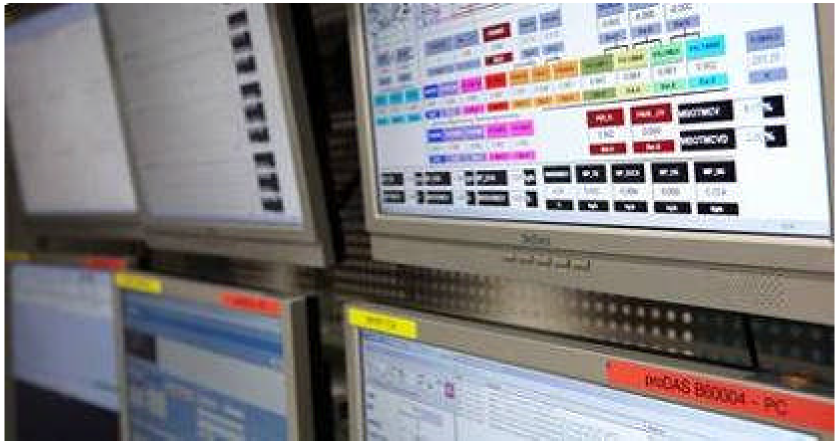


Data Acquisition - Capabilities List

HPC testbed proDAS - 1650 channels up to 200Hz

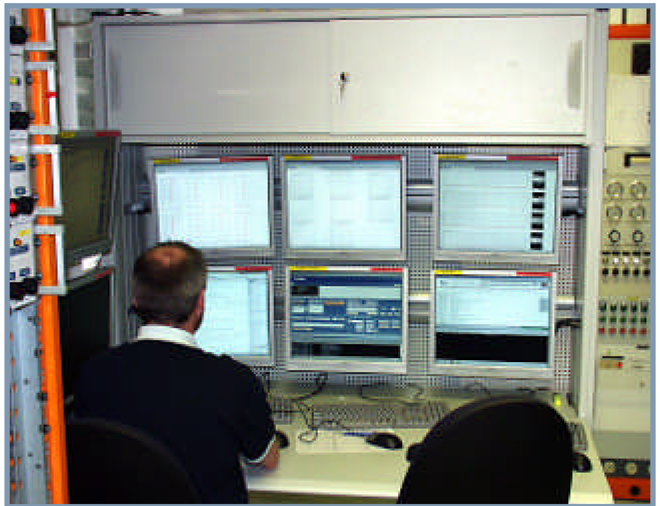
Type	Channels	Cut Rate [Hz]	Comment
pressure	564	20s per scan	mech. Scanivalves
pressure	464	200Hz	pressure bricks
temperature	464 + 35	20Hz	thermocouples + RTDs
miscellaneous	120	up to 200Hz	voltages, frequencies

LPC testbed proDAS - 1500 channels up to 200Hz

Type	Channels	Cut Rate [Hz]	Comment
pressure	564	20s per scan	mech. Scanivalves
pressure	464	200Hz	pressure bricks
temperature	348 + 35	20Hz	thermocouples + RTDs
miscellaneous	120	up to 200Hz	voltages, frequencies

Special Measurement Techniques

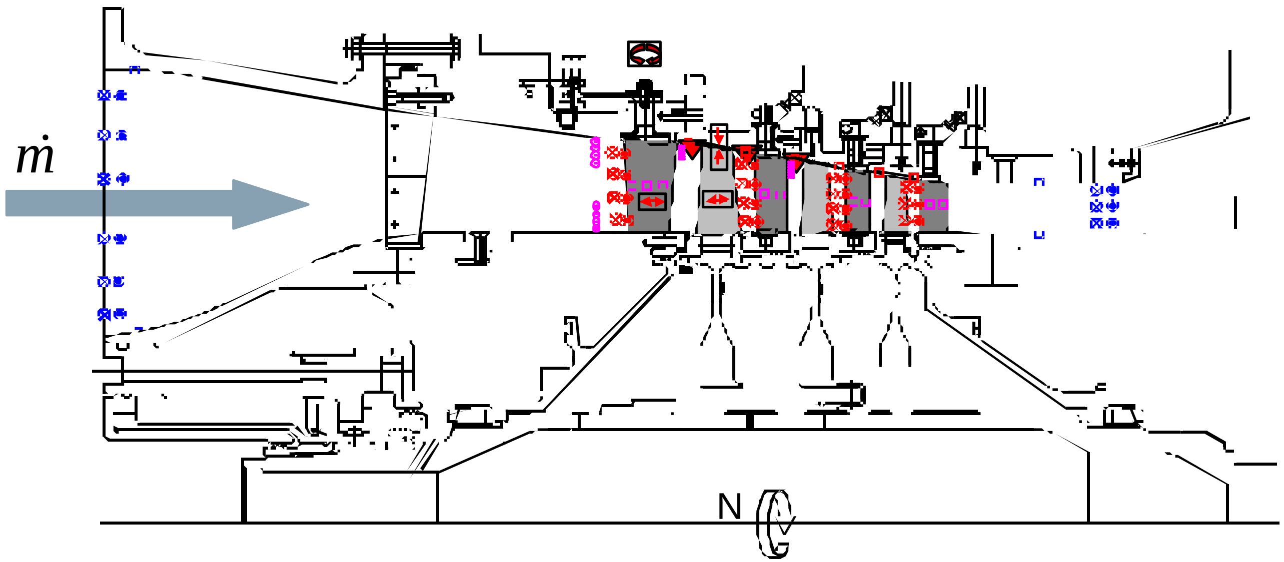
Type	Channels	Cut Rate [Hz]	Comment
analogue	56	up to 102kHz	analogue input
analogue	48	up to 204kHz	analogue input and power supply
tip timing	56	2.5MHz	upgradeable
tip clearance	48	N/A	upgradeable



Instrumentation Overview

Instrumentation:

- Inlet / Exit
- Stages
- for add. measurements



Measured Values:

Total temperature	T_t	⊠	Vane setting		all stages
Total pressure	p_t	◉	Tip clearance		all stages
Static pressure	p_s	□	Tip timing		all stages
Mass flow	$\dot{m}$		Strain gauges		all stages
Rotor speed	N		Dynamic pressures	▼	all stages

Calculation of Overall Compressor Performance

Measurement of: T_t ⊗ and p_t ◉

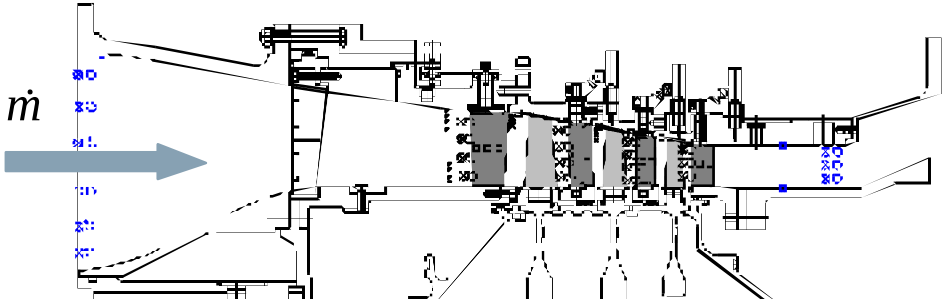
- Total Pressure Ratio: $\Pi = p_{t,aus} / p_{t,ein}$

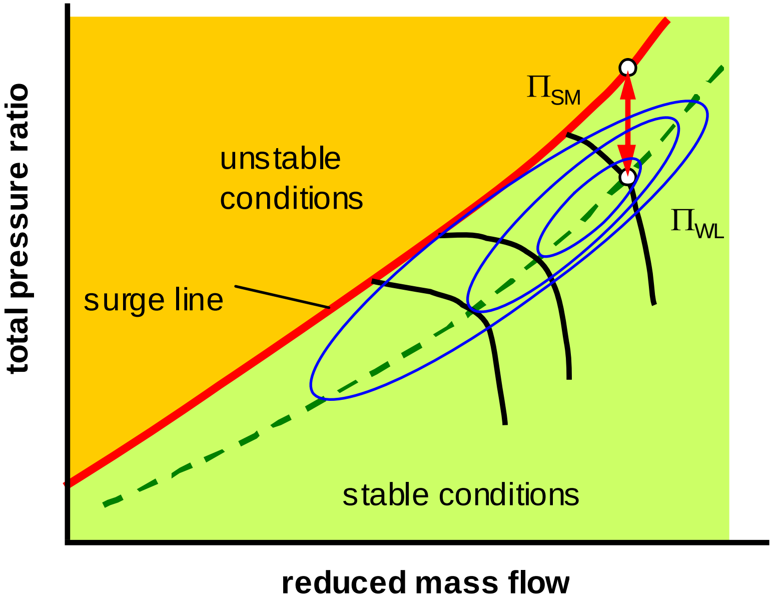
- Reduced Mass Flow:

$$\dot{m}_{red} = \dot{m} \sqrt{T_{t,ein}} \Big/ p_{t,ein}$$

- Efficiency: η

For various speed lines





➡ **Compressor performance**

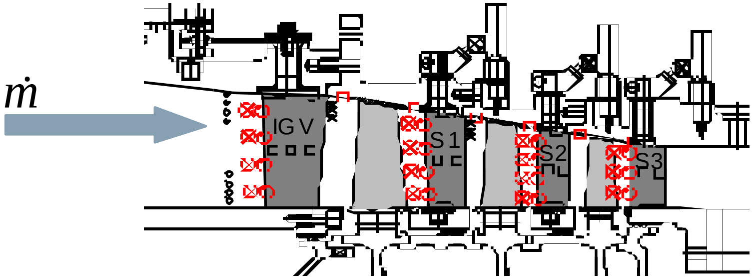
➡ **Calibration of design tools**

Stage Mapping and Optimization

Measurement of: T_t ⊠ and p_t ●

- Stage map and stage losses

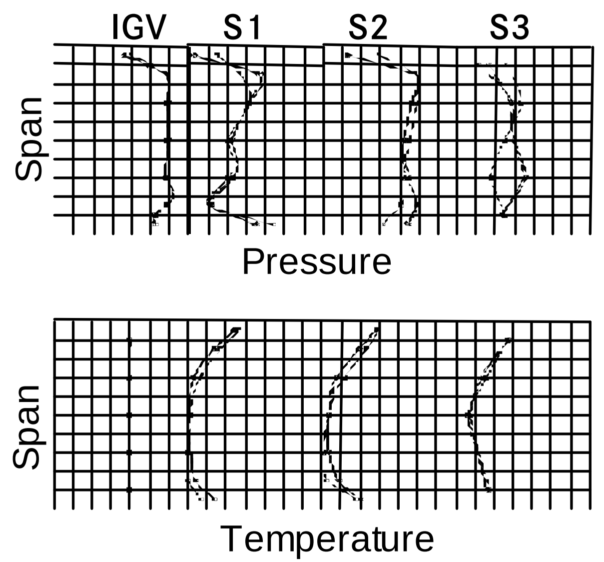
Stage characteristics
(surge margin, efficiency, ...)



- Radial distribution

Analyses of radial spans

Calibration of design tools



Leading edge instrumentation

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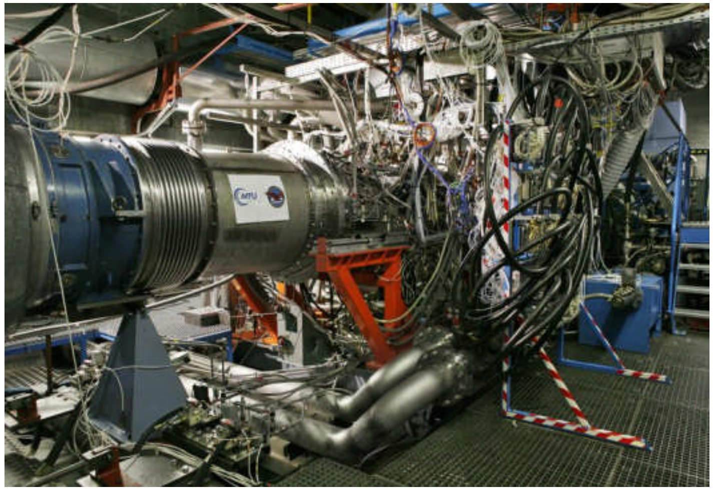
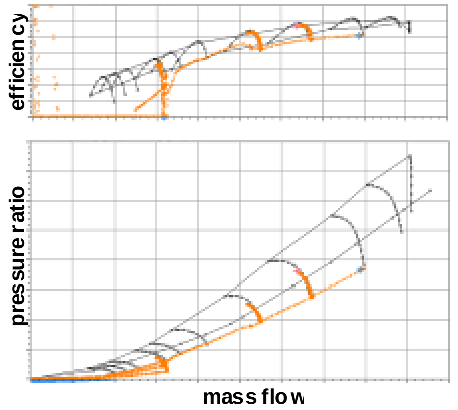


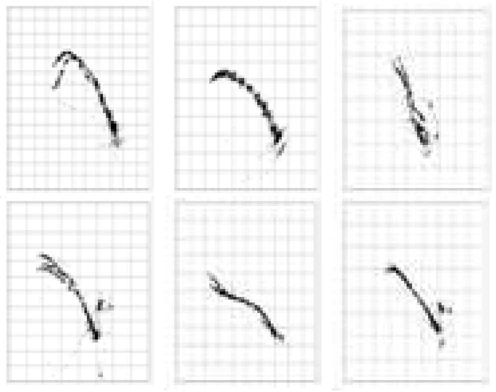
Online Visualization

Visualization of Data and Diagrams on up to 10 Screens:

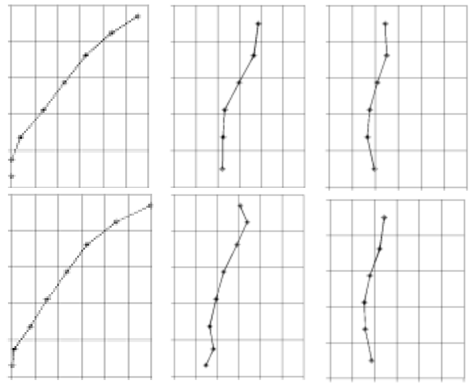
Compressor Map



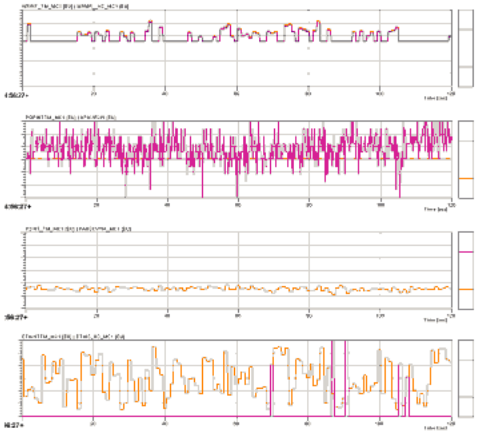
Stage Characteristics



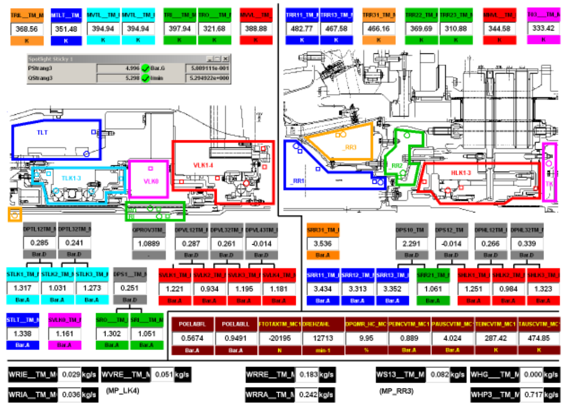
Radial Profiles



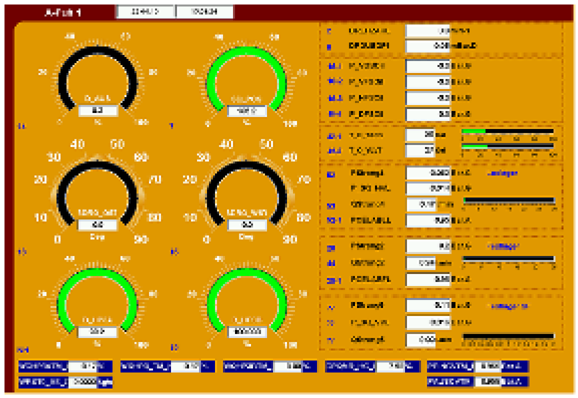
Strip Charts



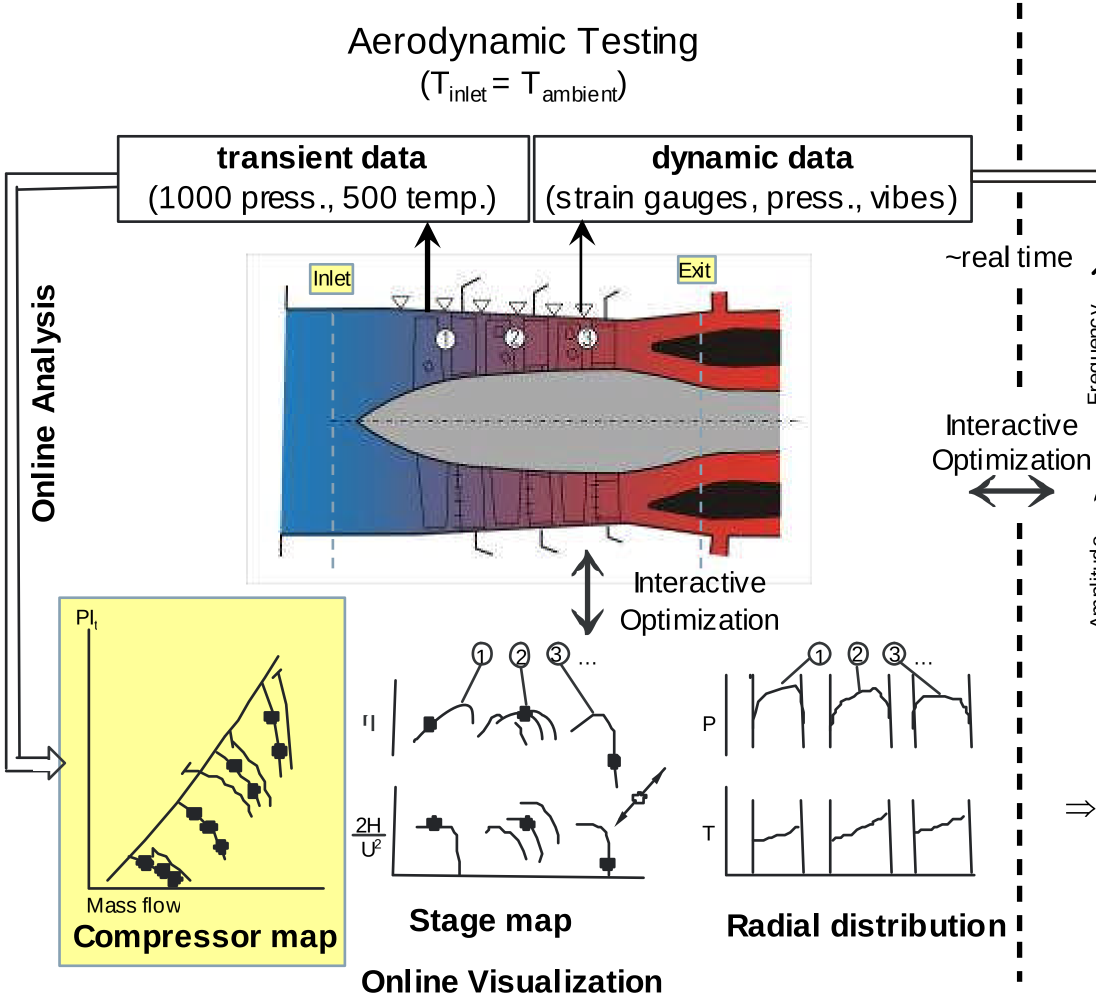
Health and Safety

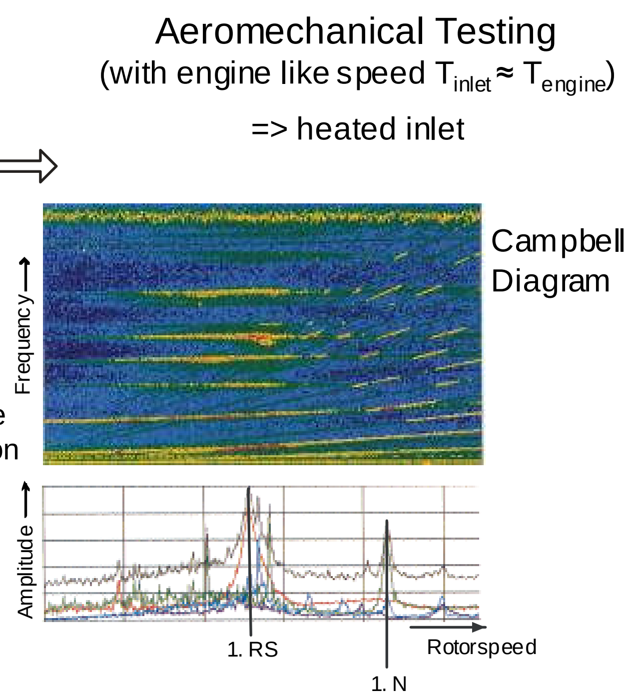


Testbed



Interactive Testing





⇒ **for interactive testing and optimization online analysis and visualization are designed for detailed analysis of aero, performance and mechanical parameters**

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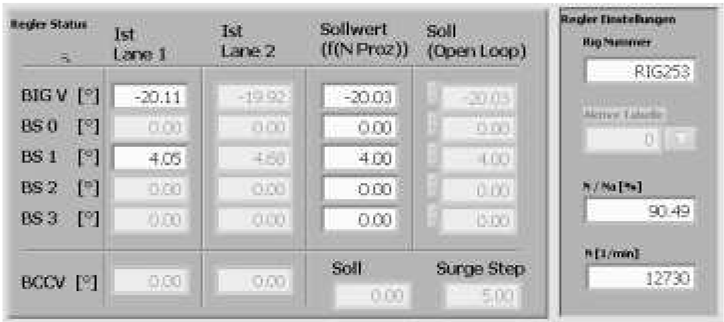
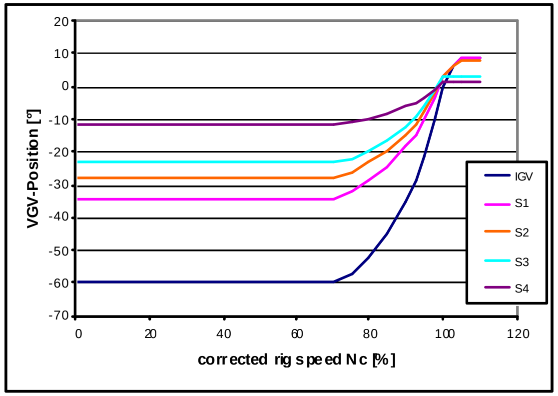
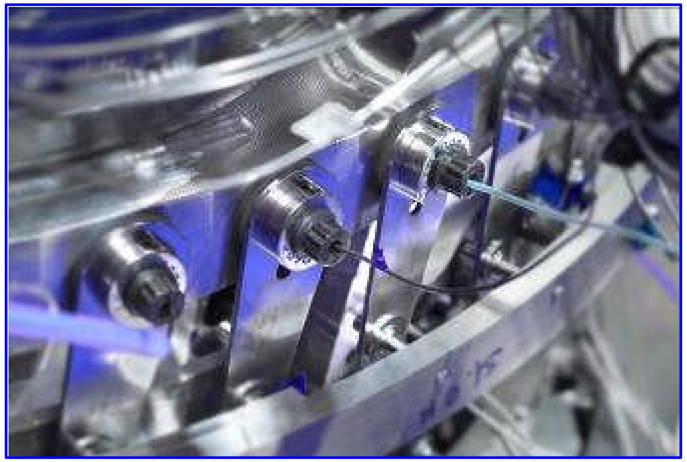


VGV-Controller & Surge Detection / Reaction System (1)

Control of Variable Guide Vanes (VGVs)

- hydraulic control system for 5 variable guide vanes
- variable vane positioning to predefined schedule or individual manual settings
  - 5 VGV-schedules can be implemented:
    - VGV-Position = f (N_{aero})
    - N_{aero} = f(rig inlet temperature and rig speed)
  - individual setting of each stage for optimization
- predefined safety VGV-schedule for surge events and transients



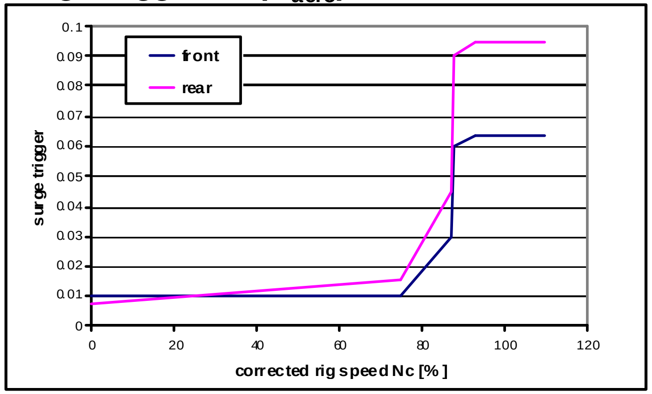


VGV-Controller & Surge Detection / Reaction System (2)

Surge Detection

- surge detection by dynamic pressure signals and MTU surge algorithm
- surge trigger fine tuning after first test results to adapt the surge detection system to the individual compressor characteristics
- individual surge trigger for front and rear stages
  - surge trigger schedule = f (N_{aero})

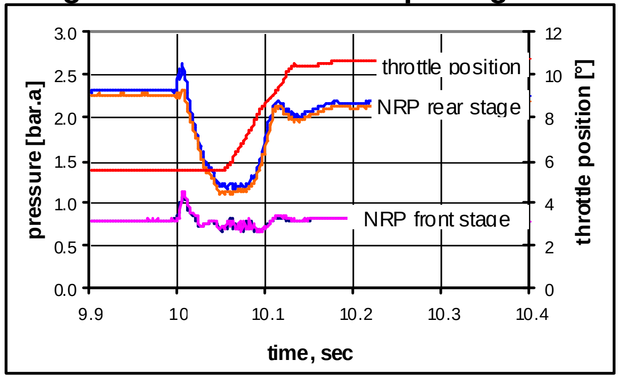
surge trigger = f (N_{aero})



Surge Reactions

- automatic VGV positioning to a predefined „safe VGV-schedule"
- opening of rig exit throttle
- opening of the „MTU surge bleed valve" in 30 ms
- automatic recording of test data before (from a ring buffer) and after surge event

surge event and throttle opening



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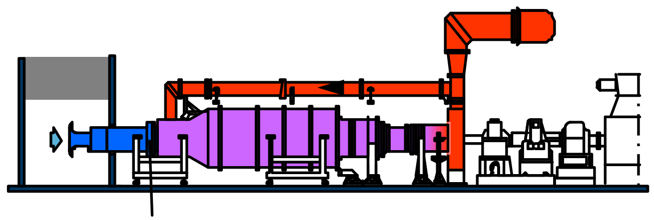
Heated Inlet for Engine Like Speeds (1)

As the similarity parameter for speed is $n_{mech}/\sqrt{T_{inlet}}$ the inlet temperature has to be raised for hpc to get engine like mechanical speeds. MTU hpc testbed provides to different ways to do this:

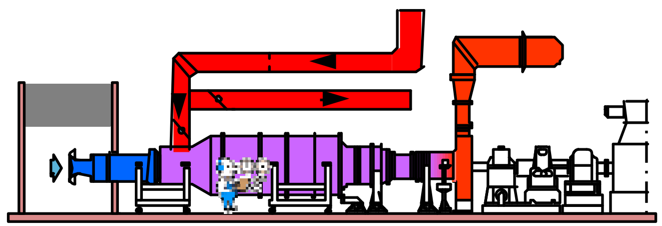
Hot Gas Return

- return of hot compressor exit air (up to 550°C) to heat up inlet temperature
- used for quasi stationary running of the rig



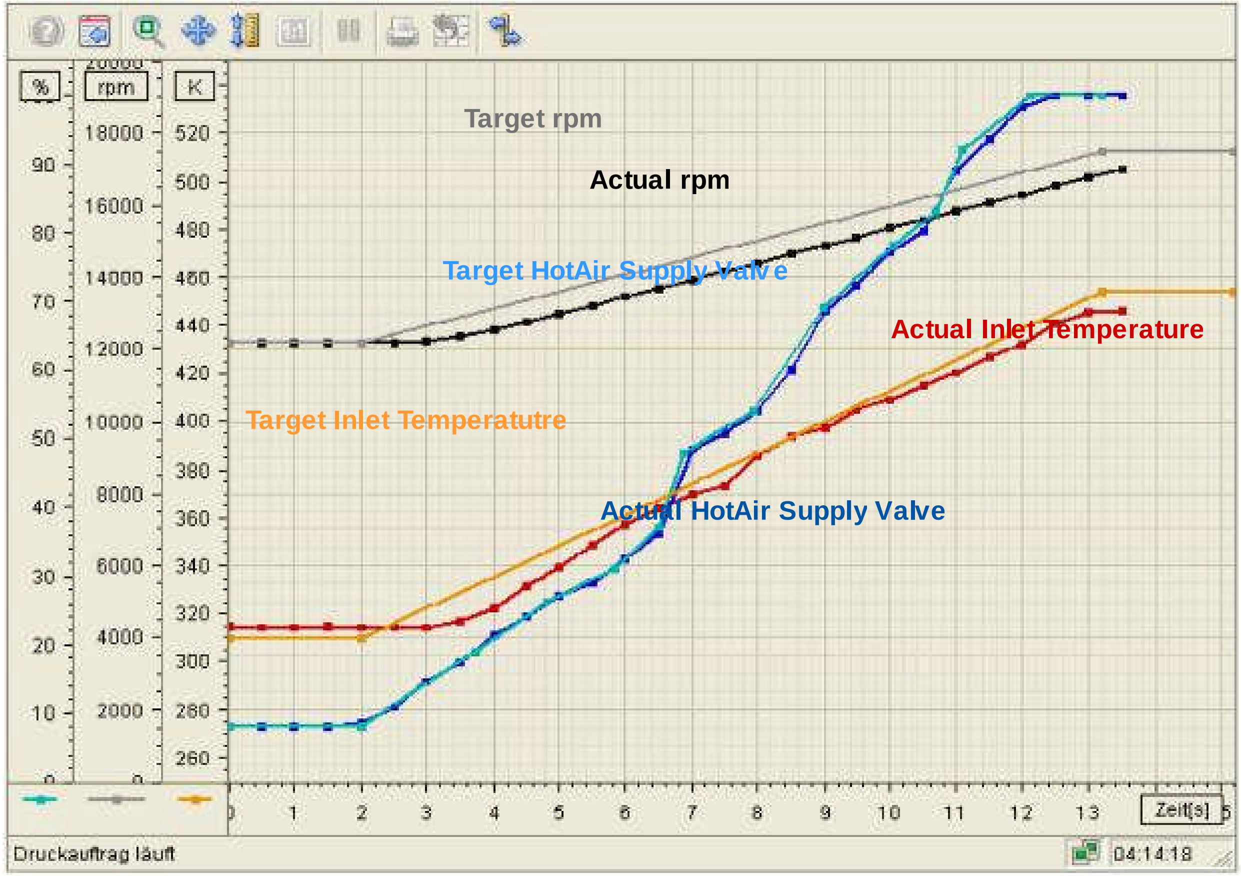
External Inlet Heating

- hot air from external compressors and air heater (about 5kg/s and 450°C)
- bypass for fast change of inlet temperature for engine like de- and accels
- control system for valves in hot air supply, bypass and speed to realize speed changes in a few seconds from idle to max power and back



Heated Inlet for Engine Like Speeds (2)

Transient Test Sequence of a 12 Second Acceleration



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Summary

MTU Aero Engines has two testbeds for compressor rig testing. It is possible to test low, intermediate or high pressure compressors for both aero / performance and mechanical analysis.

For the different types of compressors special features are implemented, e.g. heated inlet for high pressure compressors to simulate engine like conditions or separate core and bypass exhaust pipes and throttles for low pressure compressors.

When running modern multi stage compressors with variable guide vanes, control systems are used for safe de- and acceleration.

Instrumentation, data acquisition and online analysis are designed for quick health and safety monitoring and detailed analysis of aero, performance and mechanical parameters.

⇒ more details about the MTU analysis tool (online and offline) is shown in the (following) presentation:

“Compressor Rig Testing at MTU Aero Engines: Model-Based Data Analysis“