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Improved Sensor Technology for Gas Turbine Instrumentation developed in the EU Project HEATTOP

AERODAYS-2C1-Flohr.ppt

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EUROPEAN COMMISSION
European Research Area

MINISTERIO DE CIENCIA E INNOVACIÓN

CDTI Centro para el Desarrollo Tecnológico Industrial

SEVENTH FRAMEWORK PROGRAMME

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Introduction

- Key demands in European gas turbine engine industry:
    - Improving efficiency
    - reliability
    - lower ownership costs
    - environmentally friendly engines
- Instrumentation is enabling technology, affecting those demands
- Challenge: Instrumentation to be placed in hostile environment.
- To tackle the challenge, research is needed in technologies:
    - gas path aerodynamic measurement
    - component temperature measurement
    - tip clearance measurement

→ R&D activities in those areas supported by HEATTOP project.

Starting point - State of the Art

Lab Gap Matrix evaluation of current sensor capability vs. OEM needs revealed:

- Sensors not applicable to very hot components,
- survive only limited testing time,
- not usable for monitoring purposes,
- insufficient accuracy

The Lab gap matrix

- shows shortfalls in current sensor technologies
- answers what is holding back engine development at most
- Initiate collaborations and projects such as HEATTOP to close the gaps

Excerpt of 2010 Lab Gap Matrix by EVI-GTI and PWIG

Aero Performance

Measurand/Measurement	Combusti on system	HP Turbine	Exhaust
Pressure (MKS)	<45 bar	25-45 bar	1 bar
Temperature (MKS)	700C-2400C	1000C-1800C	700C+
TRL assessments = Red 1-4, Yellow 5-6, Green 7-9			
1. Airflow Measurements	EU	EU	EU
Overview of gaps			
2. Gas Path Measurements			
Overview of gaps			
2a. Gas Path: Dynamic Pressure			
2b. Gas Path: Temperature			
2c. Gas Path: Pressure			
6.Noise			
Overview of gaps			
Enabling thechnology: Wires and Intercon			
Overview of gaps			

Download from http://www.evi-gti.com

HEATTOP – Project deliverables

- **HEATTOP stands for:**

  Accurate **H**igh Temperature **E**ngine **A**ero-**T**hermal Measurements for Gas-**T**urbine Life **O**ptimization, **P**erformance and Condition Monitoring

- **Project-focus on measurement techniques for:**
  - Gas flows temperature, pressure and velocity
  - Solid structures temperatures
  - Turbine blade clearances and vibration

→ Leading to Development of:
- Advanced thermocouple technology
- New gas path pressure and temperature measurements
- Embedded sensors, radiation thermometry and thermo-graphic phosphors
- Tip clearance measurement system

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The Consortium and Work Share

Partner	Country	Main Focus
Siemens AG		➢ Sensor definition ➢ Engine tests
Rolls Royce		➢ Sensor definition ➢ Engine tests
Volvo Aero		➢ Sensor definition ➢ Engine tests
Vibro-Meter AG		➢ Tip Clearance sensor
Vibro-Meter UK		➢ Pyrometry ➢ Thermo-couples
KEMA		➢ Pyrometry
CESI RICERCA		➢ Gas temperature sensor
Farran		➢ Tip Clearance sensor
VKI		➢ Probe for in-situ pressure meas
Oxsensis		➢ Optical sensor for pressure
AOS GmbH		➢ Packaging for fibre optical sensor
Auxitrol		➢ Pyrometry ➢ Thermocouples
IPHT		➢ Bragg fibres for optical sensor
Univ. Cambridge		➢ Multiplexed gauges ➢ Thermocouples
Univ. Lund		➢ Thermo Phosphors
Onera		➢ Thin Film TC
Univ. Oxford		➢ Probes for pressure and temperature

- Specifications and requirements
- Technology development
- Providing validation facilities

Sensor technology development by

- Industrial Partners
- SME
- Research Institutes
- Universities

- Validation of sensors and codes in rigs and engines of OEM
- Dissemination

Overview of technology developments in HEATTOP

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Thermocouple Life and Accuracy improvements

1. Fast response thermocouple
2. Optimized high accuracy TC
3. Novel material TC with minimized drift
4. Ceramic TC concept for T>1500°C
5. Thin film TC

Optical measurement of solid structures temperatures

1. Embedded Fiber Optic Sensors
2. Online calibration pyrometer and dual wavelength pyrometer
3. Thermographic Phosphor paint

Gas path measurement

1. Fast Response Cooled Total Pressure Probe at T>1600°C
2. Fiber optic dynamic pressure sensor
3. Intermittent choked nozzle for stagnation pressure and temperature
4. Total pressure and thin film gauge temperature
5. Non intrusive IR sensor for TIT

Tip Clearance measurement

1. Mm-wave sensor for online blade tip clearance measurement

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Main Steps for Sensor Development

1. Define requirements and specifications by OEMs/end user
2. Technology development by sensor manufacturer in collaboration with OEM
   - Application needs
   - Proof of concept
   - Lab tests
3. Verification of performance and results with end user **Review**
4. Validation testing in realistic GT rig **Review**
5. Validation testing in realistic test engine
6. Final documentation and review of technology **Review**
7. Long term tests of complete system in customer engine
8. Fleet implementation

Instrumentation Technology Readiness Level (TRL) Definitions

TRL	Specific Description
9	Service proven, part of I&C
8	Demonstrated production system
7	Engine field tests with full range of conditions
6	Realistic engine, low level support
5	Application in dirty test rig or engine with high specialist support
4	Component tests in lab and rig
3	Prove of concept
2	Concept design, analytical assessment
1	Idea and basic principle

The TRL approach on the example of Oxsensis Fiber Optic Sensor

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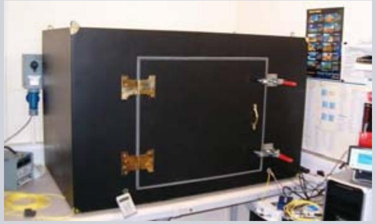
TRL 3: Concepts proved analytically & experimentally in lab
- Mechanical properties established
- Feasibility demonstrated
- Adaptation of design for engine integration

TRL 4: Demonstrations in specified lab test environment
- Temperature capability: heating sensor body to >1200°C
- Static pressure tests
- Lifetime
- Acoustic tests

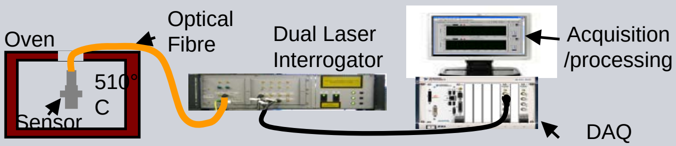
TRL 5: Components for prototype system build and tested
- Temperature endurance tests of packaging
- IP rig tests

TRL6: Prototype demonstration tests in rig environment
- Combustion rig test at DLR and Siemens test bed engine
- Rig tests at 1000°C at Rolls Royce

TRL7: Demonstration in Engine environment
- 4 transducers tested in BTB 501FD3
- ~ 200h of operation with ~180 starts
- One year in use at customer field site



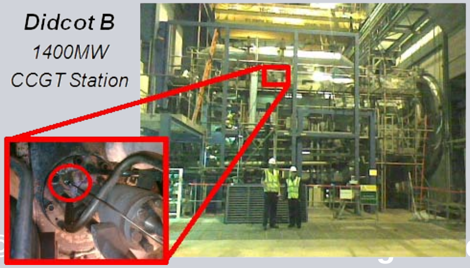
Acoustic test box



Set up for soaking tests

Pressure measuring at 1200°C

Sensor head heated to 1000°C



Dynamics measurement at BTB, Comparison to standard transducer

Further results summarized:
Intrusive probes for flow measurements

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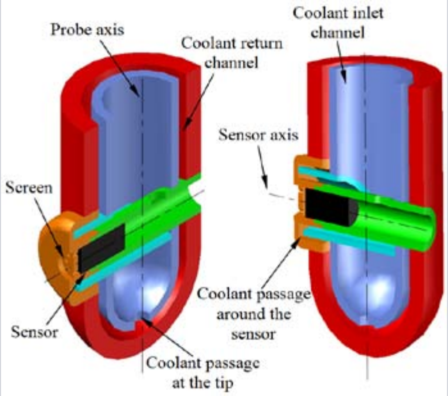
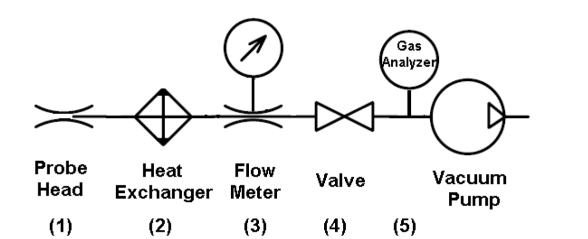
- VKI developed fast response total pressure probe
- Miniature piezo-resistive Kulite pressure sensor in probe tip allows bandwidth of at least 40 kHz
- Proven at temperatures up to 1550°C
- Water-cooled, TRL 5

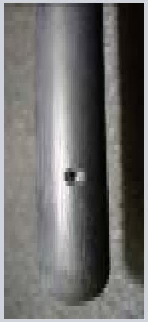


Fast response probe (principle and hardware)

- UCAM developed an Intermittent choked nozzle probe for stagnation pressure and temperature
- Successfully tested up to 1627°C, TRL 5
- Accuracy for temperature in the order of 0.6%



Principle



Installation in R-R Viper engine

Intrusive and non-intrusive probes for flow measurements

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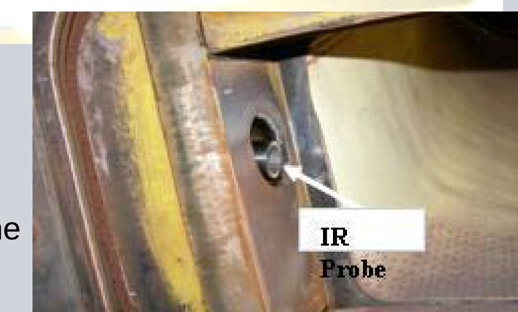
- Univ Oxford developed fast response probe for unsteady temperature and pressure
- Piezo-resistive Kulite pressure sensor, dual thin film for temperature
- Un-cooled probe, inserted into gas flow in time scales of 100ms
- Fast moving traverse mechanism

Fast response Kulite pressure probe

- ERSE developed IR measurement technique for gas temperature
- Exploits strong absorption of combustion gas in select bandwidth
- Delivers spatial averaged gas temperature value
- Calibration to reference temperature
- TRL 4



Installed probe at the combustor exit of a rig

Improved Thermocouple for Fast Response Measurements

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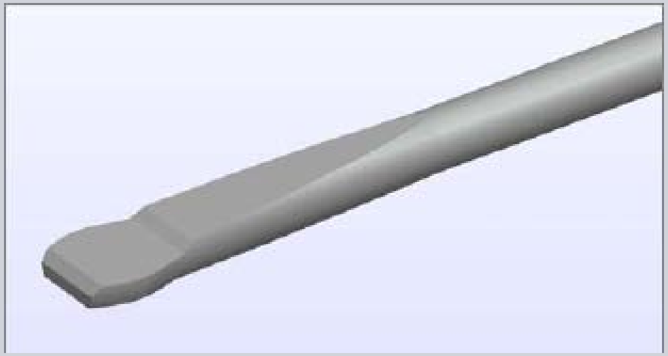
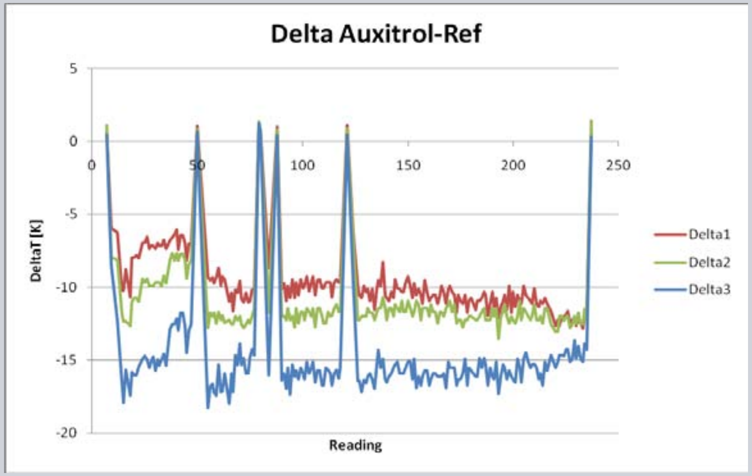
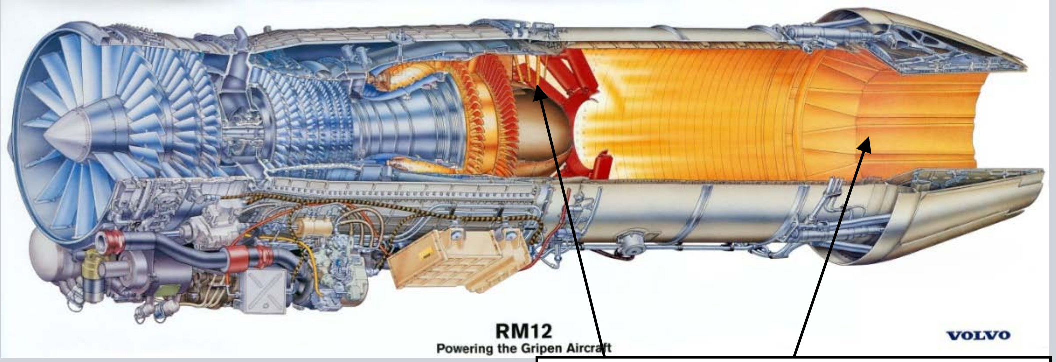
- Accurate, high frequency response and rugged thermocouples by Auxitrol and Volvo
- Wall temperature at high mass flow rates
- Response time: 0.2sec at Ma2
- Higher accuracy due to reduced stagnation effect
- Biggest benefit for OEM: reduced installation time and ruggedness. TRL 6



Optimization of conduction (material, shape, contact between Tc and engine casing…)

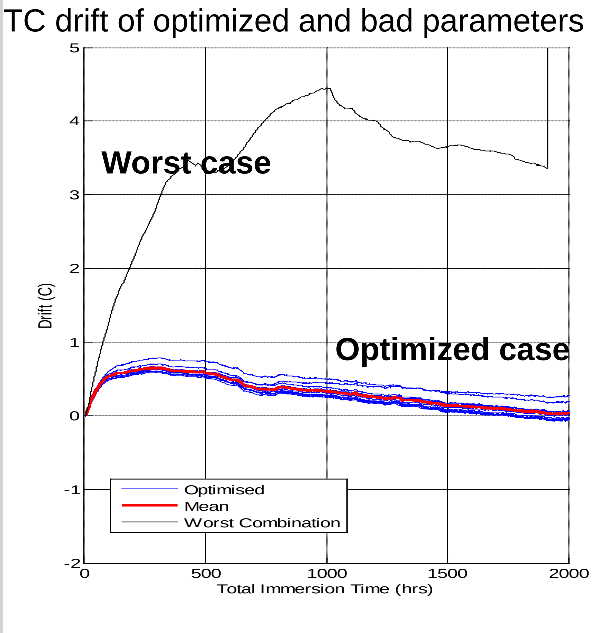


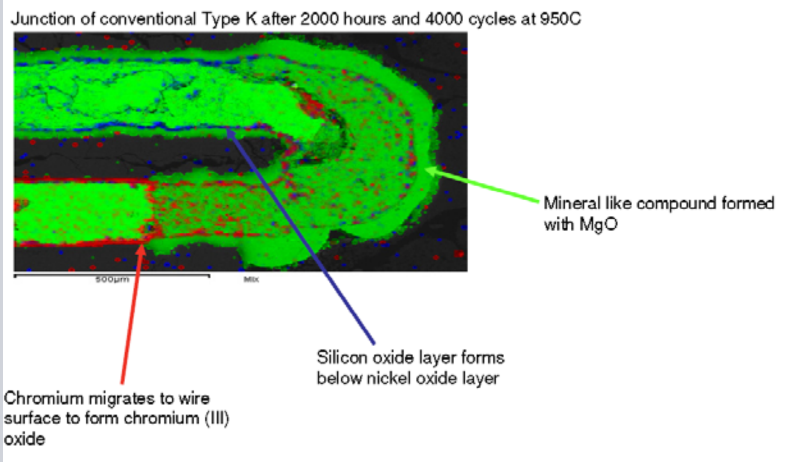


RM12 engine for validation

Improved Type K Thermocouples with Low Drift

- <u>Meggitt</u> analyzed TC to understand material, temperatures and manufacturing effects on accuracy and drift
- Wide range of thermocouples were tested using DoE approach (Taguchi)
- Optimum combination has substantially better performance of accuracy and drift for temperatures up to 1050°C





- In depth material analysis for understanding of degradation mechanisms
- Univ Cambridge suggest a new configuration and material selection for measurements at temperatures up to 1200°C with low uncertainty (0.2%)

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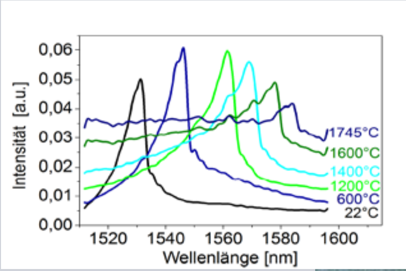
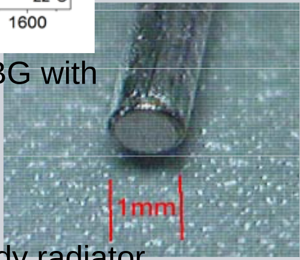
Sensors for Solid Temperature Measurement

Fiber optic sensors

- IPHT, AOS and Siemens developed a number of fiber optic sensors for up to 1200°C to be embedded in engine components
- Silica and Sapphire fibers with Fiber Bragg Gratings, multiplexable for multiple measurement points.
- Black body radiator for highly space resolved measurements



Wave length shift for FBG with temperature



Black body radiator

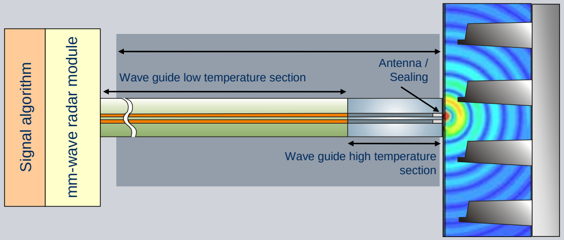
Advanced pyrometers

- KEMA developed Boroscope radiation thermometer with online calibration. Protruding hot path only for a few seconds, retracted for calibration
- Meggitt (VM-UK) assessed degradation and long term stability of pyrometer system
- Effective purge system and a dual-wavelength detector minimize contamination and increase service intervals

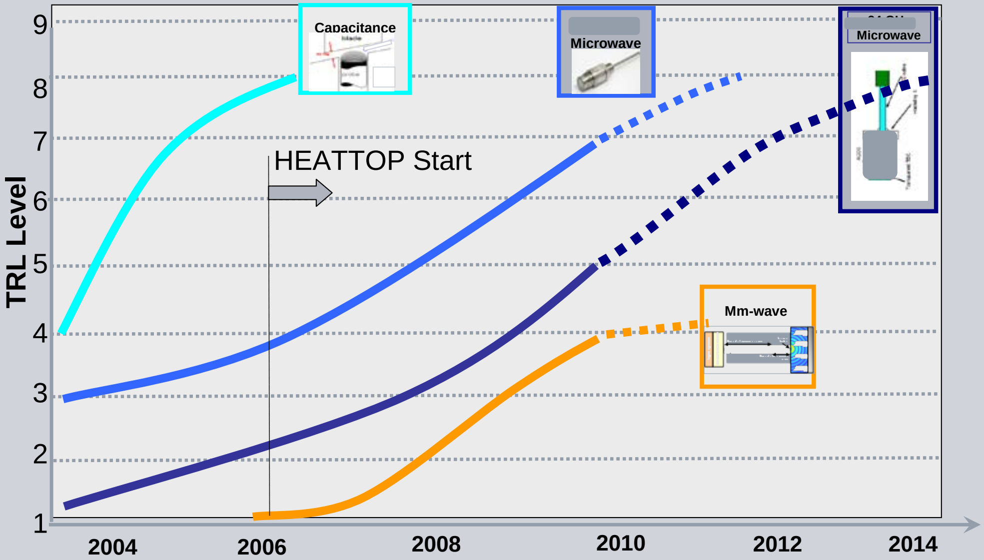
Online calibration pyrometer

Tip Clearance measurement

- Clearance optimization is needed for higher efficiency, reliability of the turbine and improved operational flexibility
- Siemens and Vibrometer developed a new system for measurement of tip clearances of turbine and compressor blades
- The technology applies RF mm-wave in the range of 77 GHz.
- Accuracies of 0.1mm were partly achieved. To assure this accuracy over a wide clearance range of 0-10mm more work is required.



Concept (left) and tip of the sealed RF antenna



TRL status of most common techniques

A variety of sensor technologies for temperature and pressure measurement was evaluated and implemented

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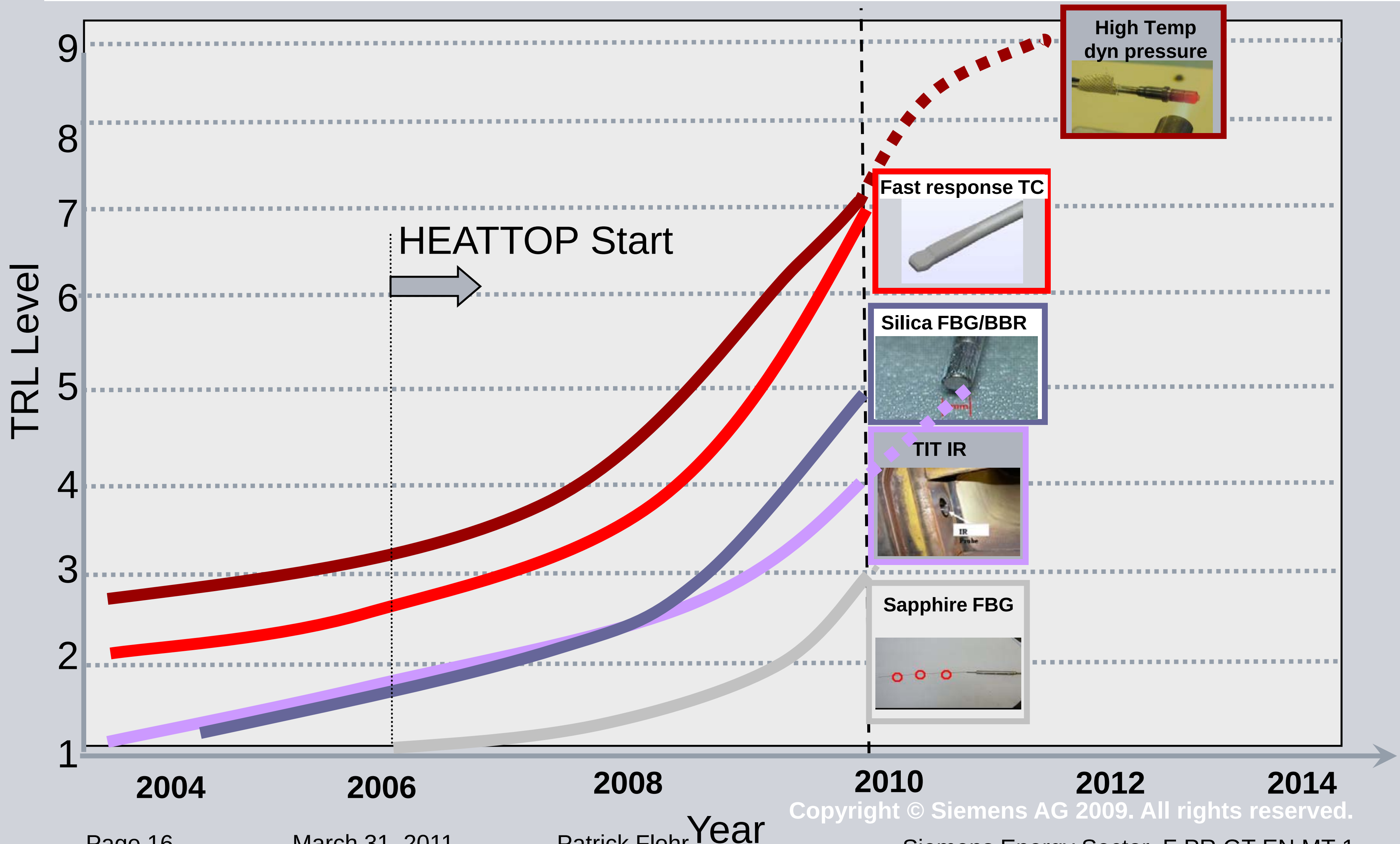


Summary and Conclusion

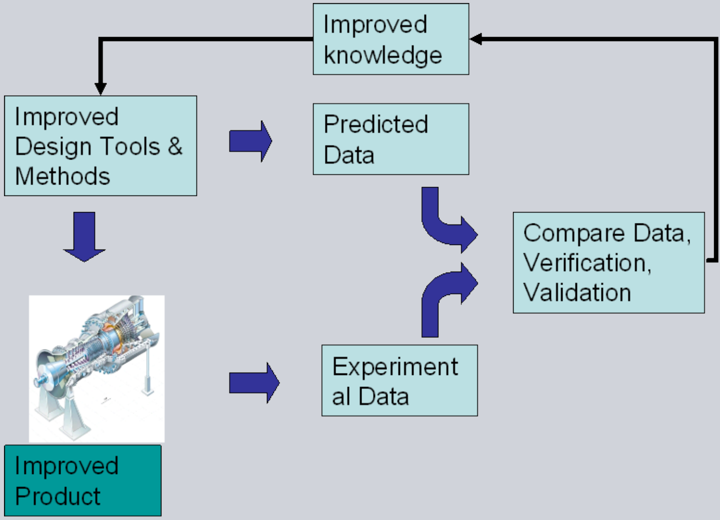
In HEATTOP 17 new, more durable and more accurate sensor systems were developed

→ Measurement in regions inside the engine not accessible before.

→ A few “Firsts” were generated. Jumps of 2 or 3 TRL classes.

→ Sensors for more flexible instrumentation at more interesting locations

→ Understand degradation mechanisms and limits of accuracy



→ Early collaboration between OEM and sensor developer is critical for success

→ Some patent applications, dissemination and lectures of the new knowledge is available

This innovative project helps us to secure technology leadership in current and new products.

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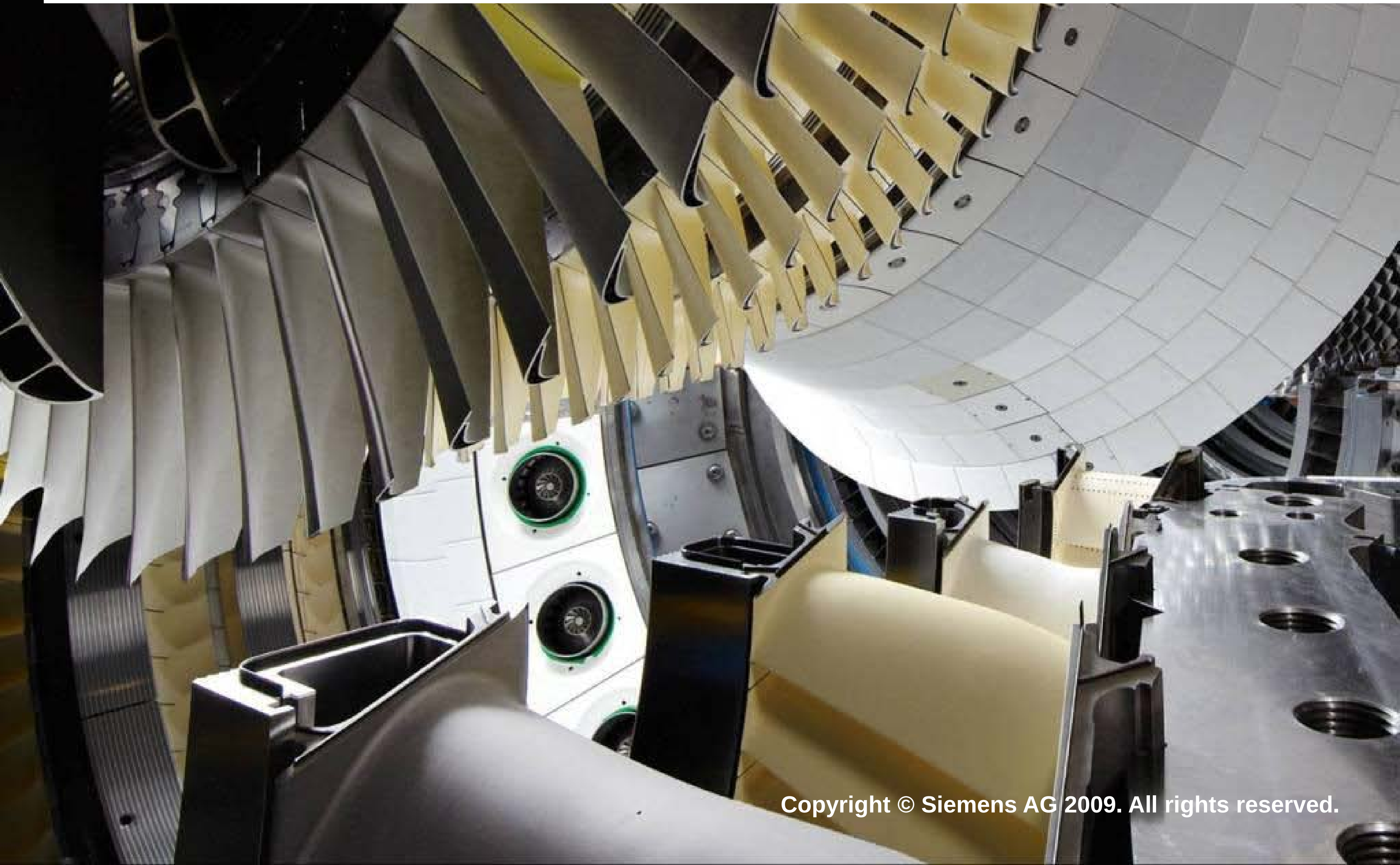
Acknowledgement

- This project was supported by a significant EU contribution to the OEMs, other Industrial Partners, Universities and Research Institutes.
- The project was funded out of the Sixth Framework Program of the EU
- The shown results and figures were generated by the respective partners in HEATTOP

Thank you for your attention!



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