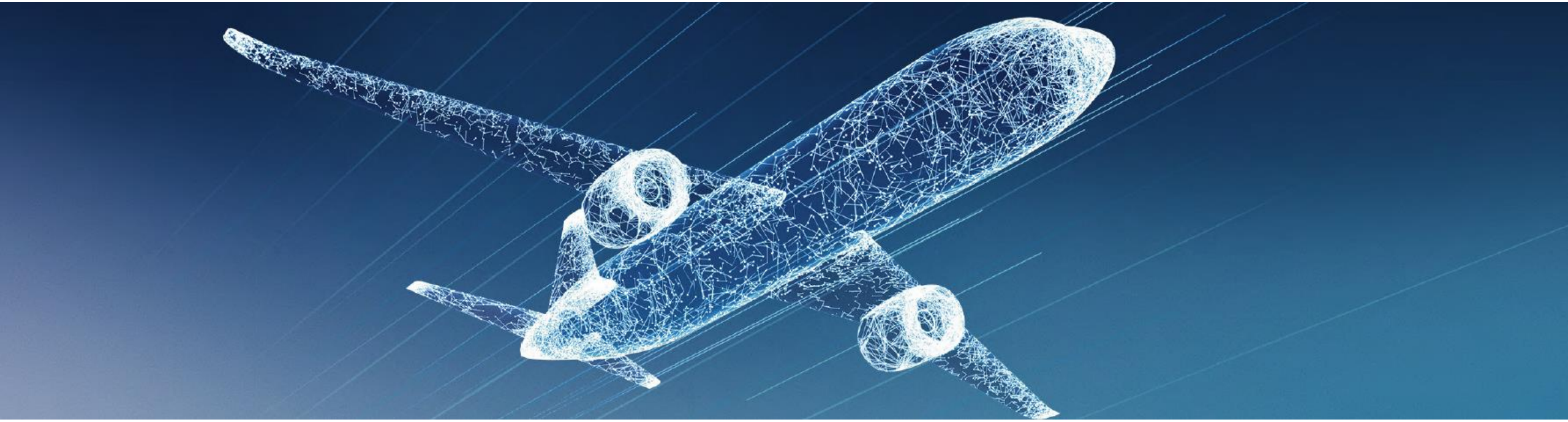


Herausforderungen an Flugantriebe der Zukunft und ihre Materialien

12.09.2024 / TUM Expertenforum: Zerstörungsfreie Prüfung für die nachhaltige Energietechnik der Zukunft / Prof. Dr. Jörg Eßlinger

Proprietary Notice

This document contains proprietary information of the MTU Aero Engines AG group companies.
The document and its contents shall not be copied or disclosed to any third party or used for any purpose other than that for which it is provided, without the prior written agreement of MTU Aero Engines AG.

This document contains no listed technical data according to the German and European Union export control lists or U.S. origin technical data listed stricter than EAR99 or 9E991.

Agenda

- Aero Engines Business
- Future Propulsion Concepts
- Technologies: Materials, Processes, and Design
- NDT-Methods: Specifics and Needs

Aero Engines Business

A passenger aircraft is made up of up to

6 million components

Fuel consumption per 100 passenger kilometers:

2.9 liters of kerosene

Nearly doubling the active fleet

to **48,000 aircraft** by 2040

~ 2 billion people

out of 7.95 billion have flown in an aircraft to date

The geared turbofan reduces

75% of the noise footprint

Our track record: partners and customers appreciate MTU's excellence

Commercial OEM business

Share of total revenues ca. 26%

Balanced product portfolio in all thrust categories

Decades of partnership with OEMs

Military OEM business

Share of total revenues ca. 8%

European and U.S. engine programs

Leading partner of the German Armed Forces

Commercial MRO business

Share of total revenues ca. 66%

Services: maintenance, leasing and asset management

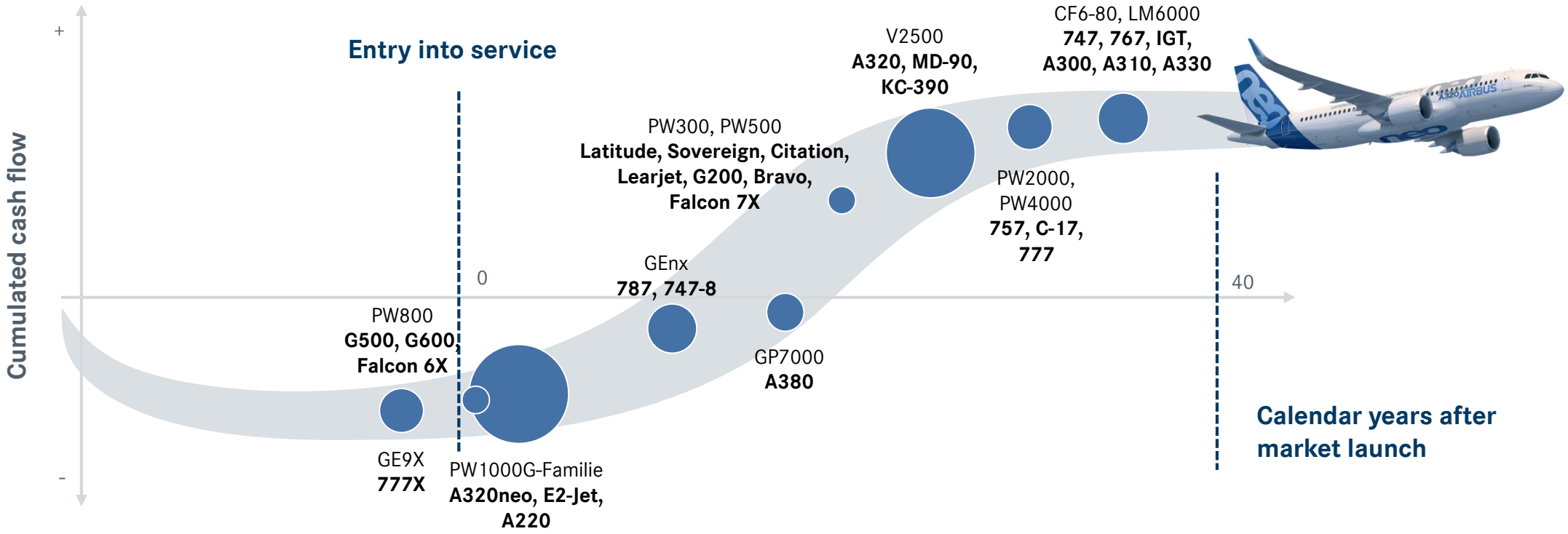
Direct customer business, partner of OEMs and airlines

MTU group fiscal year 2023*: Revenue € 6.3 billion / EBIT € 818 million

*Adjusted values

Preliminary FY 2023 Results

A balanced portfolio and products in all thrust categories ensure MTU's long-term success



Technology | R&D | Production | Aftermarket

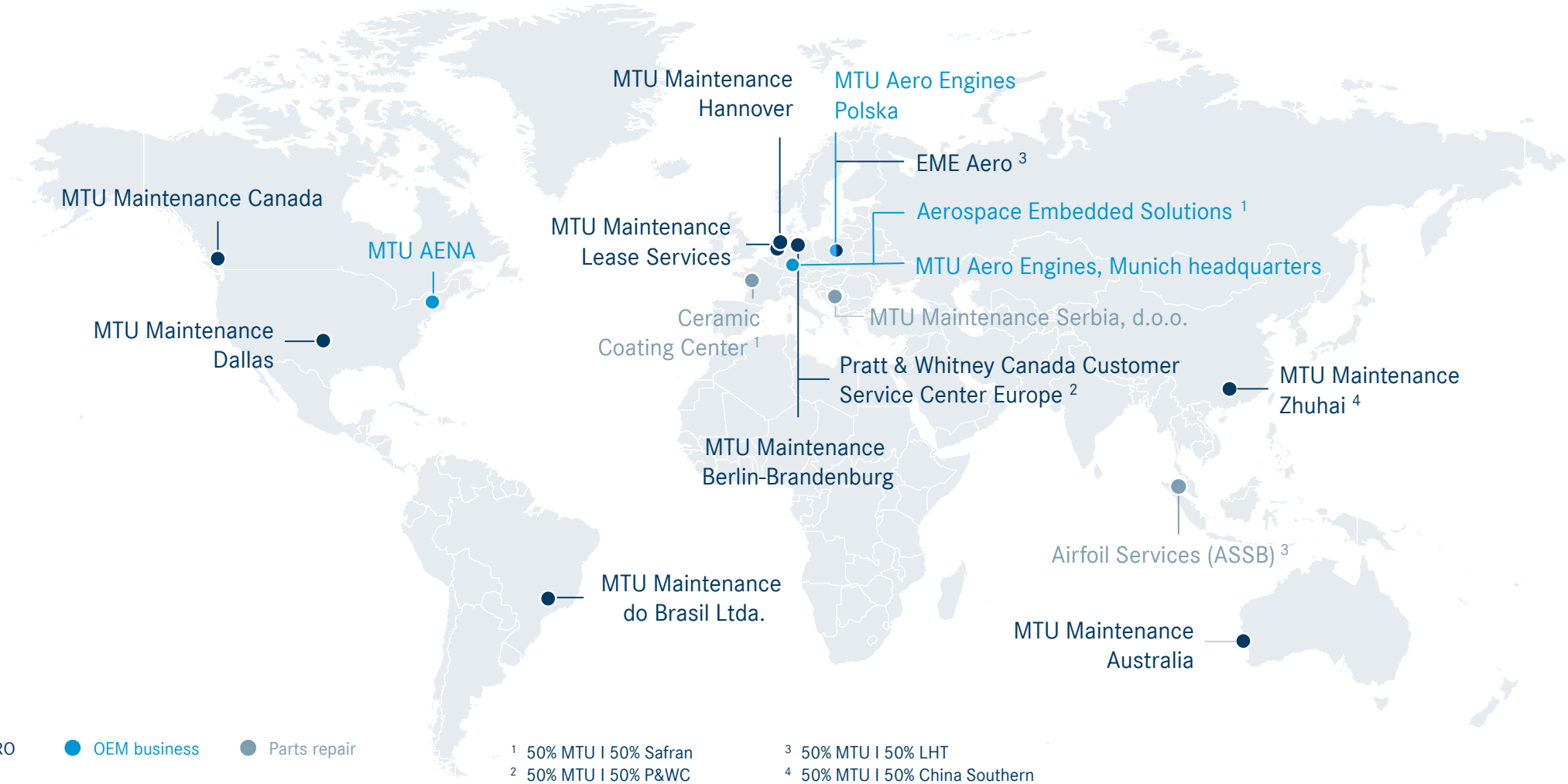
MTU is an essential partner in the engine value chain

Material suppliers*	Engine component suppliers*	**Subsystem/module suppliers***	Engine OEMs*	Airframers*	**Airline operations**
CPP	Senior Aerospace	Kawasaki Heavy Industries, Ltd.	GE Aviation	Airbus	
PCC	Hanwha Aerospace	IHI	Pratt & Whitney	Boeing	
Alcoa	MB Aerospace	Mitsubishi Heavy Industries, Ltd.	Rolls-Royce	Embraer	
ATI		MTU Aero Engines	Safran	Gulfstream, Dassault Aviation	
				Bombardier, Cessna, Comac	MRO: Engine MRO – MTU Maintenance

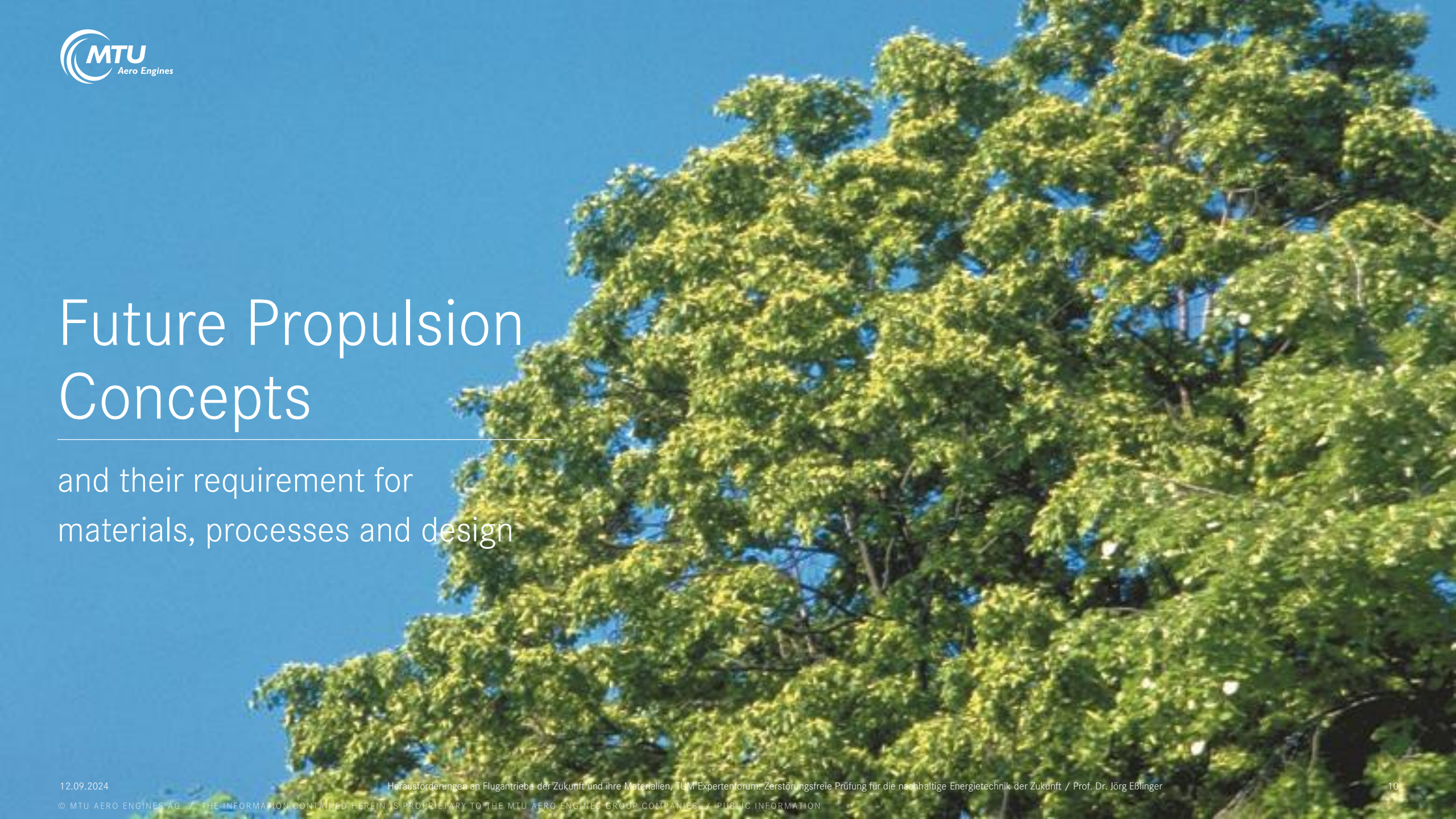
OEM market | **Aftermarket**

*selected market participants

With our locations worldwide we are close to our customers



1 50% MTU I 50% Safran
2 50% MTU I 50% P&WC
3 50% MTU I 50% LHT
4 50% MTU I 50% China Southern

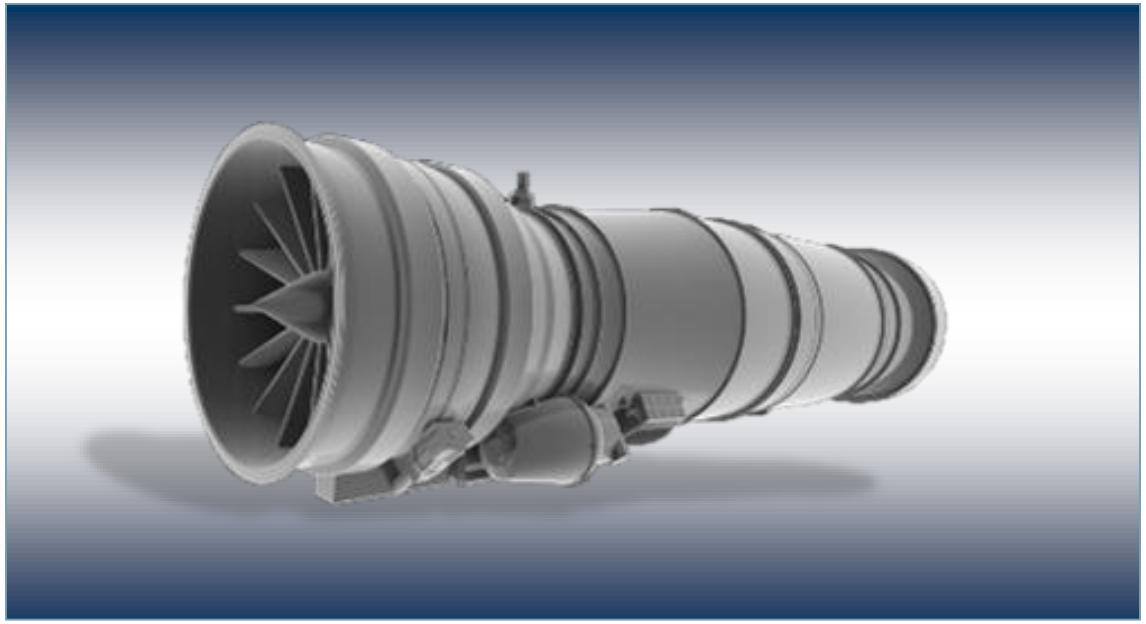


Future Propulsion Concepts

and their requirement for materials, processes and design

Requirements by new high-performance engines

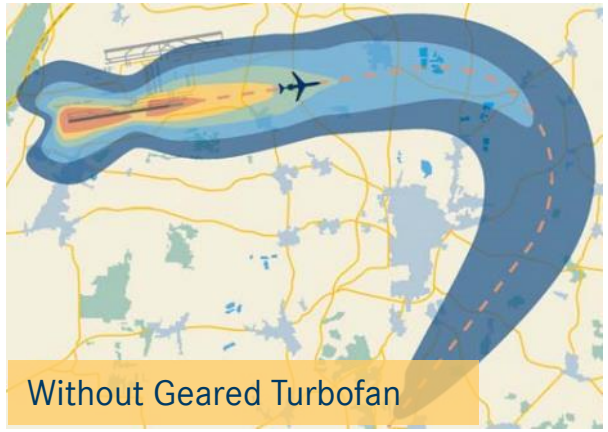
Future combat air system



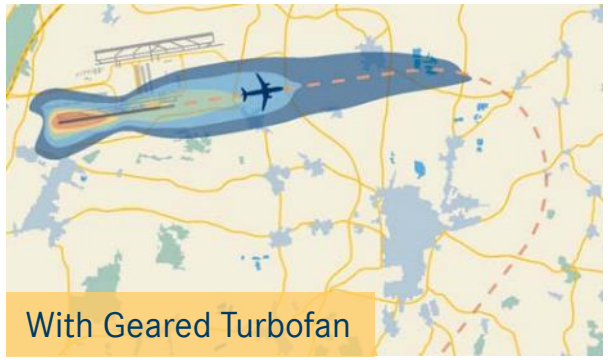
⇨ Highest temperatures & mechanical loading – lowest possible weight

The Geared Turbofan Is Already Setting New Standards

Noise Footprint

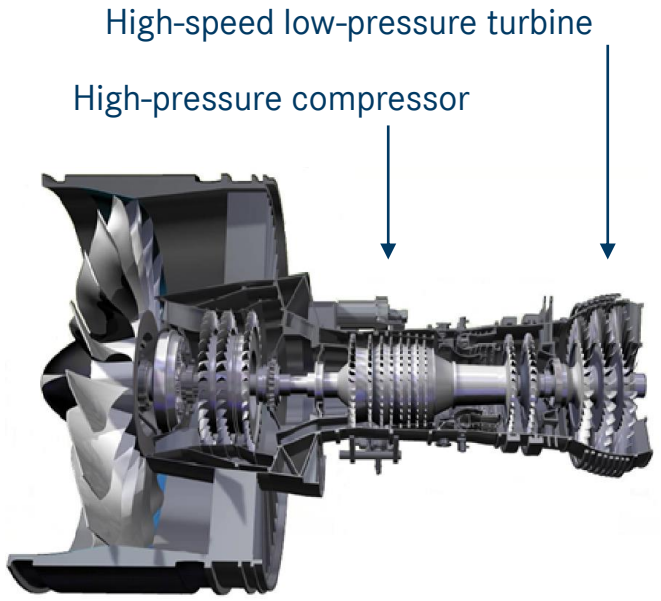


Munich International Airport (MUC)



Noise Simulation: Pratt & Whitney SEL Contour Source: Wyle Laboratories

MTU Contribution



Geared Turbofan reduces:
- Noise footprint by 75%
- Fuel consumption and CO_2-emissions by 16%
- NO_x-emissions by 50%

Chosen for three Airframes

Airbus A320neo

Airbus A220

Embraer E2-Jets Gen2

Requirements by new concepts in civil aviation

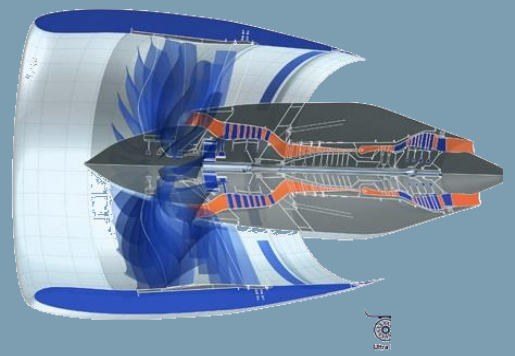
Emission free flying

Evolutionary | **Revolutionary**

Optimized and newly concieved gas turbine using sustainable aviation fuels

Electrification

Gen 2 GTF

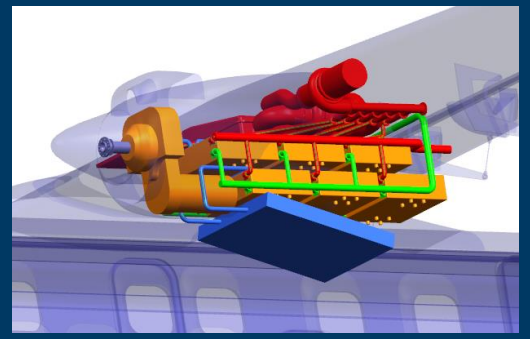


- Further reduction in fuel burn and noise

Revolutionary Gasturbine

- Significantly reduced climatic impact

Flying Fuel Cell™



- Almost climate neutral

⇨ **New, additional components (weight!) – H_2O & H_2 & cryogenic atmosphere – Electrification**

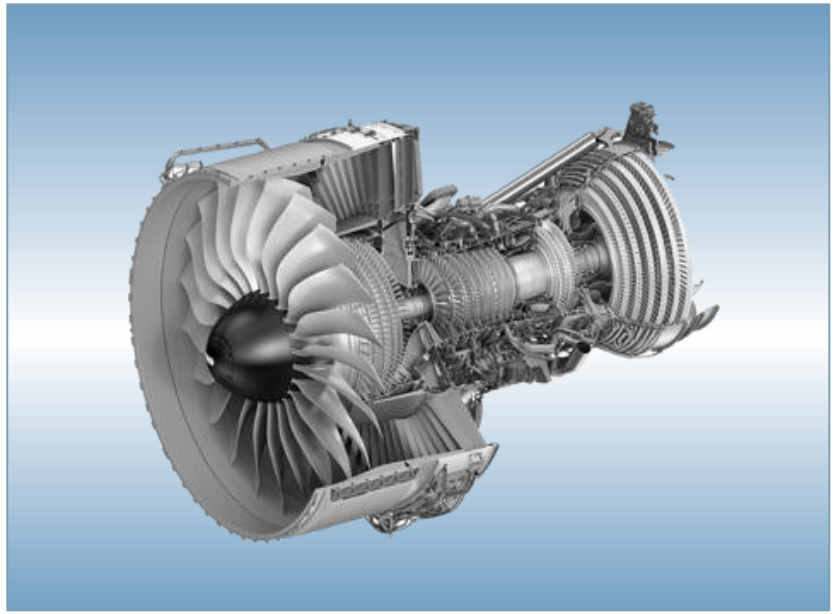
Requirements by growing fleet

Costs and consumption of resources in production and operation

Nearly doubling the active fleet to
48,000 aircraft by 2040

A passenger aircraft is made up of up to
6 million components

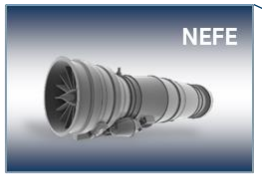
An engine‘s life cycle spans
25 to 50 years

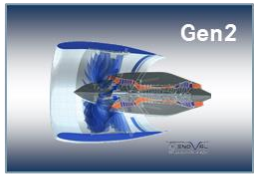


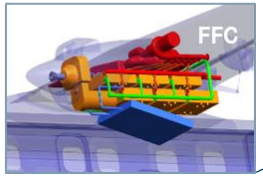
⇨ **Economical manufacturing processes & materials – high life span & robustness – maintenance**

Technologies: Materials, Processes, and Design

The „assignment“: technology trends in materials, processes, and design to enable powerful-ecofriendly-competitive engines







High-performance: Maximum load capacity with minimum weight

- Low density – high-temperature / high-strength - robust materials
- Light-weight design

Economic-ecological: Cost-efficient and resource-saving

- Lower-cost substitutes
- Near net shape raw parts
- Stable quality, robustness, & high life span (simulation, coatings, repair)

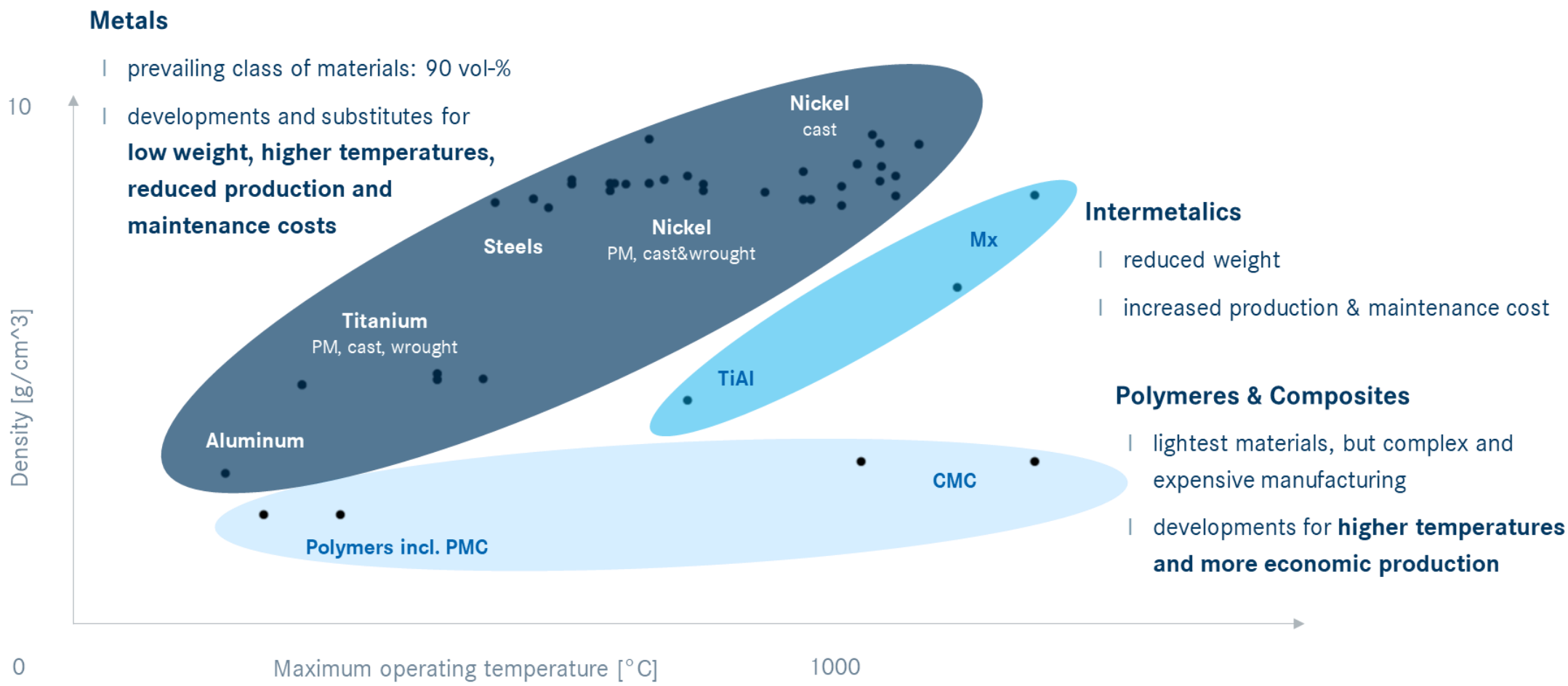
Novel: New functionalities, atmospheres, and components

- Electrification
- H_2 , H_20, and low temperatures
- Compensation of weight increases

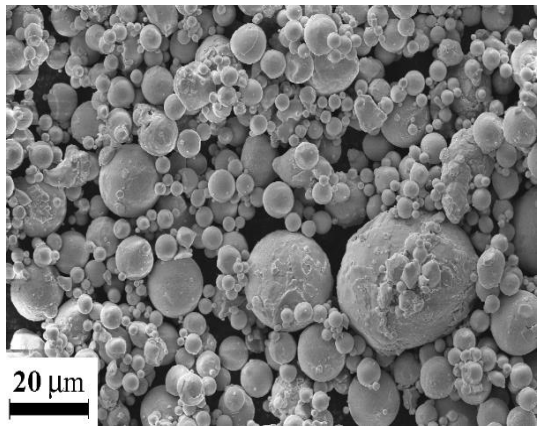
Extensive: Significantly extended portfolio, high expenditures and risks

- Qualify to air-worthiness
- Reduction of development efforts
- Strategic-cooperative approaches (industry & science & politics)

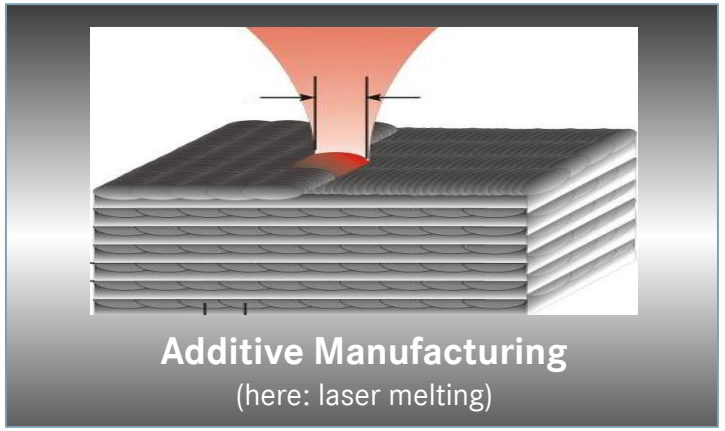
Application and development needs of high-temperature and light-weight materials



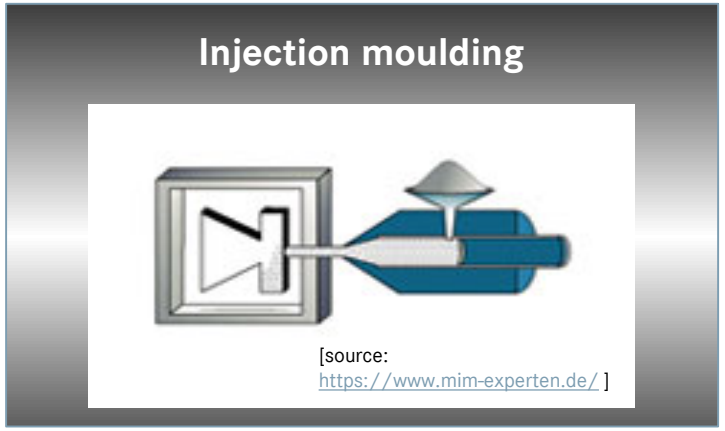
Powder-based production to save resources and enable light-weight design



Higher degree of freedom by powder-based raw material



- Complex geometries
- Graded materials

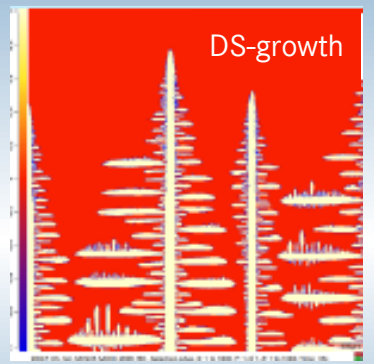


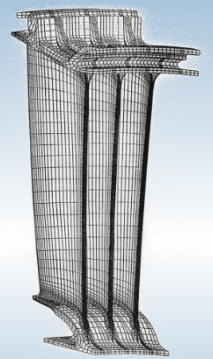
- High parts volumes
- High surface quality

Near net shape raw parts & light-weight design

Measures to realise cost-efficiency in production and operation, 1 of 2

Virtual development





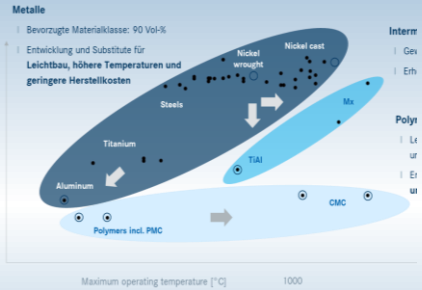
Simulation of processes

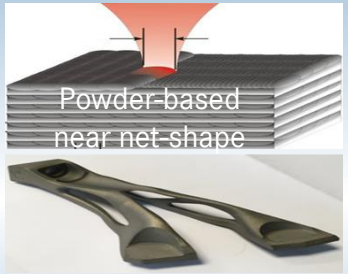
➢ accelerated development

Precise lifing analysis

➢ design to manufacturing and robustness

Production costs



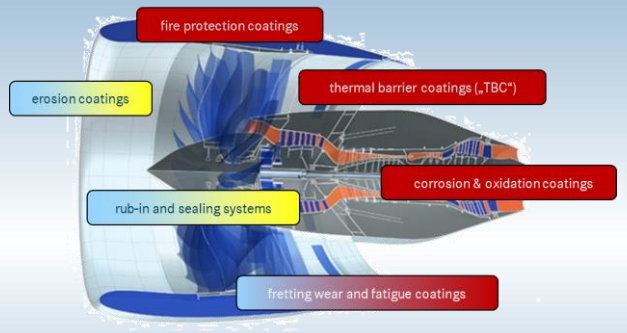


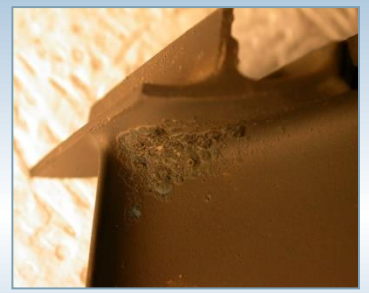
➢ **Low-cost substitutes of materials**

➢ **Resource-saving and faster production processes**

Measures to realise cost-efficiency in production and operation, 2 of 2

Protective coatings

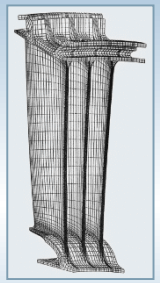




Multifold life vs. partially increased costs

- ➢ Surface degradation as main cause of parts‘ replacement
- ➢ More than 60% of parts with life benefit by coatings

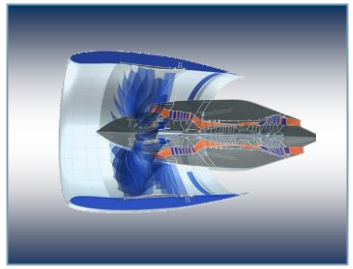
Maintenance and repair



Robust design, testability, and repair development

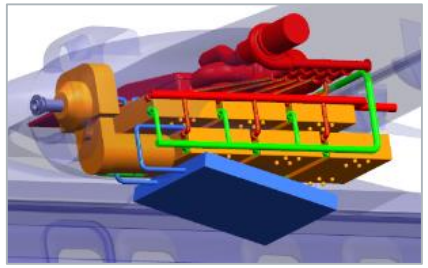
- ➢ Increased rate to reuse

Qualifying materials of new propulsion concepts in accordance with airworthiness requirements



H_2-burn

Revolutionary Gasturbine



Electrochemistry

Flight engines requirements relative to car engines:

- **10-fold life span**
- more than **100-fold reliability**

accompanied by

- **highest demands** with respect to material **quality and characterisation**

Needs for materials characterisation by new propulsion concepts:

- **impact of H_2 and H_20** on corrosion and embrittlement
- targeted **electrochemical properties**
- **broadened materials portfolio** (coatings & foils, light-weight metals & polymers)

including needs for

- **novel test equipment and methods of design**

NDT-Methods: Specifics and Needs

Aero engine-specific aspects for non-destructive testing

High lifetimes and reliability

Picture by:
MTU mediapool

- Need for high POD* / low rate of false negatives
- Relevance of rare defects
- Many NDT-steps of wide-spread types along value chain

* Probability of detection

Strict regulations by the authorities

LBA Luftfahrt-Bundesamt

Federal Aviation Administration

EASA European Union Aviation Safety Agency

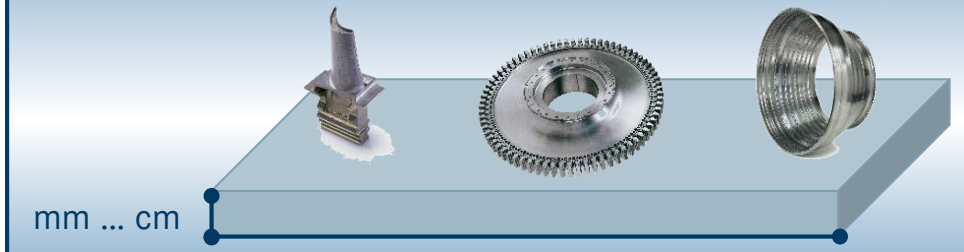
- High efforts to certify new methods and providers

Parts of high value

Picture by:
MTU / mediapool

- Need for low rates of false positives!
- High value NDT methods may be economic

Shapes and dimensions of parts

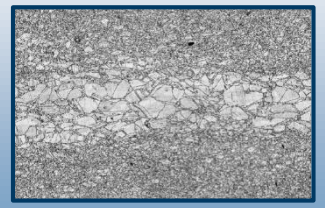


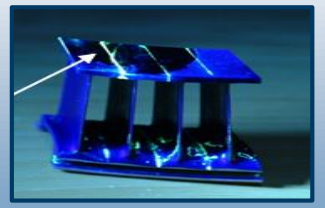
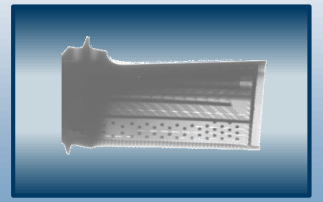
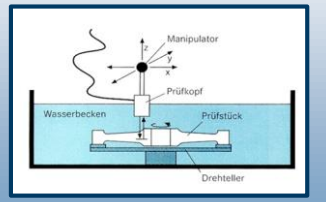
Pictures by: MTU / mediapool

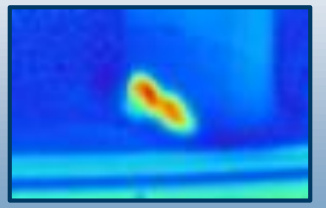
Material quality attributes and methods for non-destructive testing in aero engines

An Overview

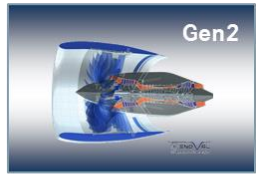
- **The relevant material quality attributes** to be screened by NDT are similar to related business areas
  - Surface: **chemical reactions, non-flatnesses (nicks, dents, raised material), cracks**
  - Volume & near surface: **chemistry, microstructure, inclusions & segregations, cracks / cavities/ separations, residual stresses**
- The **NDT-methods used** are various and mostly conventional
  - Surfaces: **Visual** inspection, **FPI** (fluorescent penetrant inspection), **etching, EC** (eddy current), **MT** (magnetic particle inspection)
  - Volume (and near-surface): Physical methods as **US** (ultrasonic), **X-Ray (also as CT), EC** (eddy current)
  - For special applications and optional further methods: **thermography, magnetoscopy, neutrons, positrons**

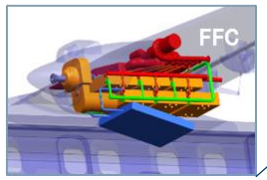





Trends and needs for non-destructive testing in aero engines

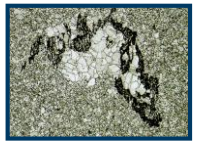


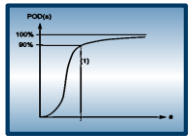


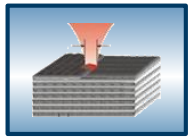
Even higher engine performance and undiminished high reliability

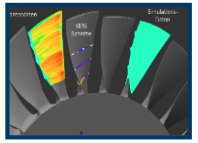
Novel loadings and processes

Economic-ecological production & operation of high parts‘ volumes





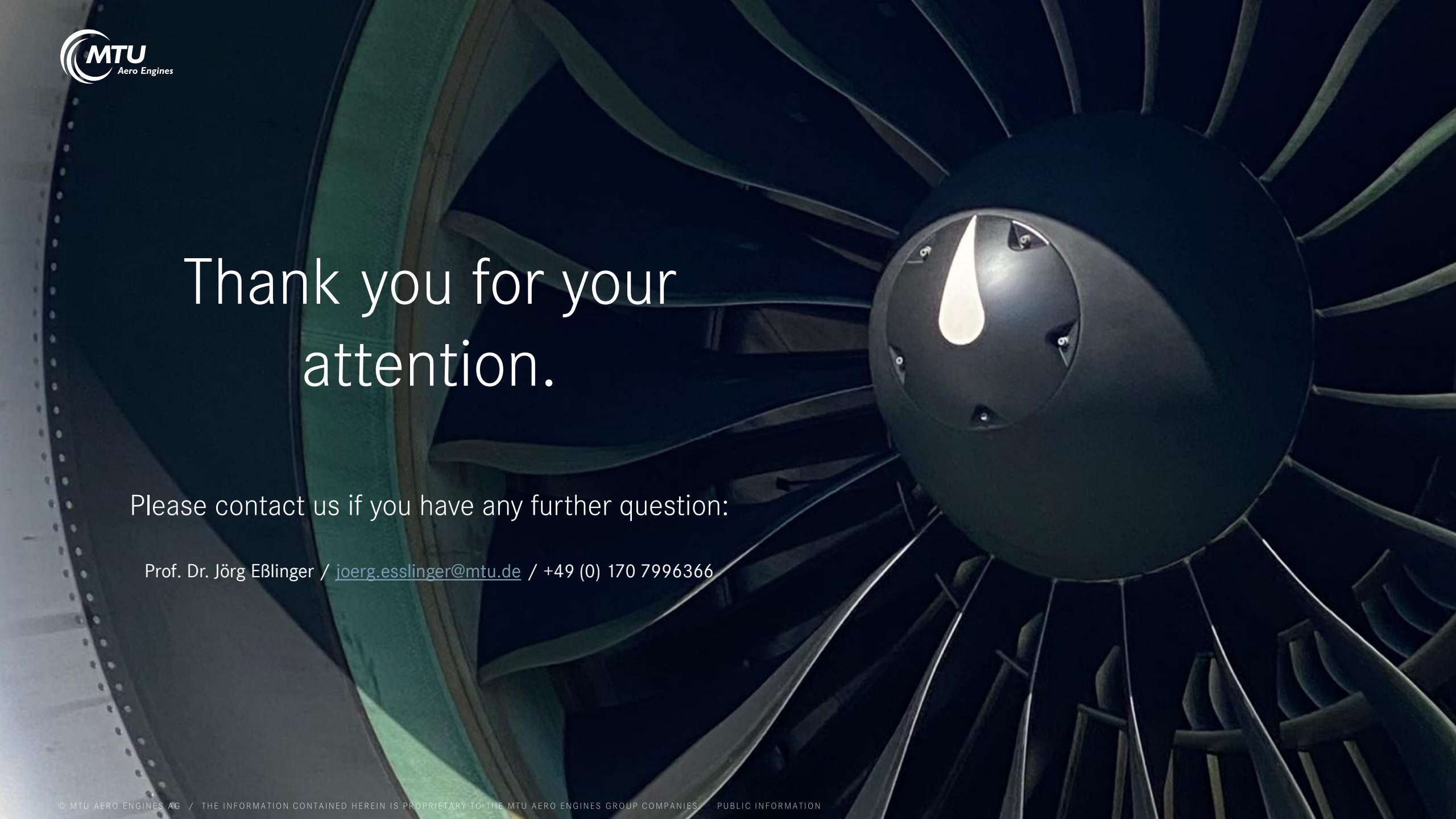




Pictures by: MTU

- **Higher POD* for deep & adverse positioned defects**
- **Higher NDT-resolutions, maintaining high level of POD**
  (E.g. by reduced X-Ray beam diameters with increased intensities as by synchrotron)
- **NDT-methods for H2: amount of loading and damage**
- **NDT-related online process-monitoring methods**
- **Automatization of NDT-processes** (E.g. robotics, AI)
- **On-site NDT**

* Probability of detection



Thank you for your attention.

Please contact us if you have any further question:

Prof. Dr. Jörg Eßlinger / joerg.esslinger@mtu.de / +49 (0) 170 7996366