Prof. Dr.-Ing. Jan Hendrik Dege

Production Technology in Aviation - Between Decarbonization and Record Orders

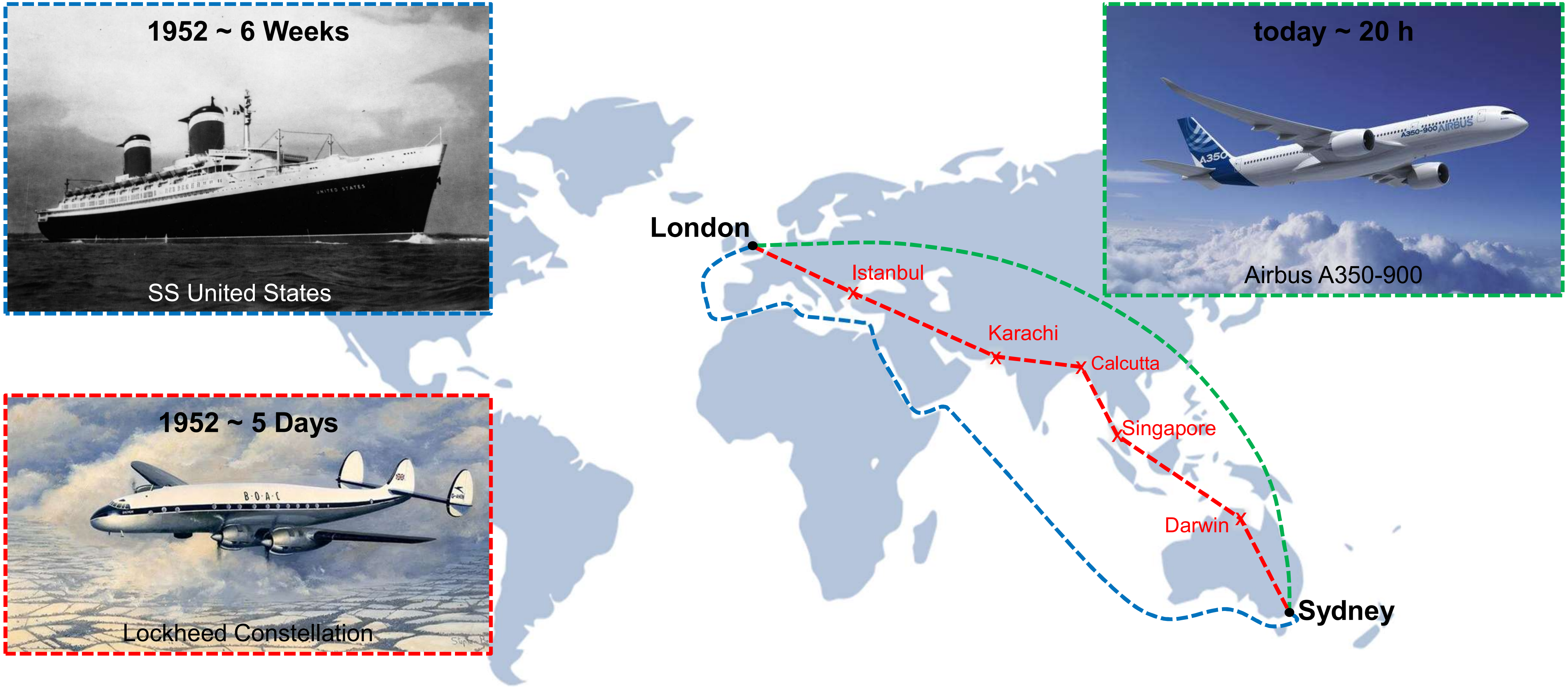
Institut für
Produktionsmanagement und -technik

12.05.2025

Prof. Dr.-Ing. habil. Hermann Lödding | Prof. Dr.-Ing. Jan Hendrik Dege
ipmt@tuhh.de | www.tuhh.de/ipmt

TUHH

Why to fly?



British Overseas Airways Cooperation Timetable, Wikipedia, AIRBUS, GMFC

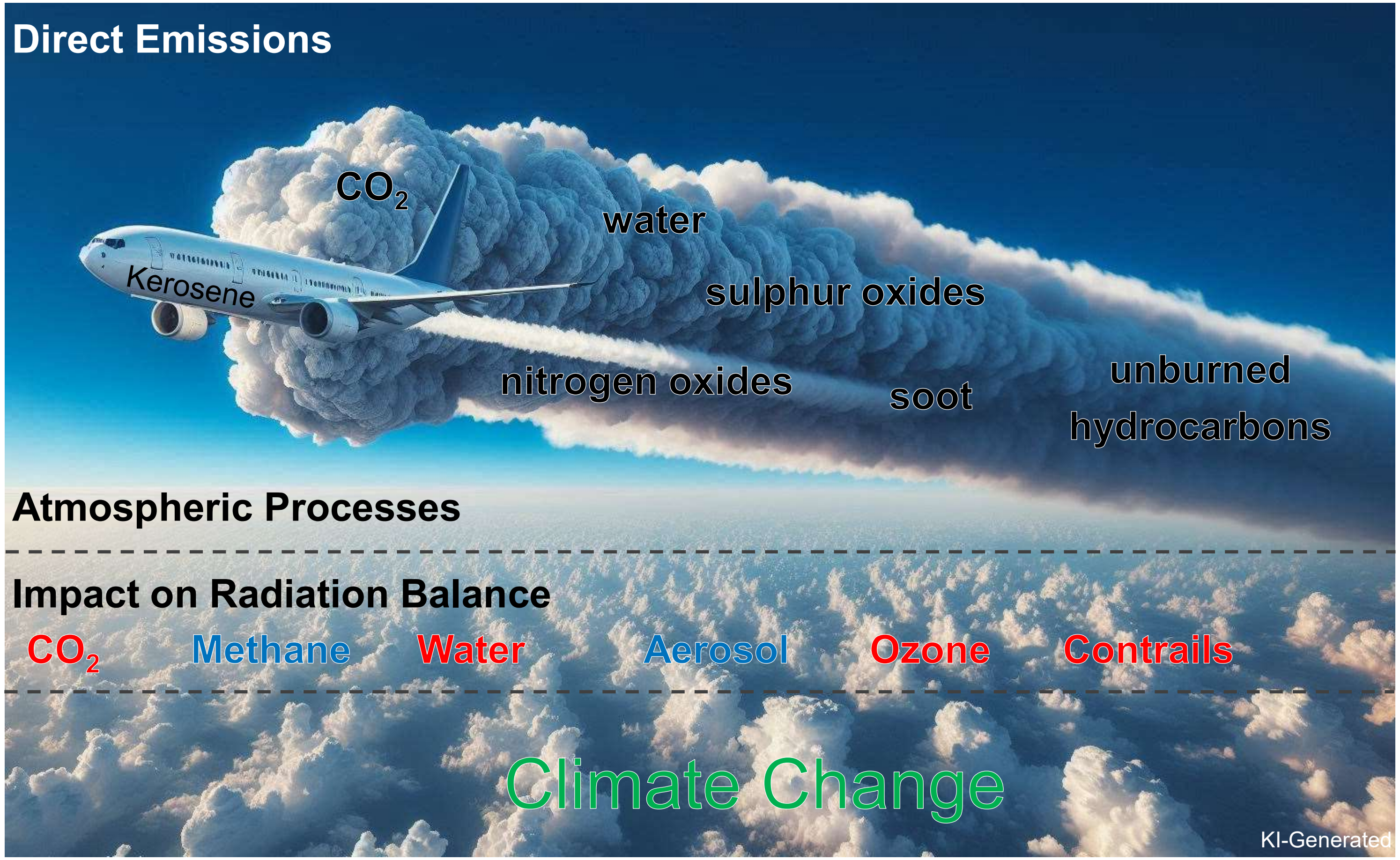
©

Why to fly?

Flying connects people, markets, and cultures across national borders and continents.

©

Why not to fly?



- The actual contribution of air traffic to climate change is approximately three times greater than the contribution of CO2 emissions alone.
- In 2018, air traffic was responsible for about 5.5% of human-induced global warming.

Climate Impact of Air Traffic – Scientific Knowledge, Developments, and Measures, German Environment AgencyFactsheet 1: Climate-Damaging Effects of Air Traffic, Öko-Institut e.V. ©

Agenda

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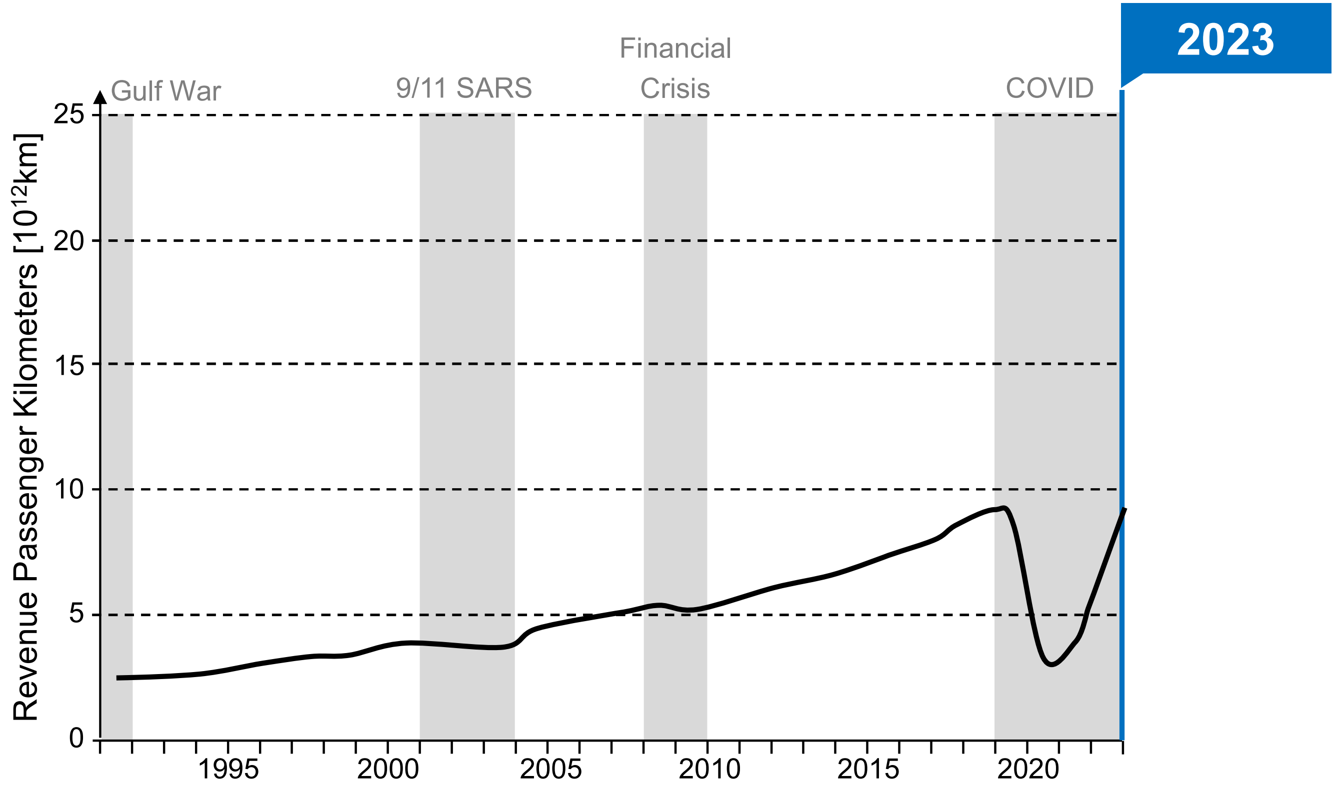
Development of Global Passenger Air Traffic (AGMF 23)



AIRBUS Global Market Forecast 2023/24

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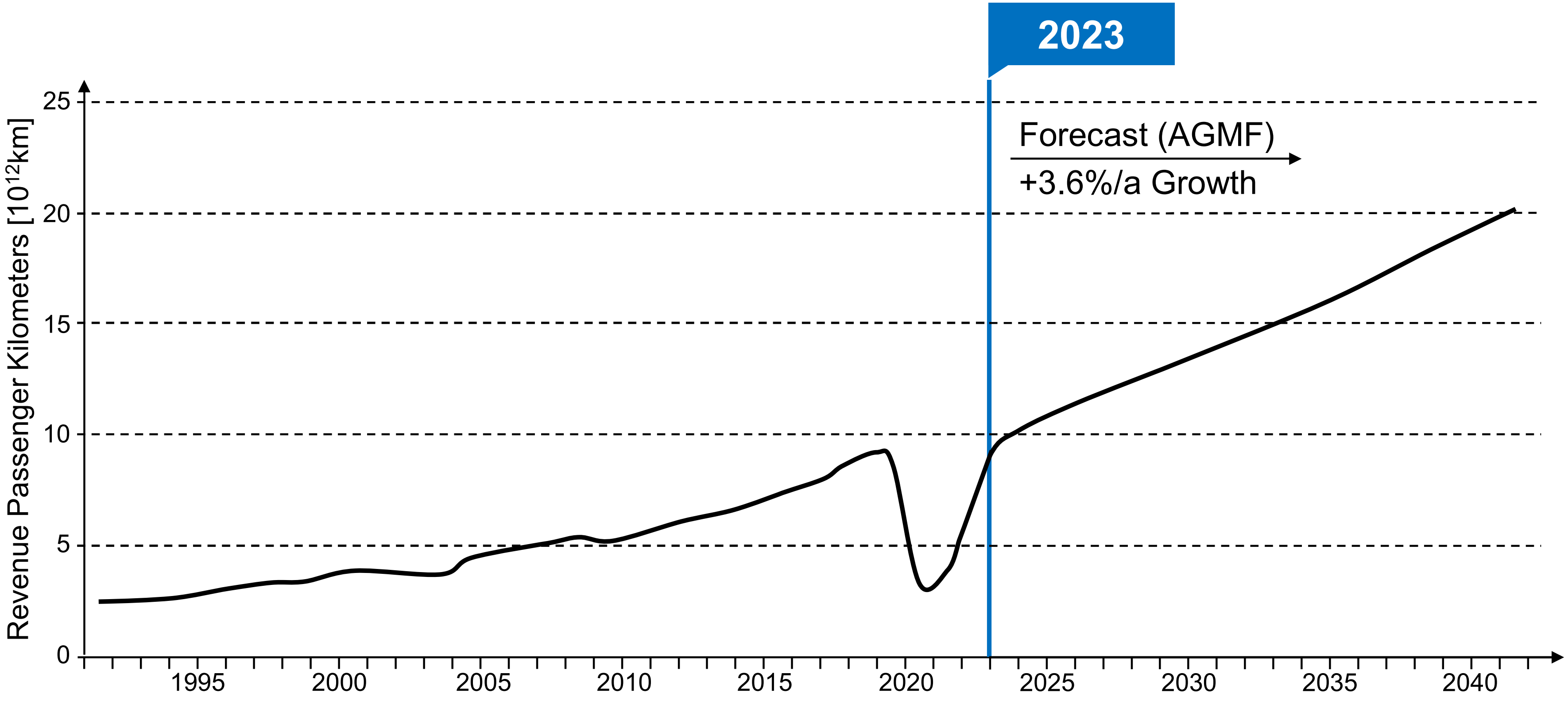
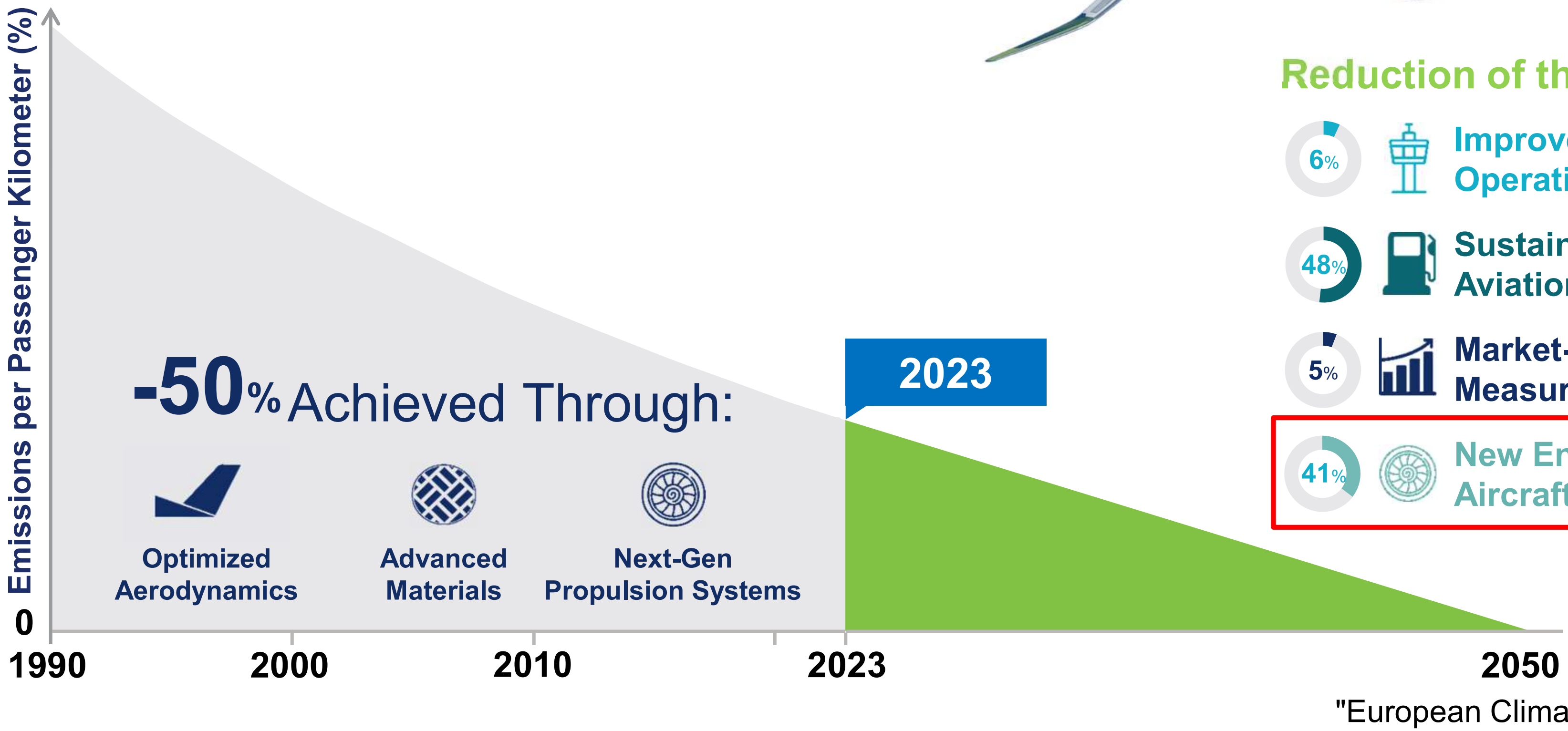
Development of Global Passenger Air Traffic (AGMF 23)



Demand Forecast 2024–2043: **42.430 Aircrafts** (55% Growth, 45% Replacement)

AIRBUS Global Market Forecast 2023/24

The Path to Emission-Free Flying at AIRBUS (AGMF 23)



Reduction of the Remaining 50%

- 6% Improved Aircraft Operations
- 48% Sustainable Aviation Fuels (SAF)
- 5% Market-based Measures
- 41% New Engine & Aircraft Technologies

AIRBUS AGMF 23

© 36896

AIRBUS ZEROe Study – Entry into Service by ~~2035~~ → 2040 - 2045

< 100 Passengers

< 1850 km

Hydrogen Hybrid Turboprop Engine (x2)

Liquid Hydrogen Storage & Distribution System

< 200 Passengers

< 3700 km

Hydrogen Hybrid Turbofan Engine (x2)

Liquid Hydrogen Storage & Distribution System

AIRBUS © 36897

AIRBUS ZEROe vs A321XLR

The volumetric energy density of H2 is four times smaller than that of kerosene!

A321 XLR

- 220 Passengers
- 8700 km
- Geared Turbofan Engine (x2)
- Kerosene SAF*

ZEROe Turbofan

- < 200 Passengers
- < 3700 km
- Hydrogen Hybrid Turbofan Engine (x2)
- Liquid Hydrogen Storage & Distribution System

*SAF = Sustainable Aviation Fuel

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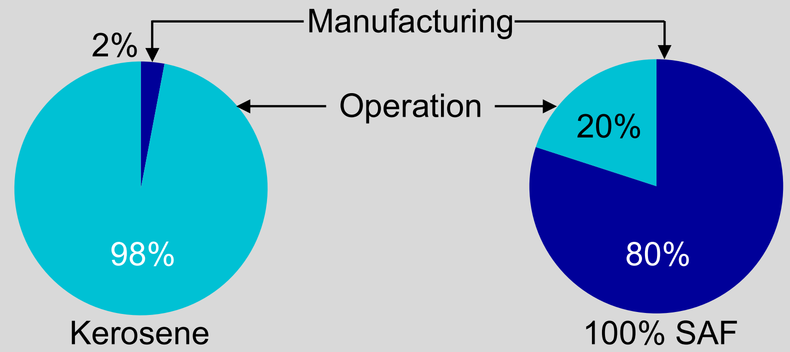
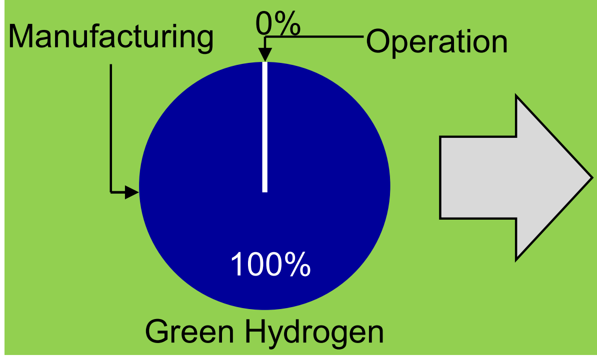
AIRBUS ZEROe vs. A321XLR – Share of CO_2 Emissions from Manufacturing

CO2 Emissions over the Entire Lifecycle



CO2 Emissions over the Entire Lifecycle



The focus in Aircraft Manufacturing will increasingly shift towards its CO2 Footprint.

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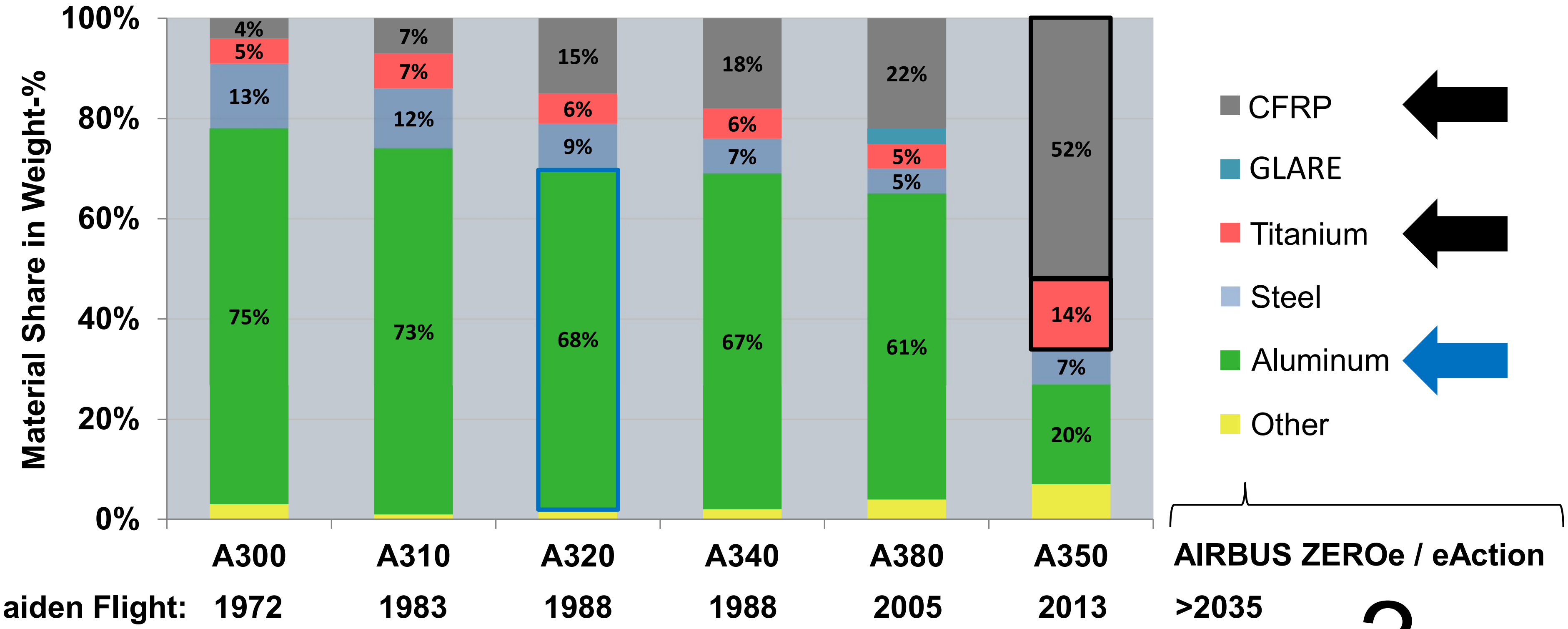
Material Composition of AIRBUS Primary Structure



High Aluminum Content in the actual Single-Aisle A320

Increase in CFRP & Titanium in the Latest Aircraft Generation

Dege, J., Surmann, T.: Key Competencies for the Economic Manufacturing of Titanium Structural Components in the Aerospace Industry, Hagener Symposium 2016 © 36900

Energy Consumption of a Production Site
Example of the Premium AEROTEC Plant in Varel 2022

Aluminum: **14.800 t/a**
Titanium: **420 t/a**

21.000 Different
Tools

1.100 Employees
(600 in Production)

Electricity:
18.5 GWh/a

Gas:
11.8 GWh/a

Energy Demand
Raw Material Production
Ti: 109 kWh/kg
Al: 17 kWh/kg

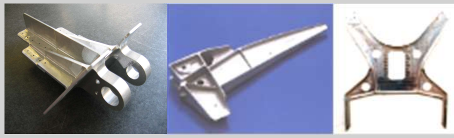
13.500 t/a
Chips

230 GWh/a

4 t/a
Carbide

5 Mio. Parts/a

Small Components <0.5m



Large Components <7.5m

Turned Parts <Ø1.2m

25.000
Different Parts/a

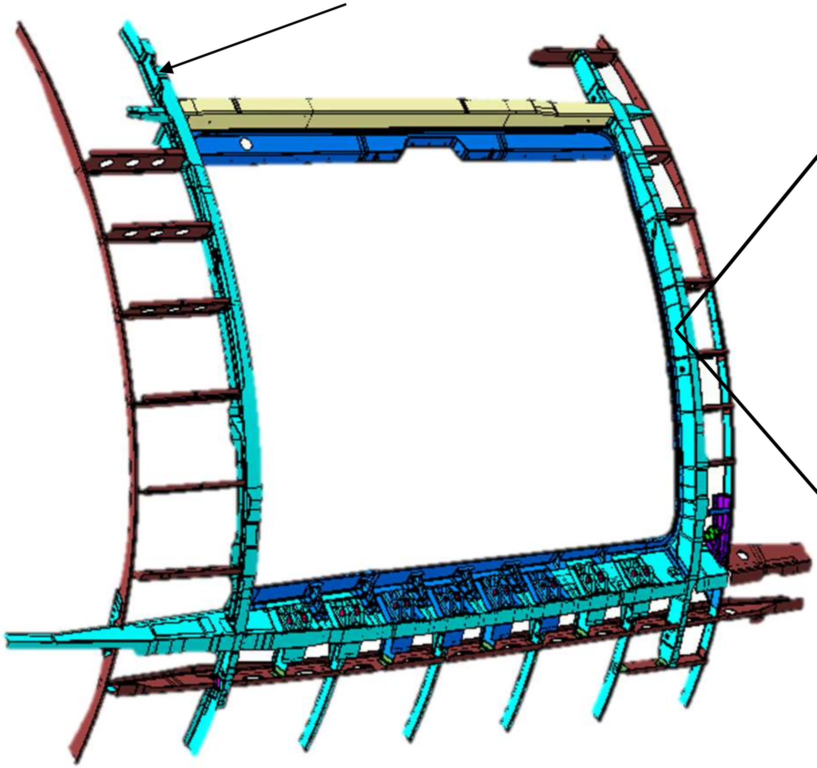
Status 2022

Lange, M.; Dege, J.: Sustainable Aviation: Aircraft Concepts and Production, 5. Wiener Produktionstechnik Kongress, 2022; www.wind-energie.de

© 36901

Conventional Process Chain for Titanium Structural Components

A350 Titanium Doorframe



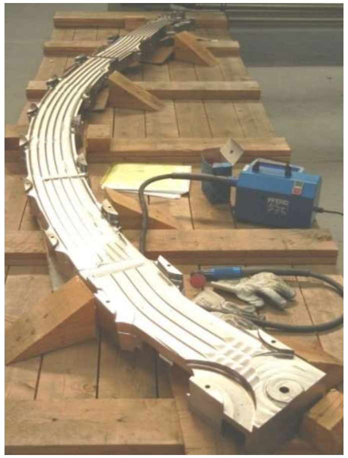
Open Die Forging
→ Cross Section

Open Die Forging
→ Hull Curvature

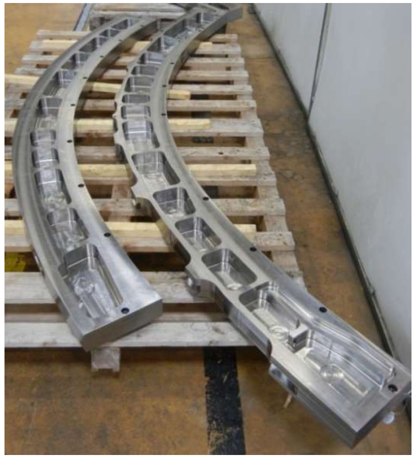
Dege, J., Lange, M., Surmann T.: Herausforderungen und zukünftige Entwicklungen bei der Fertigung metallischer Luftfahrtstrukturen, Schwarzsee Talk, Extramet, 2018 ©

Conventional Process Chain for Titanium Structural Components

Premachining



Machining of Clamping Surfaces



Rough Milling of Pockets

Finish Milling of the Final Part

Raw Part Weight ≈ **550 kg**

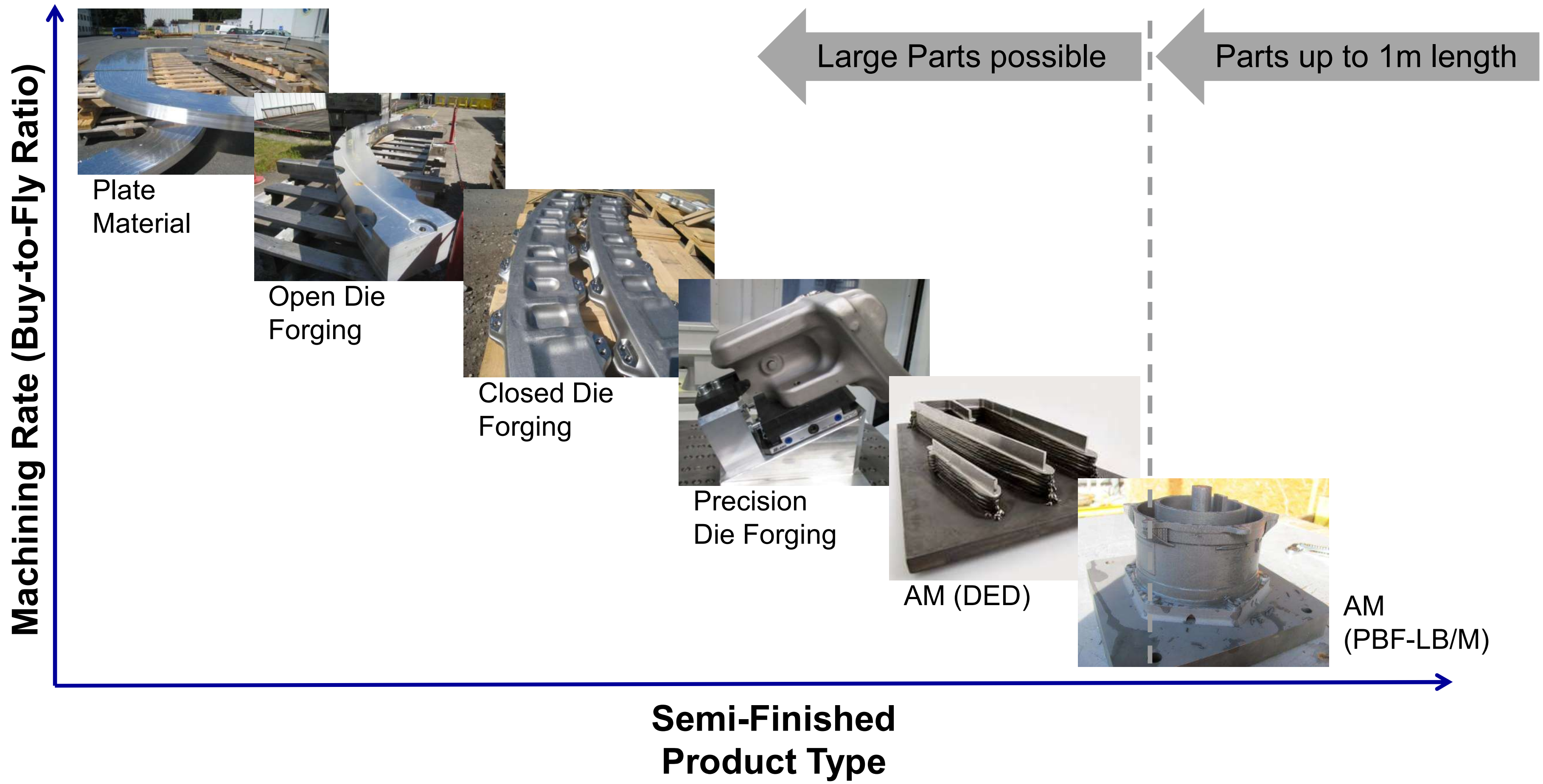
Buy to Fly Ratio: **22 (95%)**

Finished Part Weight ≈ **25 kg**

+

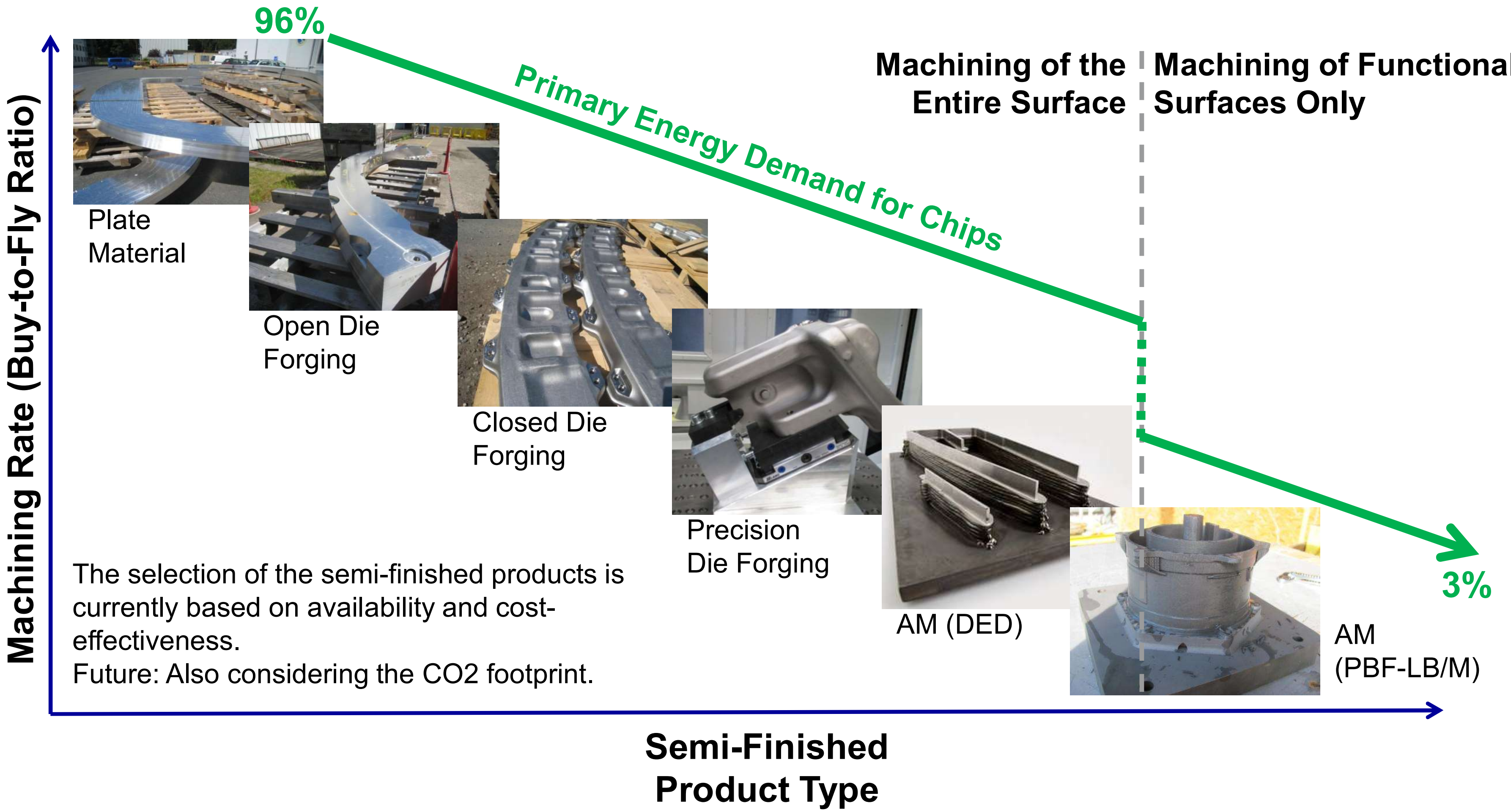
Dege, J., Surmann T.: Schlüsselkompetenzen für eine wirtschaftliche Fertigung von Titanstrukturbauteilen in der Luftfahrtindustrie, Hagener Symposium 2016

Semi-Finished Product Type Depending on the Machining Rate



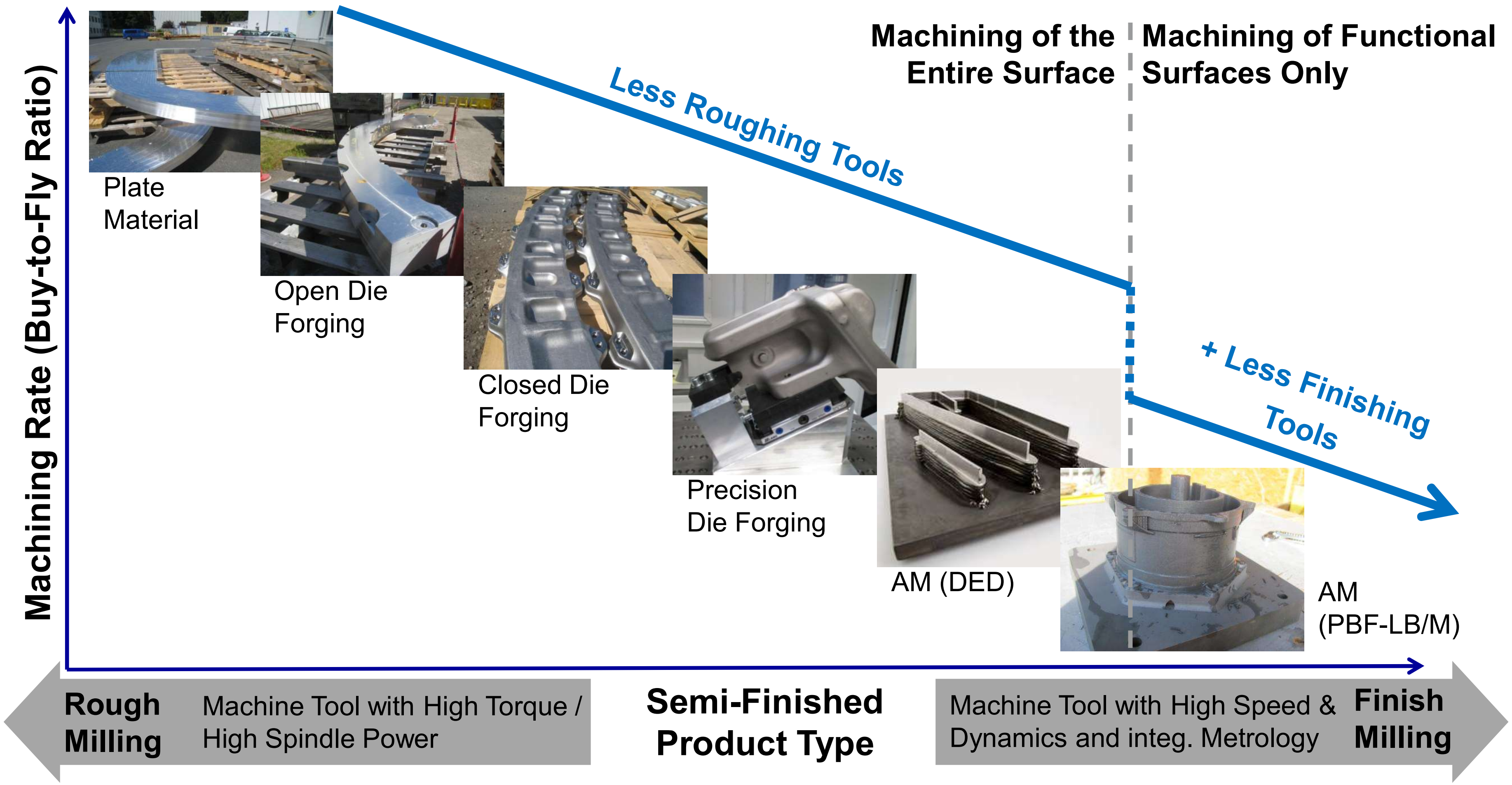
Dege, J.: Zwischen Auftragsrekorden und Dekarbonisierung – Herausforderungen in der Flugzeugproduktion, Wernesgrüner Werkzeugsymposium, 2024; PAG 2024 © 36904

Semi-Finished Product Type Depending on the Machining Rate



Dege, J.: Zwischen Auftragsrekorden und Dekarbonisierung – Herausforderungen in der Flugzeugproduktion, Wernesgrüner Werkzeugsymposium, 2024; PAG 2024

Semi-Finished Product Type Depending on the Machining Rate



Dege, J.: Zwischen Auftragsrekorden und Dekarbonisierung – Herausforderungen in der Flugzeugproduktion, Wernesgrüner Werkzeugsymposium, 2024; PAG 2024

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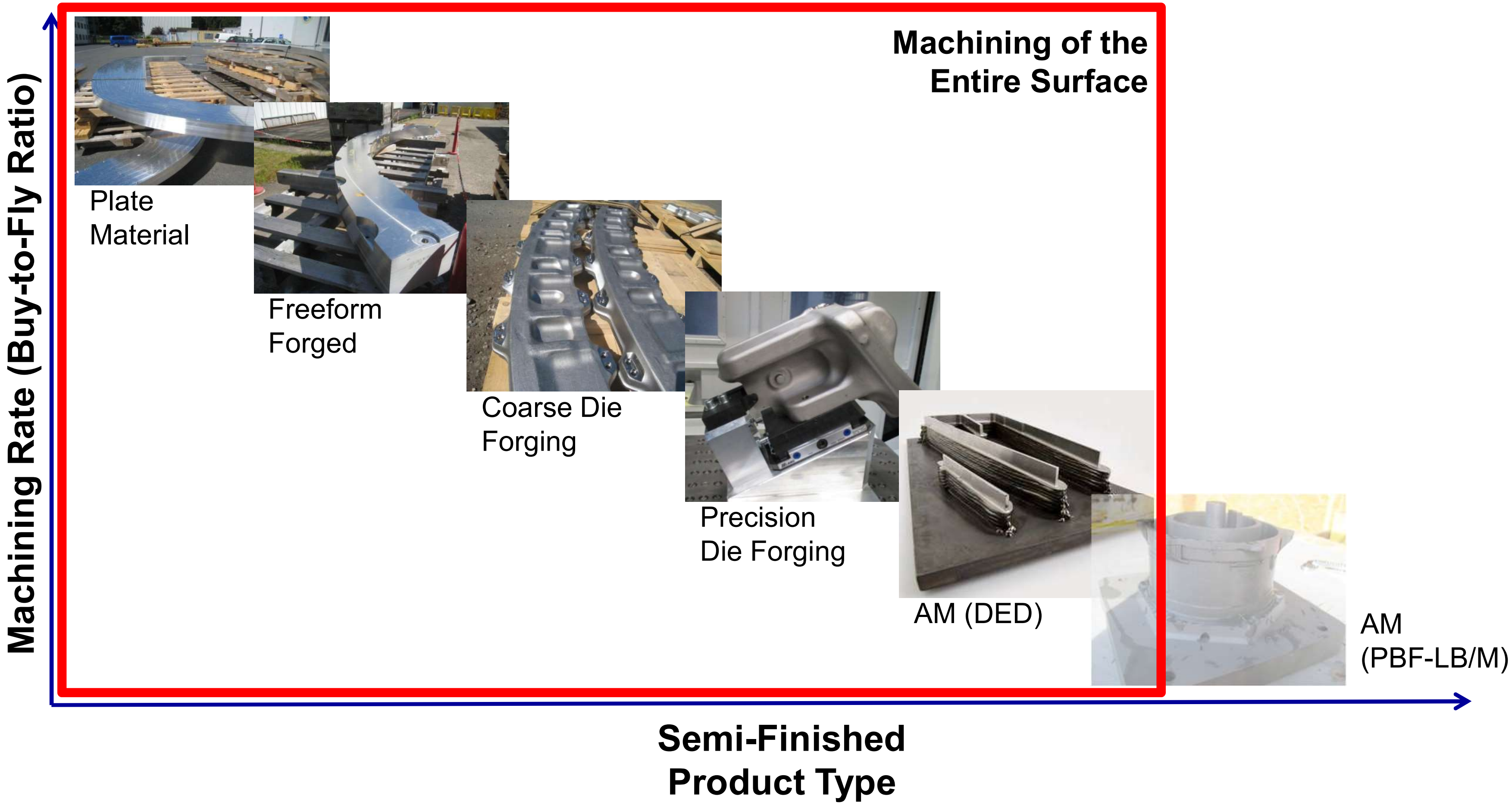
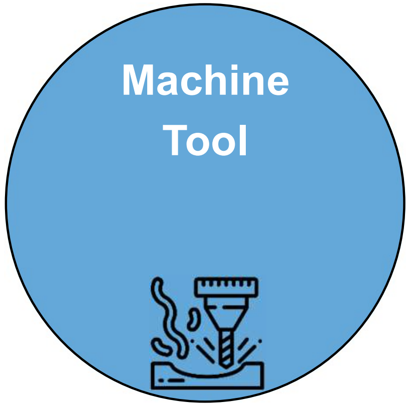
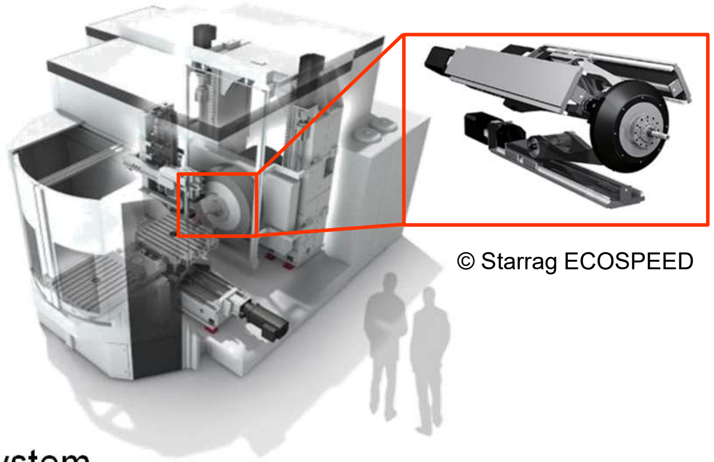

Machining Rate (Buy-to-Fly Ratio)
Machining of the Entire Surface
Plate Material
Freeform Forged
Coarse Die Forging
Precision Die Forging
AM (DED)
AM (PBF-LB/M)
Semi-Finished Product Type

© 36904



Aluminum:
- Spindle Power P_s = 120 – 150kW
- Speed n ≥ 30.000 min^{-1}
- High Jerk / Acceleration
- **Machine Tool Limits the Process!**

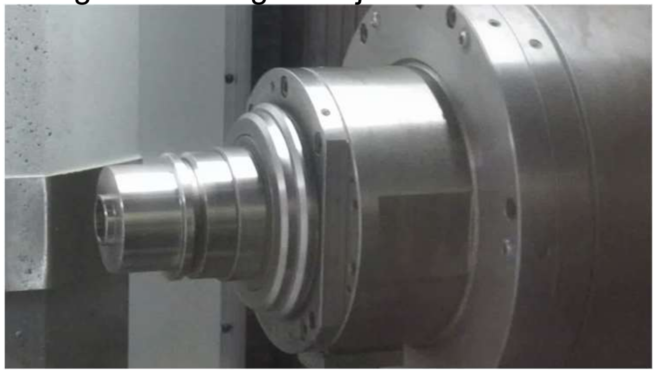
Titanium:
- Spindle: M_{max} > 1500Nm
- Interface: HSK125
- Rigid Machine Structure
- High Performance Coolant Supply System



© Starrag ECOSPEED

Finish Machining: Jerk j ≈ 150 m/s^3

Rough Machining: Jerk j ≈ 600 m/s^3



Premium AEROTEC GmbH, MAG, Starrag AG

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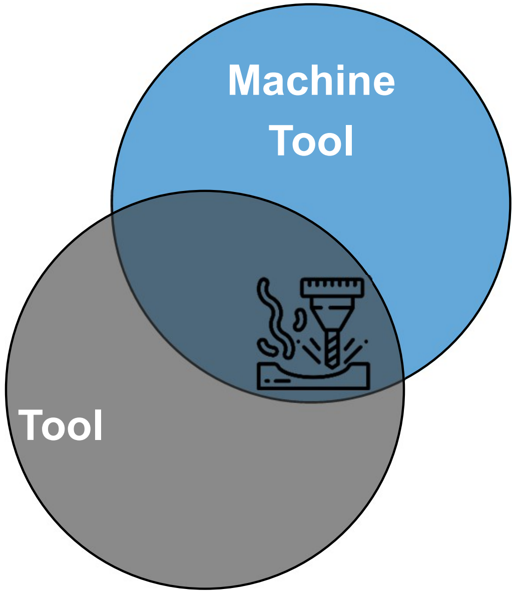
Cutting Tool



Aluminum:

- Tool Flute Design (MRR > 11l/min)
- Process Damping through Macrogeometry and Flank Face Chamfers

Titanium:

- Stabilized Cutting Edges
- Heat-Resistant Substrates
- Customized Coatings
- Coolant Supply System Friendly Design (e.g. PBF Body)
- **Tool Limits the Process!**

Face Milling Cutter with Tangential Insert

© Walter, PAG, IPMT

+85% MRR in Titanium Milling @AIRBUS, Varel

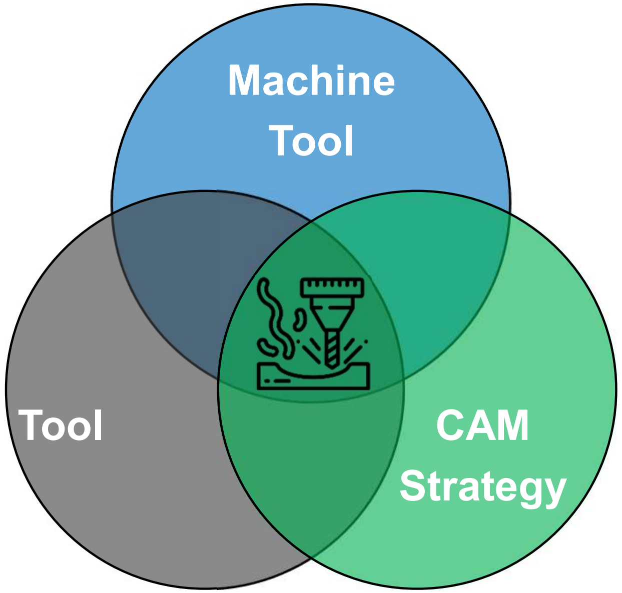
CFD Simulation Cooling Fluid

Additively Manufactured Face Milling Cutter

© Walter, PAG, MTI

Kellinger,T. Zielgerichtete Kühlschmierstoff-Zufuhr in additiv gefertigten Fräswerkzeugen (TACOMA). 2023
Dege, J; Heuwinkel, M; Möller, C.: Entwicklung eines tangentialen Walzenstirnfräskonzeptes für Titanstrukturbauteile, Konferenz Schwer Zerspanbare Werkstoffe, 2021

© 36907



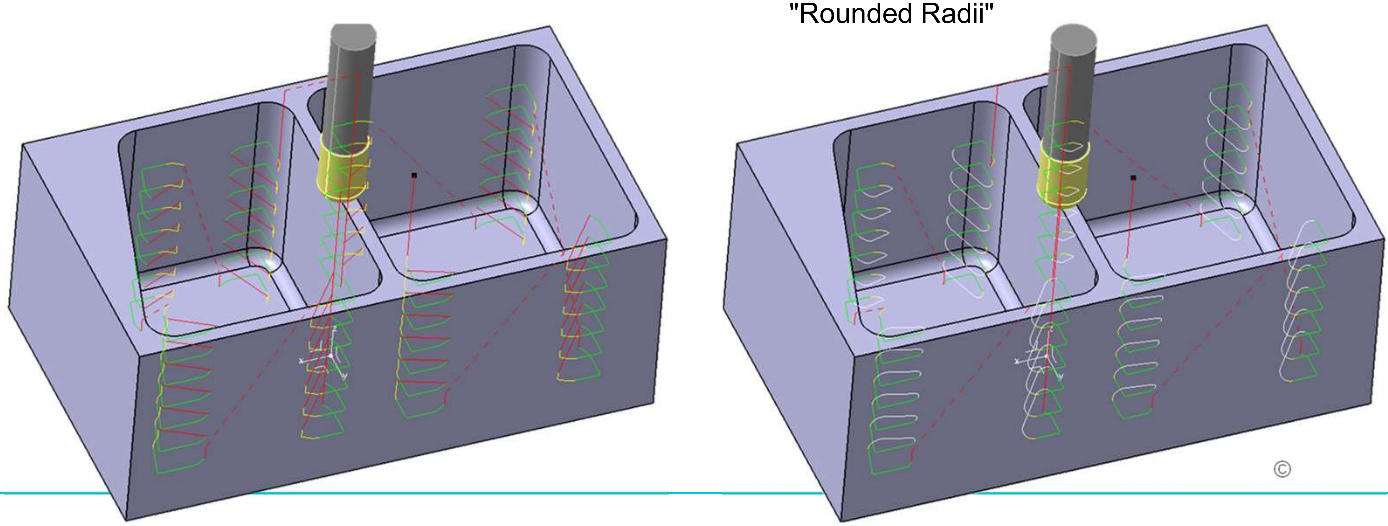
NC-Programming and -Strategy:

- Consider Tool Load (e.g., "Roll-on Entry" in Titanium Machining)
- Strategies for Machining Compliant Components (e.g. "Waterline Milling")
- Dynamic-Optimized Path Planning

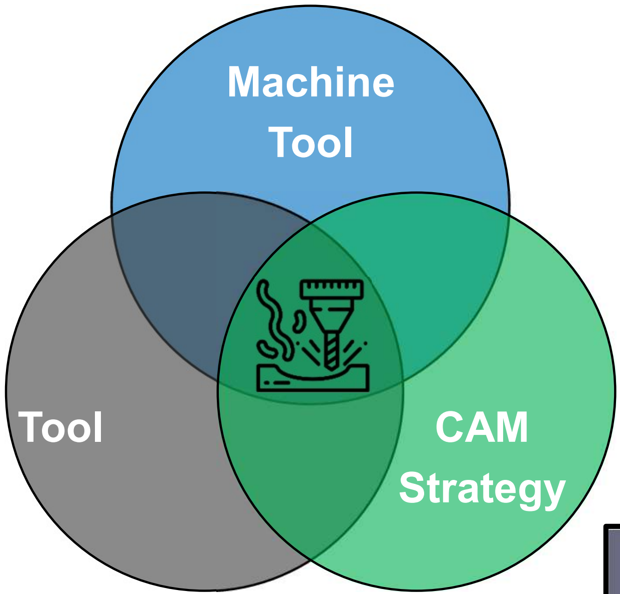
Pre-Milling of Pocket Corners

Standard Strategy **t = 40,66s**

Entry and Exit with "Rounded Radii" **t = 18,19s**



Premium AEROTEC GmbH, Kim Kappen, Jan Dege © 36908



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Pre-Milling of Pocket Corners (Aluminum)

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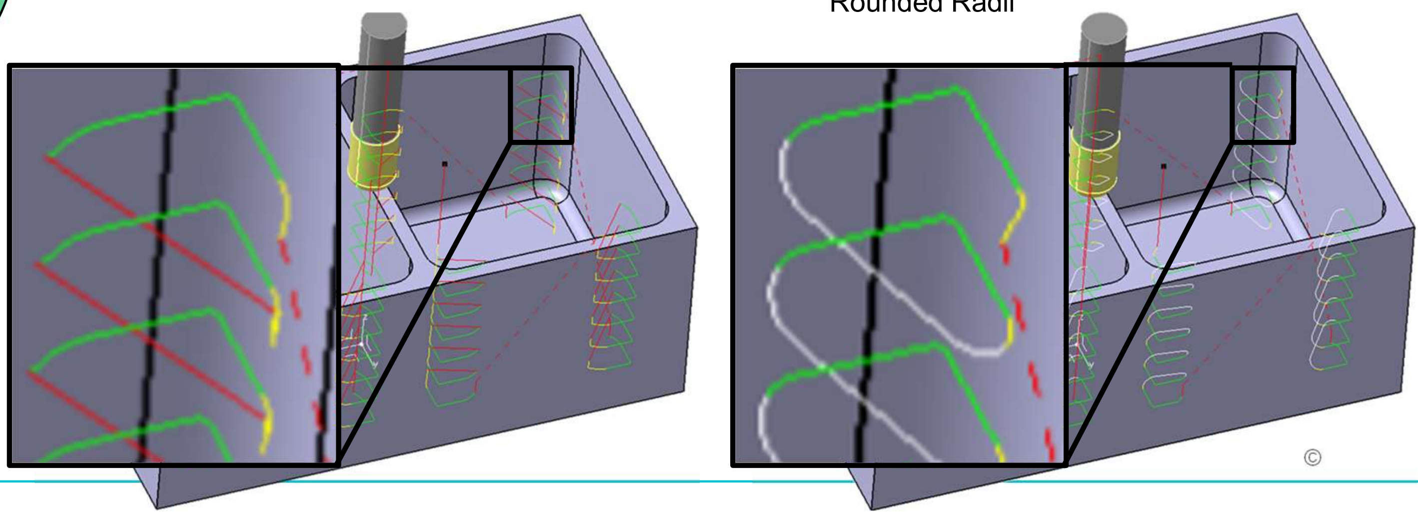
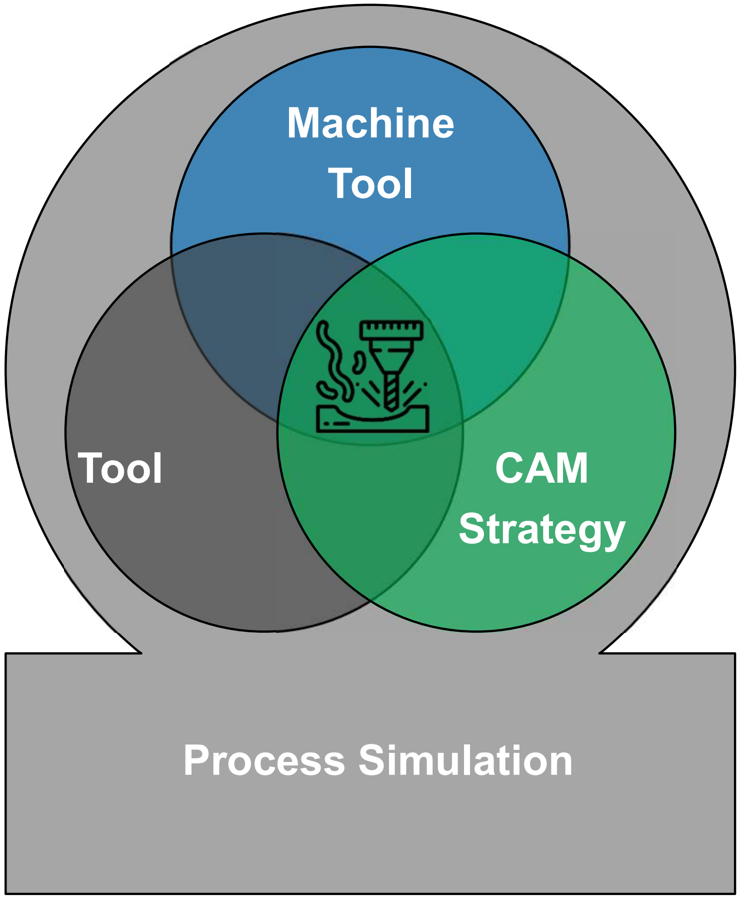
Entry and Exit with "Rounded Radii" **t = 18,19s**

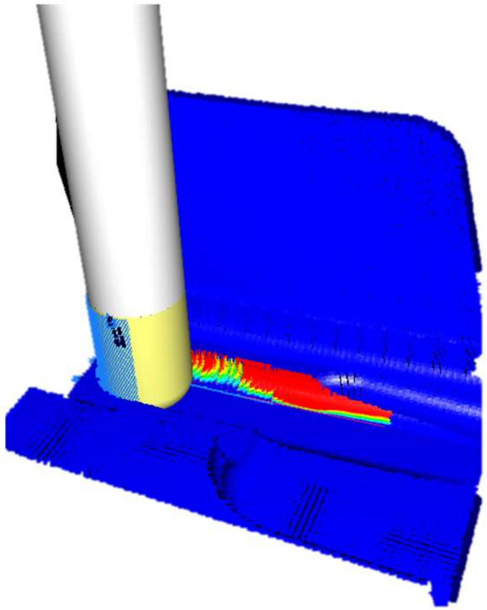


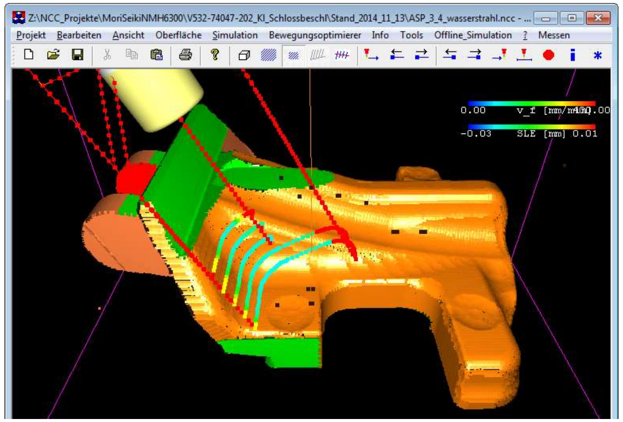
Premium AEROTEC GmbH, Kim Kappen, Jan Dege © 36908

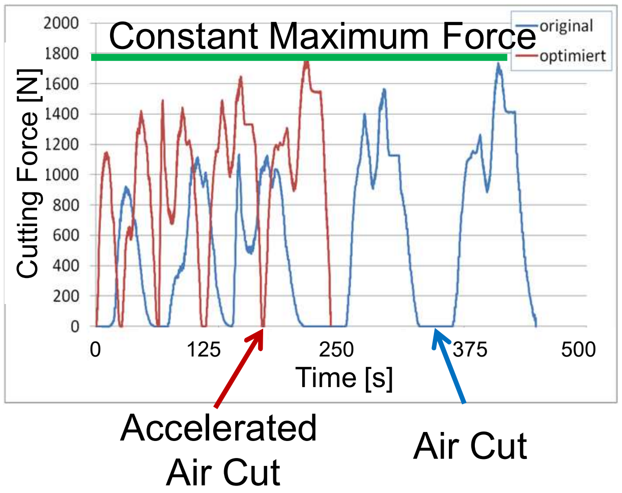


Process Simulation

- Modeling of Contact Conditions
- Load-Adapted Control of Feed Rates
- Model-Based Process Monitoring
- Tool Wear Prediction

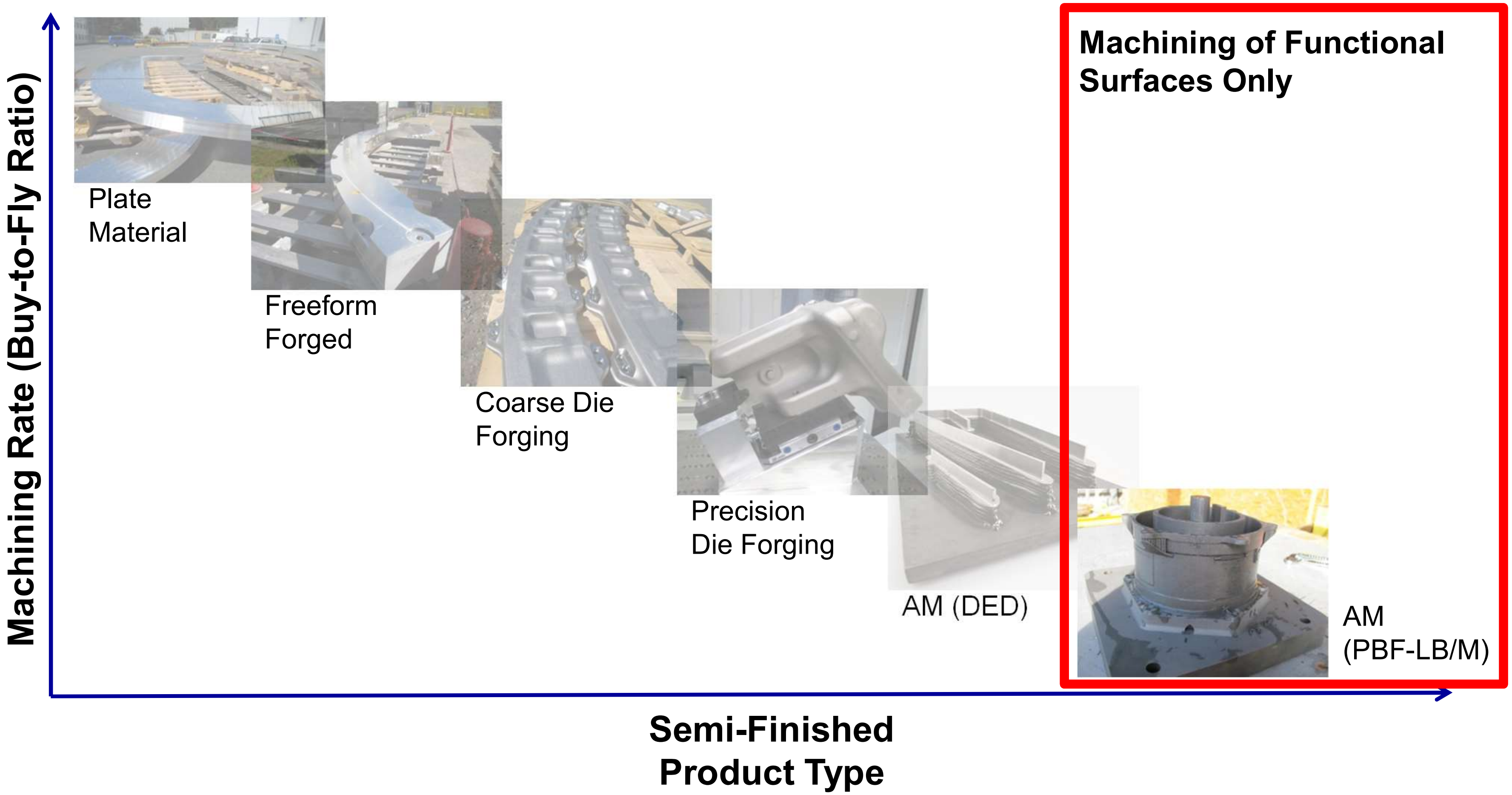






Premium AEROTEC GmbH, Dr. Tobias Surmann © 36909

Semi-finished Product Type Depending on the Machining Rate



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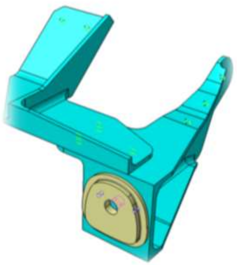
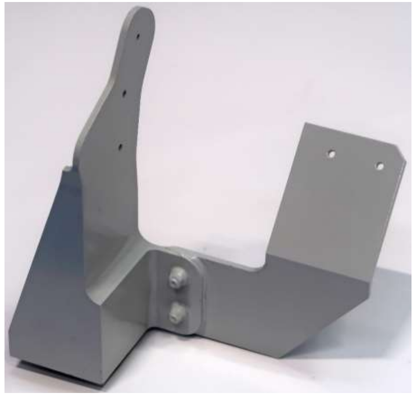
Subtractive vs. Additive Design

Conventional Design

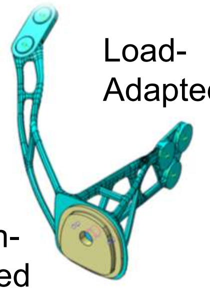




407 gram

AM - Design

Load-
Adapted



Function-
Integrated

148 gram

- 64% Weight Reduction
- Less Assembly

Dege, J.: Herausforderungen an die Spanntechnik für additiv gefertigte Bauteile, MIN Workshop, IPMT Hamburg, 2019

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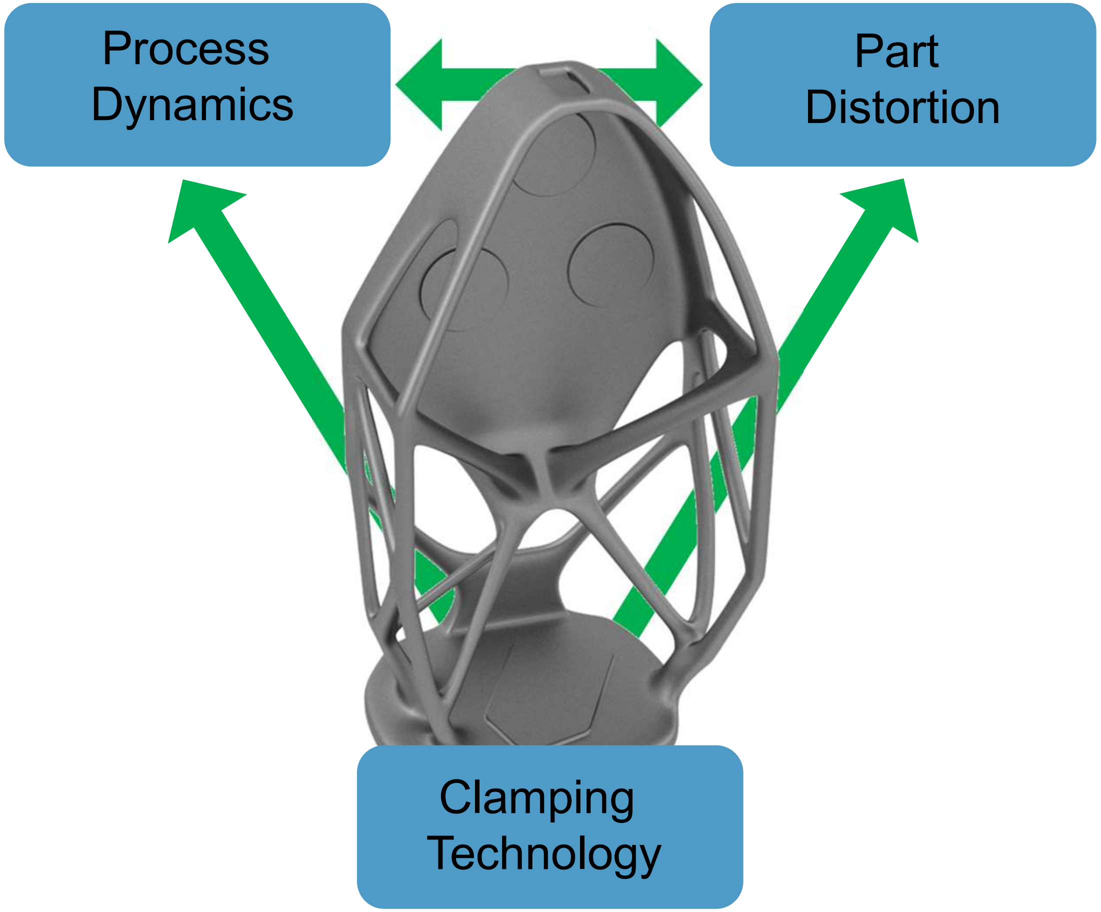
Challenges in Machining Additively Manufactured Components



Dege, J.: Herausforderungen an die Spanntechnik für additiv gefertigte Bauteile, MIN Workshop, IPMT Hamburg, 2019

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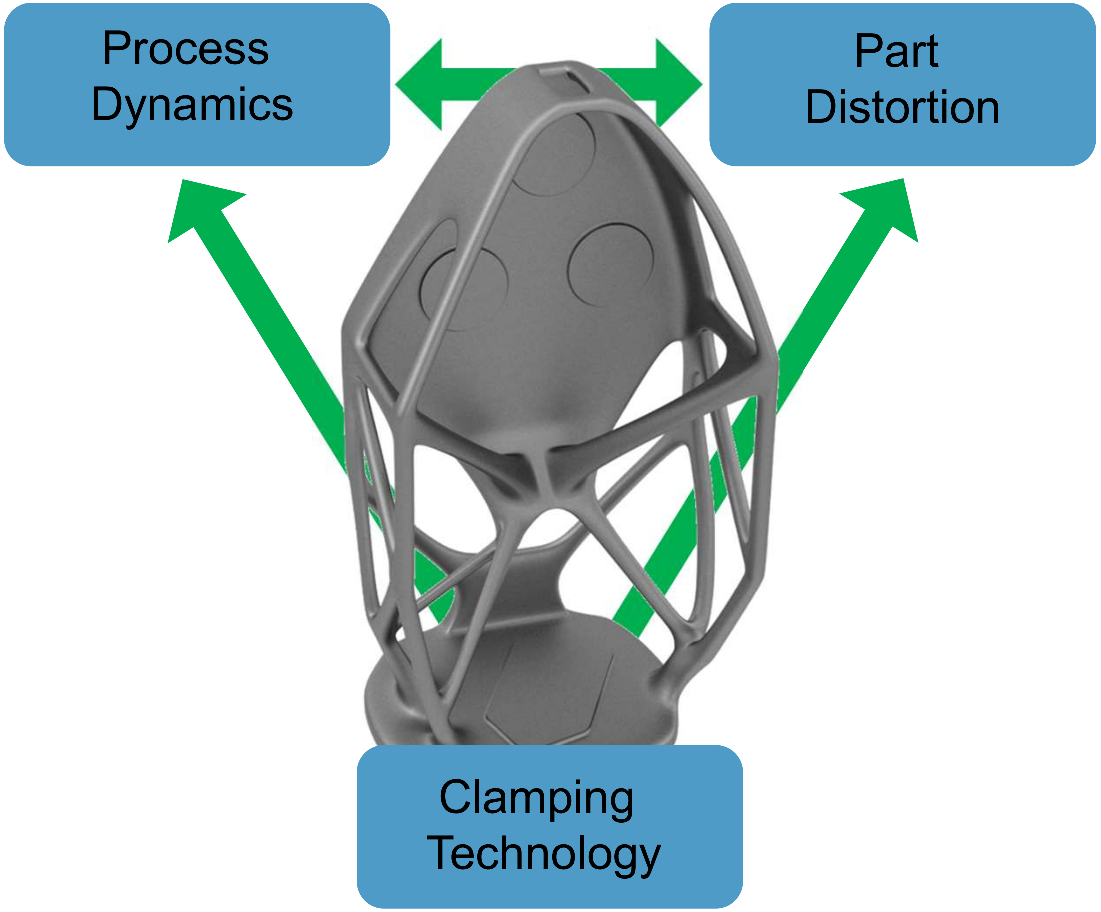
Challenges in Machining Additively Manufactured Components - Clamping Technology



Clamping Technology:

- Load-Adapted Design Leads to Many Freeformed Surfaces and Compliant Structures

Solutions:

- Form-Flexible Clamping Systems
- Design of Clamping Points / Clamping Tabs
- Contoured Clamping Jaws
- Alignment on the Machine Tool Required

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Agenda

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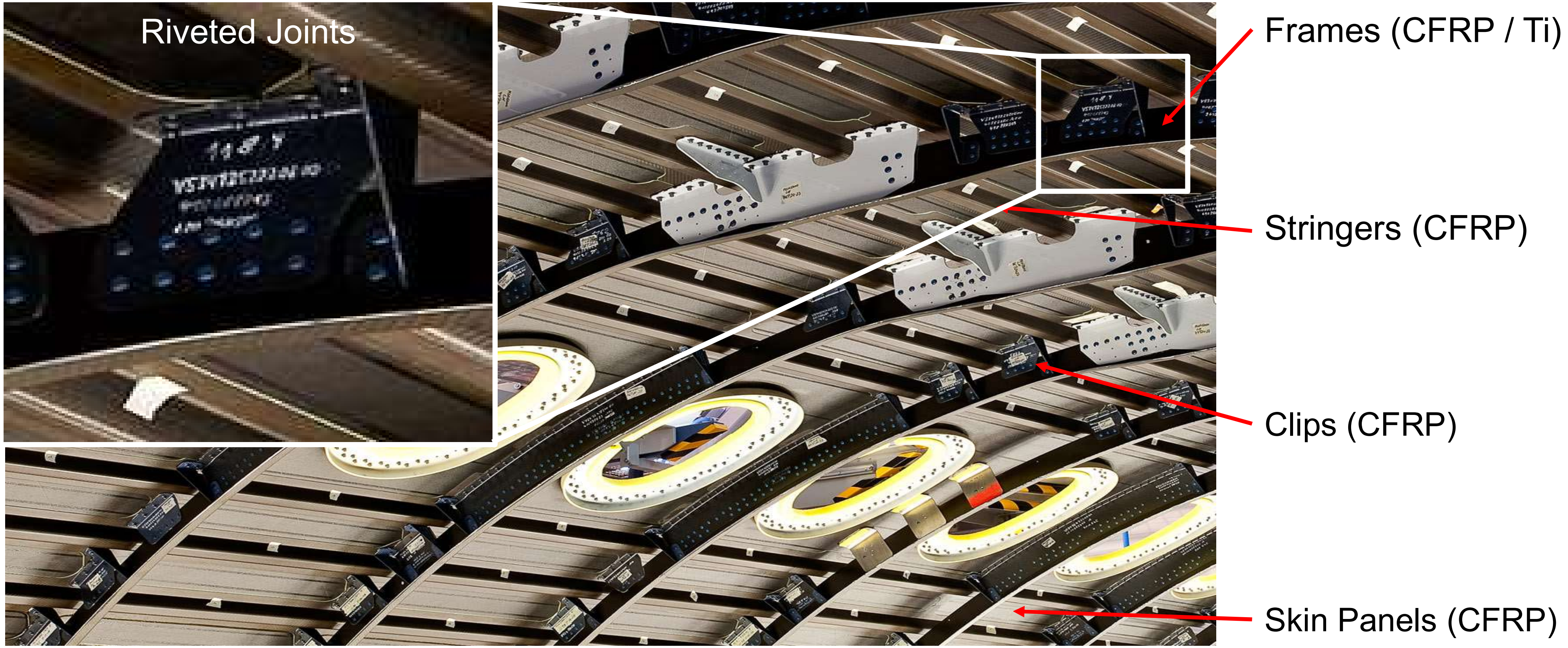
Assembly of Airbus A350 - Riveted Joints



- AIRBUS: Approximately 150 million rivet holes per year
- The Increasing Use of CFRP and Titanium Requires New Solutions for Hole Machining

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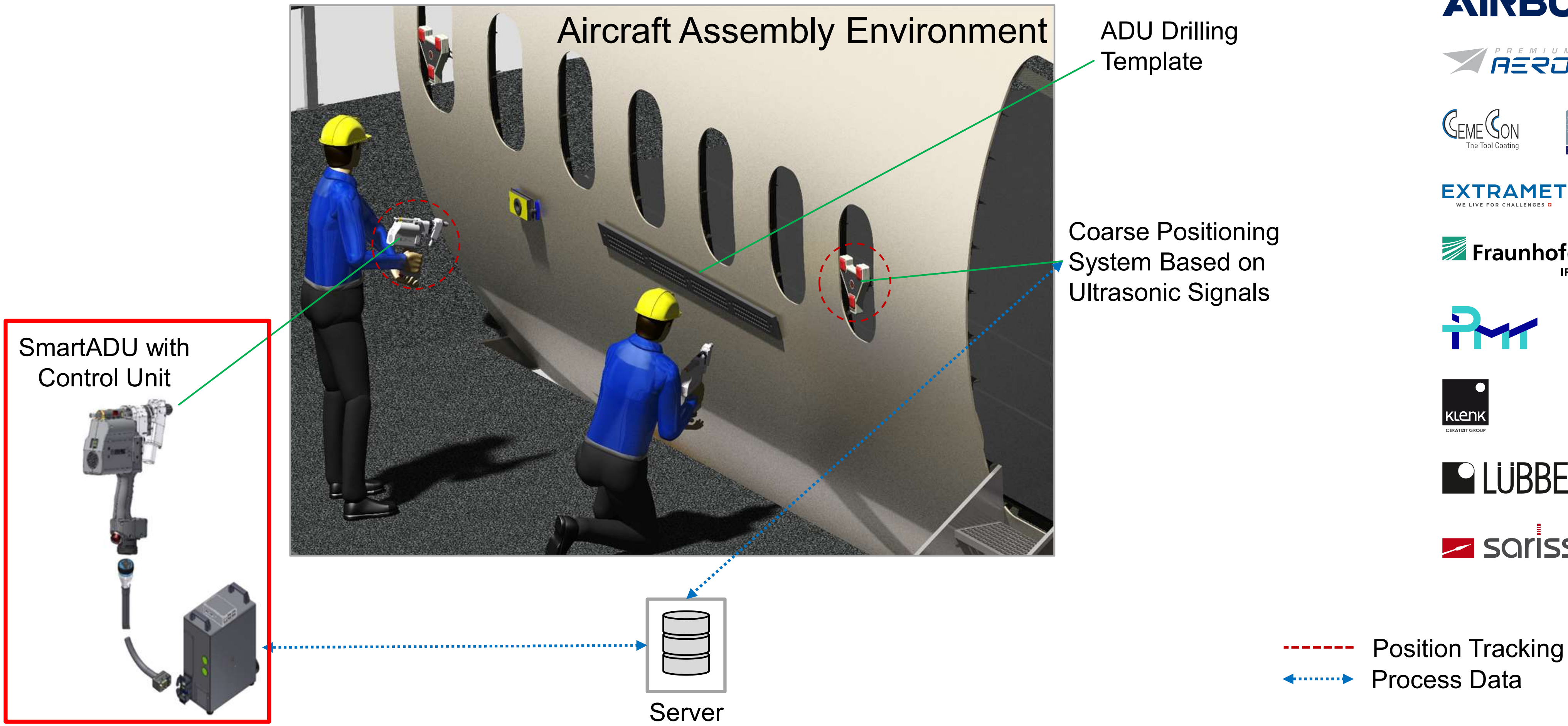
SmartADU2020 Project – Process Flow



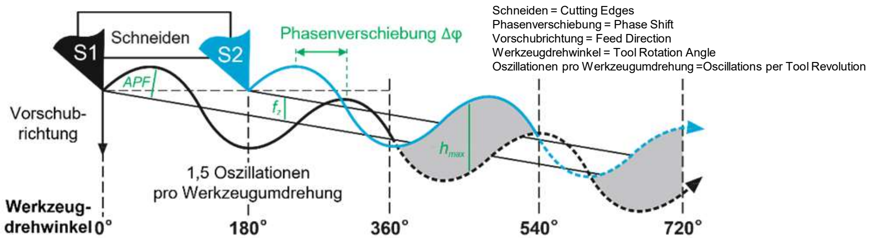
ADU: Advanced Drilling Unit

© 36922

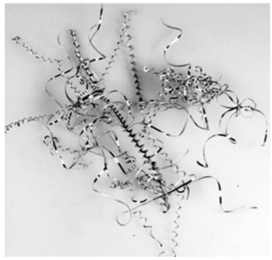
SmartADU2020 – Advanced Drilling Unit (ADU)

Advanced Drilling Unit

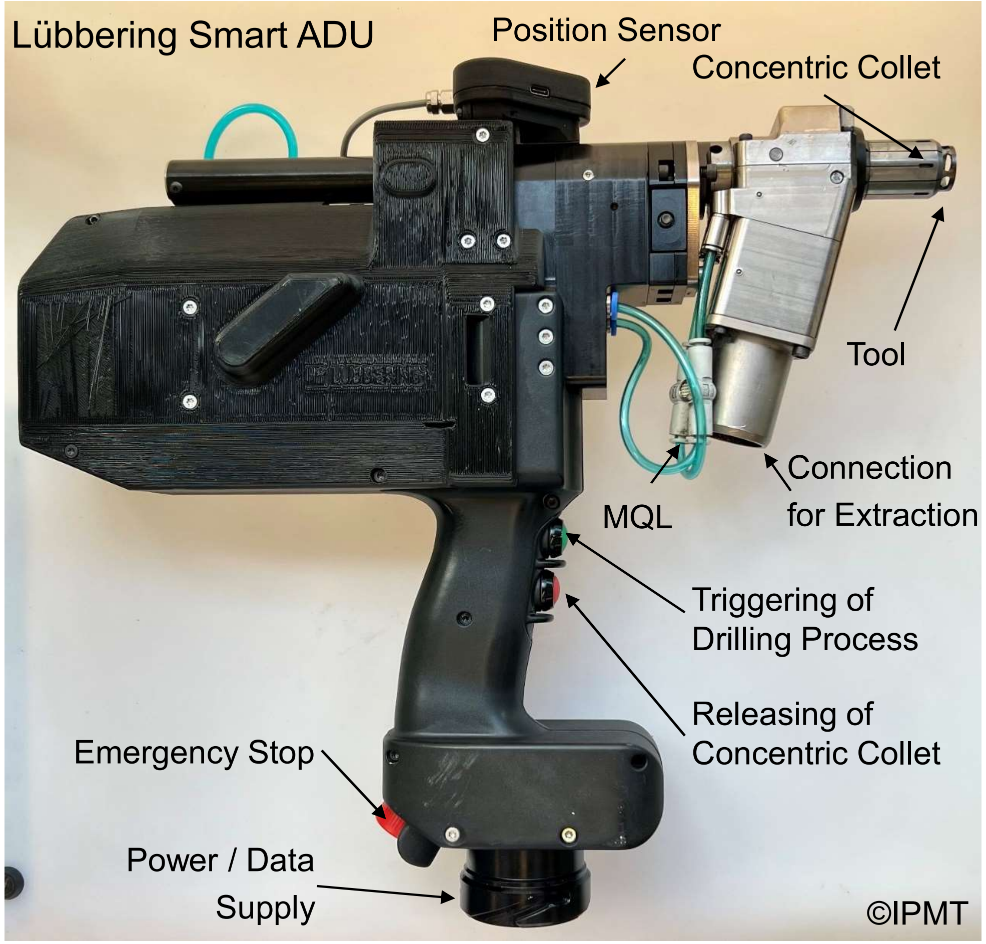
- Electric Main and Feed Drive
- Analysis of Drive Currents Enables Process Monitoring (ML Algorithms)
- MQL System (Minimal Quantity Lubrication)
- Peck-Feed System (Improved Chip Breaking)



Without Peck-Feed



With Peck-Feed



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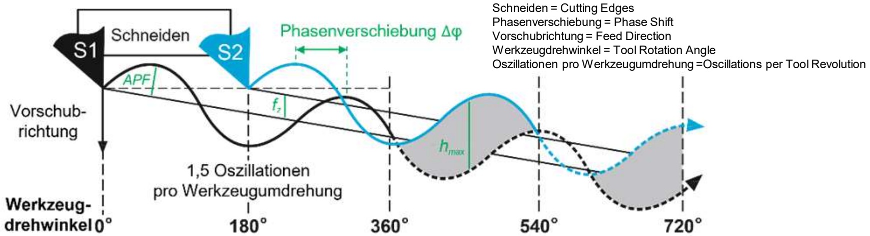
SmartADU2020 – Control Parameter Progression of a Parameterized Drilling Program

Advanced Drilling Unit

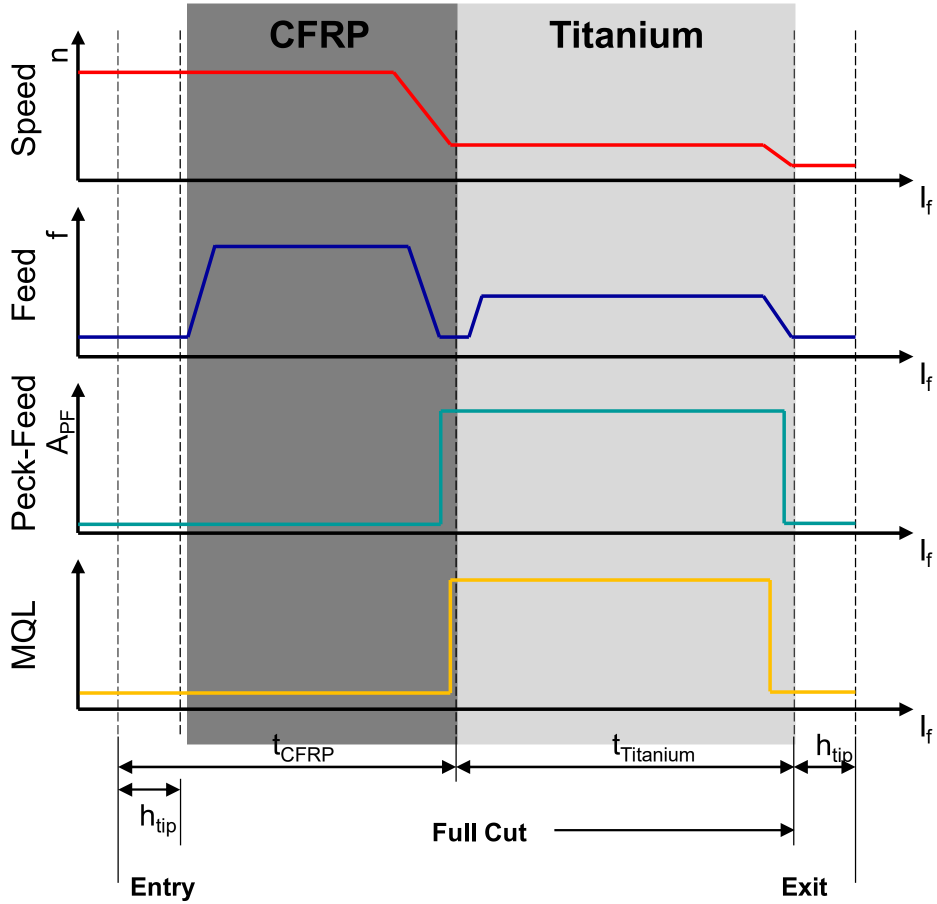
- Electric Main and Feed Drive
- Analysis of Drive Currents Enables Process Monitoring (ML Algorithms)
- MQL System (Minimal Quantity Lubrication)
- Peck-Feed System (Improved Chip Breaking)
- Fully Programmable Drilling Programs



Without Peck-Feed

With Peck-Feed

Drilling Process



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Advanced Drilling Unit

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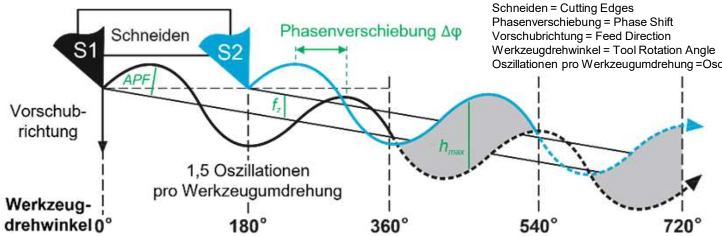
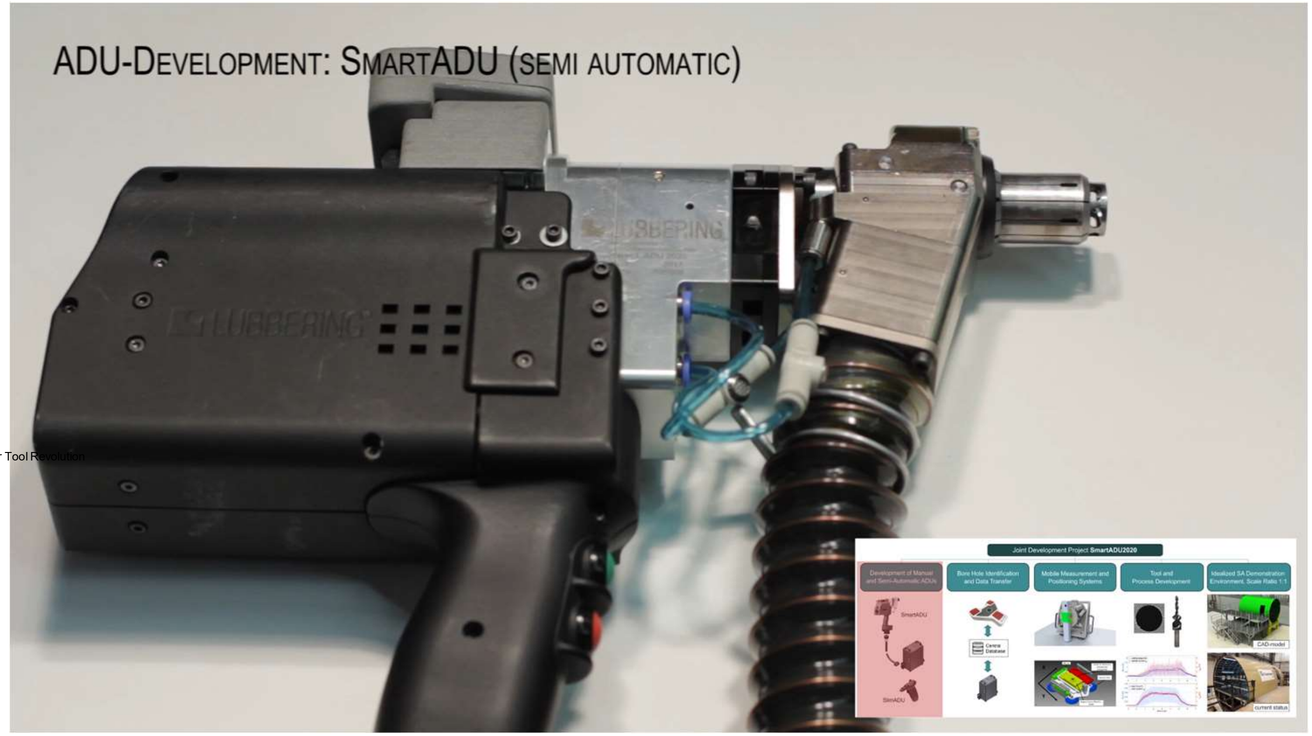


Schneiden = Cutting Edges
Phasenverschiebung = Phase Shift
Vorschubrichtung = Feed Direction
Werkzeugdrehwinkel = Tool Rotation Angle
Oszillationen pro Werkzeugumdrehung =Oscillations per Tool Revolution

Without Peck-Feed

With Peck-Feed



Countersink Drilling Tool

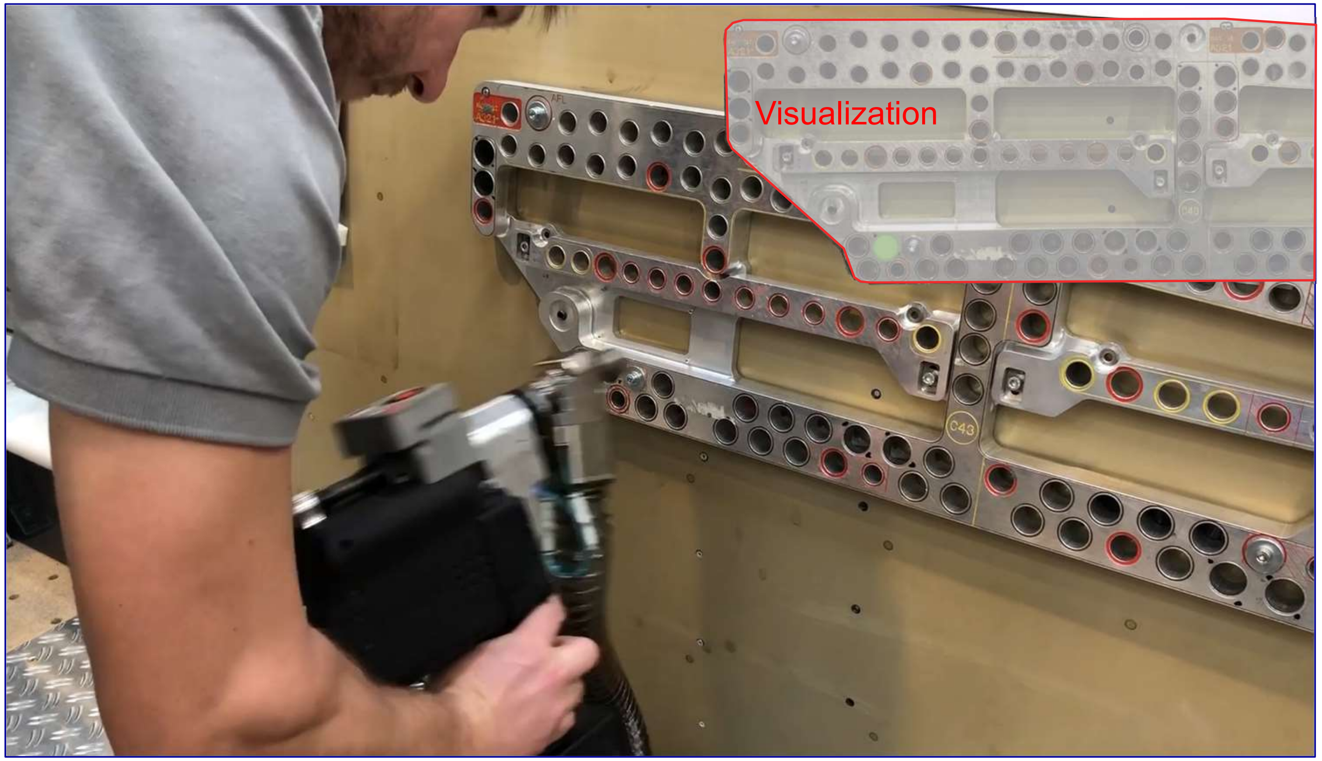
CVD Diamond Coated

© 36925

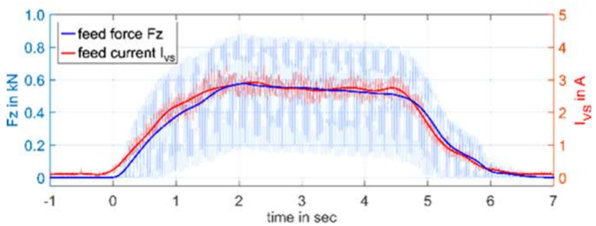
SmartADU - Geolocation

Geo-Localization /Visualization

- Continuous Monitoring of the TCP (Tool Center Point) in Relation to the Drilling Template
- Drilling Sequence is Predefined
- Drilling Process Cannot Be Triggered if Positioned Incorrectly
- Position and Process Data are Stored for Each Hole (Quality Assurance)



- Next Drilling Position (blue)
- Ready to Drill (yellow)
- Drilling Successfully Completed (green)
- ADU at Incorrect Position (red)



→ Process Monitoring

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Agenda

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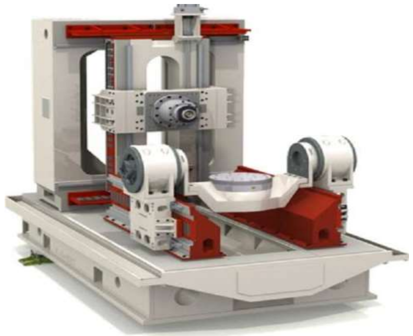
Summary

- Global Demand for Aircrafts is Increasing Significantly
- Alternative Propulsion Systems shift the focus of CO_2 Emissions from Aircraft Operation to Aircraft Production
- Near-Net-Shape Semi-Finished Products can Reduce the CO_2 Footprint
- The Triad of Machine Tool, Tool, and CAM Strategy Remains Crucial for Cost-Effectiveness
- Geolocalization and Digitalization during Drilling Operations enhance Process Safety and Quality

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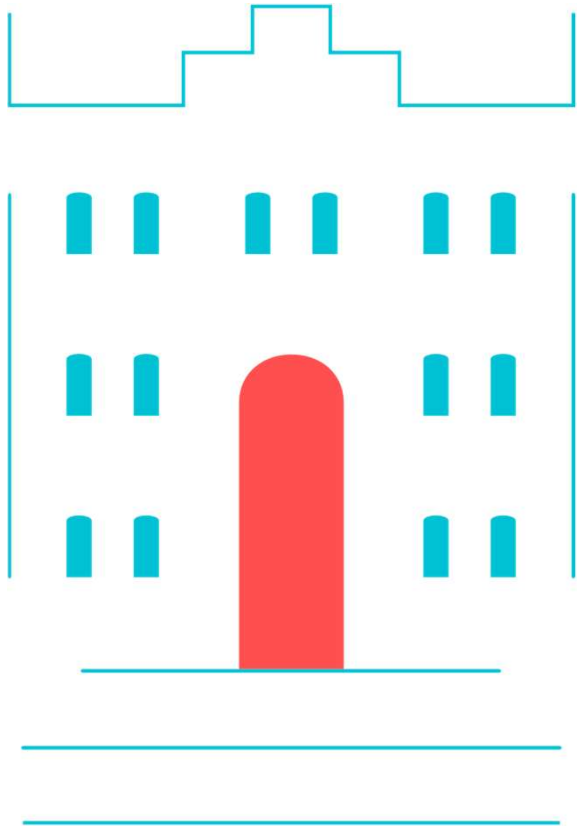
Kontakt

Prof. Dr.-Ing. Jan Hendrik Dege

+49 40 42878-3133
jan.dege@tuhh.de

Institut für Produktionsmanagement und -technik
Technische Universität Hamburg
Denickestraße 17 | 21073 Hamburg
www.tuhh.de/ipmt | LinkedIn



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