


Gearing up
for High Volume GTF™ Production

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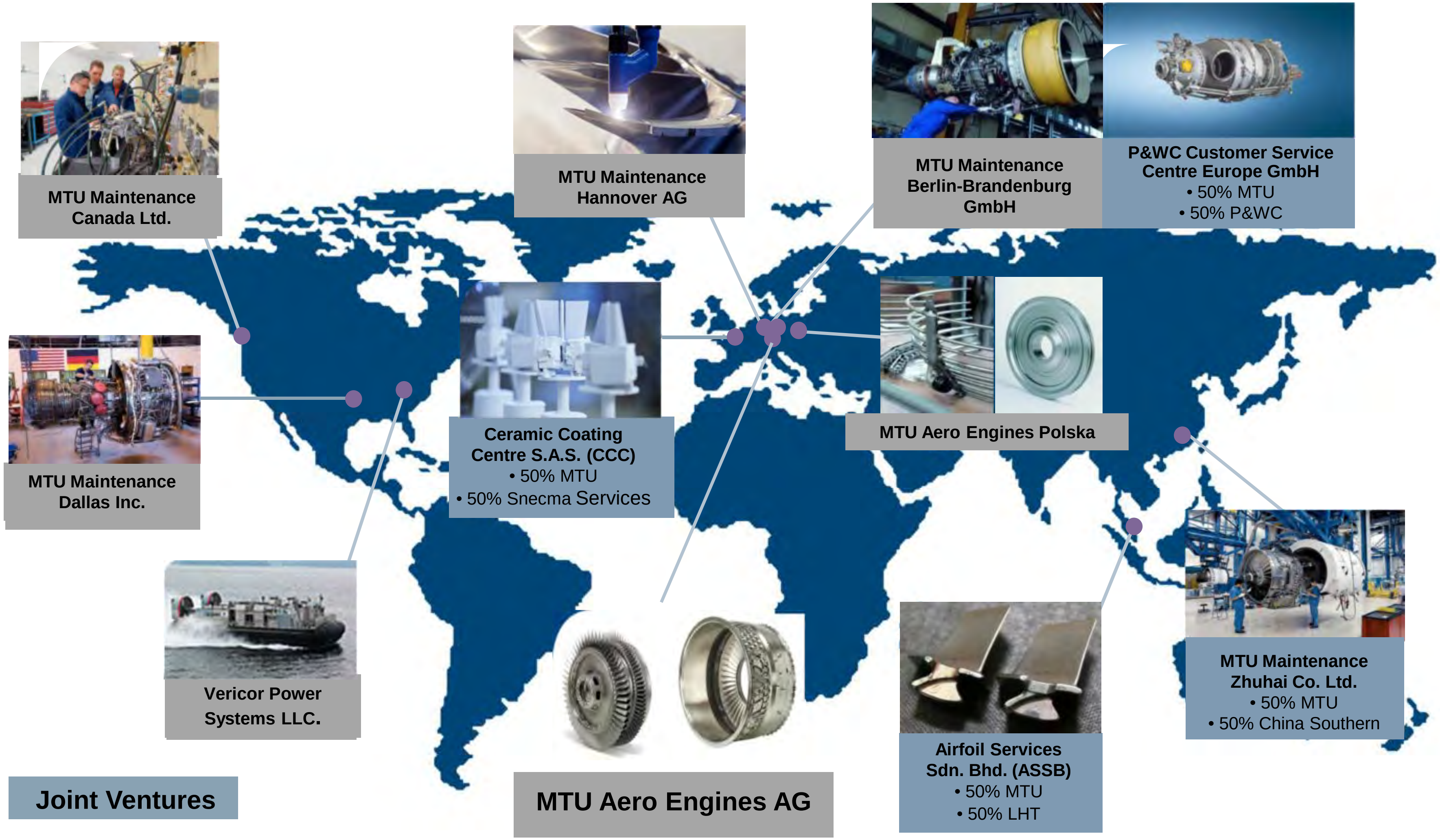
MTU Aero Engines AG
29th ICAS Congress, St. Petersburg, Russia
September 7 - 12, 2014

Contents

MTU Aero Engines, Munich, Germany

- Company’s headquarters and at the same time the largest of the company’s operations
- Employees: ~ 4.500 / 8.500 global
- Office of the Board of Management and Administration
- Design, development, manufacture, testing and marketing of commercial and military engine components and engine subsystems
- Assembly and repair & overhaul of military engines

MTU – Global Network & Customer Proximity



MTU Aero Engines Business Segments

Commercial OEM	Military OEM / MRO	Commercial MRO
• Risk- and Revenue-Sharing	• Major Partner in European Programs	• Largest Independent Provider
• Compressors and Low Pressure Turbines	• Turboshaft, Turboprop and Jet Engines	• Strong Market Share (CF34, V2500, …GE90)
• Presence in all Market Segments	• High tech Components and System Integration	• Presence in Growing Markets

47 %	15 %	38 %

Total Revenues MTU Group 2013: ~ 3.740 M€

MTU Aero Engines: The Company

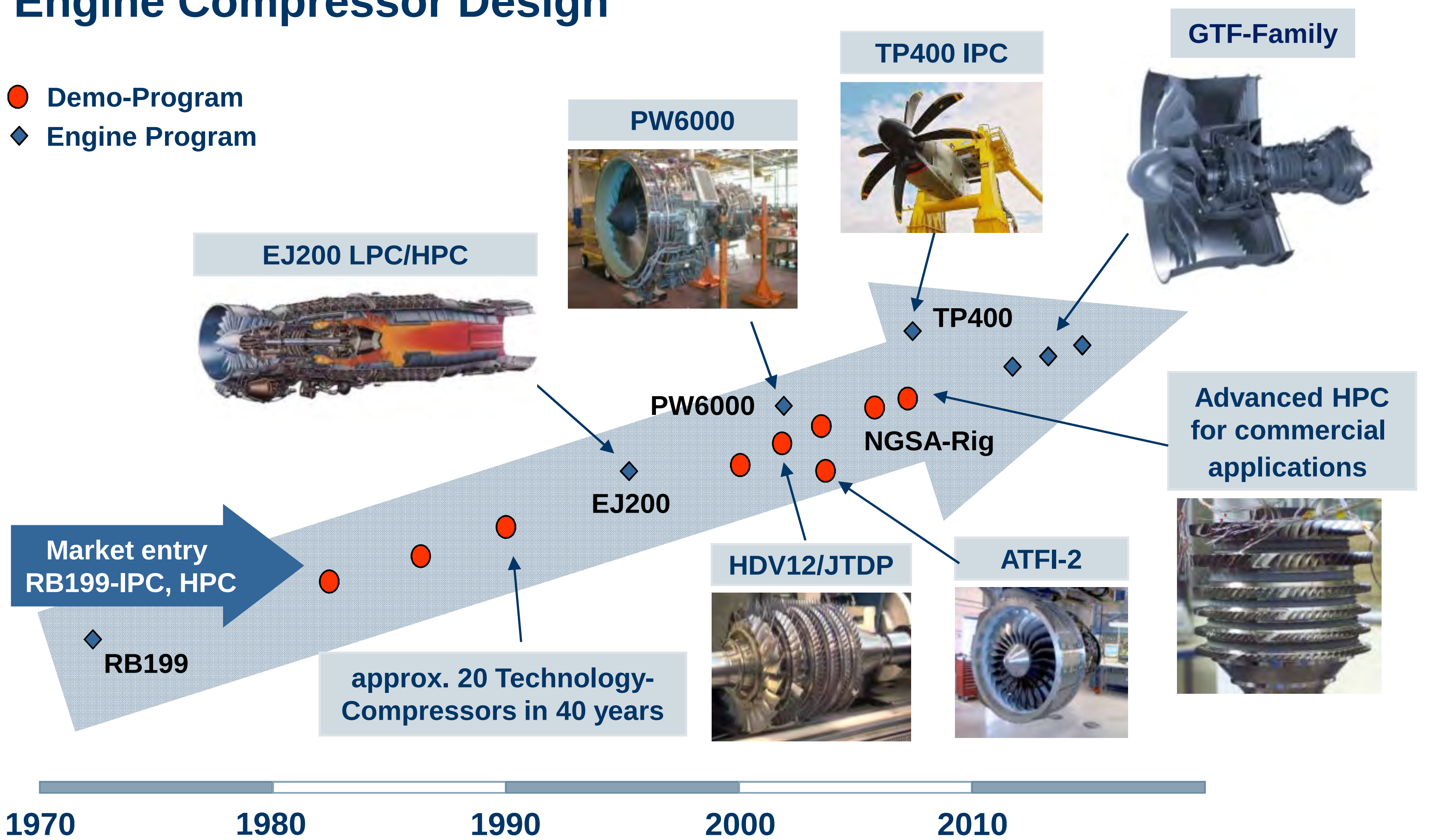
Technological Background and Recent Applications

Examples of Cutting Edge Technology Development

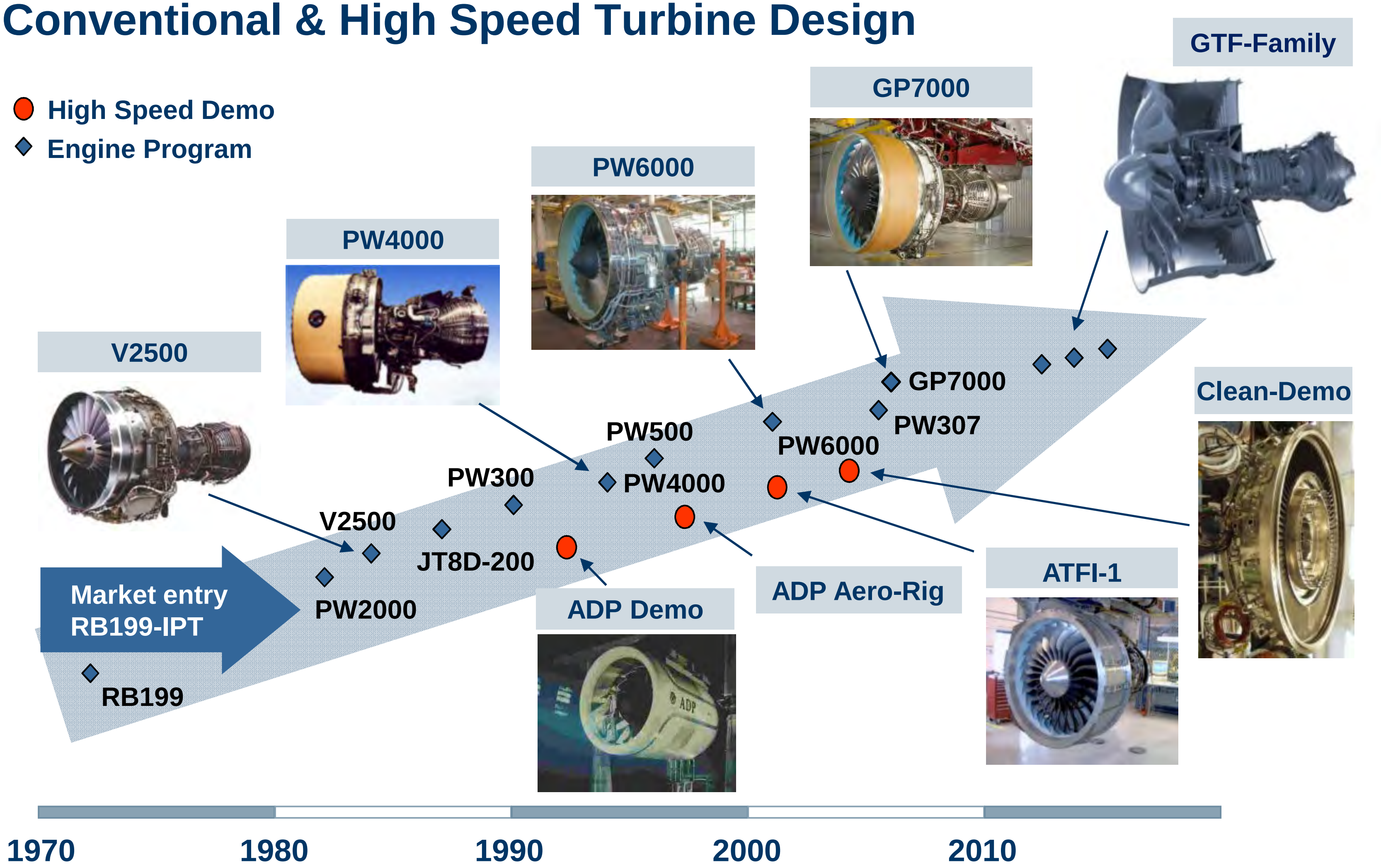
Advanced GTF - Engine Design & Production

Engine Technology Roadmap

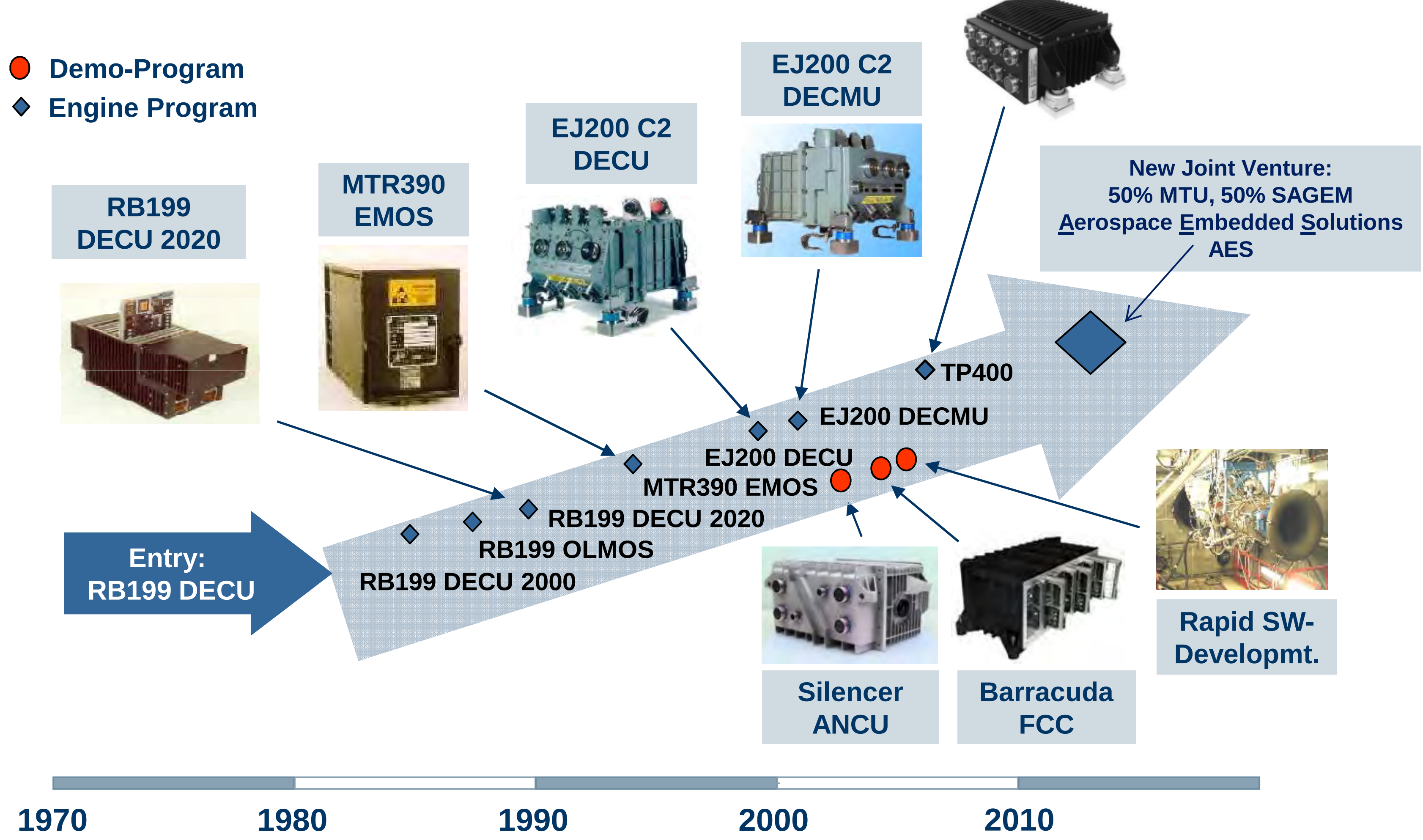
40 Years of Experience in Engine Compressor Design



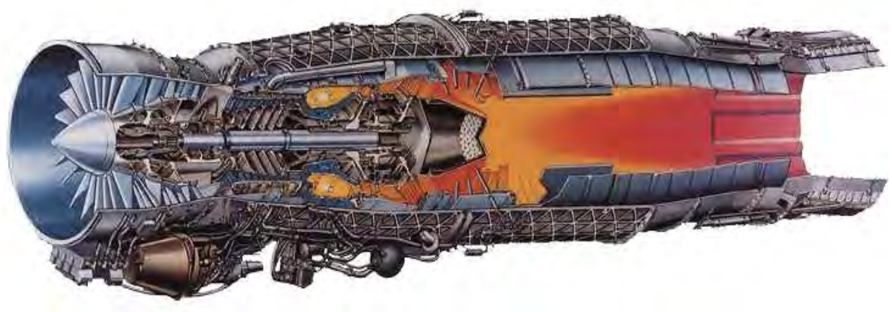
40 Years of Experience in Conventional & High Speed Turbine Design



30 Years of Experience in Engine Control & Monitoring



Military Engine-Design:
Pacesetter of Advanced Engine Technology

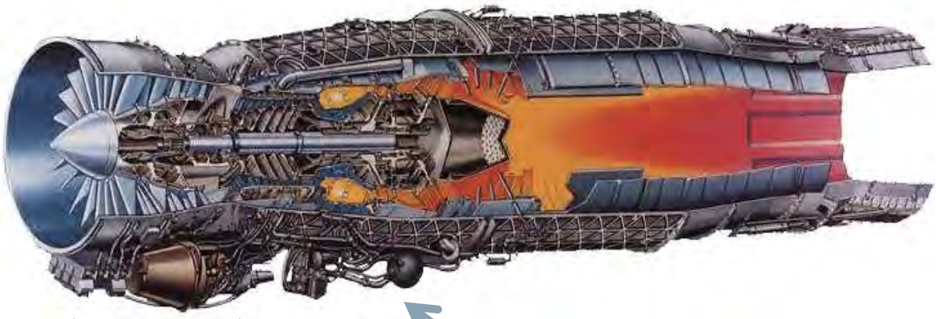


Powering the Eurofighter: EJ200 Engine
- More than 1500 Engines ordered by 6 nations
- 1000th Engine delivered on May 23, 2013 to Spanish Air Force

Proven In-service:
- Excellent operability & reliability demonstrated in over 400.000 engine flight hours
- Exceptional performance: Thrust and fuel consumption
- No reported surge events within full flight envelope
- Excellent performance retention
- Effective increase in time-between-overhauls demonstrated
- High tolerance to FOD and sand ingestion

EJ200: Compressor Technology made by MTU

Partners of Eurojet Turbo GmbH: RR, Avio, ITP, MTU



LPC-Module

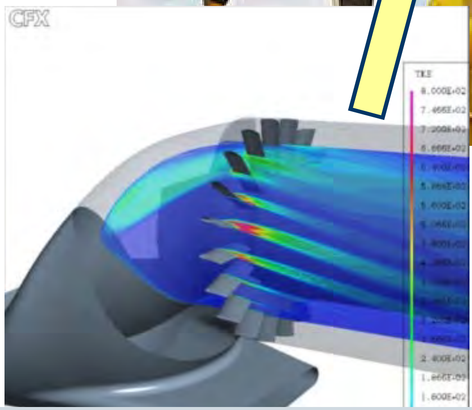
Variable Inlet Guide Vane (VIGV)

HPC-Module

MTU-Share: Development 33%, Production 30%
- Complete compression system (LPC, VIGV, HPC)
- Digital engine control & monitoring unit DECMU
- Final assembly of German Airforce engines

Compression System Characteristics:
- 3-stage all Blisk LPC with no inlet guide vanes
- Single stage VIGV in front of HPC
- 5-stage HPC incorporating 3 BLISK stages and 2 conventionally bladed stages
- High stability against manoeuvre loads
- High aerodynamic and mechanical loading

European Turboprop TP400:
Power for the A-400M



Application of advanced CFD-methods
for integration of IPC and intake

Thrust: 4 x 8200 kW (11000 shp)

Delivery to customers started:
1st A/C to French Airforce on Aug. 2, 2013

Partners of Europrop International EPI:
MTU, RR , Snecma, ITP

MTU-Workshare of 21.5% includes:
- 5-stage IPC
- 1-stage IPT and shaft
- Controll-System (ASW)
- EPMU (HW & SW)
- Components of fuel-system
- Engine assembly & Testing

The GP7000 Engine - Powering A380

MTU‘s LP-Turbine demonstrating outstanding performance

1st delivery to „Emirates“ Airlines
Hamburg, July 28, 2008

GP7000 Engine:

- MTU: Program share 22.5 %
  LP-Turbine
  Turbine Center Frame
  400 modules delivered
- Partner: General Electric
  Pratt & Whitney
  Snecma
- Engine certification January 2006

The GEnx Turbine Center Frame Development

MTU entered the Program in 2009

Successful high volume program consequently drawing technology from the GP7000 program

Main Functions:

- HP-spool bearing support structure
- Transition flow path from HPT to LPT
- Supply cooling air for HPT and LPT drums
- Provide bearing oil supply

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Examples of Cutting Edge Technology Development

Advanced GTF - Engine Design & Production

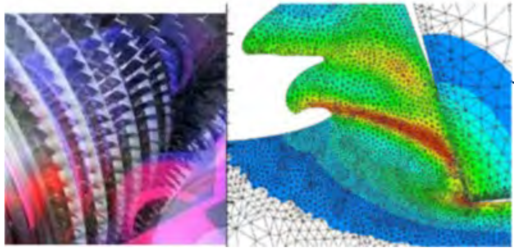
Engine Technology Roadmap

Key to Our Success - Competent R&D Partners and Suppliers

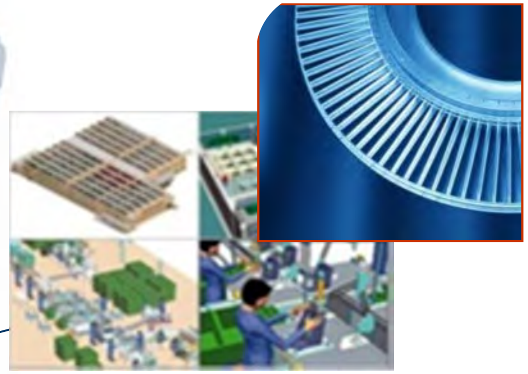
MTU Centers of Competence for Technology Development

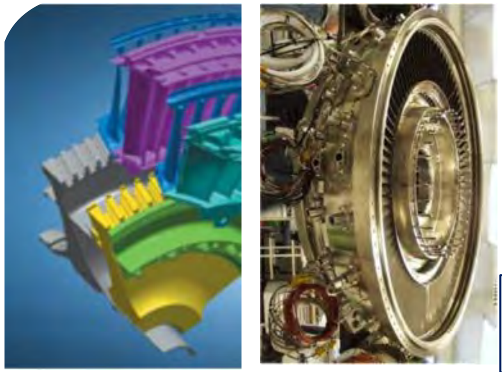
DLR Cologne & Stuttgart:
CoC "Engine System Technologies 2020plus"

RWTH Aachen:
CoC "Compressor"



University of Hannover:
CoC "MRO"





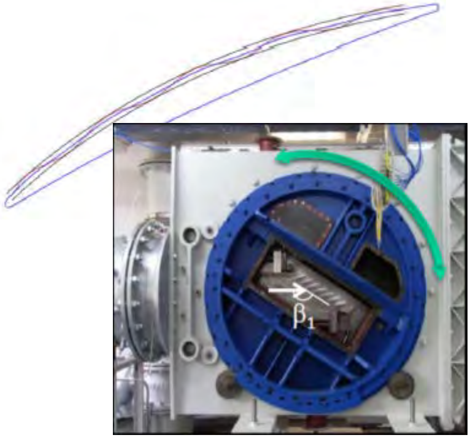
University of Stuttgart:
CoC "Turbine"

Technical University of Munich:
CoC "Design & Production"

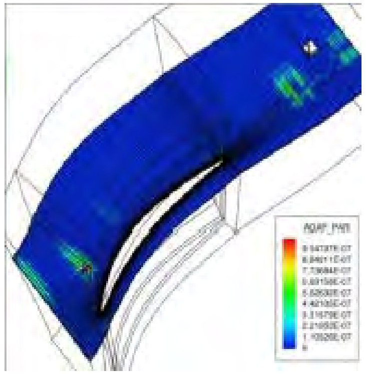
University of Armed Forces, Neubiberg:
CoC „More Electric Engine“

Recent Examples in Compressor Technology Development

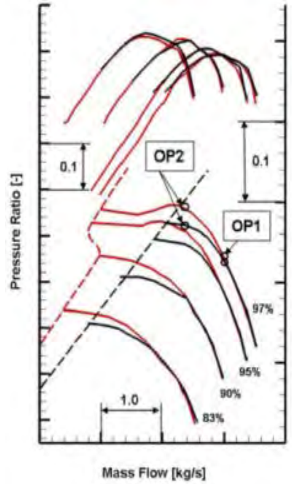
CoC „Compressor“, RWTH Aachen



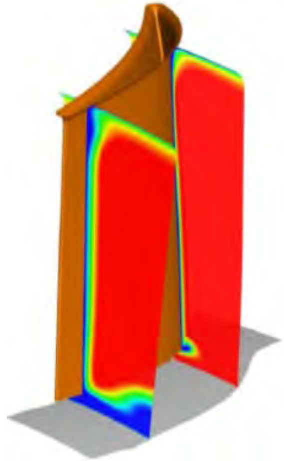
Impacts of manufacturing deviations



Improving CFD-accuracy at Off-Design



Casing Treatment for HPC



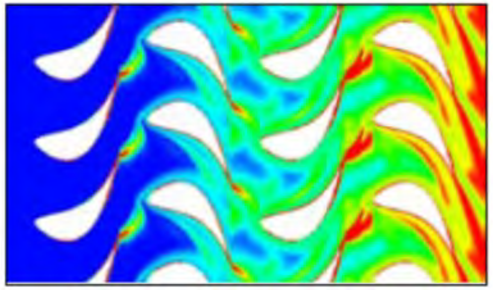
Hub-Treatment

High aspect ratio bladings

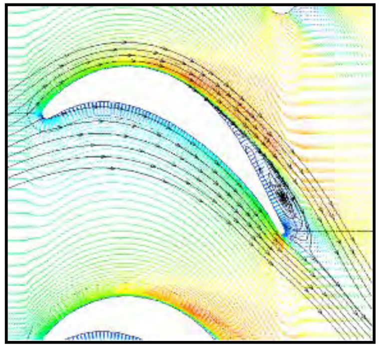
- **Impact of manufacturing deviations**
  Impact of manufacturing deviations on aerodynamic characteristics
- **Improvement of CFD-accuracy at Off-Design conditions**
  Increasing prediction accuracy at Off-Design
- **„Casing Treatment“ for HPC**
  Effectiveness of Casing Treatments applied at HPC rear stages
- **„Hub Treatment“**
  Improved stability and hub blockage reduction for shroud-less guide vanes
- **High aspect ratio bladings**
  Impact of higher blading aspect ratios on aerodynamics and stability

Recent Examples in Turbine Technology Development

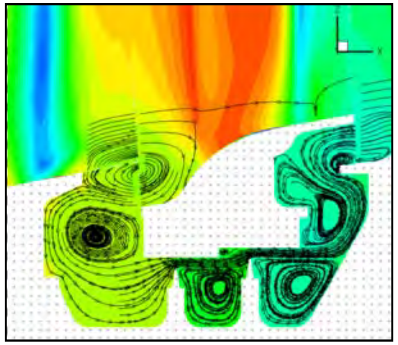
CoC „Turbine“, University of Stuttgart



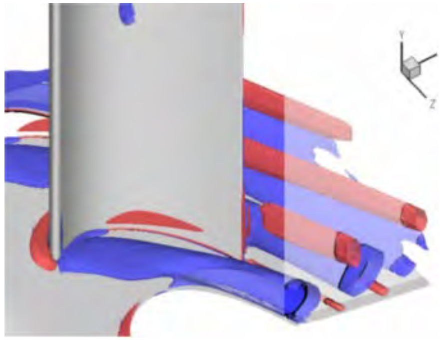
Benefits from unsteady Flow Effects



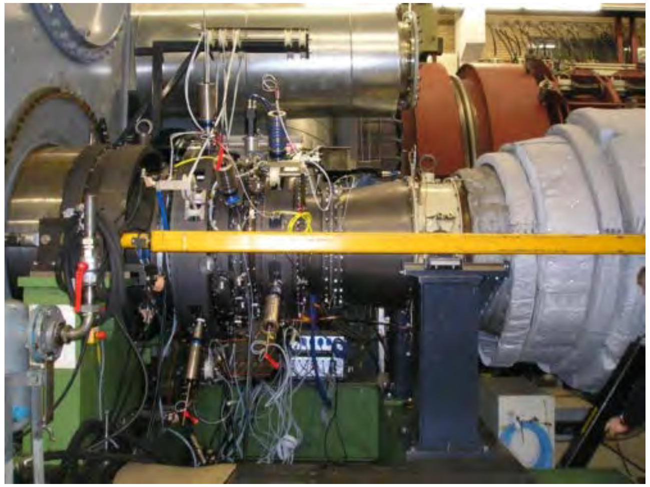
Low-Re Aerodynamics



Loss Reduction



Integrated 3D-Design

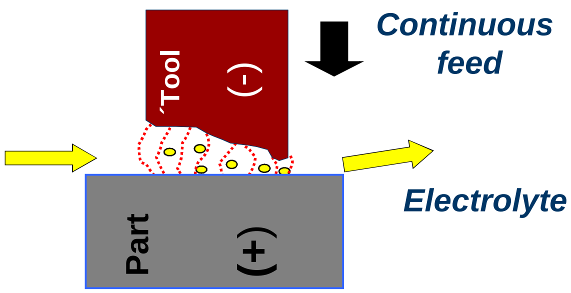


Research Turbine at ATF Stuttgart

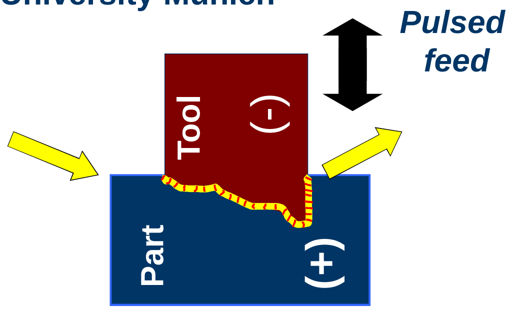
- **2-stage LPT Research Rig at ATF of Stuttgart University**
  Realistic LPT geometry and blading design
  Application of advanced diagnostic & measurement techniques
- **Benefits from unsteady Flow Effects**
  Utilisation of rotor-stator interactions, mixing flow & unsteady work effects
- **Low-Re Aerodynamics**
  Optimum aerodynamic loading for small Re-numbers (< 100.000)
- **Loss Reduction**
  Minimization of secondary flow losses, leakage flow - main stream interactions, secondary air and cooling air flow detrimental impacts
- **Integrated 3D-Design**
  Efficiency improvement by integrated 3D-Design, i.e. endwall contouring

Pulsed Electro-Chemical Machining (PECM)

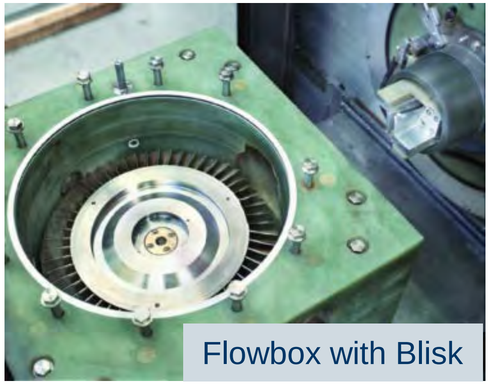
CoC „Design & Production“, Technical University Munich



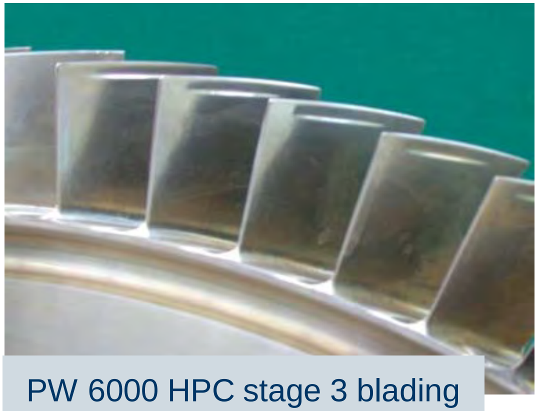
Convent. ECM for rough machining
- Large gap
- Lower accuracy
- High material removal rates



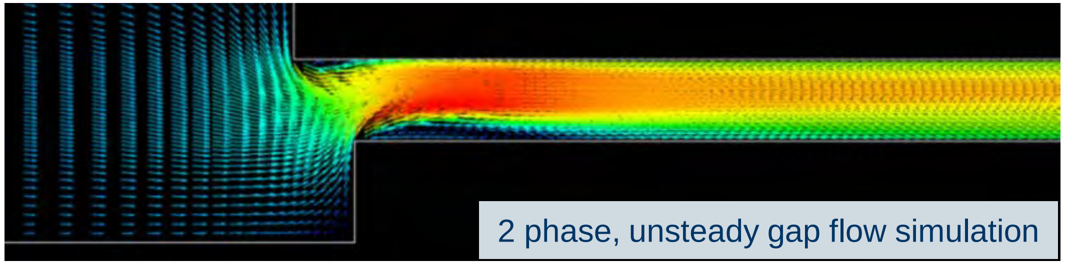
Pulsed ECM for finishing
- Narrow, controlled gap
- Pulsed current flow
- Improved accuracy of forming
- Lower material removal rates



Flowbox with Blisk



PW 6000 HPC stage 3 blading



2 phase, unsteady gap flow simulation

Process-Simulation:
- Sensitivity analyses and optimisation of process parameters (gap width, pressure ratio, strength of current, voltage, tool vibration frequency, etc…)
- Optimisation of material cutting rate
- Reduced scrap parts rate

Superior process to machine small to medium sized 3D-Blisks from Ti- and Ni-based alloys:
- High degree of reproducibility
- Superior accuracy
- High cost-effectiveness

PW & MTU's Geared Turbofan

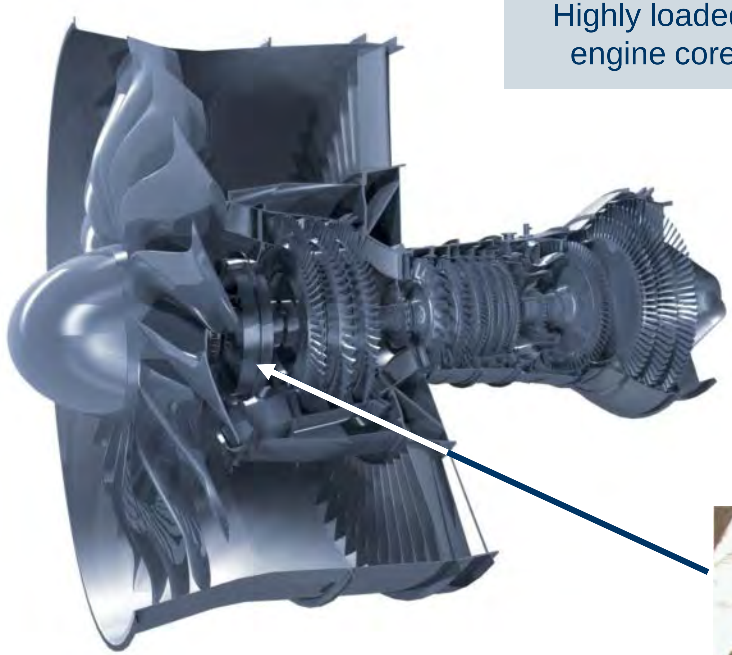
Highly loaded engine core

High Bypass-ratio 12 + Low speed Fan

High speed LP-Turbine

Reduction gear, reduces LP-spool speed by 3:1

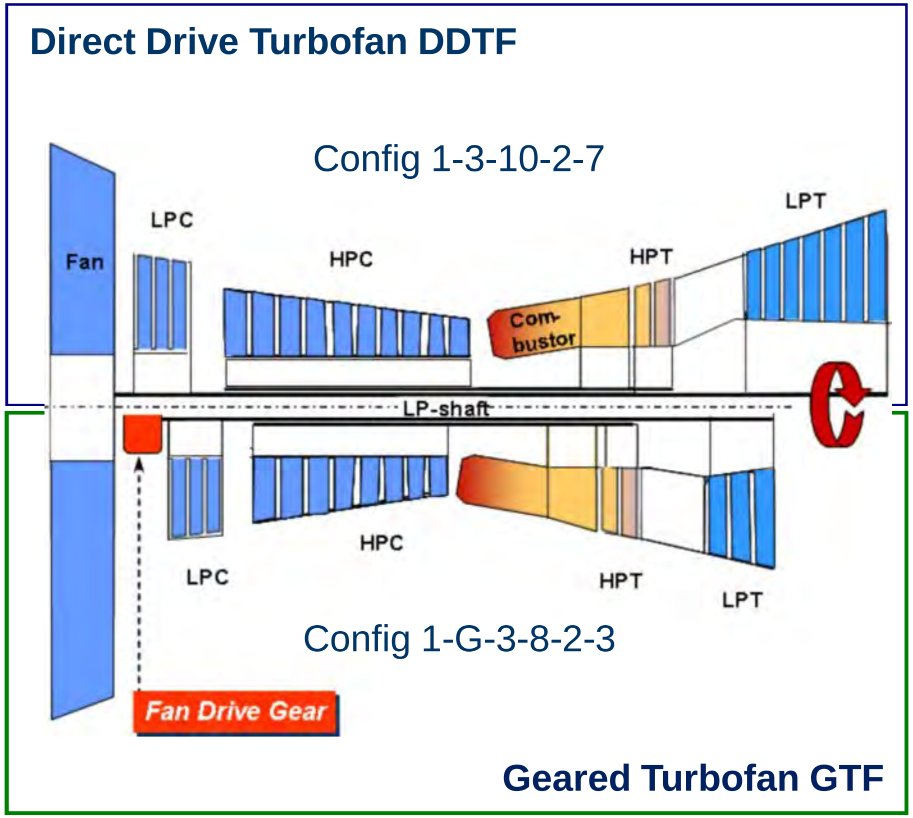
High speed LP-Compressor



Technological Benefits:

- 15% reduction in fuel consumption
- 20- 24 dB reduction in noise emissions, rel. stage 4
- 50% reduction in NO_X-emissions, rel. CAEP6
- 30- 40 % reduction in maintenance costs by low stage and parts counts in both LP-components

Geared Turbo Fan compared to Direct Drive Turbo Fan



GTF relative to DDTF:

- 25% less stages
- 45% less airfoils
- lower cycle temperature

➡ **lower maintenance cost**

- higher propulsive efficiency
- higher low spool component efficiencies
- shorter & lighter

➡ **3% less fuel burn**

- 3 to 4 dB quieter (EPNdB, cum.)

Compared to the DDTF the GTF concept achieves a significant competitive advantage

Profitable Power for multiple Applications

Mitsubishi MRJ
78-92 seats
PW1200G: 15-17 klbs
EIS: 2017

Bombardier CSeries
110-135 seats
PW1500G: 21-23 klbs
EIS: 2015

Irkut MS-21
150-212 seats
PW1400G: 24-33 klbs
EIS: 2017

Airbus A320NEO
138-199 seats
PW1100G: 24-33 klbs
EIS: 2015

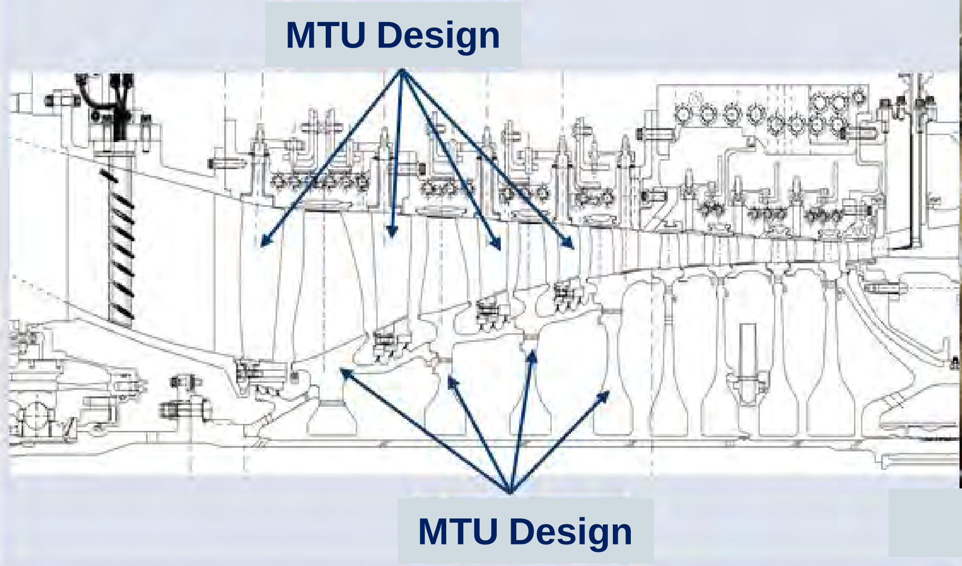
Embraer E-Jet Gen2
78-124 seats
PW1700 G / 1900 G:
17-23 klbs
EIS: 2018

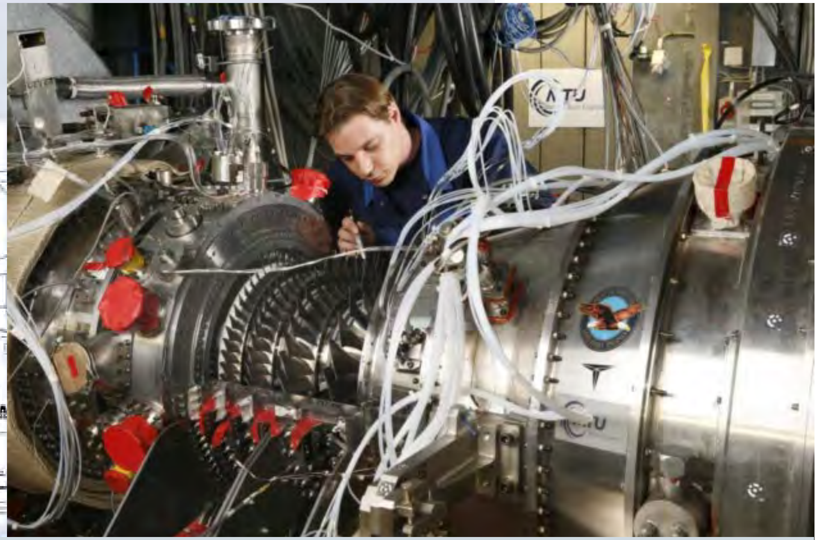
- Successful flight testing of PurePower PW1000G by B747 & A340 in 2008
- First applications in modern “single aisle” aircrafts, EIS from 2015
- The GTF engine concept is not limited to a specific thrust range

Summation: ~ 5500 firm orders & options

Joint MTU-PW HP-Compressor Design

„Common-Core“ Application in 15-33 klbs Thrust Engine Family



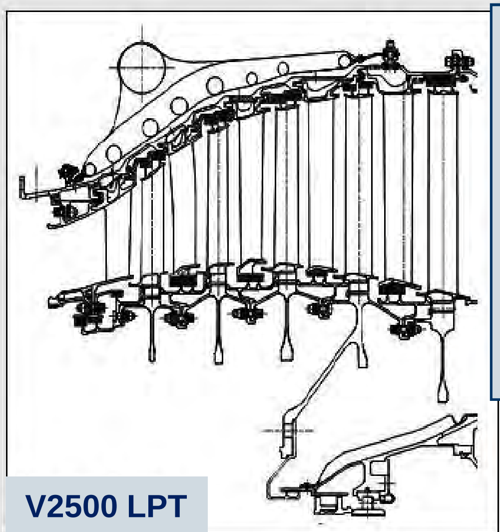


MTU HPC Rig Testbed

Jointly designed MTU / PW - HPC successfully tested at MTU in 2007:
- Efficiency goals with margin exceeded
- Surge margin requirements met and partially exceeded

MTU's High Speed LPT Design

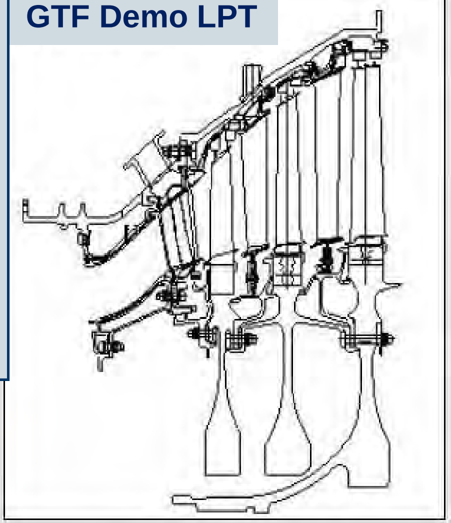
Saving Weight, Cost and Fuel



V2500 LPT

- Similar Power
- 60 % higher speed
- 50 % fewer stages
- 60 % fewer airfoils
- 30-40 % lower weight

GTF Demo LPT

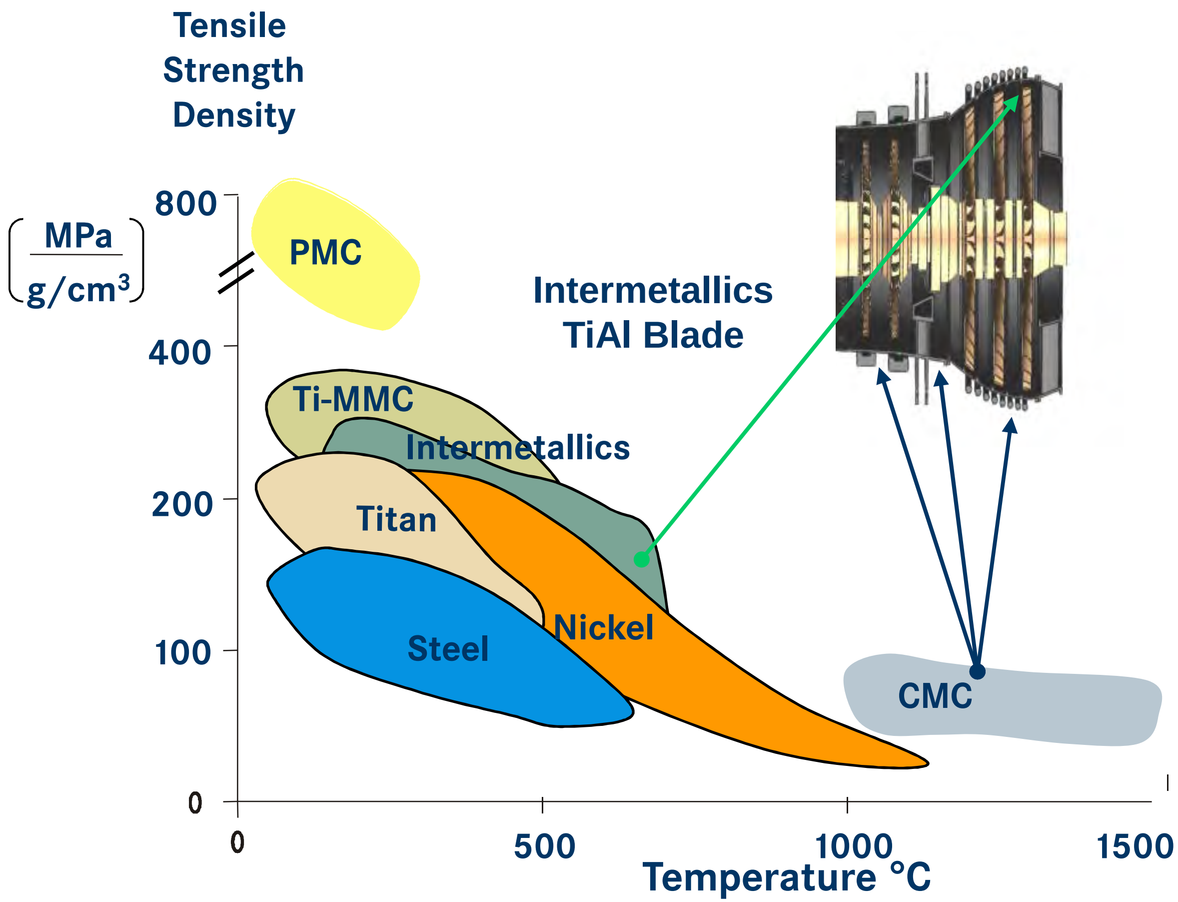


Technical features:
- Reduced stage - and airfoil count due to higher circumferential speed
- Reduced weight and maintenance cost
- High efficiency due to low aerodynamic loading
- Low noise emissions due to high blading interaction frequency

Test-Rig at Stuttgart University ATF
- 600 Pressure tapping points
- 200 Temperature measuring stations
- 80 Rotational speed, gaps, etc…

Advanced Materials for reduced Turbine Weight

Challenges for Design and Supply Chain



Challenge Low Ductility:

- Design Integration
- Machining
- Handling
- Supply Chain
- Cost

Ceramic Matrix Composites (CMCs) **Intermetallics**

Ready for Take-Off: New BLISK Production Plant at MTU

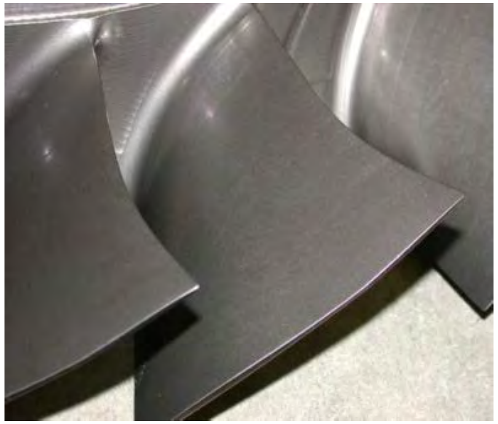
Production Capacity: 4000 BLISKs per year

Economic and Excellent Quality Manufacturing Technology

High Speed Cutting of Compressor BLISKs

High Speed Cutting

Stripe-Milling



Perfect Surface after Grinding

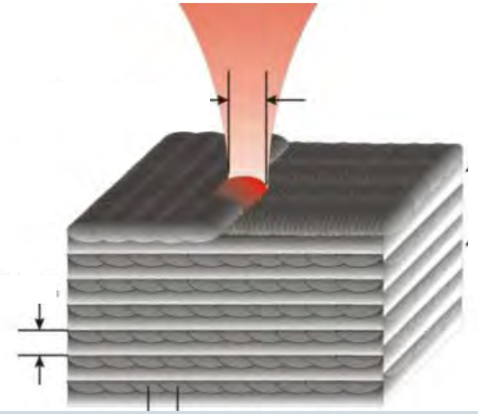
Manufacturing Compressor Front Stages

High Speed Cutting:

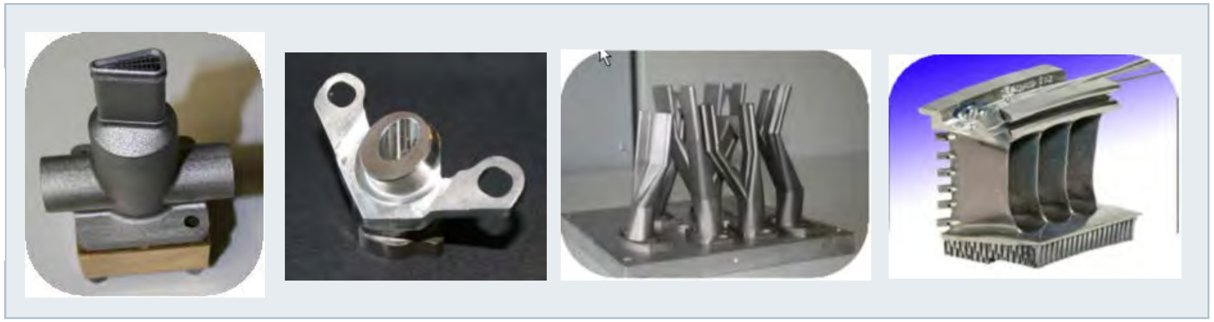
- Cutting speeds of 300 m/min and 6 axial feed rates of 6m/min
- Optimized milling strategies assure minimum processing times, costs and optimum surface quality
- Best suited for medium sized blades
- Well established for Ti-BLISKs, adapted processing parameters assure economic and high quality Ni-BLISK production

Additive Manufacturing Challenges Conventional Productions

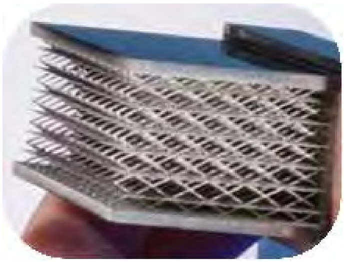
Opportunity for Improved Product Design



Laser-sintering of various materials using Laser- or Electron Beam as energy source



Examples of produced engine parts for development engines

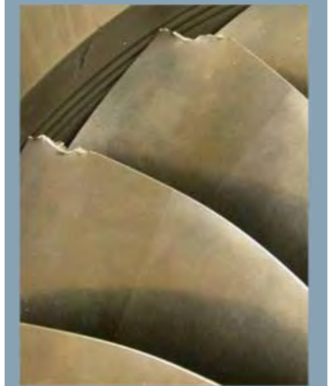


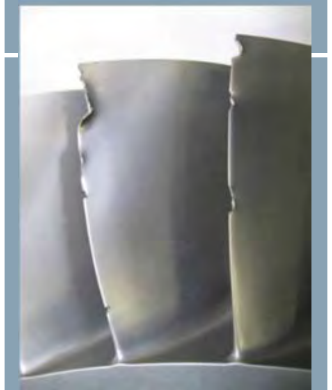
Benefits:
- Economic manufacturing of raw parts by replacing casting parts
- High production flexibility & realisation of innovative design concepts
- Liberation of design from manufacturing constraints

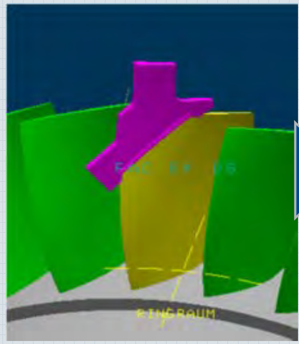
Major Challenges:
- Material & surface quality
- Process stability
- Certification rules

→ **Potential: 30% of Engine Parts**

Blisk Repair - A Key Capability for Future Aero Engines

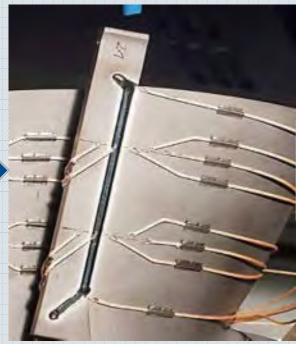






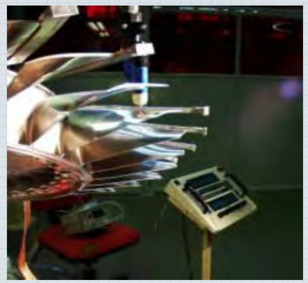
Design & Patch

Patching of compressor
Blisks by
Plasma Welding



Local Heat
Treatment to release
internal stresses

Adaptive Milling
to rebuild airfoil shape

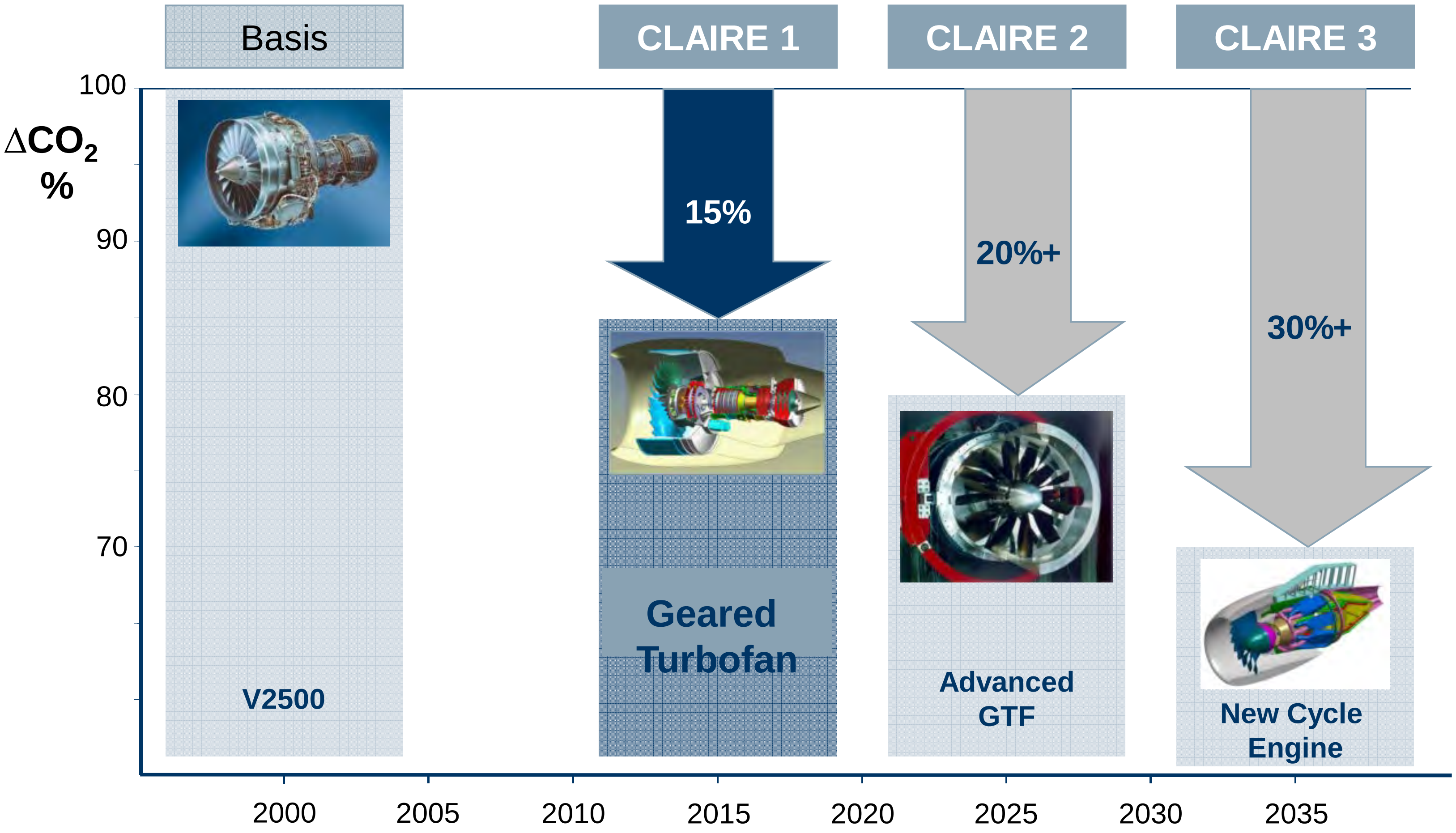


MTU is a worldwide leader in offering Patching as BLISK Repair Technique

Contents

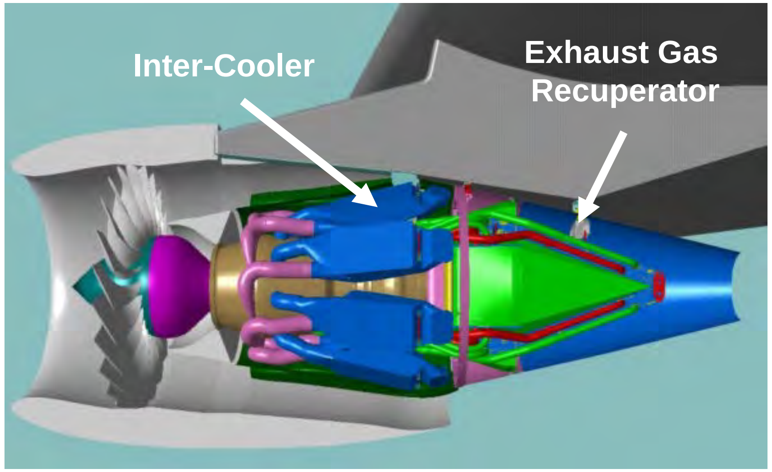
MTU Technology Roadmap - CLean AIR Engine, CLAIRE

The Geared Turbofan - First Step to Reality

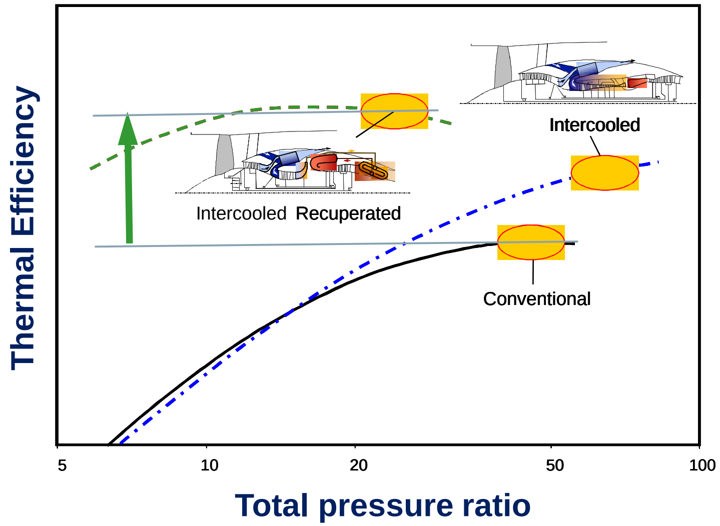


GTF including Inter-Cooling and Exhaust Gas Recuperator

First Design-Studies



Validation at ATF of Stuttgart University, 2005



Within the scope of the EU-Programme CLEAN (2000 - 2005) European Engine Companies developed advanced technologies for future GTFs including heat exchangers

Thank you for your Attention