

# Process Monitoring as online tool for Quality Assurance

06.11.2019, Alexander Altmann, Liebherr-Aerospace Lindenberg GmbH

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**LIEBHERR**

# Liebherr – a family business



The family shareholders active in the Group (from left to right):

Jan Liebherr, Stéfanie Wohlfarth, Sophie Albrecht, Philipp Liebherr, Patricia Rüb, Johanna Platt, Isolde Liebherr and Willi Liebherr

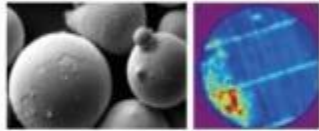
11/14/2019

**LIEBHERR**

# Additive Manufacturing by Liebherr-Aerospace


**2010**

Start research work




Powder, heat treatment, parameters, monitoring, etc.

**2015**

Machine for Titanium 



Machine for Nickel & Aluminum 


Build up teams for AM




**2017**

Process Qualification



LBA approval & Titanium qualified 

Nickel qualified 

**2018**

Additional machine & boost of AM team for start of production



**2014**

100 + Prototypes  
Manufacturing & Testing



**2016**

Flight Test on A320 & ATR 600  
First parts of air management system



**2017**

Flight Test on A380  
First hydraulic part on primary flight control system



**2018**

Serial production of parts



# Roadmap for AM Aerospace Applications



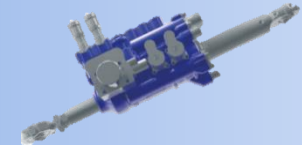
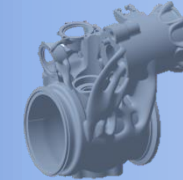
Air Systems



Hydraulic Systems  
Landing Gears

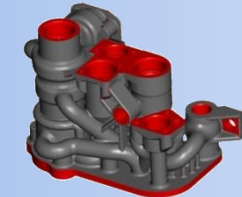
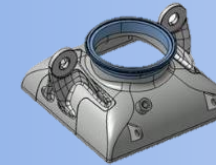
+ **Volume**

**Multifunctional systems**  
**Class 1 & 2**



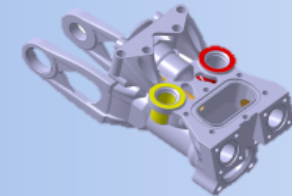
+ **Criticality**

**Critical & high complex**  
**Class 1 & 2**  
**High fatigue**



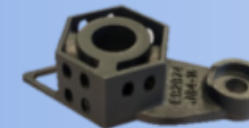
+ **Complexity**

**Non critical fluid carrying**  
**Class 2**  
**Low fatigue**



**Industrial  
Certification**

**Non critical**  
**Class 2 & 3**  
**No fatigue**



AM Product Portfolio

2018

# First Production Parts



**Sensor Bracket  
for Landing Gear**

Weight reduction:



Increased stiffness:



Conventional Design



Additive Manufacturing Design

## A350 Nose Landing Gear

- Modification in approval process
- Qualification tests passed
- EIS End 2018



**ATR Bleed valve  
locking device**

Weight reduction:



Conventional Design



Additive Manufacturing Design

## ATR 42/72 NAMS

- Qualification test passed
- First Flight January 2019
- EIS End 2019

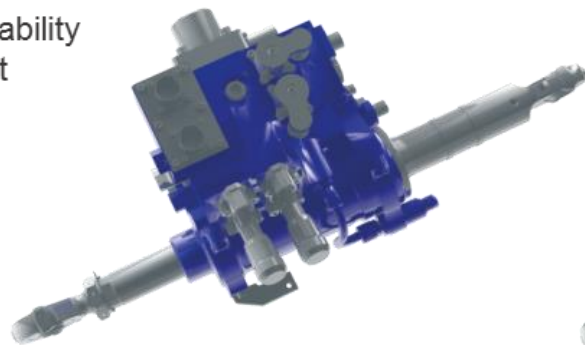
# Vision, Integrated Actuators and Valves

- Improvement of system reliability
- Reduction of assembly cost

Weight reduction:



Compact design space  
for thin wing applications:



Conventional Design



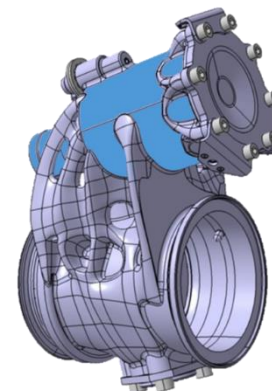
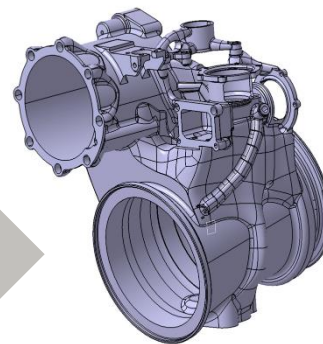
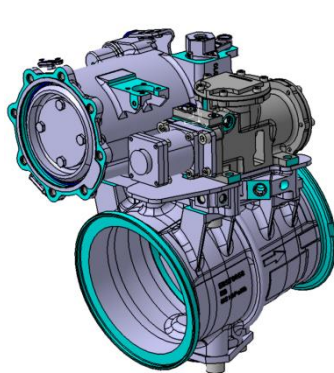
Additive Manufacturing Design

- Better integration and compactness of internal functions
- Cooling functions embedded
- Improved stress capacity for engine vibrations

Weight reduction:

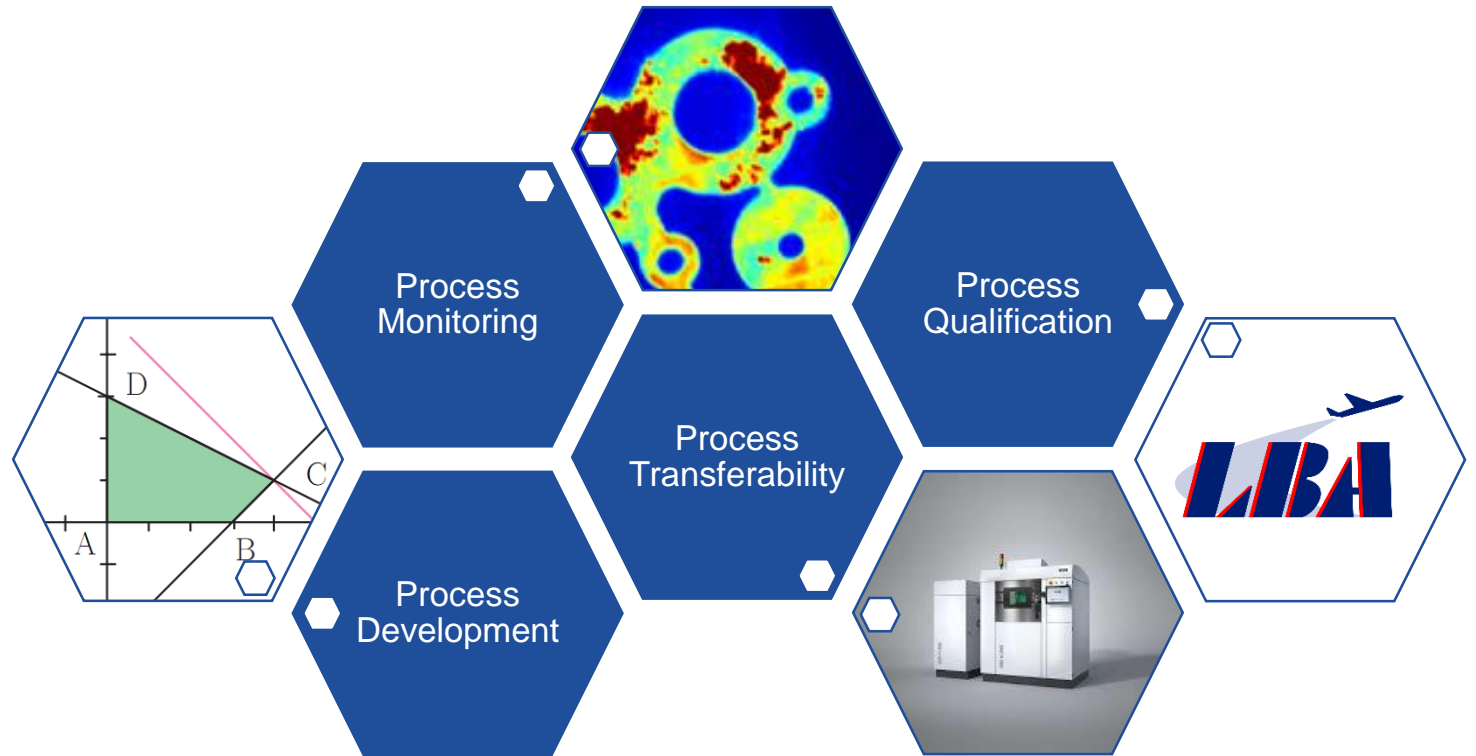


Cost reduction target:

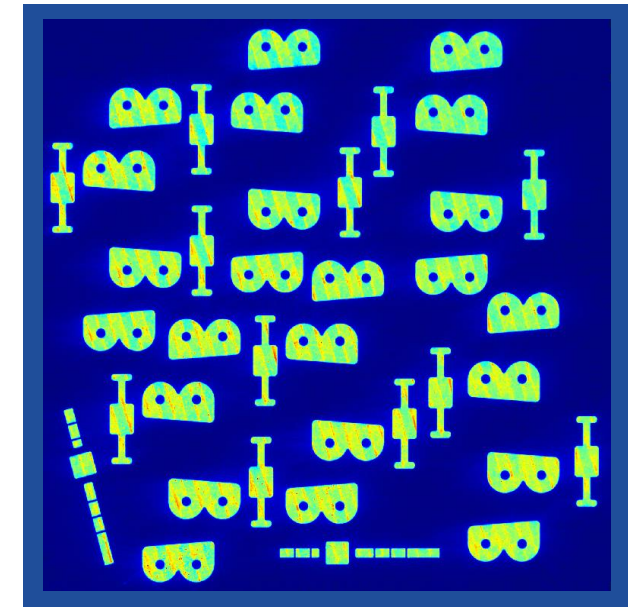
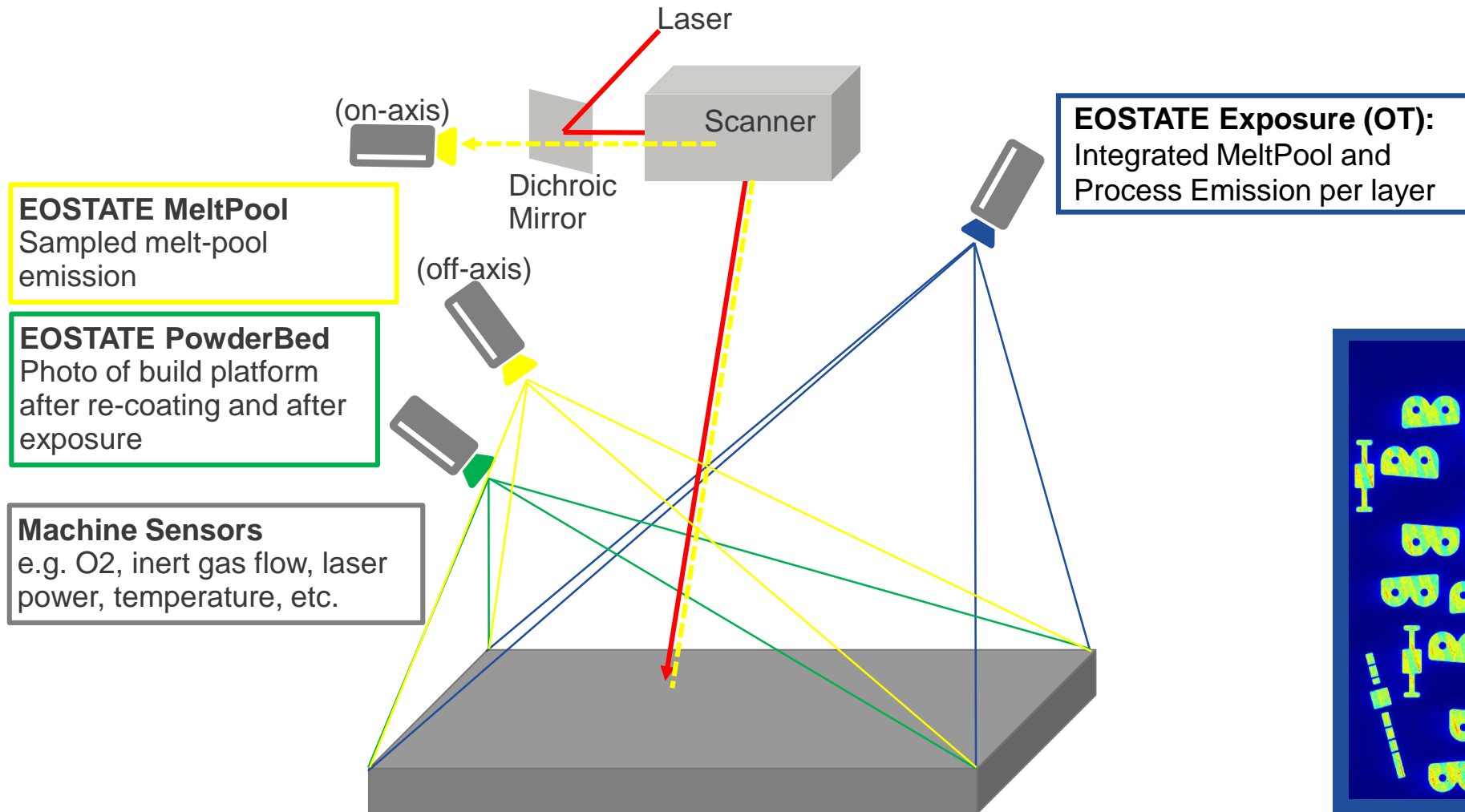


# Motivation for Online-Monitoring

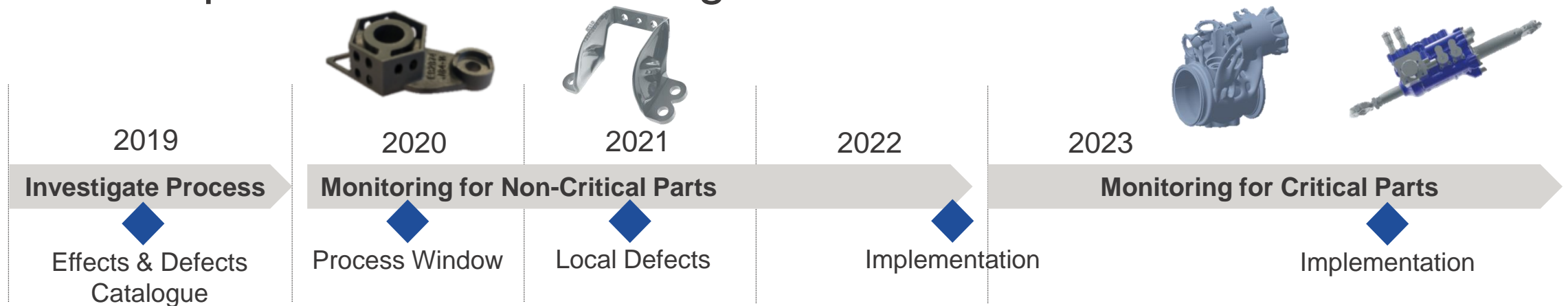
- Reduction of cost per part – NDT
- Enabling complex parts
- Deep insight into building process
- Process transferability



# Online-Monitoring Systems

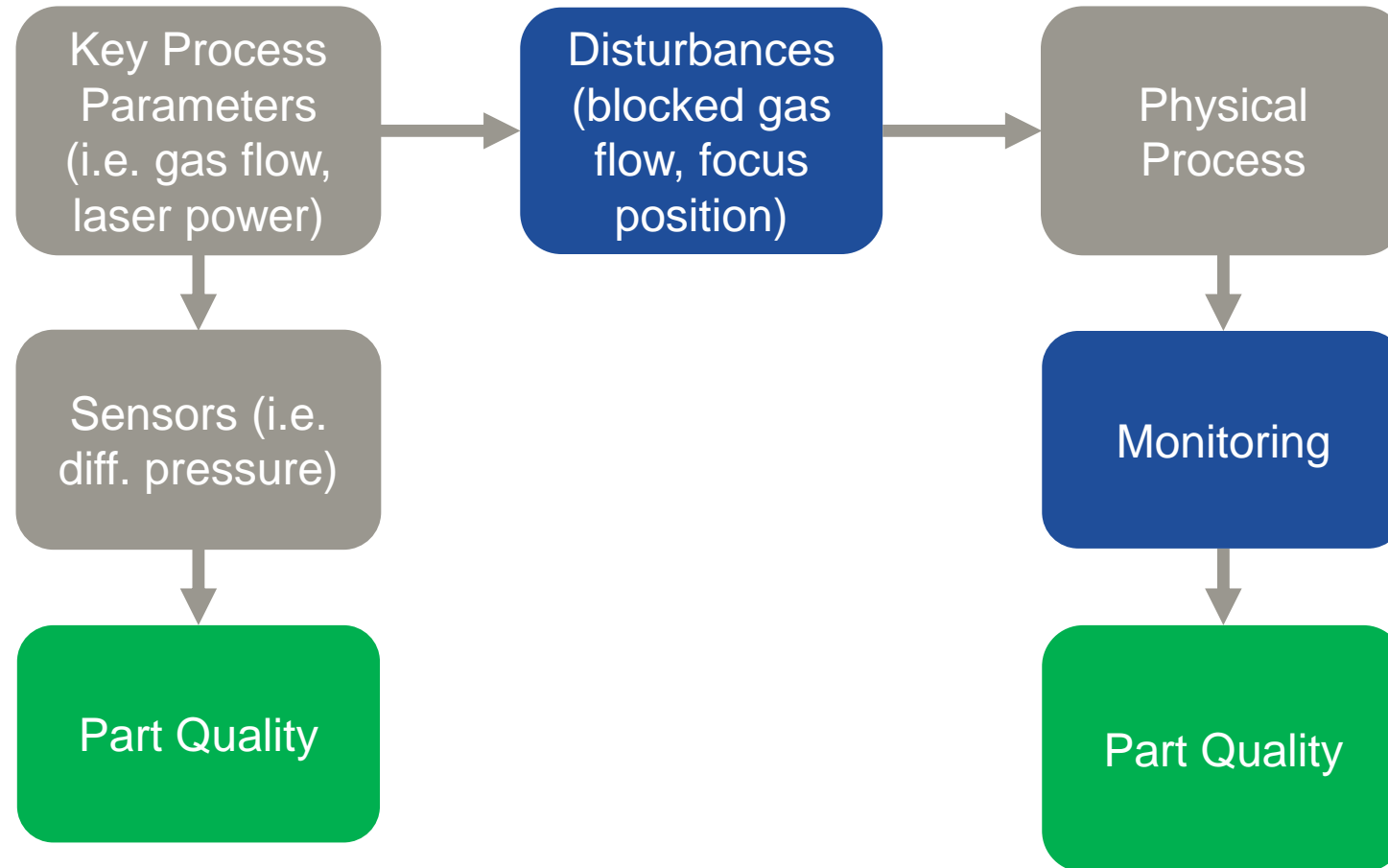


# Roadmap for Online-Monitoring



- **Effects & Defects Catalogue:** Knowledge of all relevant effects and defects regarding Online-Monitoring
- **Process Window:** Monitoring using a baseline and sensor data fusion
- **Local Defects:** Find and classify relevant local defects
- **Non-Critical Parts:** Implementation phase
- **Critical Parts:** Implementation phase

# Importance of Online-Monitoring

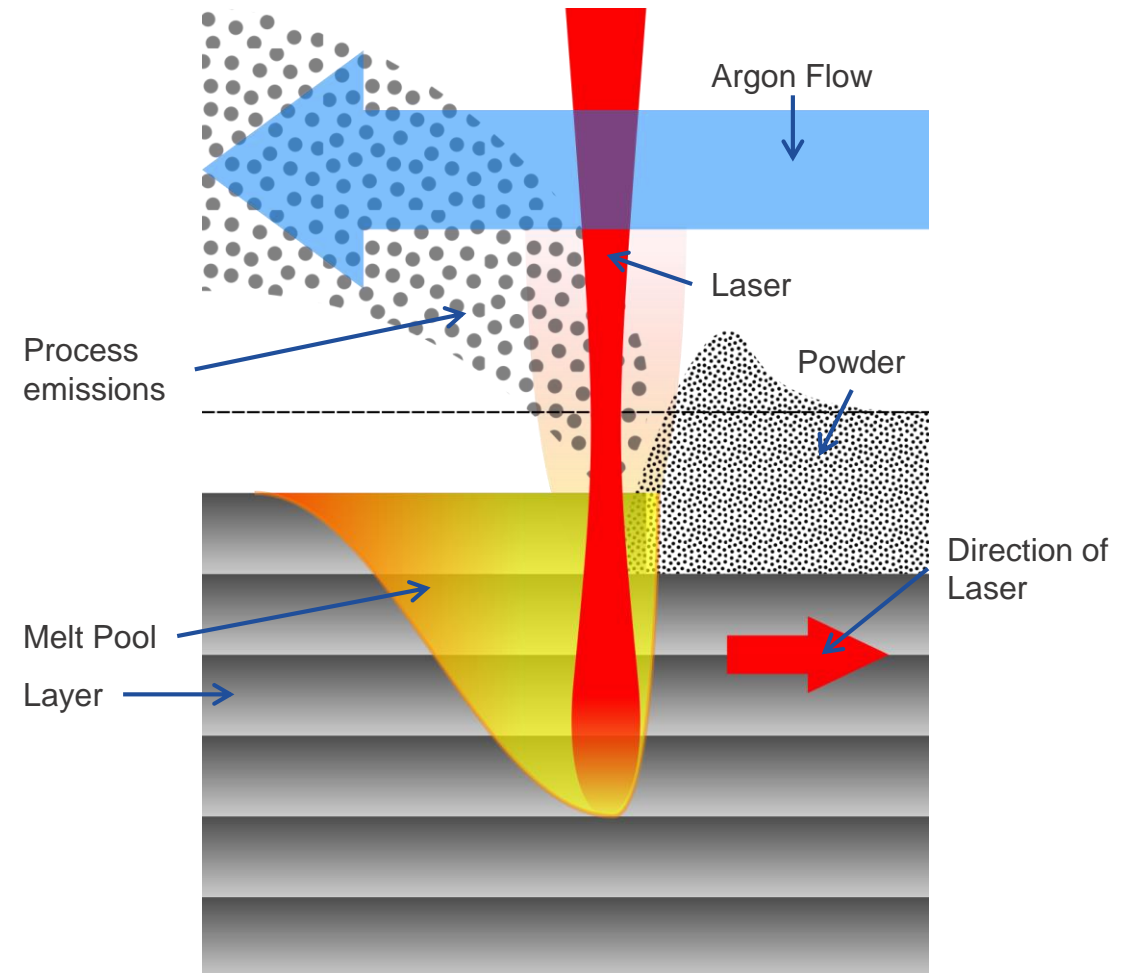


# Process Influences

- Laser Power
- Hatch Distance
- Laser Scanning Speed
- Focus Position
- Argon Flow
- Layer Thickness
- Temperature
- ...

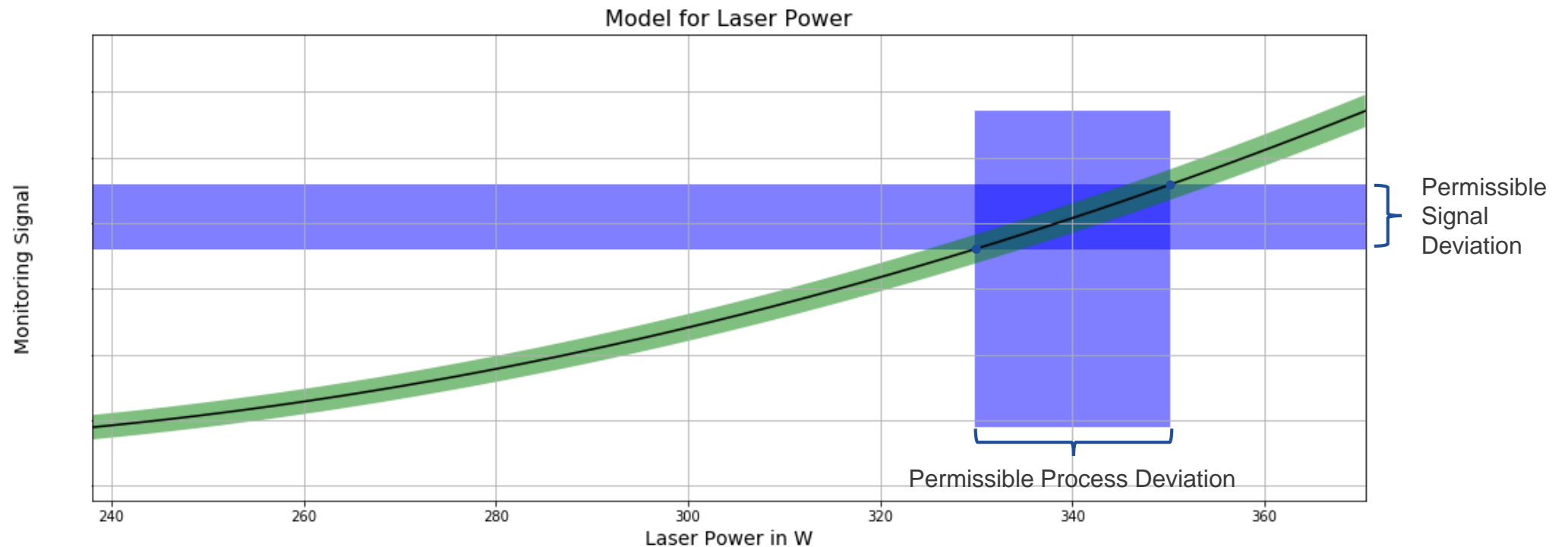
➔ Each parameter has permissible window

➔ Deviations cause defects



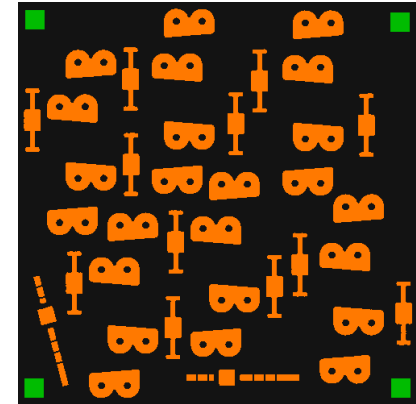
# Online-Monitoring Sensitivity To KPPs

- Online-Monitoring signal is sensitive to KPPs
- Using the permissible deviation of the process to calculate permissible deviation of the online-monitoring signal



# Non-Critical-Parts - Monitoring of process by reference

- Fusion of different sensors
- Compare parts to reference/fingerprint
- Observe relevant defects
- Track performance of jobs/parts over time

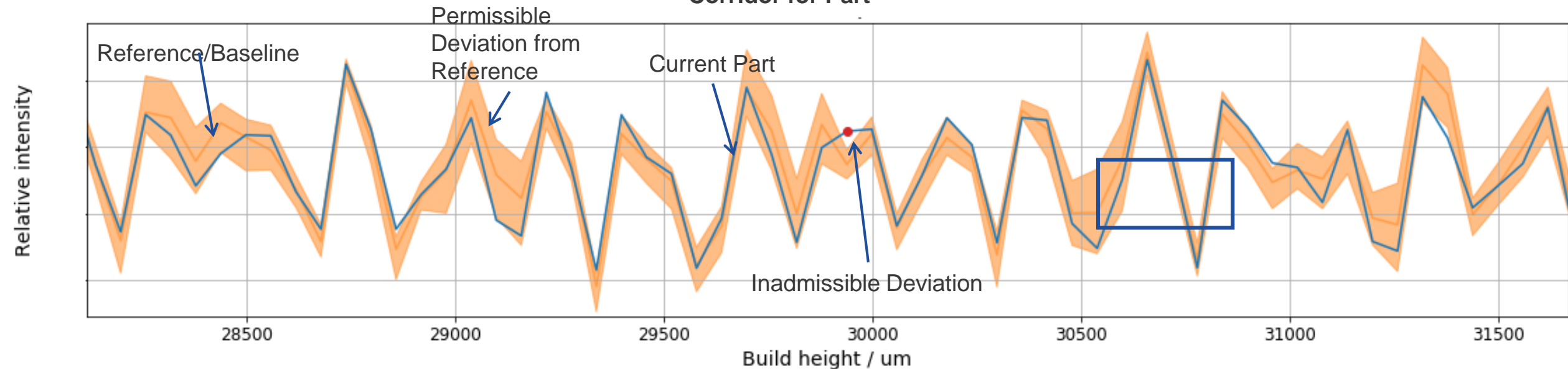


Reference  
Geometries

+

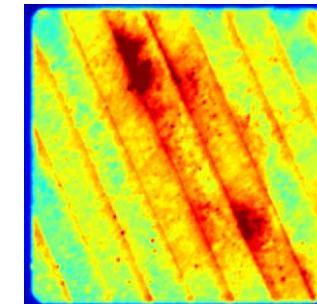
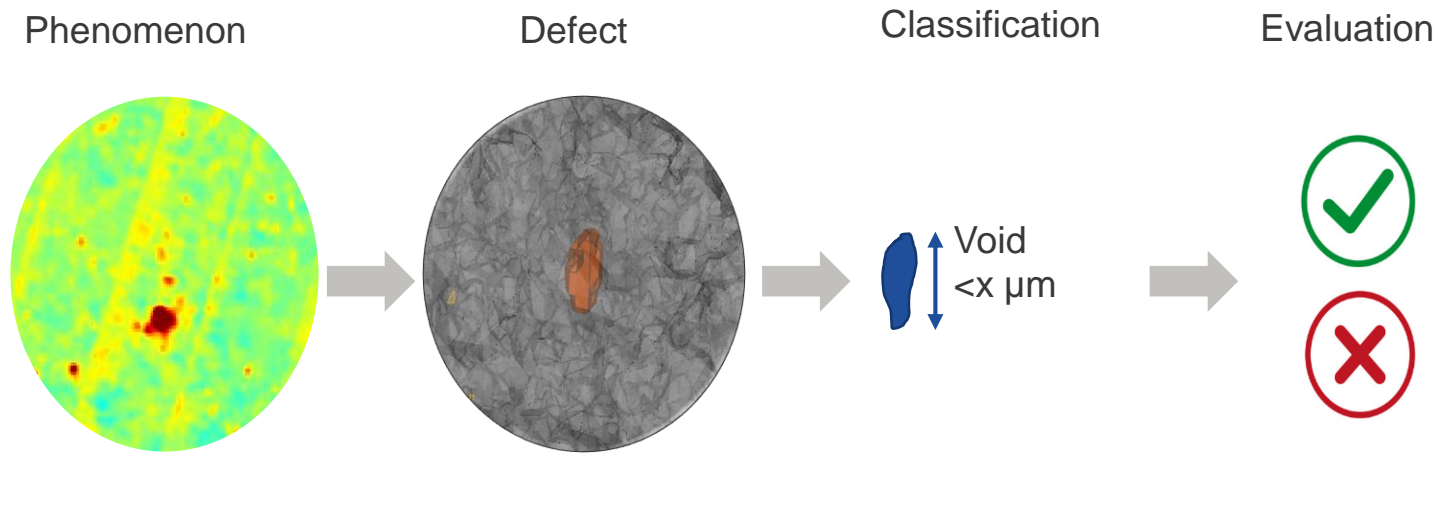
Parts

Corridor for Part

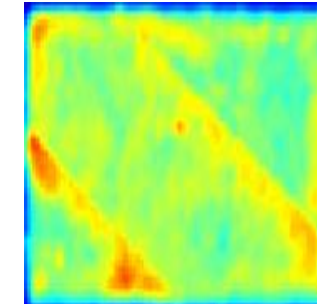


# Critical-Parts – Monitoring of process and local defects

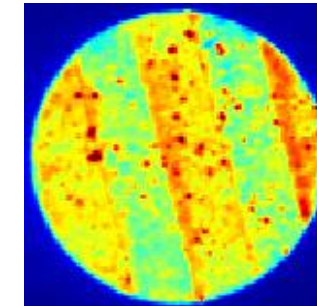
- Required:
  - Extensive knowledge about all relevant phenomena and defects
  - Detection and classification relevant of **local defects**



Laser scattering  
on smoke



Local  
overheating due  
to short vectors



Balling effects

# Summary & Challenges

## Summary

- Monitoring is sensitive to KPPs and can be used for QA for non-critical parts

## Challenges

- „Proof of Concept“ for local defects and critical-components
- Maturity of available monitoring products
- Data management
- Standardization and acceptance (authorities and customers)

# Ni718 - Robustness of additive manufacturing

06 November 2019

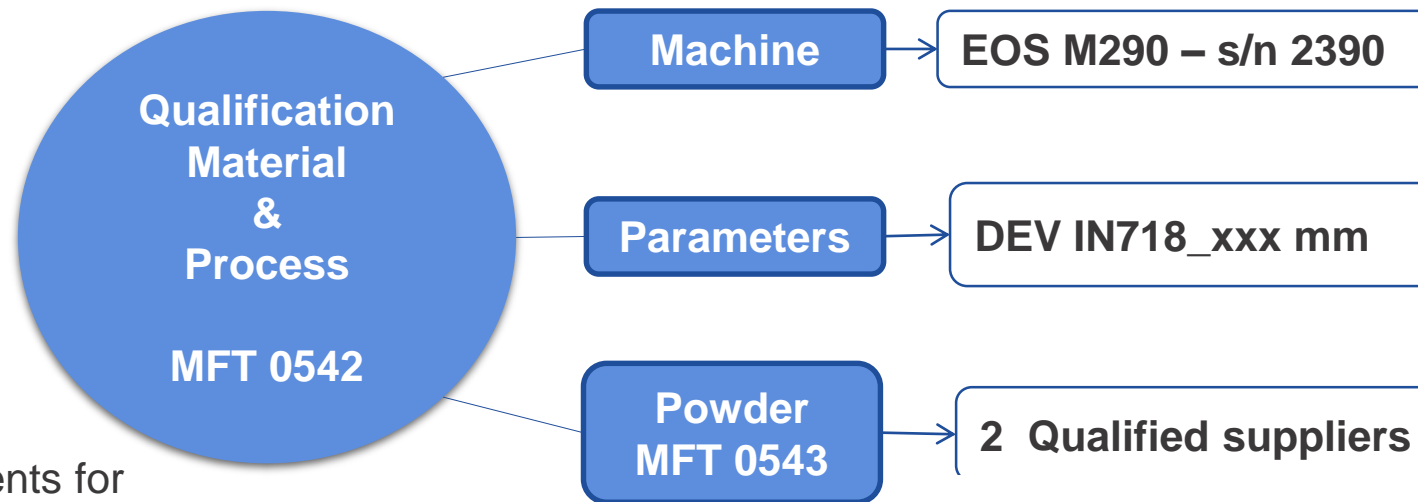
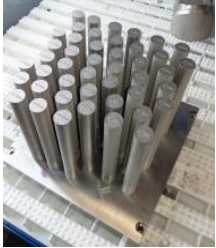
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**LIEBHERR**

# Nickel Alloy 718 - Process Qualification

Additive Manufacturing = Special process

Internal Liebherr Quality Standards



## MFT 0542

Defines the requirements for the Materials / Processes qualification applied to AM

## MFT0543

Defines requirements for the development, supply, storage and control of metal powders for AM

General	AM-System		Part inspection	Process chain
AM-Design Guideline ✓	AM-Operation Manual ✓	AM-Periodic Check of Key Process Parameters ✓	WI Microscopy and Determination of Porosity ✓	AM-Surface Finish Ti Alloys ✓
Powder Procurement ✓	AM-Process Qualification ✓	AM-Serial Testing ✓	Penetrant Testing ✓	HIP von AM-Ti6Al4V ✓
FMEA for EOS M290 ✓	AM-Process Parameters ✓	AM-Maintenance Manual ✓	X-Ray Examination ✓	
			Digital Radiography ✓	

# Ni 718 - Qualification material test results

## Tensile tests

- 50 test specimens tested
  - As build, machined, with and without heat treatment (HT)
  - Several building axes X,Y, Z,45° ⇒ lowest values in vertical axe (Z)
- Test results after HT and build following Z axe

**UTS : 1332 MPa (+7% to ASTM F3055 )**

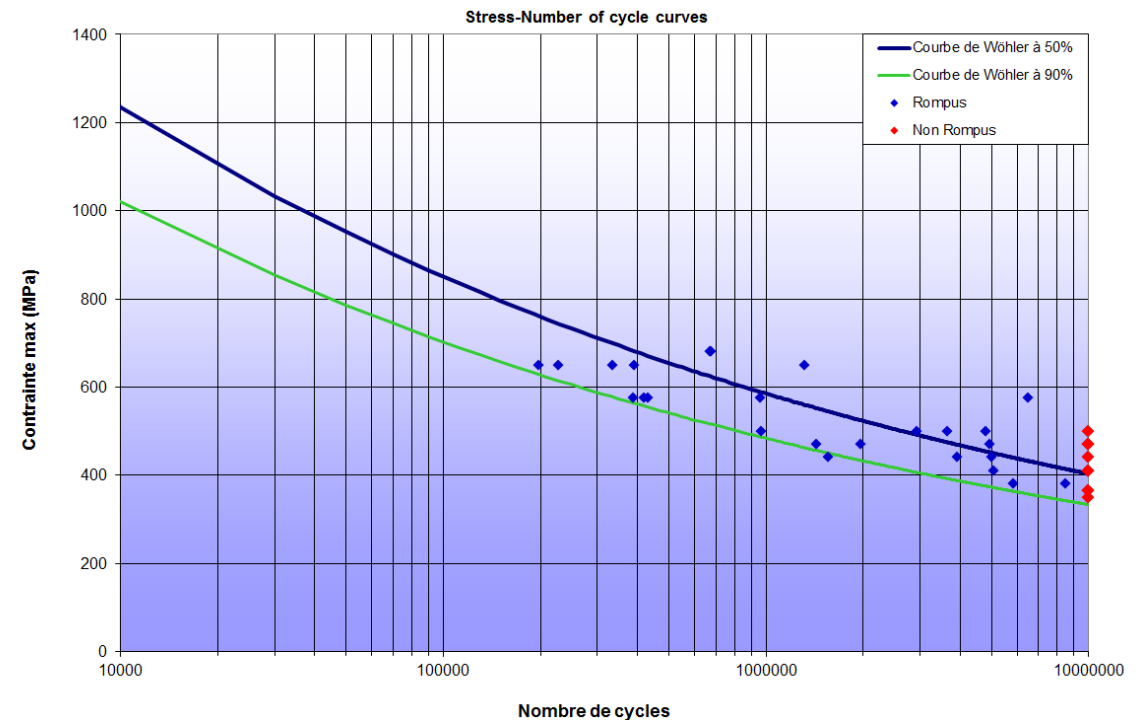
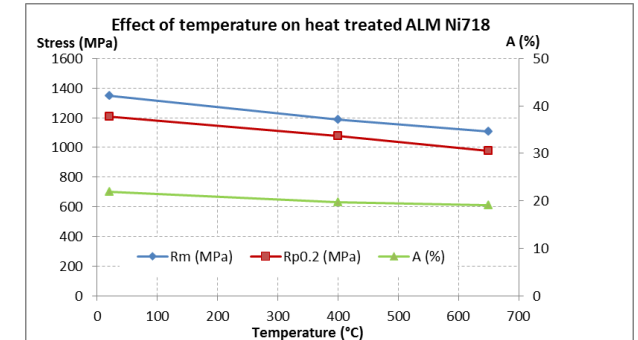
**YTS : 1084 MPa (+17% to ASTM F3055 )**

**A : 21% (+57% to ASTM F3055)**

Dispersion < 1% (and consistent with our current database)

## Fatigue tests (machined sample)

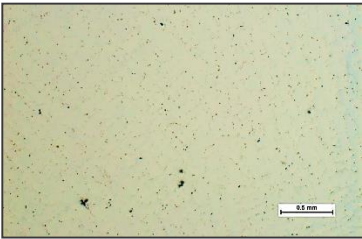
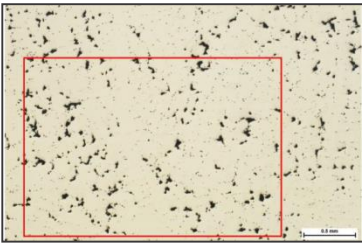
- 40 specimens tested
  - + 23% to casting specimens



# Ni718 AM versus casting

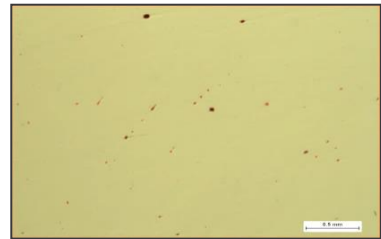
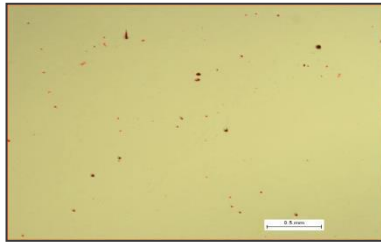
## Ni718 Porosity

**Casting**



Porosity level  
1 to 3%

**AM**



Porosity level  
< 1%

Ni 718	Casting	AM	
UTS	827 MPa	1332 Mpa	+61%
YTS	724 MPa	1084 MPa	+49%
Fatigue limite (90%)	270 MPa	333 MPa	+23%

# Vibration test results on AM part

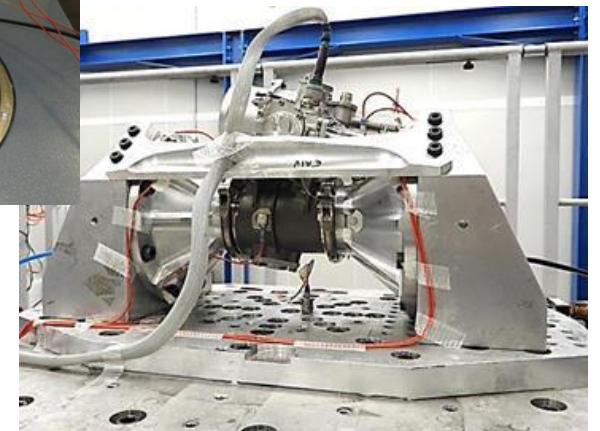
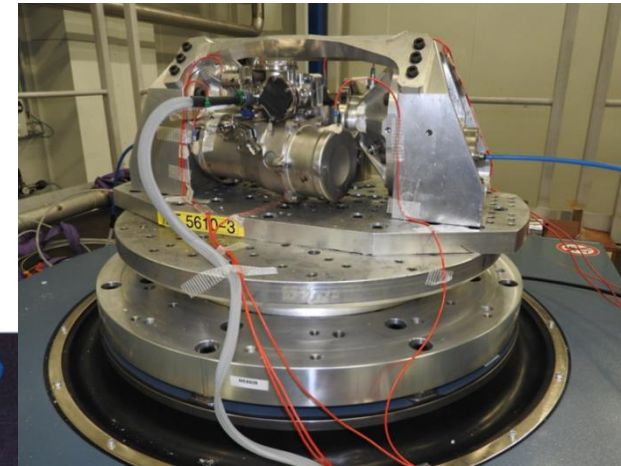
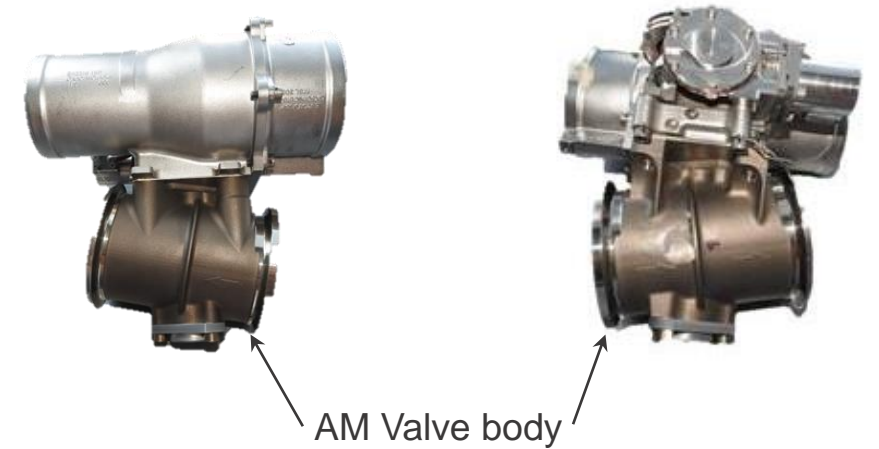
Engine Bleed Valve with valve body manufacture in Ni718 AM

Same design like casting part

Vibration level applied : **42.9 Grms - 5hr / axe**

## Criteria of success

- Resarch of resonance frequency
- Leak test
- Fonctional test
- Penetrant test



# Conclusions and Way forward

## Conclusion

- Very low scatter of mechanical properties of Ni718.
- Material properties of Ni718 manufactured by AM better than casting
- Hard vibration test passed successfully on a valve body manufactured by AM
- For serial production : Despite these promising results quality controls of final parts are required

## Way forward

- Study in progress to assess the impact of KPP variation on scatter- Today's results are promising
- Effect of surface roughness and surface finishing on fatigue properties to be evaluated