DIGITISED AND TRACEABLE TESTING FOR GAS TURBINE COMPONENTS AND MATERIALS

European Turbomachinery Conference, EVI-GTI session, 24-28 April 2023

Technical presentation, reference 23-06, no. 7.3 | T. Kluge, S. Reh

DLR

Agenda

- Introduction: Test and Simulation for Gas Turbines
- Test facilities for materials and rotating components
- Digital transformation for testing and simulation

TESTING AND SIMULATION FOR GAS TURBINES

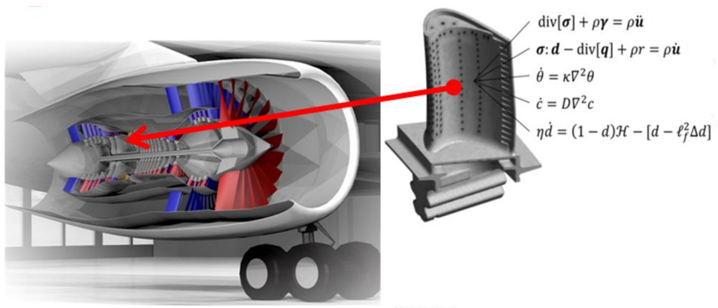
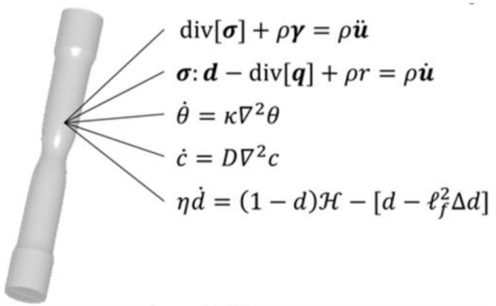
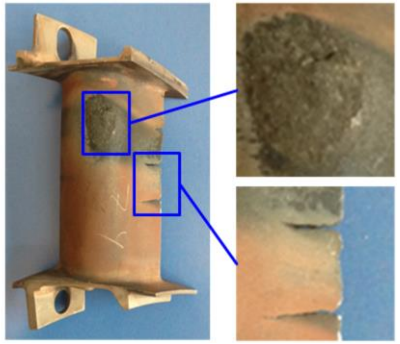
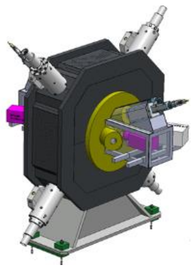
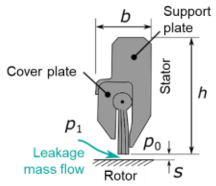
Research portfolio

❶ **Goal:** Modelling of all physical conditions and components

❷ Prediction of service life

❸ Development of models for accumulated damage and service life

❹ Validation on large-scale component test stands

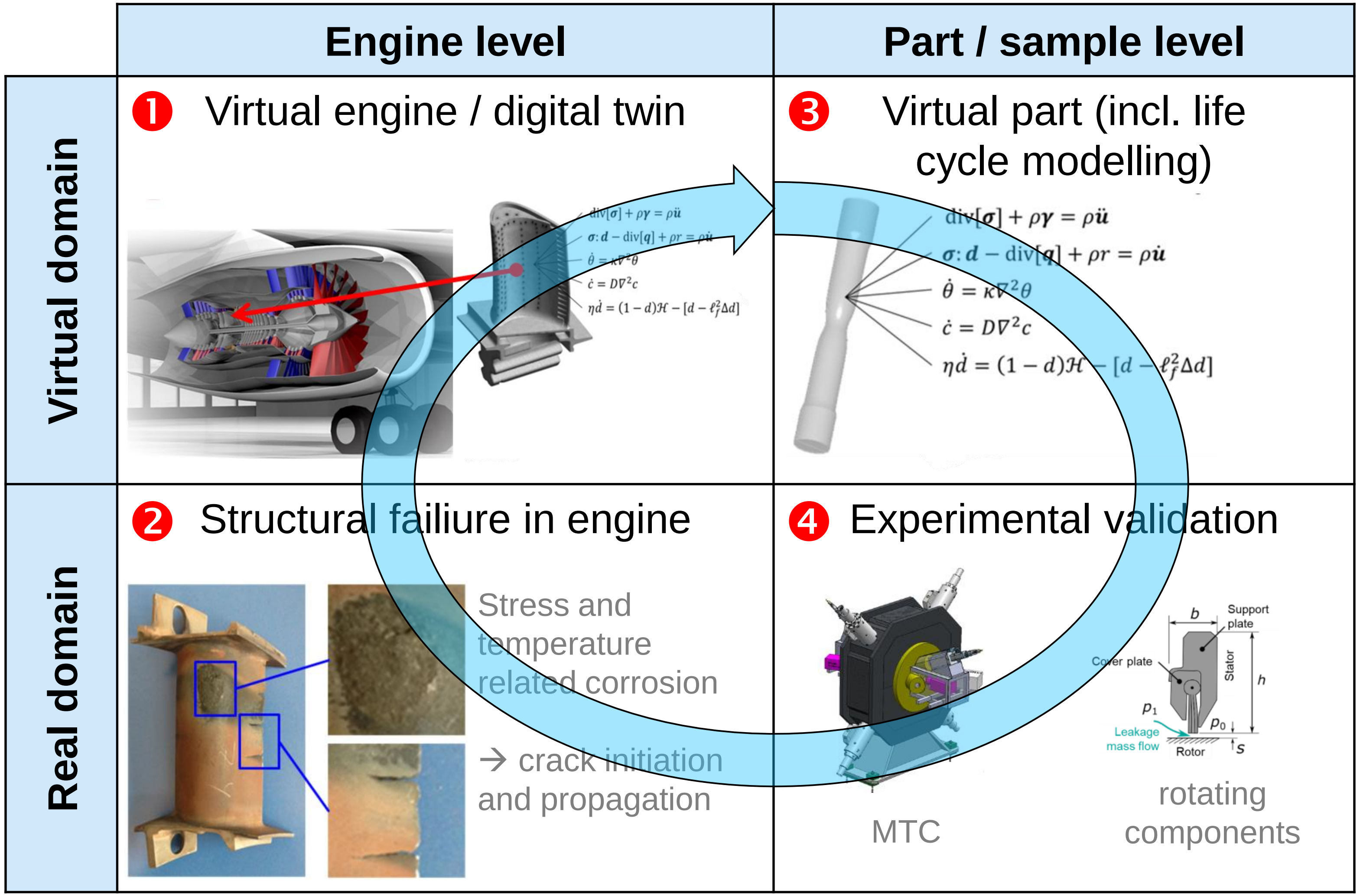
	Engine level	Part / sample level
Virtual domain	❶ Virtual engine / digital twin 	❸ Virtual part (incl. life cycle modelling) 
Real domain	❷ Structural failure in engine  Stress and temperature related corrosion → crack initiation and propagation	❹ Experimental validation  MTC  rotating components

Research portfolio

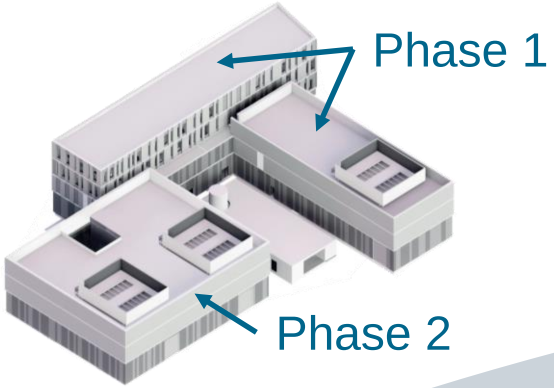
360° Digitisation / Institute 4.0

- Processes for e.g.
  - Simulation
  - Experiments
- Materials
- Resources, e.g.
  - Machines
  - Sensors
- Results, e.g.
  - Images
  - Files

Described by ontologies.



Current situation



Today

Technologiezentrum Augsburg

First test stands in operation

Additional test stands in planning stage

2024

Move into new building (phase 1)

Operation of large-scale MTC and rotating component test stands

Planning stage of test stands for phase 2

2026

Extension building (phase 2)

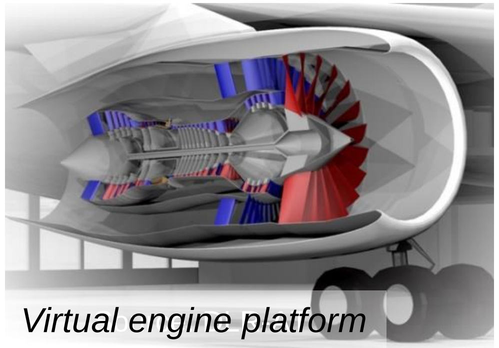
(Re-)Commissioning of additional test stands:

- 3 rotating component test stand
- 2 MTC test stands

Focus in simulation

Virtual engine

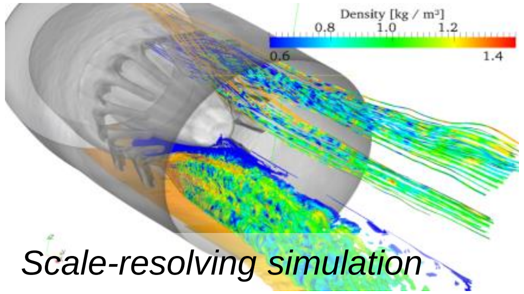
- Coordination of virtual engine platform at DLR
- Digitisation of all processes and multi-physics incl. components and interactions
- Parameterised and automated simulation tool chain



Virtual engine platform

Scale-resolving & multi-fidelity CFD simulation

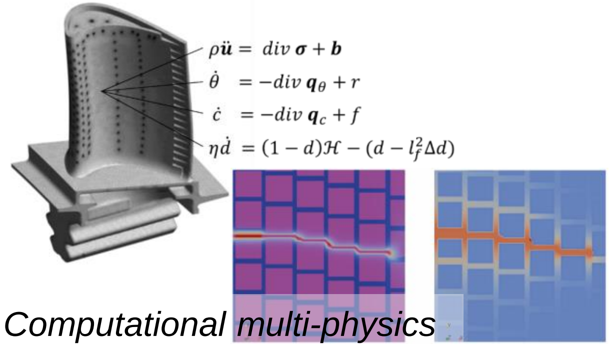
- Development of numerical methods for multi-fidelity CFD
- Development of hybrid-zonal methods (multi-fidelity vs. RANS)
- Validation on all scales



Scale-resolving simulation

Computational multi-physics for complex materials

- Development of multi-scale simulation and phase-field models
- Damage propagation and service life under engine-representative conditions



Computational multi-physics

Focus in testing
Experiment & validation

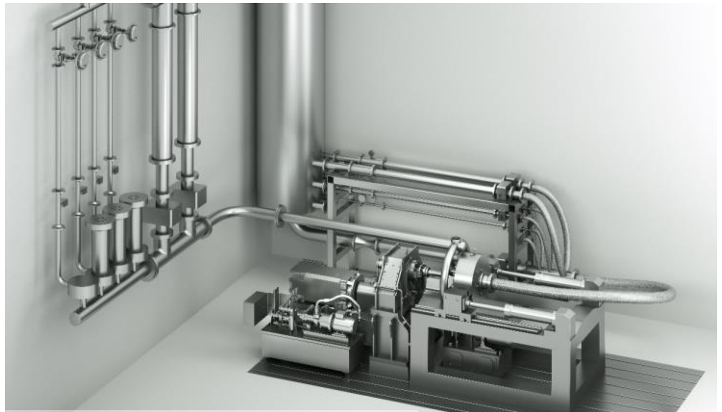
Rotating component test stands

- Experimental testing of full-scale rotating components
- Secondary air system and seals (cooling / service life impact)
- Power gear box (service life impact / damage)

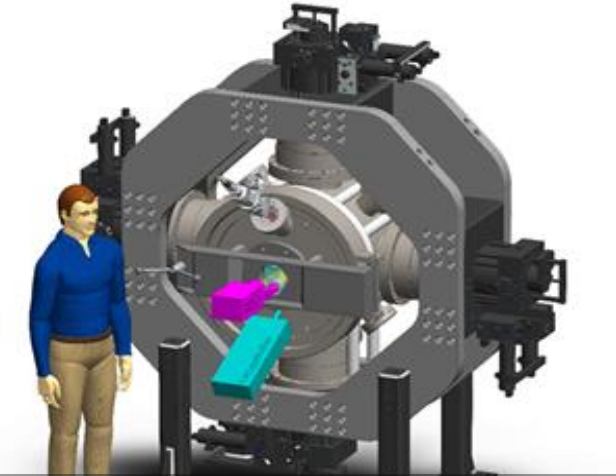
Life cycle of materials with engine-representative loads

- Multi-axial, mechanical loads (static, cyclic, transient)
- High pressure: 10 bar … 20 bar
- High temperatures: 300…1400ºC
- Corrosive combustion gases: NO, CO, SO_2, H_2, H_2O, salt, …
- Flow speeds > 500 m/s

Duration > 2000h for long term effects



multiple rotor test stands



test of parts/materials under thermomechanical & chemical loads

TEST FACILITIES

Materials micro analytics & measurement laboratory
The basics

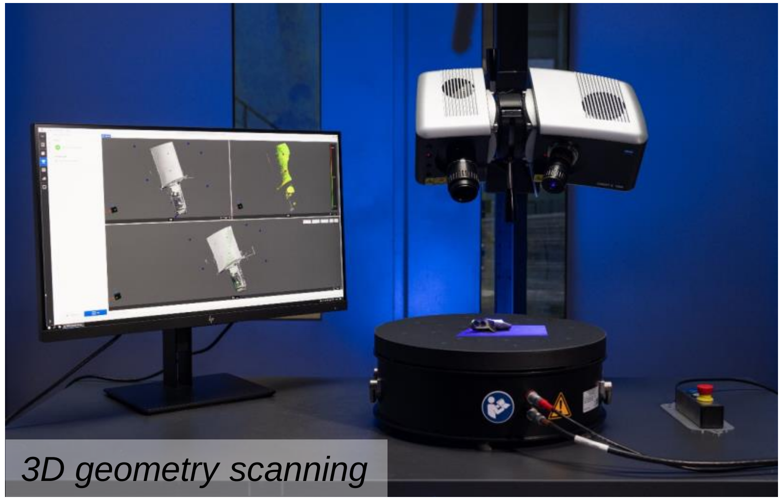
Challenge

- Increasing demands on gas turbine materials
- Necessity for improved life cycle predictions

Methods

- Micro-analytics for materials ✓ in operation
    - Extraction / preparation of samples from larger parts
    - Microscopic analysis of structure in materials
    - Measurement of corrosion, cracks, coating thickness, …
- 3-dimensional geometry scanning ✓ in operation
    - Precise geometry of sample objects
    - Digital copy of real object for simulations
- Calibration of temperature sensors ✓ in operation

materials testing laboratory



3D geometry scanning

Thermal, mechanical and chemical testing
Partial load collectives

Combined loads

- thermal + chemical → chamber oven
- thermal + mechanical (+ chemical) → ESEM + miniature load frame

Chamber oven

✓ in operation

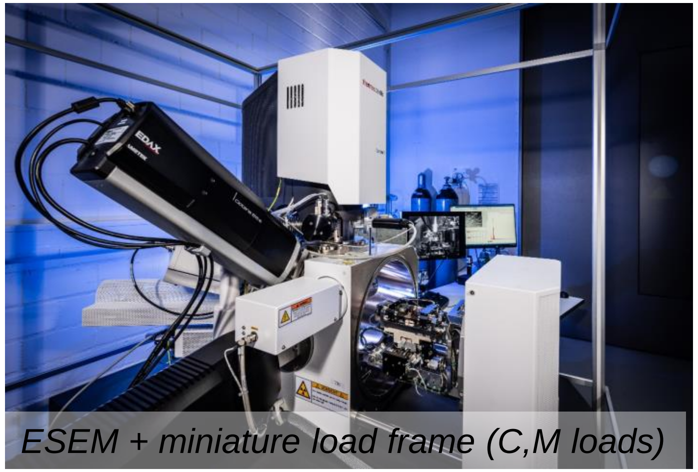
- Corrosion analysis of full-scale parts
- Temperature range: 400…1500°C
- Atmosphere: N_2, O_2, H_2O(g) (coming soon: CO_2, SO_2, CO, NO)

Environmental electron scanning microscope (ESEM)

- Characterisation of fatigue at temperatures up to 1200°C
- Miniature load frame (max. 10 kN / max. 0,13 Hz)
- In-situ analysis of small samples

✓ in operation

thermal and chemical loads on materials



ESEM + miniature load frame (C,M loads)

Thermal, mechanical and chemical testing
Engine-representative conditions

Challenge

expected 2025

Experimental validation of materials characteristics under…

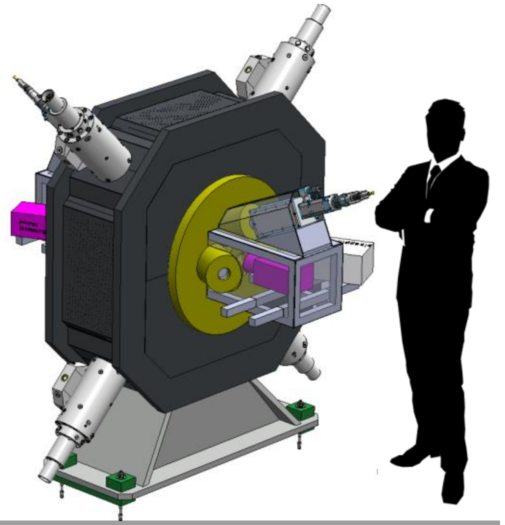
- …long term engine-representative thermal, mechanical, and chemical loads
- …uniaxial, biaxial, fretting, creep and UHCF loads

New test stands

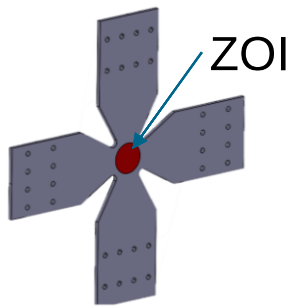
UNIAX, BIAX & Fretting, CREEP, and UHCF

- max. 20 bar in pressure chamber
- 600…1400°C in zone of interest (ZOI)
- adjustable gaseous environment, incl. max 30%-wt $H_20(g)$
- periodical application of salt in ZOI

Measurement highlights: DIC, pyrometry, and thermal imaging

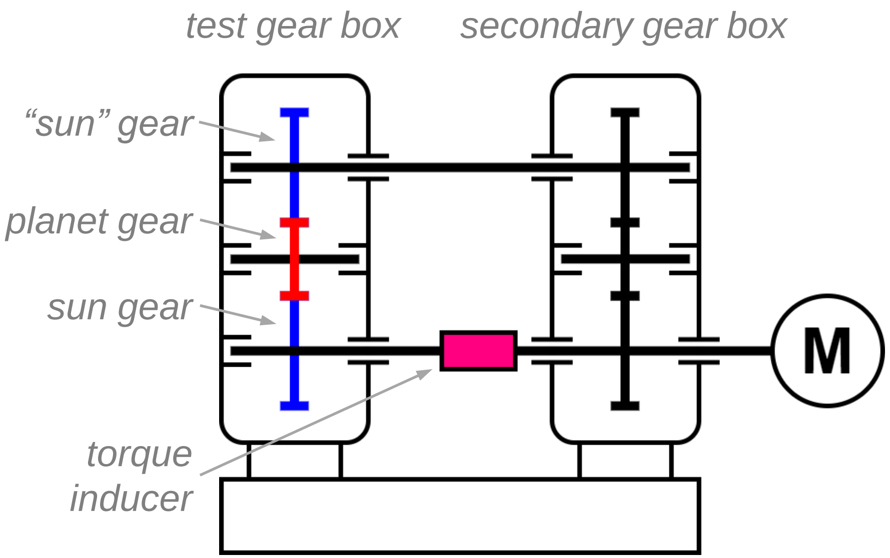


BIAX test stand with pressure chamber and instrumentation



biaxial stress sample

Rotating component test stands
Power Gearbox



gear box test stand principle

Goal

Understanding the failure modes of planet gears

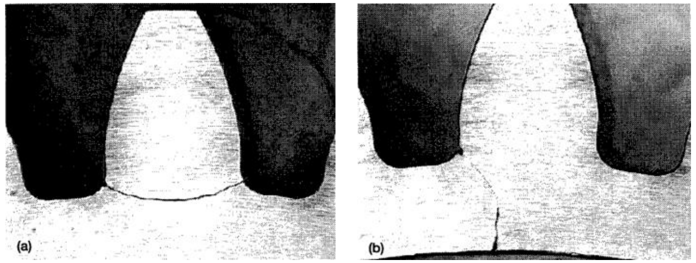
Methods

- Application of loads on gears via torque inducer
- Rotational speed set by motor
- Motor must supply power loss and acceleration only

Measurements

- Vibration and structure-borne noise
- Rotational speed and angles
- Development of crack propagation monitoring in progress

expected 2024



Sample crack propagation path for tests.
Source: Lewicki, D.G. (1996) Effect of Rim Thickness on Gear Crack Propagation Path. NASA Technical Memorandum 107229.

Rotating component test stands
Brush seals

Goal

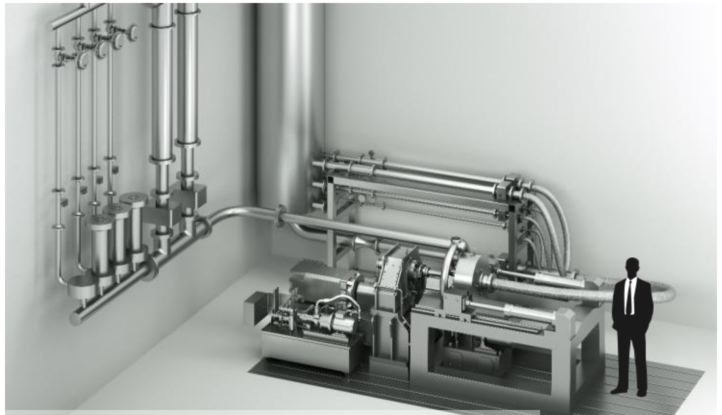
- Characterisation of brush seals in engine-representative conditions
- Validation of FSI simulations

Technical specifications

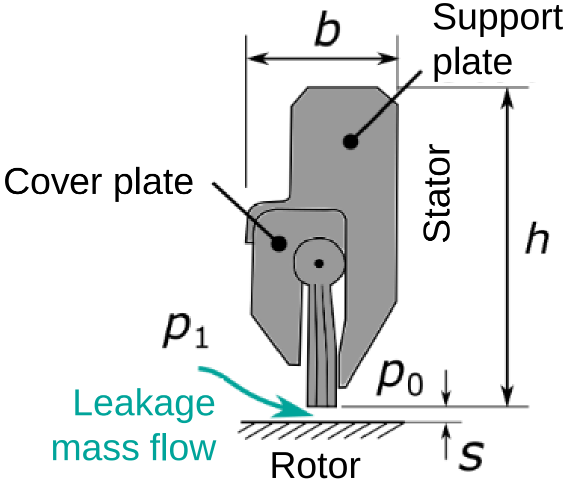
- Circumf. velocity / rotor diameter: 420 m/s at Ø300 mm
- Air temperature: max. 400°C
- Pressure difference: max. 4 bar

Methods

- Variable gap size, gap measurement
- Analysis of heat dissipation during contact
- Measurement of wear due to contact



rotor test stand I + brush seal rig



expected 2024

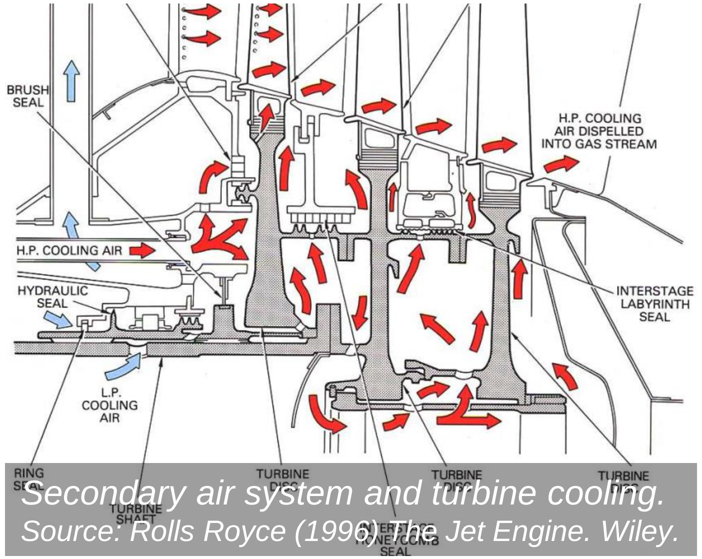
Rotating component test stands
Rotor test stand II

Goals

- Aerothermodynamic analysis of the secondary air system (SAS)
- Improved understanding of
  - the impact of bleed air extraction
  - the inlet flow of cooling channels
- Validation of CFD and reduced order models (virtual engine)

Methods

- SAS test rig (mounted on rotor test stand II)
- Measurement of complex flows in rotating cavities
- Detailed definition to be determined



Secondary air system and turbine cooling.
Source: Rolls Royce (1996) The Jet Engine. Wiley.

expected 2027

DIGITAL TRANSFORMATION

Virtual engine platform

Virtual Engine

All disciplines combined describe product geometry and characteristics

Digital twin

Production
Geometry
Material
Quality control
Supply chain

Operation & test
Test environment
Test & load conditions
Measurement data
Supply chain

Postprocessing
Damage analysis
Supply chain

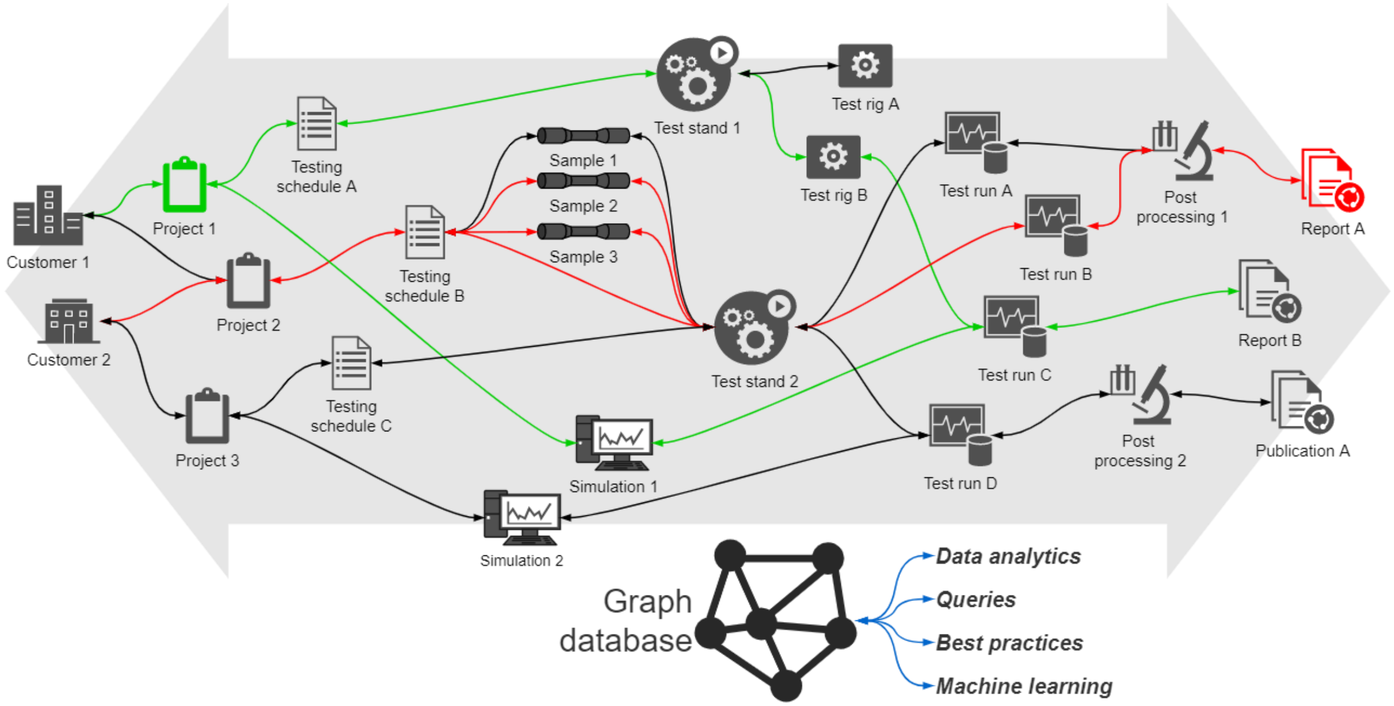
Miscellaneous
Supporting documents
Reports
Supply chain

Simulation

Description and modelling of characteristics → (remaining) service life

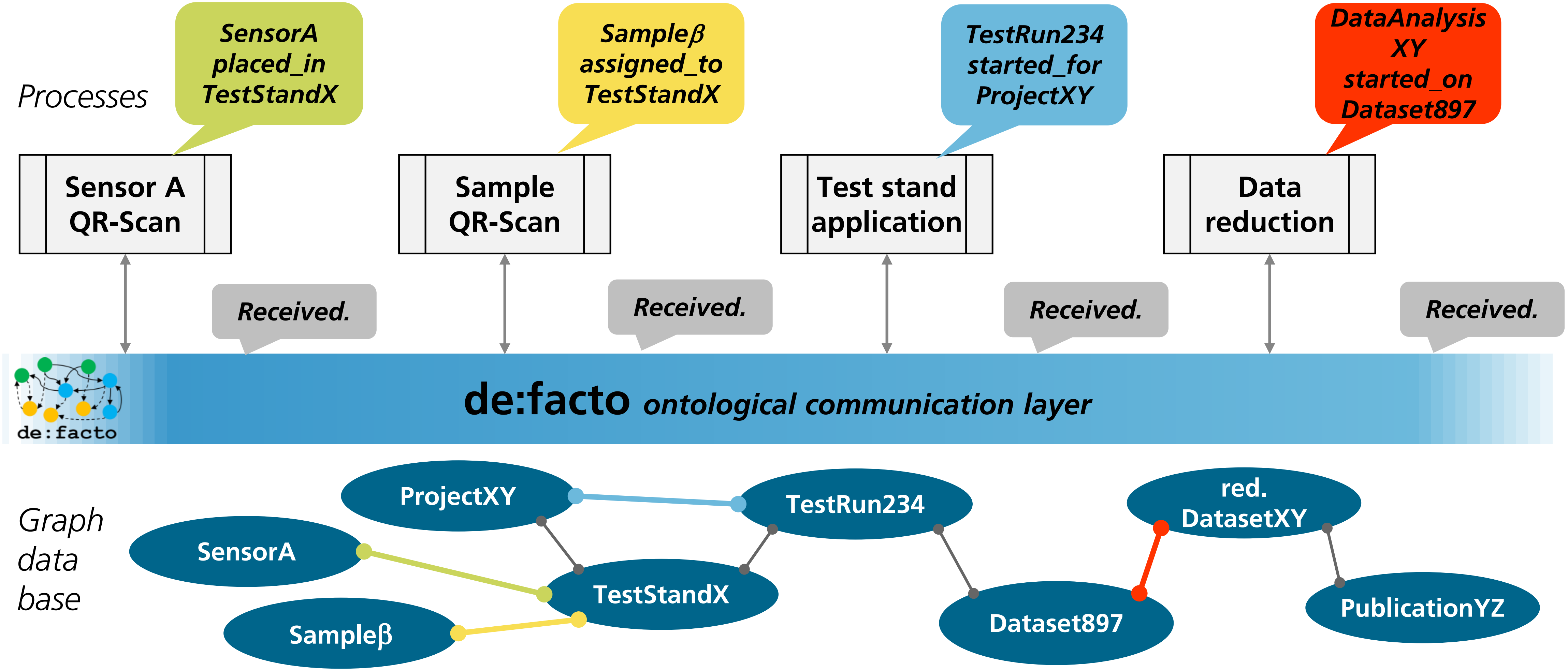
Traceability of results

- Fully digitised institute
- Inherently non-digital objects made identifiable by UUIDs / QR codes
- Relationships between entities are stored in graph database
- Entities and relationships defined by ontologies



- Complete traceability through data provenance
- Automation and process guidance

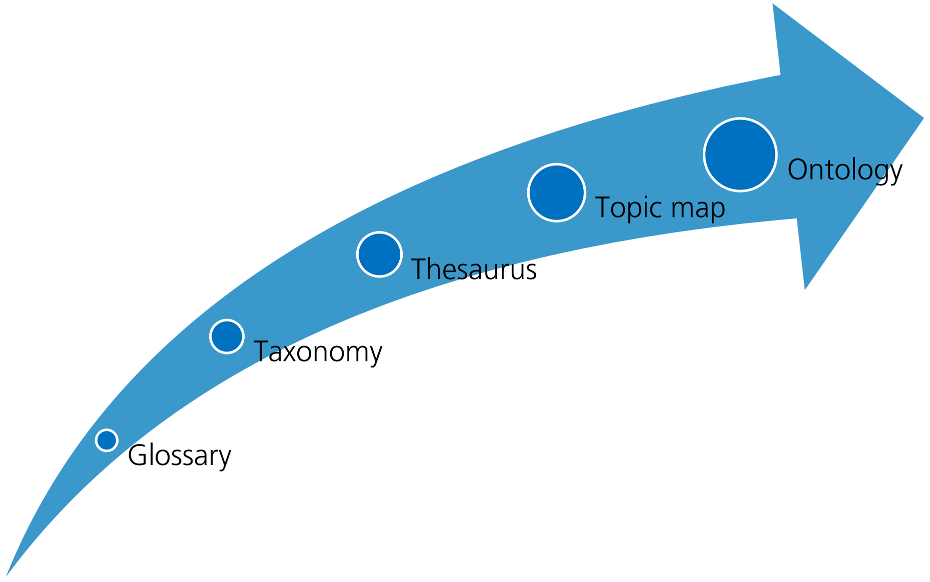
digital everything: facts described by ontologies



Ontologies – one definition (of many)

"An ontology is a formal, explicit specification of a shared, machine-readable vocabulary and meanings, in the form of various entities and relationships between them, to describe knowledge about the contents of one or more related subject domains throughout the life cycle of its existence. These entities and relationships are used to represent knowledge in the set of related subject domains."—Strassner, 2008

- Machine-readable specification of knowledge about entities and their properties in a certain domain
- Formal and shared definition
- Throughout life cycle



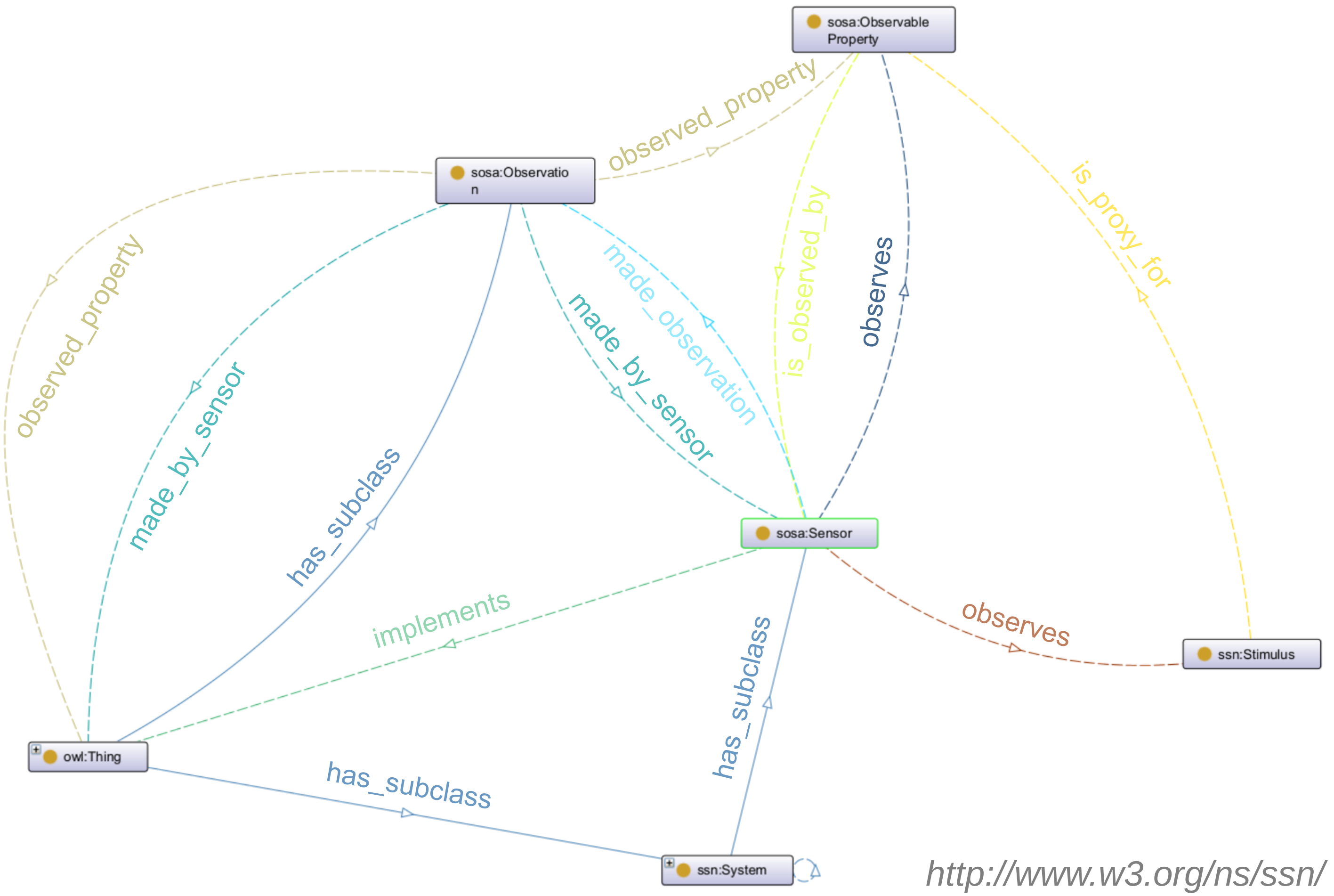
Example triples

- :TestStand :uses *some* :PowerSupply
- :Simulation :runs_on *some* :Computer

An example ontology
Semantic Sensor Network Ontology (Excerpt)

- Published ontologies available in repositories such as W3C
- May be built on for other domains

- This excerpt shows
  - relationship between sensor and observable property
  - relationship between sensor and stimulus
  - class hierarchies
  - some inverse relationships
  - …



http://www.w3.org/ns/ssn/

What is the benefit?

Consistency and sharing

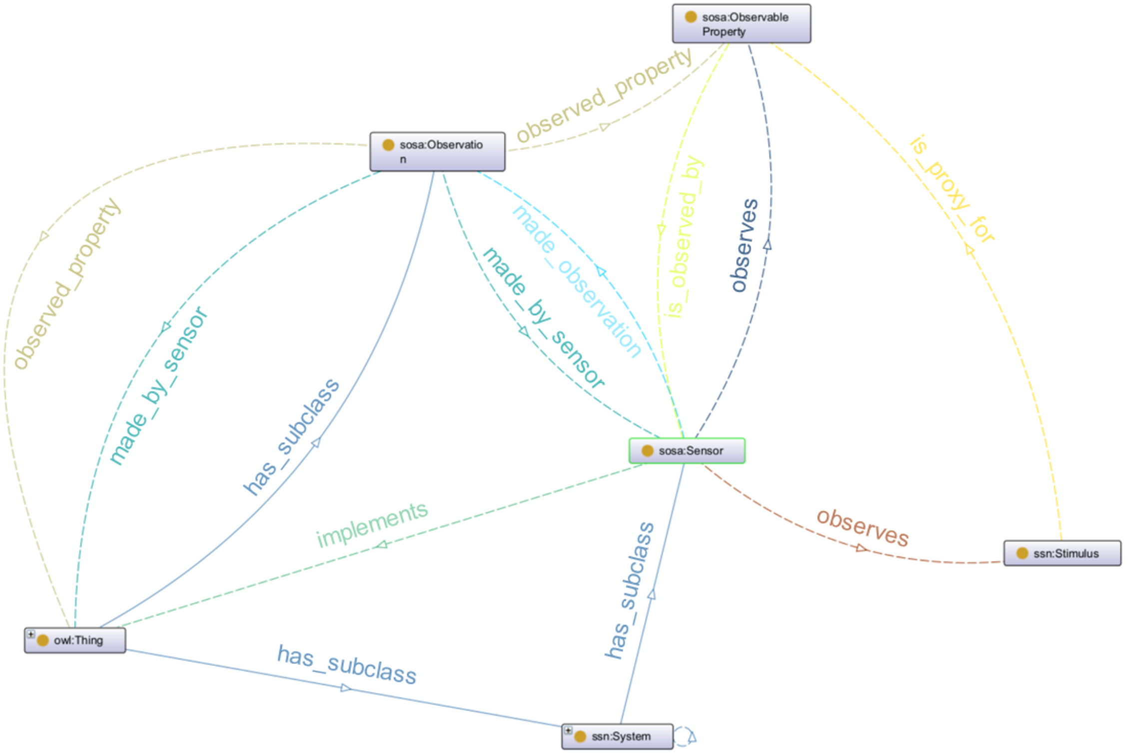
- Ontologies provide a shared set of terms
- Standardised knowledge base for reuse and maintenance

Automation

- Machine-readable knowledge about domain
- Logical reasoning within domain
- Separated operational and domain knowledge

Data management

- Explicit structure for available data
- Semantic information about data

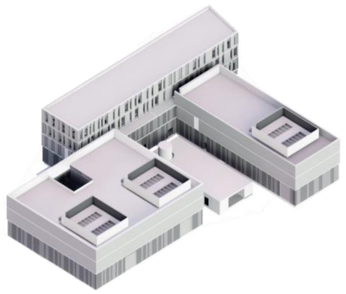


The Semantic Sensor Network Ontology (http://www.w3.org/ns/ssn/)

Summary

New institute

- Founded in 2017
- New building for offices and test field



New test field

- Materials testing laboratory and test stands
- Rotating component test stands

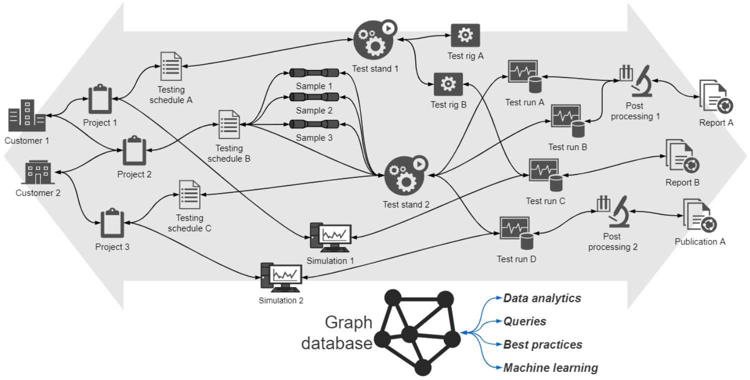
→ Validation of Virtual Engine Platform models

Digitised operations

- Development of ontologies
- Development of software solutions

→ Traceability of results

→ Publication of digitised methods



THANK YOU FOR YOUR TIME

Sources

- Strassner, J. (2008) Knowledge Engineering Using Ontologies. In: *Bergstra, J.A. (Ed.), Handbook of Network and Systems Administration.* Elsevier.
- Lewicki, D. G. (1996). Effect of Rim Thickness on Gear Crack Propagation Path, NASA Technical Memorandum 107229. In: *7th International Power Transmission and Gearing Conference sponsored by the American Society of Mechanical Engineers*.
- Rolls Royce (1996) The Jet Engine. Wiley.