Gearing up for High Volume GTF™ Production

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Contents

MTU Aero Engines: The Company

Technological Background and Recent Applications

Examples of Cutting Edge Technology Development

Advanced GTF - Engine Design & Production

Engine Technology Roadmap
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

Joint Ventures

- MTU Maintenance Canada Ltd.
- MTU Maintenance Hannover AG
- MTU Maintenance Berlin-Brandenburg GmbH
- MTU Aero Engines Polska
- MTU Maintenance Dallas Inc.
- Ceramic Coating Centre S.A.S. (CCC)
- P&WC Customer Service Centre Europe GmbH
- Vericor Power Systems LLC.
- Airfoil Services Sdn. Bhd. (ASSB)

- 50% MTU
- 50% LHT
- 50% MTU
- 50% P&WC
- 50% MTU
- 50% Snecma Services
- 50% China Southern
### MTU Aero Engines Business Segments

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

| 47 % | 15 % | 38 % |

**Total Revenues MTU Group 2013: ~ 3.740 M€**
40 Years of Experience in Engine Compressor Design

- Demo-Program
- Engine Program

- PW6000
- HDV12/JTDP
- EJ200
- ATFI-2
- TP400 IPC
- RB199
- TP400
- NGSA-Rig

- GTF-Family

- approx. 20 Technology-Compressors in 40 years

- Market entry RB199-IPC, HPC

40 Years of Experience in Conventional & High Speed Turbine Design

- High Speed Demo
- Engine Program

Market entry RB199-IPT

V2500
PW2000
PW300
PW4000
JT8D-200

PW6000
PW500
PW000

GP7000

GTF-Family

Clean-Demo

ADP Demo

ADP Aero-Rig

ATFI-1
30 Years of Experience in
Engine Control & Monitoring

- Demo-Program
- Engine Program

RB199 DECU 2020
MTR390 EMOS
EJ200 C2 DECU
EJ200 C2 DECMU
TP400 EPMU
New Joint Venture: 50% MTU, 50% SAGEM Aerospace Embedded Solutions AES
Rapid SW-Developpt.

Entry: RB199 DECU

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

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

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

Application of advanced CFD-methods for integration of IPC and intake
The GP7000 Engine - Powering A380

1st delivery to "Emirates" Airlines
Hamburg, July 28, 2008

MTU's LP-Turbine demonstrating outstanding performance

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

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

Successful high volume program consequently drawing technology from the GP7000 program
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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”
- ETH Zürich
- 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

- **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**
  - Realistic LPT geometry and blading design
  - Application of advanced diagnostic & measurement techniques
- **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

Conventional 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

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

Flowbox with Blisk

PW 6000 HPC stage 3 blading

2 phase, unsteady gap flow simulation
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Engine Technology Roadmap
PW & MTU’s Geared Turbofan

High Bypass-ratio 12 + Low speed Fan

High speed LP-Compressor

Highly loaded engine core

High speed LP-Turbine

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

Technological Benefits:

• 15% reduction in fuel consumption
• 20-24 dB reduction in noise emissions, rel. stage 4
• 50% reduction in NO\textsubscript{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

Direct Drive Turbofan DDTF

Config 1-3-10-2-7

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.)

Geared Turbofan GTF

Config 1-G-3-8-2-3

Compared to the DDTF the GTF concept achieves a significant competitive advantage
Profitable Power for multiple Applications

- 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

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

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

 PMC
Intermetallics TiAl Blade

Tensile Strength Density

MPa
( g/cm³)

PMC

Intermetallics TiAl Blade

Temperature °C

CMC

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:
• 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

Stripe-Milling
Perfect Surface after Grinding
Additive Manufacturing Challenges Conventional Productions
Opportunity for Improved Product Design

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

Potential: 30% of Engine Parts

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
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MTU Technology Roadmap - CL\text{ean AIR Engine, CLAIRE}

The Geared Turbofan - First Step to Reality
GTF including Inter-Cooling and Exhaust Gas Recuperator
First Design-Studies

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