Process Chain Optimization and Quality Assurance for the Additive Manufacturing of Aero Engine Parts

Dr. K. Dusel, 16.3.2016

Agenda

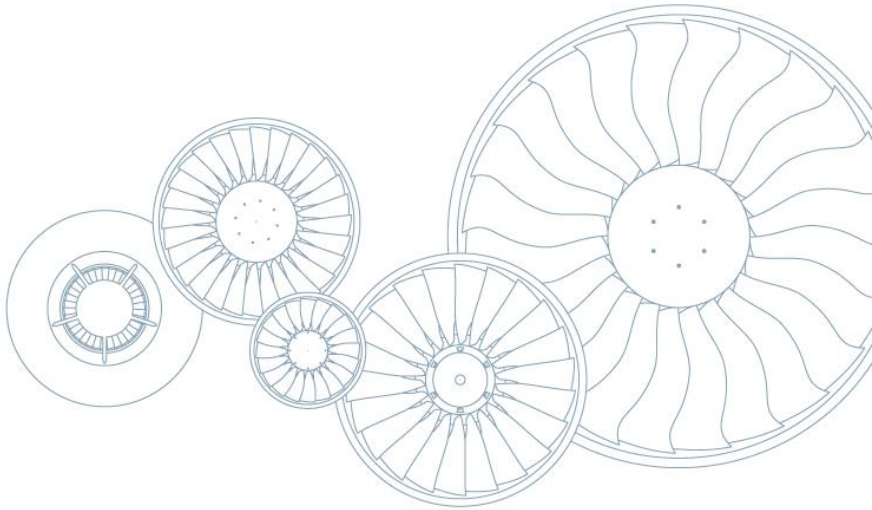
1. THE COMPANY

2. ADDITIVE MANUFACTURING @MTU

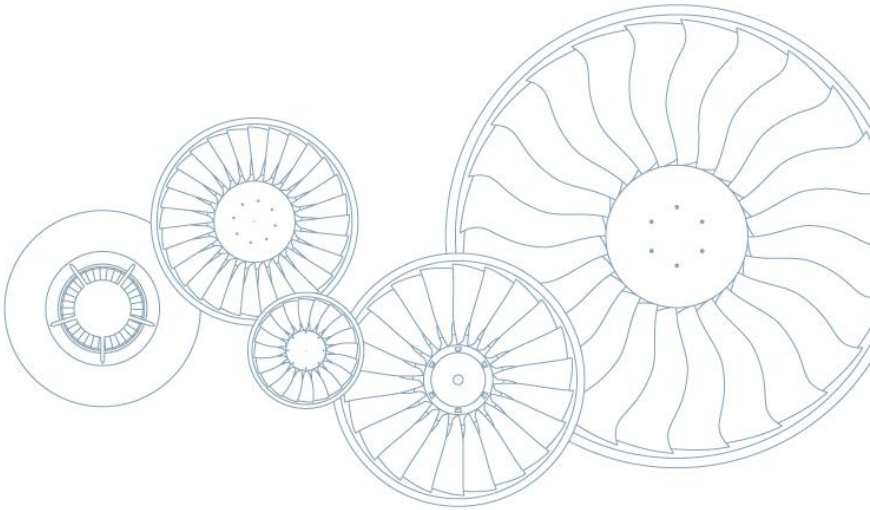
3. AM PROCESS CHAIN

4. QUALITY ASSURANCE

5. FUTURE CHALLENGES



1. THE COMPANY



MTU Aero Engines' business model

COMMERCIAL ENGINE BUSINESS

Share in sales: ~ 53%

- Balanced portfolio of products in all thrust categories
- Partnerships with OEMs going back decades

MILITARY ENGINE BUSINESS

Share in sales: ~ 14%

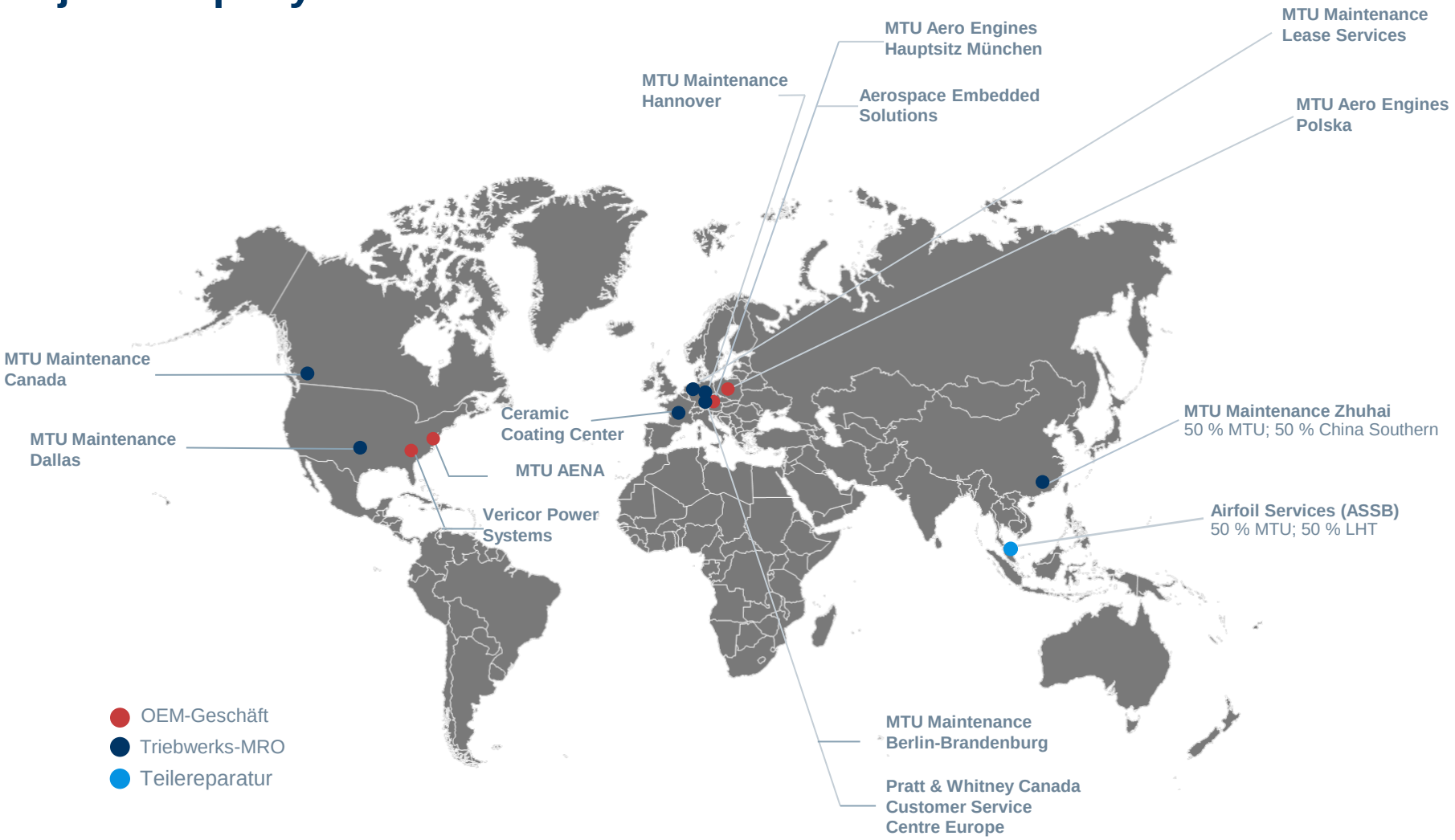
- European and U.S. engine programs
- Lead industrial partner to the German Armed Forces

COMMERCIAL MAINTENANCE

Share in sales: ~ 33%

- Access to high-growth segments
- Provider of services to airlines worldwide

Major company locations worldwide



Global MTU Aero Engines workforce

MTU Aero Engines has a total workforce of around **9,000** employees worldwide -

4,000 of which are employed by MTU Maintenance.

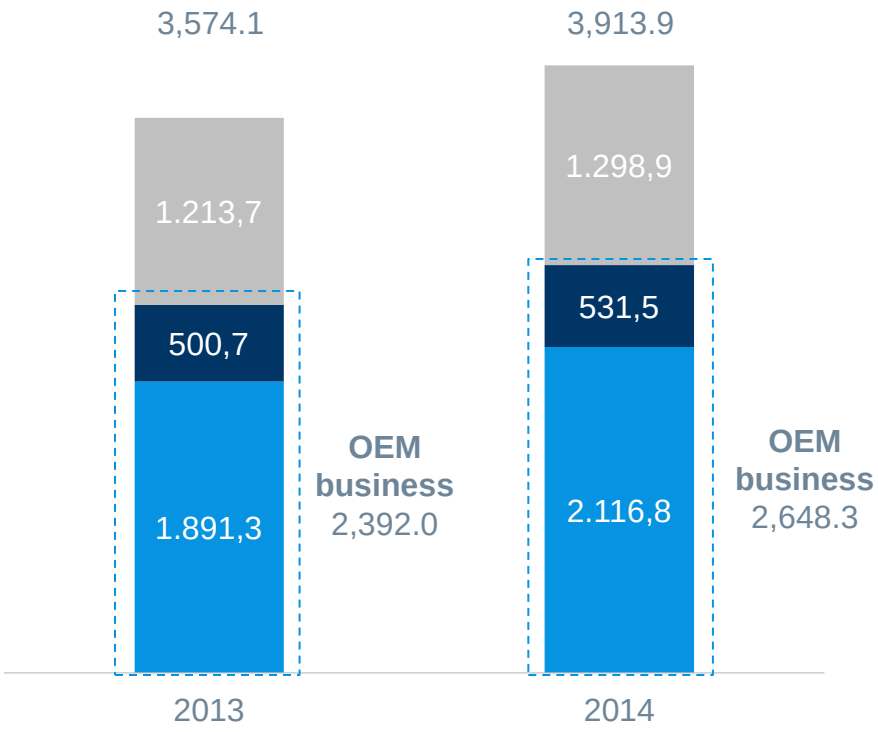
Around **7,300** people are working at our locations in Germany:

4,700 in Munich
1,900 in Hannover
700 in Berlin-Brandenburg.

MTU Aero Engines‘ workforce is made up of **48** different nations.

As of Dec. 2014

Revenues in million €

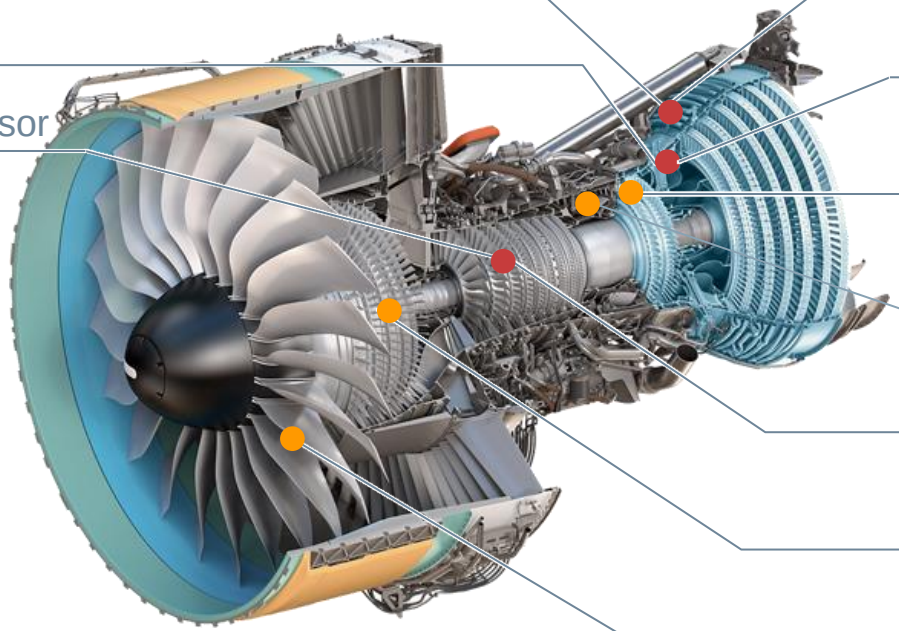


Development / Production

Low-pressure turbine

Turbine center frame

High-pressure compressor



Maintenance

Low-pressure turbine

Turbine center frame

High-pressure turbine

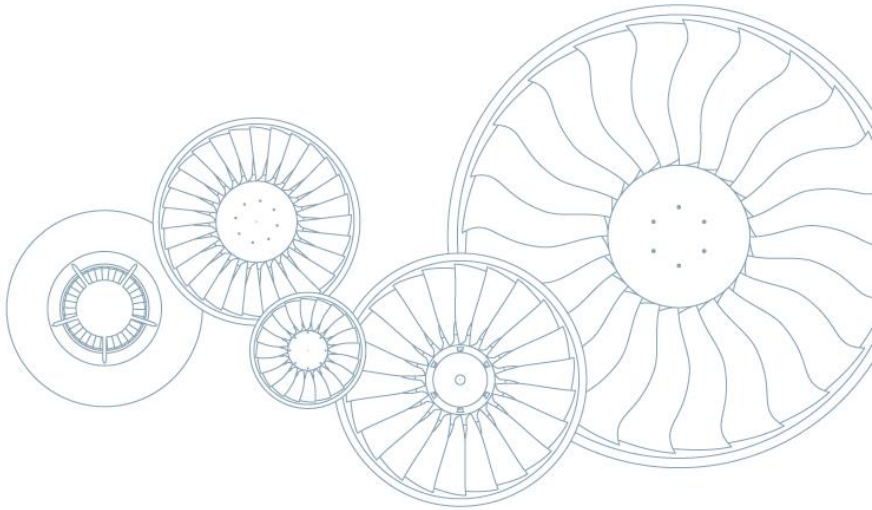
Combustion chamber

High-pressure compressor

Low-pressure compressor

Fan

2. ADDITIVE MANUFACTURING @MTU



Additive Manufacturing @ MTU

History

1997
First studies
Rapid Prototyping

2007
First metal
development parts

2010
First machine:
Manufacturing of test parts
and toolings

2011
Step 1 production
site established

2013
First series part for
„PW1133G boroscope
boss“

2014ff
Stepwise increase
in capacity and
applications

Continuous expansion of manufacturing expertise and range of applications

Additive Manufacturing @ MTU

Available AM technologies for IN718

Freeform Fabrication

Powder Bed Based

Laser

Materials:
Ni-, Co-, Fe-, Al-, Ti-base

Typ. layer thickn. 20-40µm

Typ. Ra ~4-10 µm

Electron Beam

Materials:
Ti-base, TiAl, CoCr, IN718

Typ. layer thickn. 50-200µm

Typ. Ra ~20-25µm

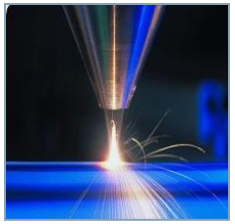
Powder Deposition

K3

Materials :
Ni-, Co-, Fe-, Al-, Ti-base

Material deposition on existing geometries (used for repair or addition of features)

LPD



Materials :
Ni-, Co-, Fe-, Al-, Ti-base

Material deposition on existing geometries (used for repair or addition of features)

Additive Manufacturing @ MTU

Additive Manufacturing Facilities

Rapid Prototyping @ MTU

- 1 Z-Printer Z650
- 1 RepRap X400

Additive Manufacturing @ MTU

- 6 EOSINT M280 production machines
- 1 EOS M290 technology machine

Materials

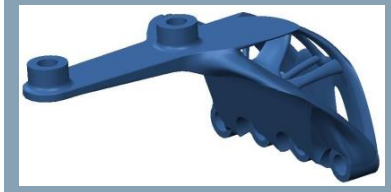
- **IN718**
- MAR-M509
- Stainless Steel 316L
- (Ti6Al4V)

►Necessity of identical **quality**, identical **material data**, higher **affordability** for **all machines**
►Increase of **build-rate** without **change of material data**
►Machine **improvements** at **constant quality**

Additive Manufacturing @ MTU

Roadmap: Phases of Implementation

Phase 3: New AM Design



Manufacturing of functional structures
to reduce weight and cost (bionic design)

Phase 2: Substitution

Cost effective manufacturing of raw parts
Substitution of castings

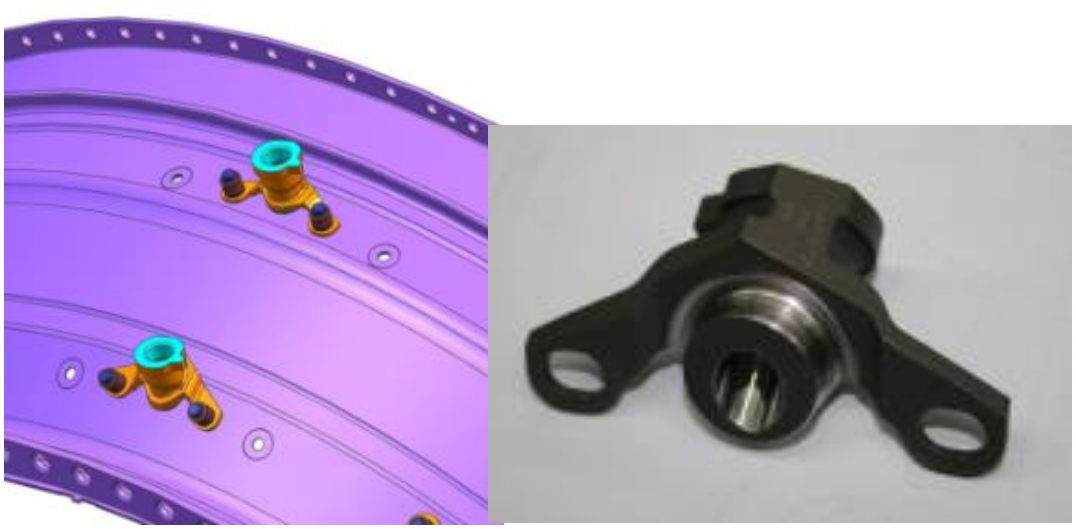
Phase 1: Tooling, Rig and Development

Manufacturing of tooling,
Rig- and development hardware

Additive Manufacturing @ MTU

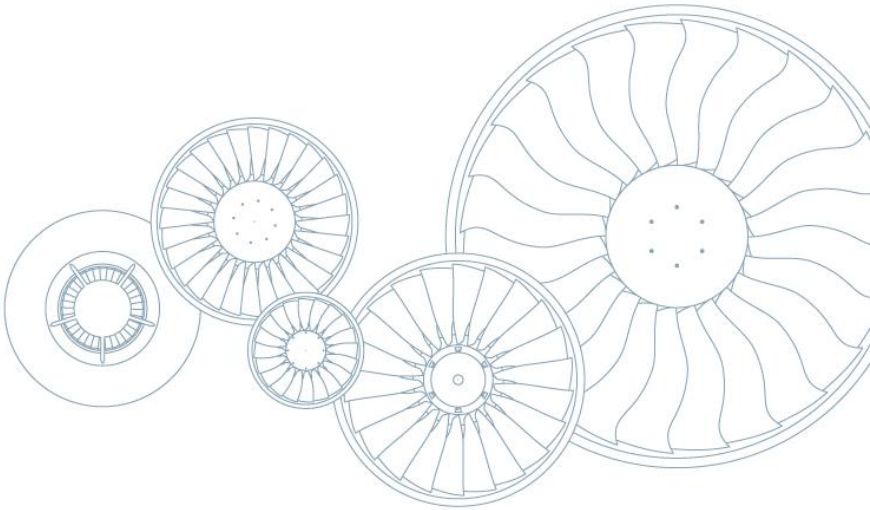
Roadmap: First AM-Production Parts

- Two part numbers per engine
- All development engines provided with AM parts
- Start of production in 2013
- Production ramp-up in 2016



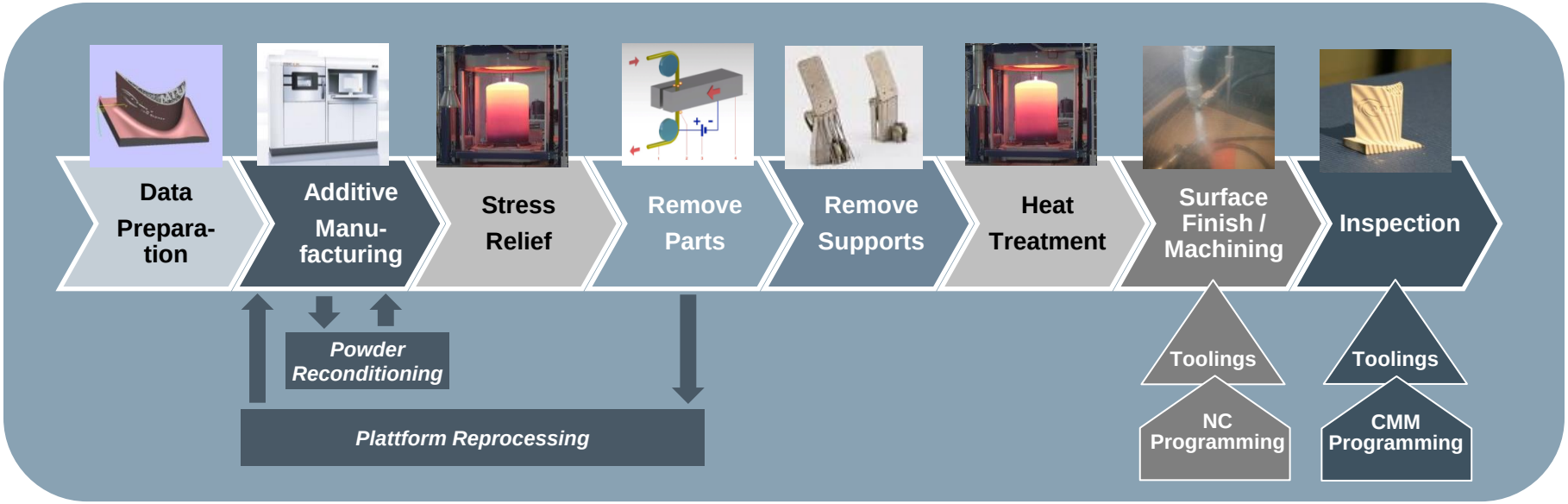
► **Serial production** of Boroscope bosses for the A320NEO has started

3. AM PROCESS CHAIN



AM Process Chain

Potential for improvements in the process chain



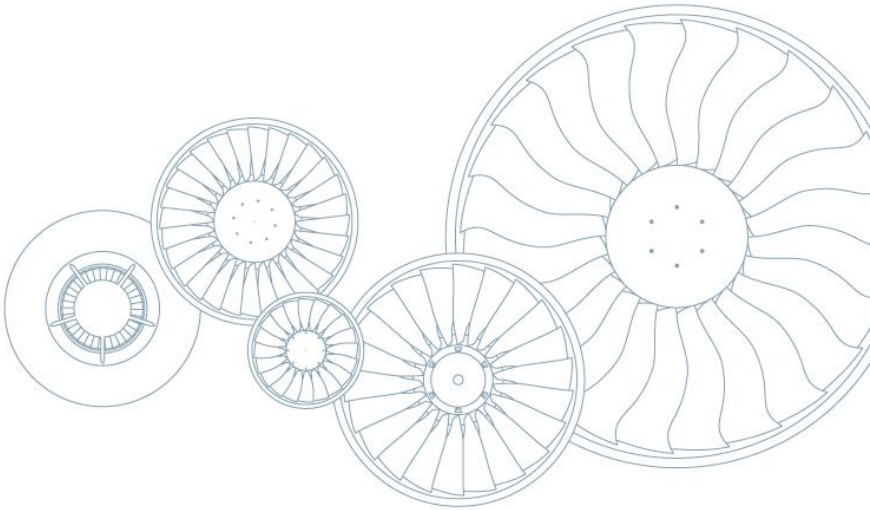
- **Potentials & required improvements**

▪ Aut. Support generation ▪ Link to ERP systems	Increase ▪ Productivity ▪ Quality ▪ Automation	▪ Increase batch size	▪ Reduce time / cost	▪ Reduce/ Eliminate effort	▪ Increase batch size	▪ Adapted machining concepts	▪ Integrate in process chain

► **Complete process chain has to be optimized**

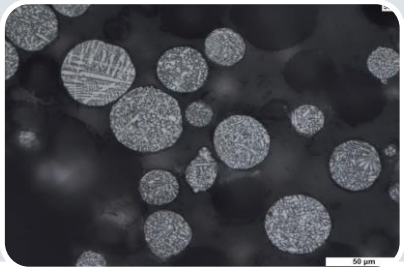
► **Big potential in optimizing downstream processes**

4. QUALITY ASSURANCE



Quality Assurance

QA Concept



QA Raw Material / Powder

Supplier

- Inspection Certificate

MTU

- Incoming goods inspection
- Requalification of used powder

QA Production Line

System suitability test

- Total Productive Maintenance
- Machine Calibration
- Machine Approval

QA Process

Process Monitoring

- **Online Tomography**
- EOState

Oxygen

- Pressure
- Z-Axis positioning
- Collisions during recoating
- Platform temperature

QA Part

Component testing/ NDT

- Visual testing
- FPI
- X-Ray
- CMM / Blue light
- Test Bars
- Sacrifice Parts

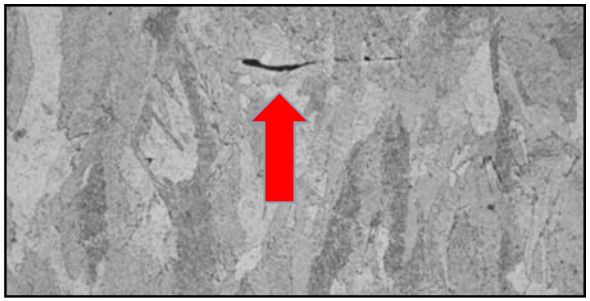
Pre-Process QA
Total Productive Maintenance

- Total Productive Maintenance established at all Machines

Quality Assurance

Rare defects

- Cannot be detected with conventional NDT



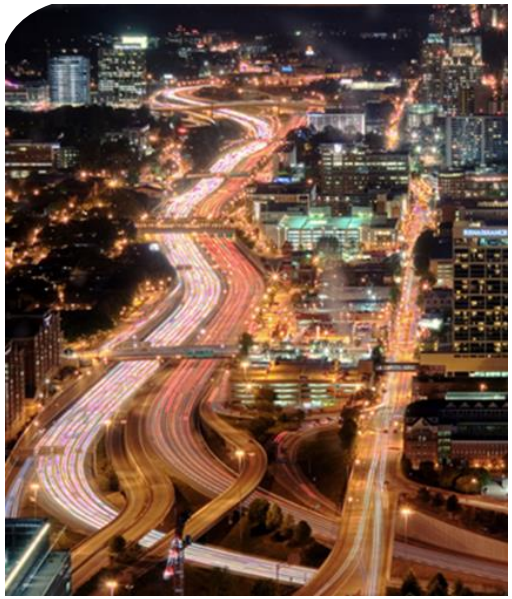
Lack of fusion

- Inside the part → No FPI
- Complex 3D-geometries → No US
- Flat → No X-Ray

► Online Process Monitoring needed
► Inspection of every single layer

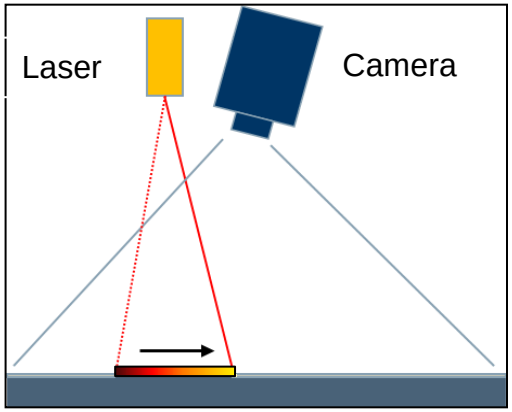
Quality Assurance

Optical Tomography



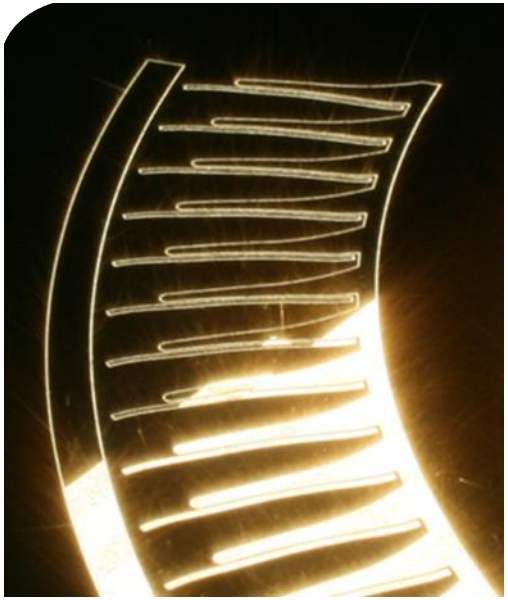
Long time exposure of urban traffic

→ traffic volume



Brightness in the picture equals radiance x time

→ Measurement for energy input / distance energy

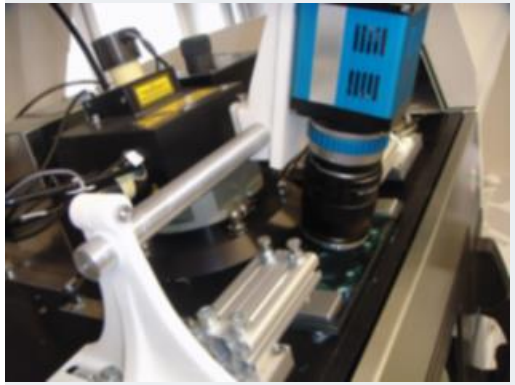


Long time exposure in additive manufacturing

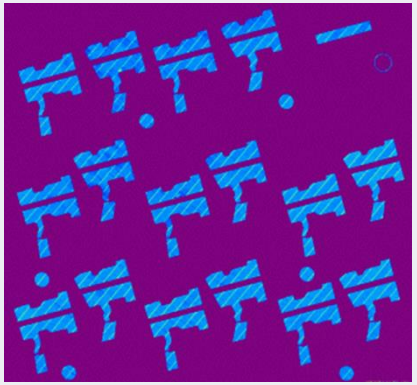
→ amount of heat

Quality Assurance

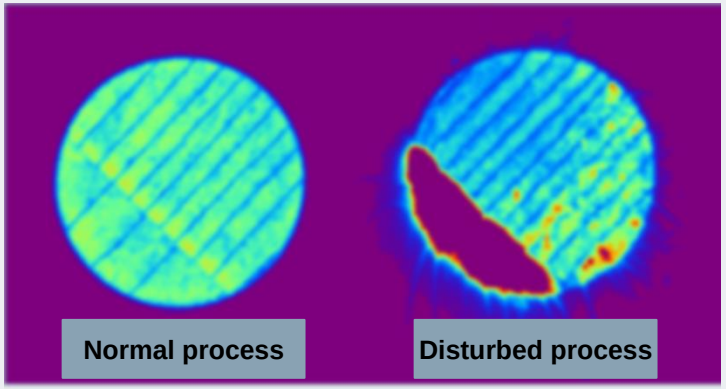
Optical Tomography

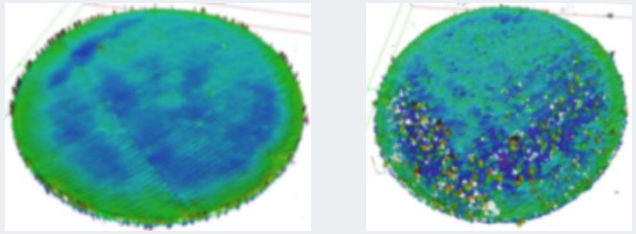


OT-System installed on every machine



Process surveillance for each layer of a job entirely





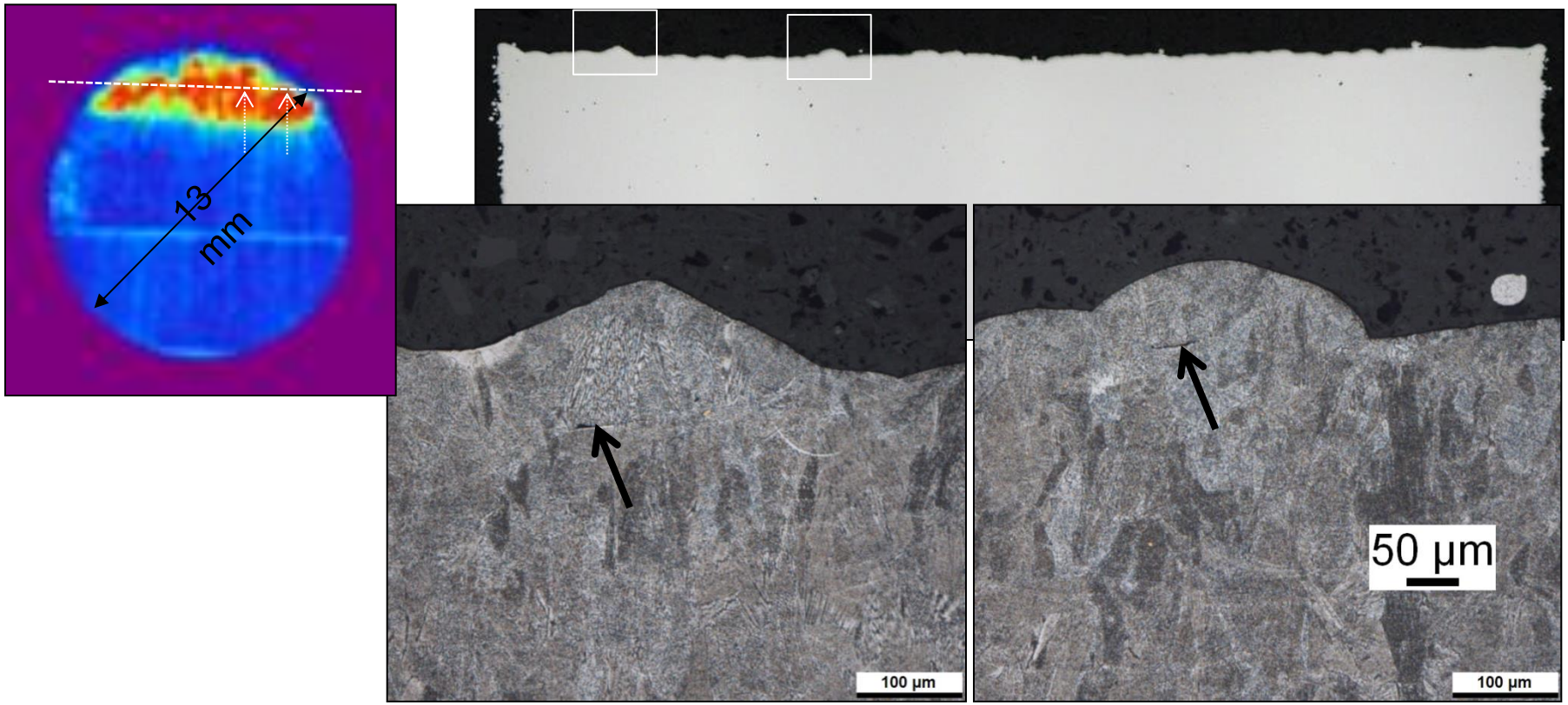
Correlation between OT-surveillance picture and the process discrepancy

- Complete monitoring of every single layer
- OT has been successfully **introduced for the first serial parts**

Quality Assurance

Optical Tomography

Lacks of fusion caused by process disturbance

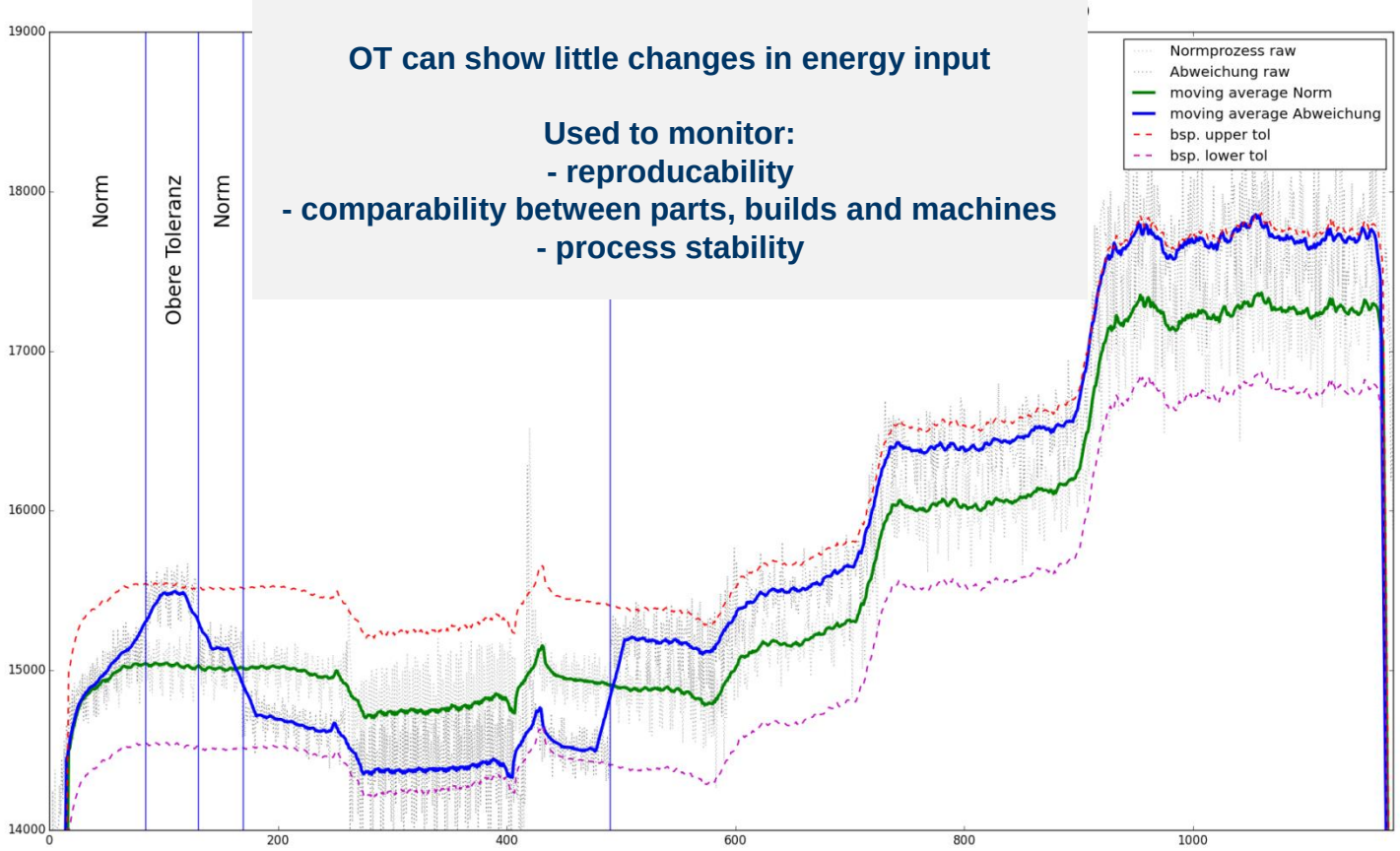


Quality Assurance

Optical Tomography

OT can show little changes in energy input

Used to monitor:
- reproducability
- comparability between parts, builds and machines
- process stability



In-Process QA

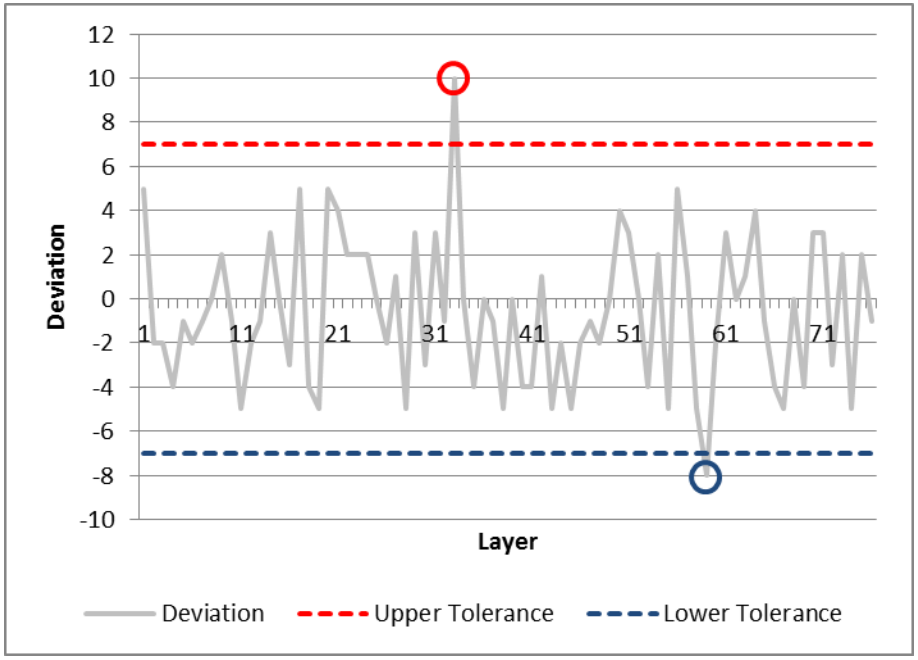
Monitoring of the Recoating Process

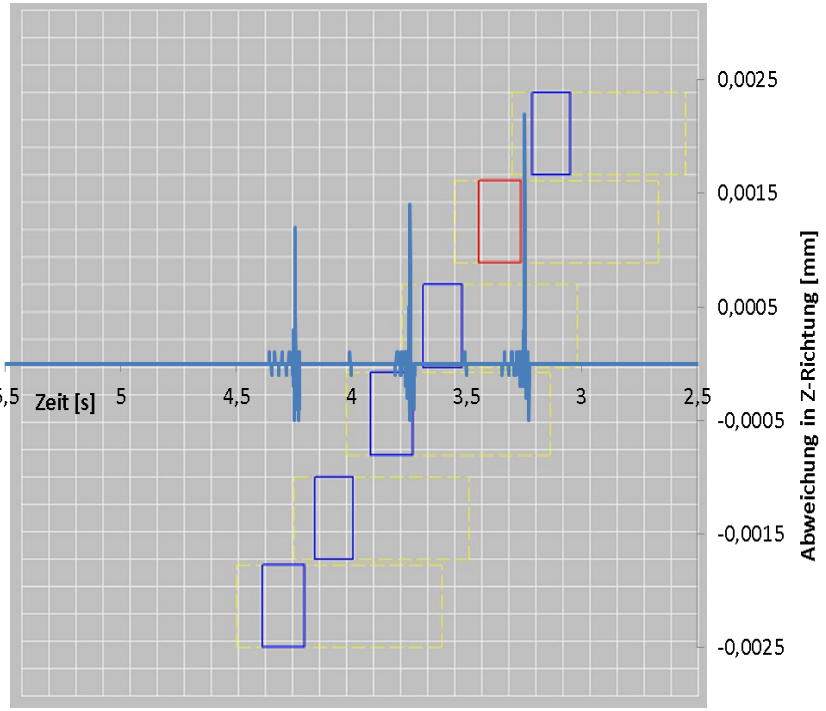
Platform position during Recoating:

→ Ensure powder thickness

Platform position during Positioning:

→Ensure free of collision recoating

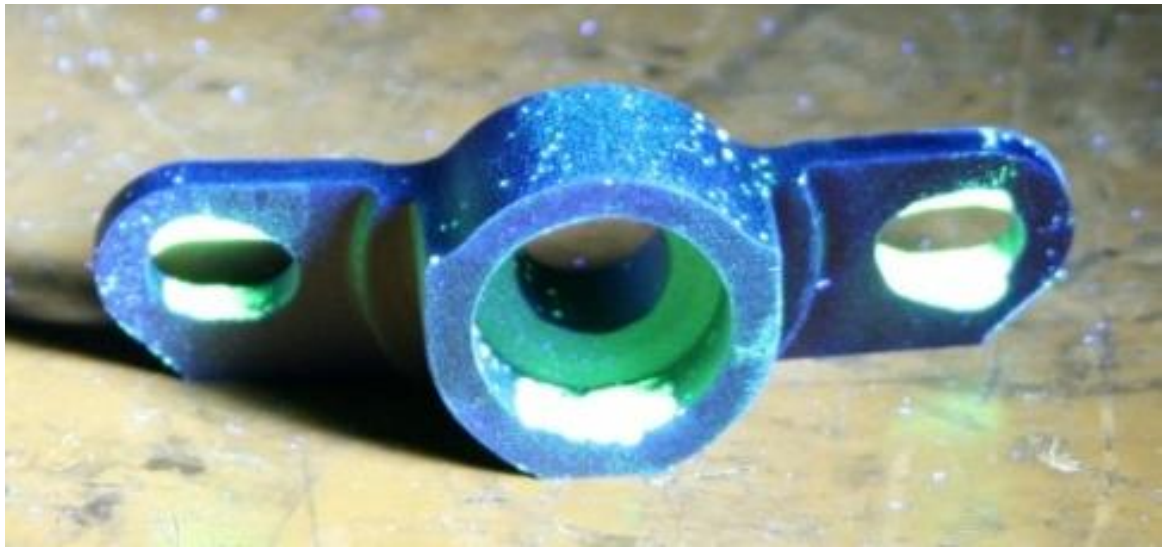




QA (Part)
FPI

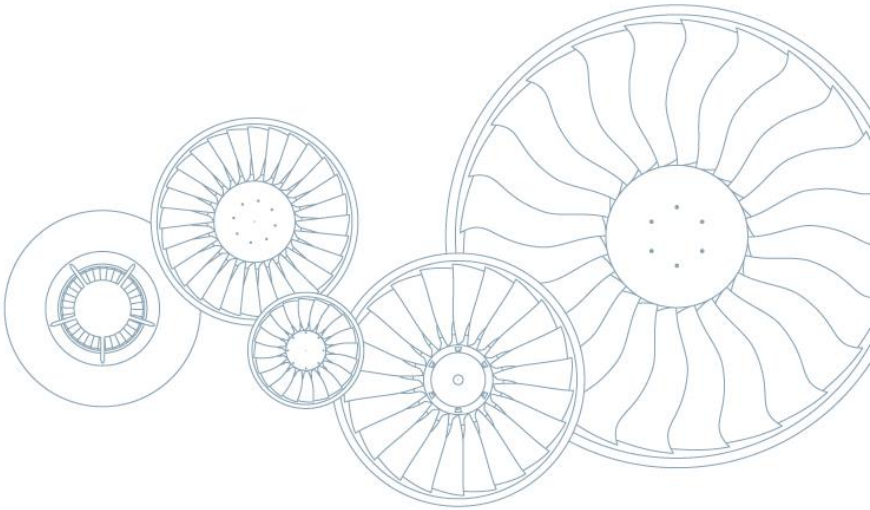
- Porosity
- Cracks (surface)

Test part with background fluorescence (early development phase)



► Background fluorescence has been reduced for FPI

5. FUTURE CHALLENGES



Challenges and Expectations

Internal challenges

- Further development of quality assurance
- Extend AM part portfolio
- Establish design rules and layout of light weight construction
- Integrated AM-production facility

Expectations towards market

- Comparability between machines
- Increase of quality and productivity
- Further development of the complete process chain
- Exchange of knowledge about critical defects
- Common material and process parameter data base



THANK YOU VERY MUCH FOR YOUR ATTENTION