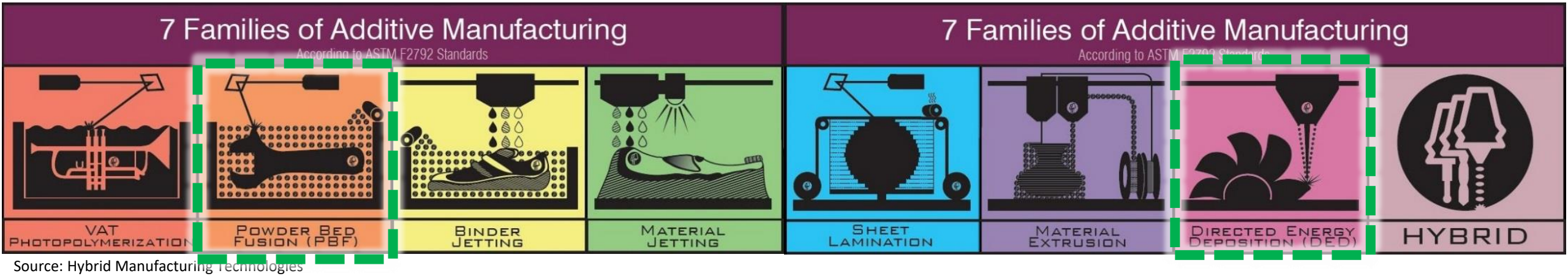
Additive Manufacturing & AM at Moog

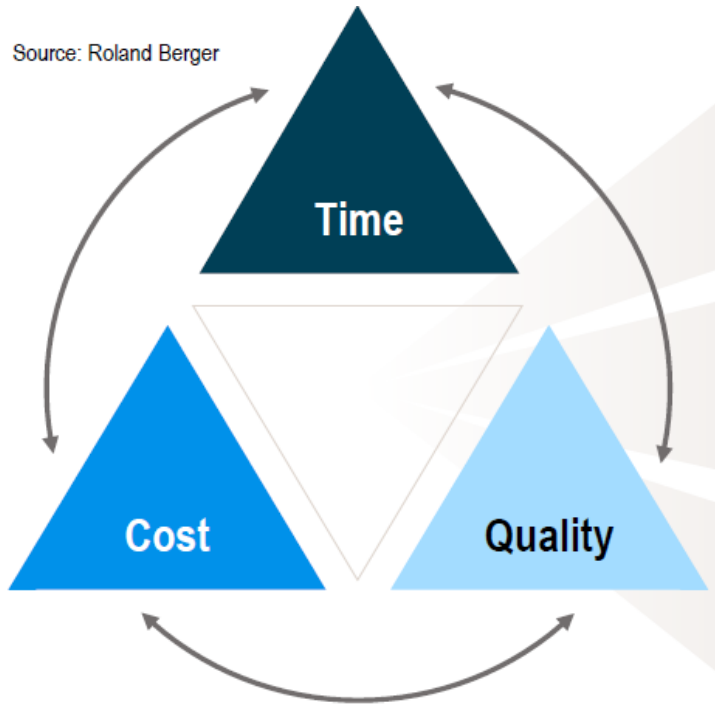
Additive Manufacturing Technologies



Source: Hybrid Manufacturing Technologies

Polymers **Metals** **Ceramics** **Composites**

Source: Roland Berger



Time

Multi-laser/multi-spot concepts as well as full powder-bed illumination increase the number of melt pools and therefore reduce the processing time – Hybrid applications as a further alternative

Cost

Increased degree of automation as well as continuous production concepts further reduce the labor intensity and thus the cost

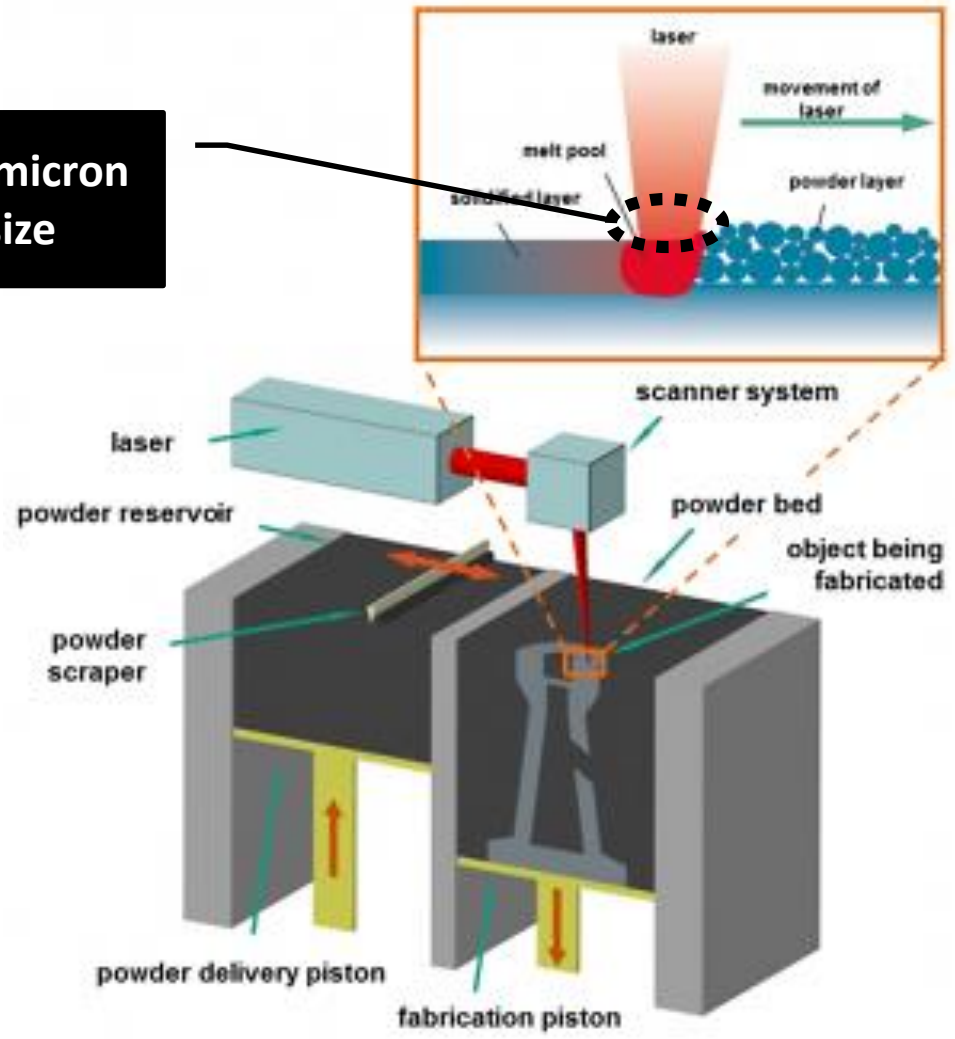
Quality

Different process monitoring systems (powder, atmosphere, coating, etc.) enable increased part quality

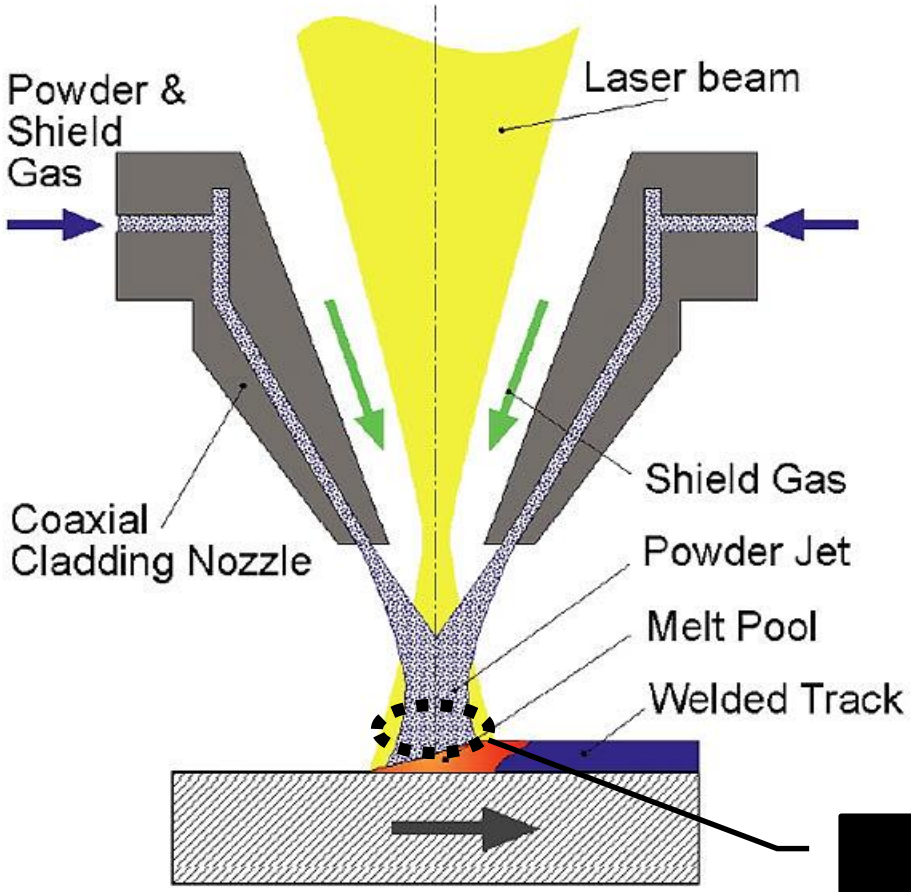
Metal AM – Aerospace Industry & Moog Focus

Laser Powder Bed Fusion (LPBF)

30 – 160 micron spot size

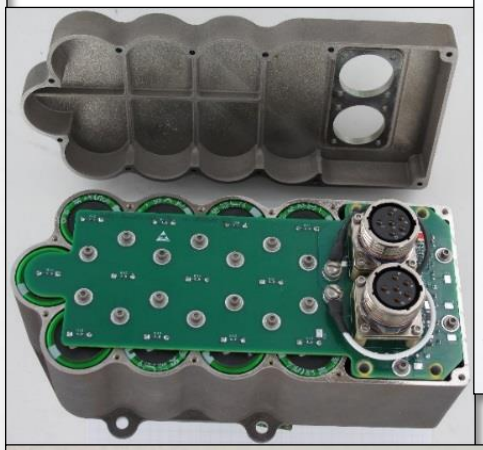


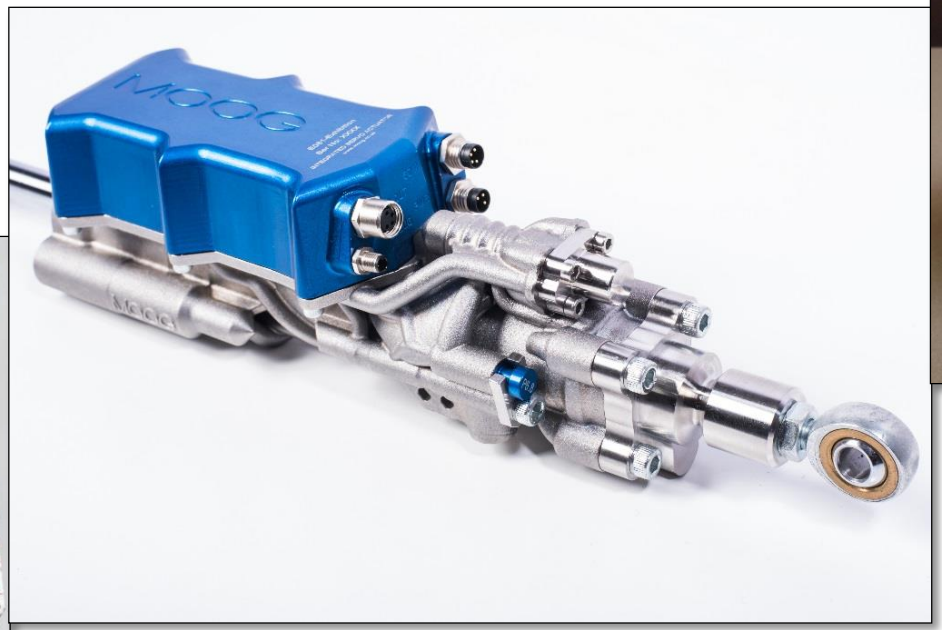
Directed Energy Deposition



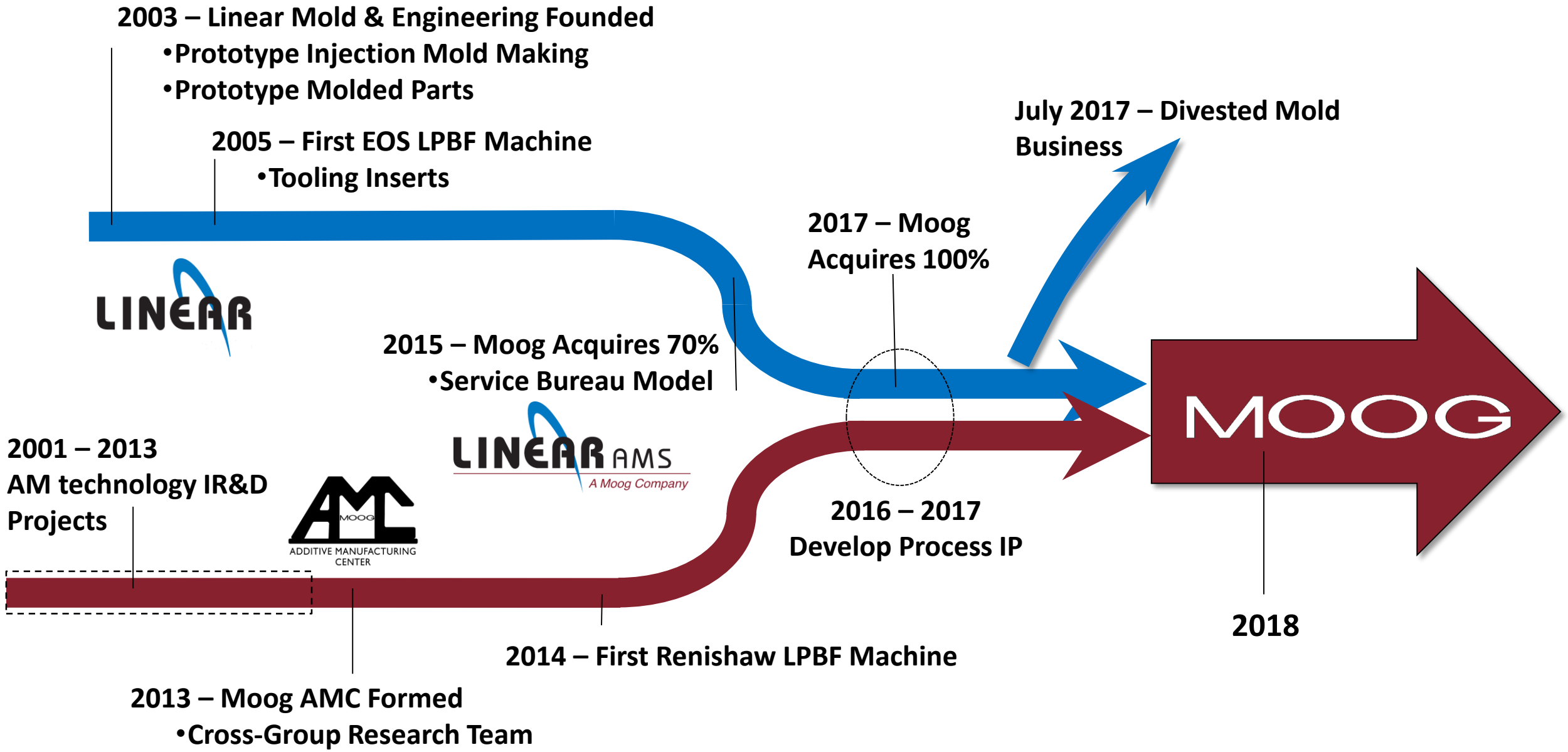
100 - 2500 micron spot size

Complex Parts



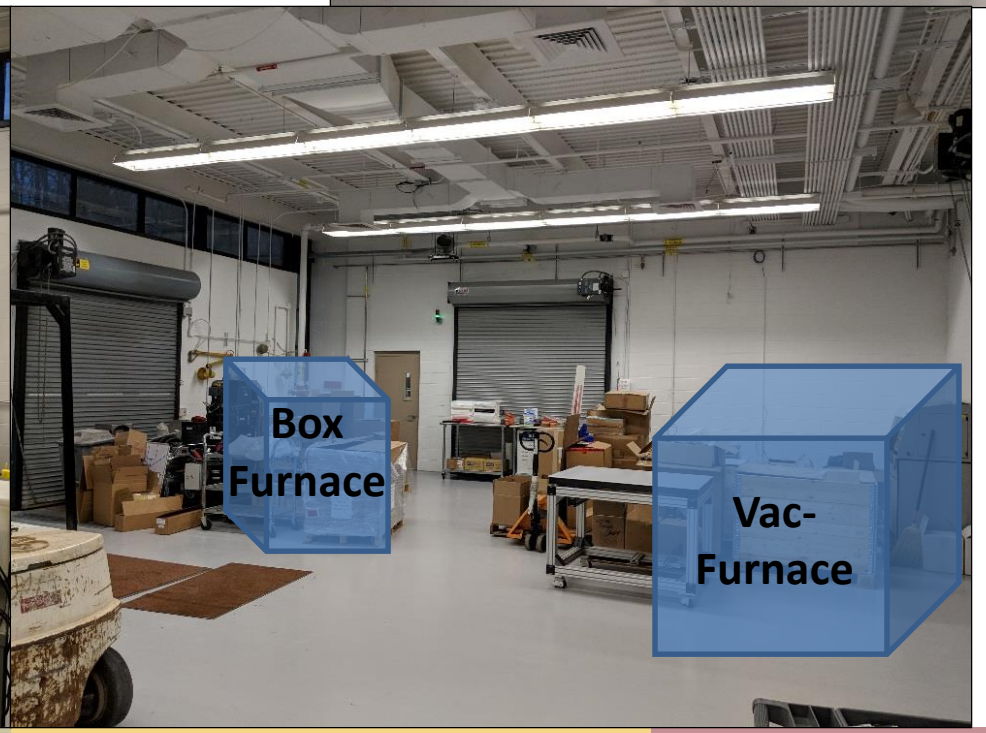


AM History at Moog

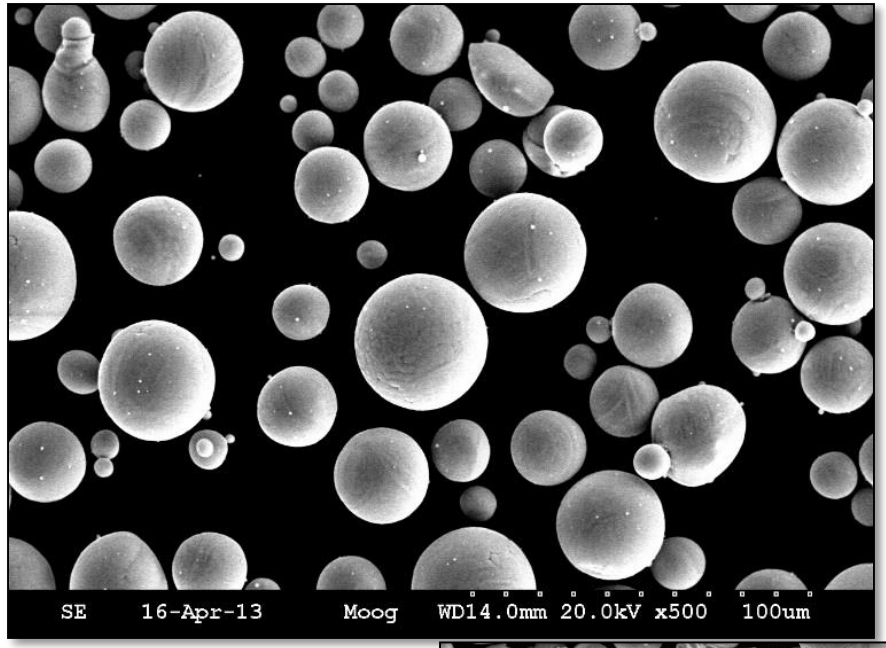


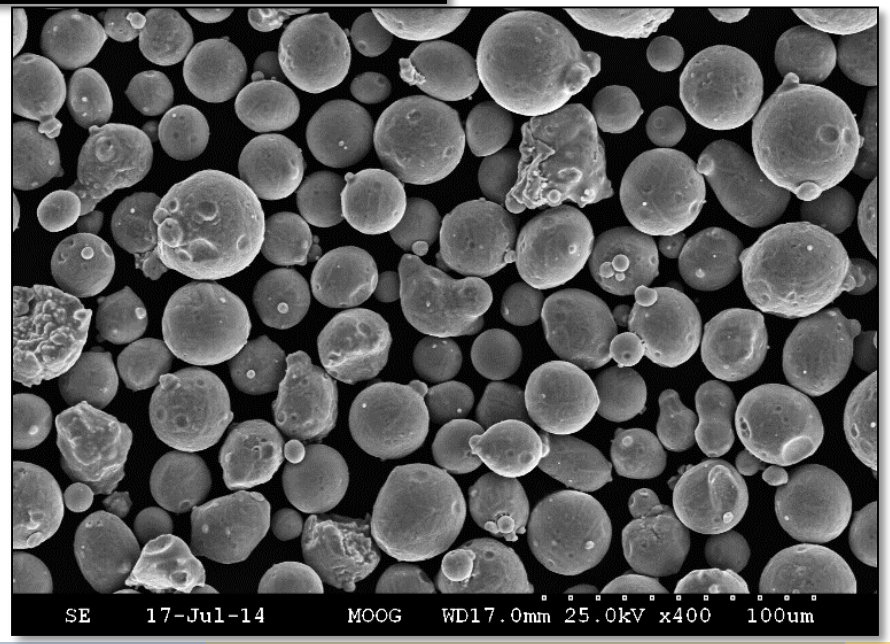
Production: 12 LPBF Machines

Production
Post Processing
Powder



LPBF Production Materials

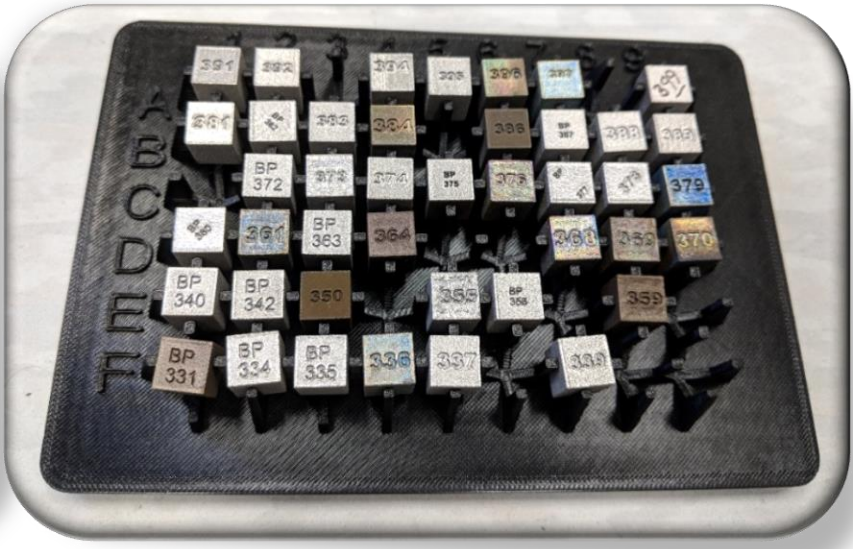




- **Aluminum: AlSi10Mg & F357**
  - Light-weight, good thermal and dynamic properties
- **Titanium: Ti-6Al-4V Gr. 5 & 23 & CPTi Gr. 1**
  - Low specific weight and biocompatibility
- **Cobalt Chrome (ASTM F75)**
  - Excellent corrosion and temperature resistance
- **Ni Alloys: Inconel 625 & 718; Haynes 25**
  - Great tensile, fatigue and rupture strength
- **Maraging Steel 300** (EOS MS1)
  - Impressive hardness and strength
- **Stainless Steel:15-5, 17-4, 316L**
  - Excellent ductility and high corrosion resistance
- **Copper: C18150 & Gr-Cop 84**

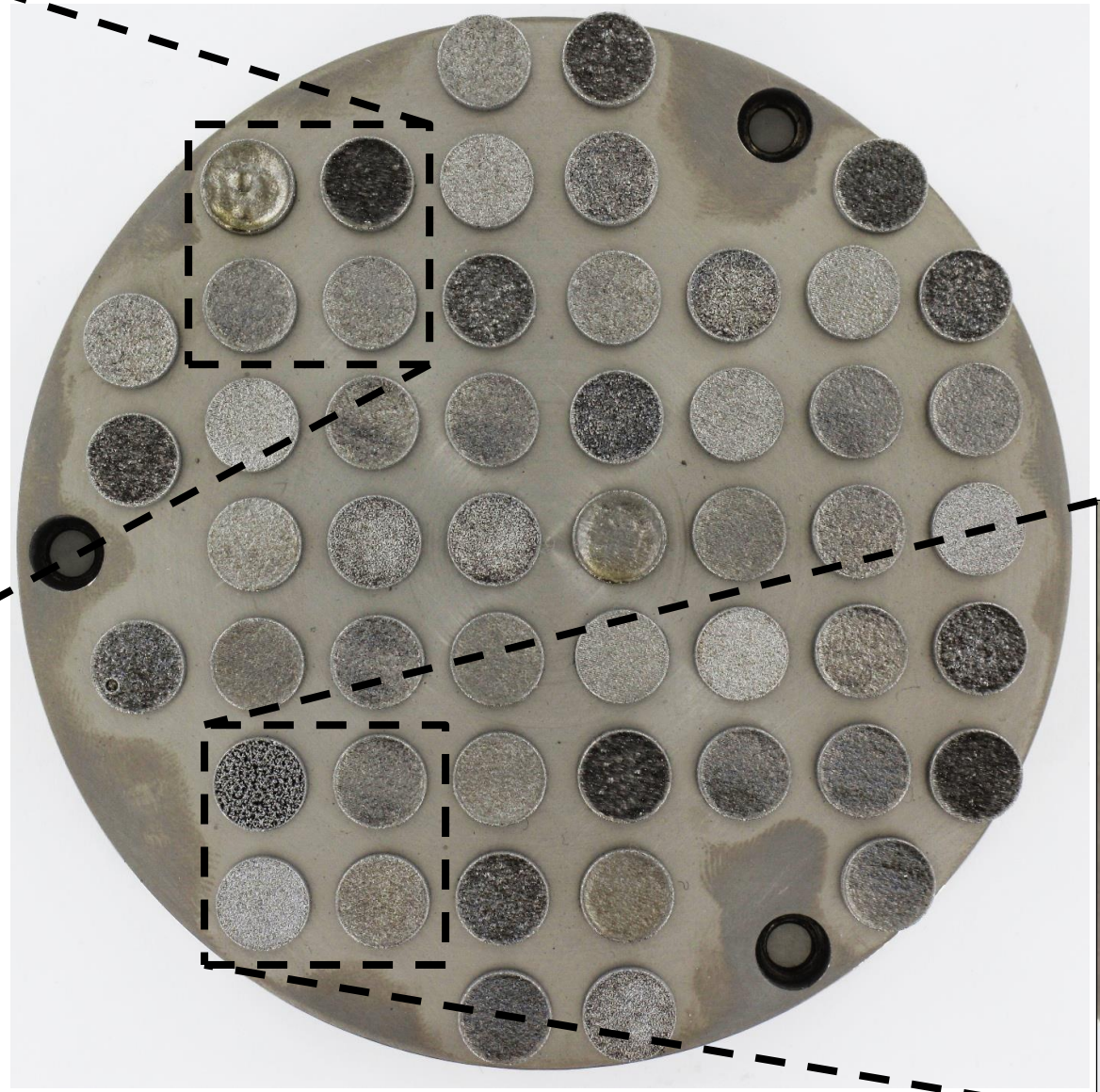
In general, any metal/alloy that welds well, can be processed with relative ease within a LPBF machine

Development: 3 Machines



Laser Parameter Development

Extra high energy density

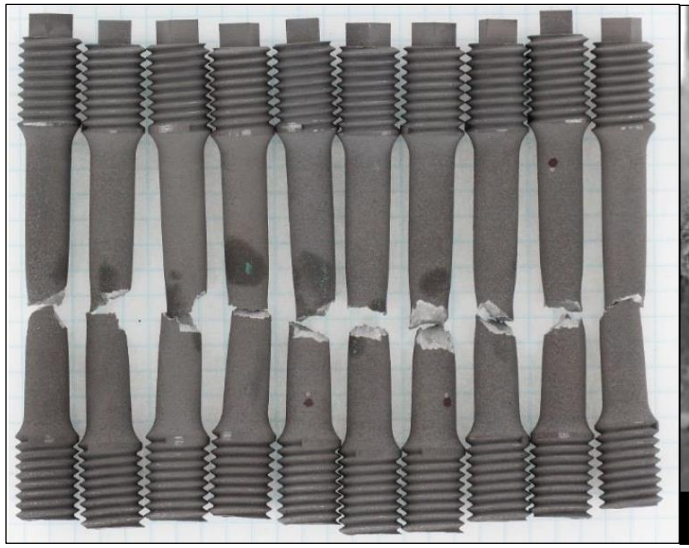


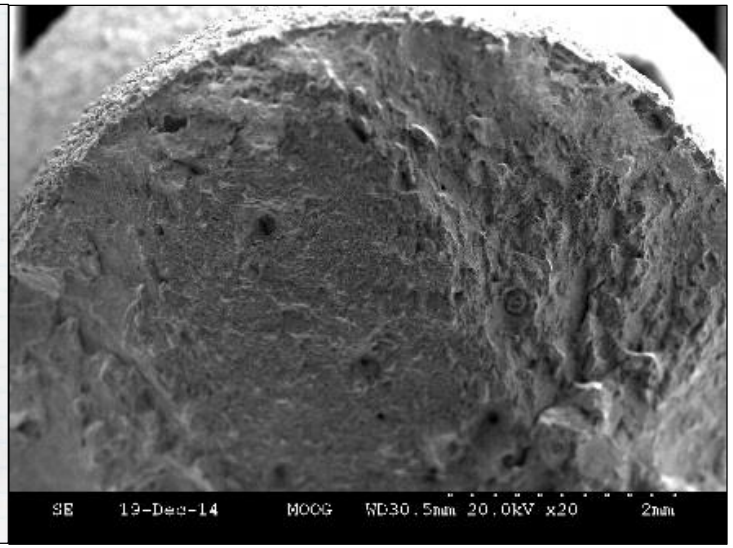
Really low energy density/very wide hatch spacing

Material Properties

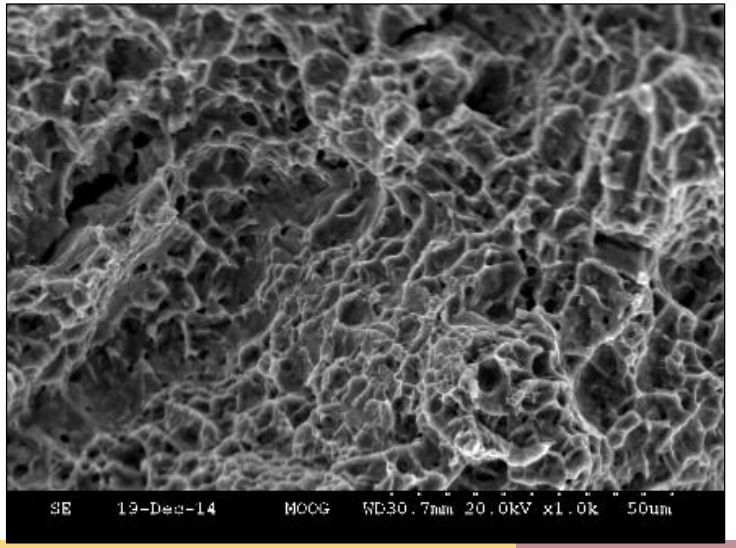
- Extensive material properties development for Ti-6Al-4V
- Meeting AMS4930 properties
  - Except fatigue
- Process control is everything

	AMS 4928	AMS4930	AMS4991	Moog LPBF Vac Furnace
	Wrought Ti-64 (G5)	Wrought Ti-64 ELI (G23)	Cast Ti-64 (G5)	AM Ti-64 ELI (G23)
UTS, ksi (MPa)	135 (931) min	125 (862) min	130 (896) min	141 (972)
Yield Strength at 0.2% offset, ksi (MPa)	125 (862) min	115 (793) min	120 (827) min	123 (848)
Elongation, % Min requirement	10	10	6	11.8
Reduction of Area, %	25	25	--	27



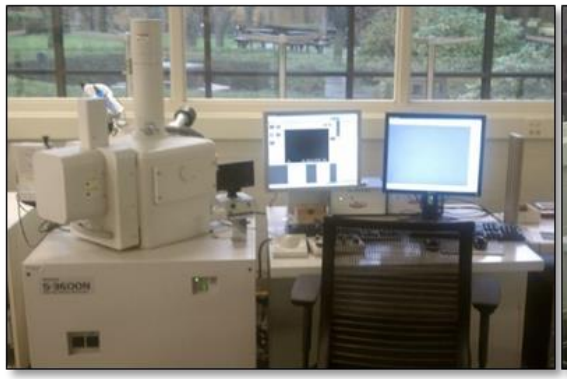


Hundreds of tensile bars per alloy



Nice ductile fracture

Analysis: Materials & Process Engineering

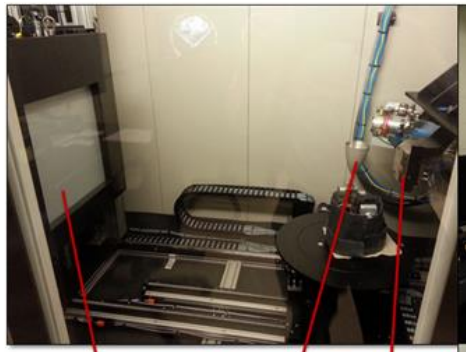


SEM

Auger

Fluid Sampling Lab

Auto Polisher



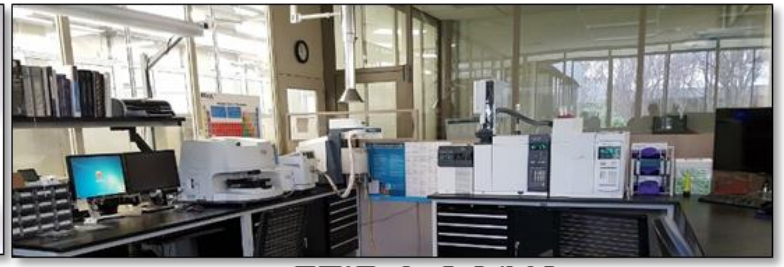
μ-CT Scanner

Mechanical Testers

Common Area Microscopes

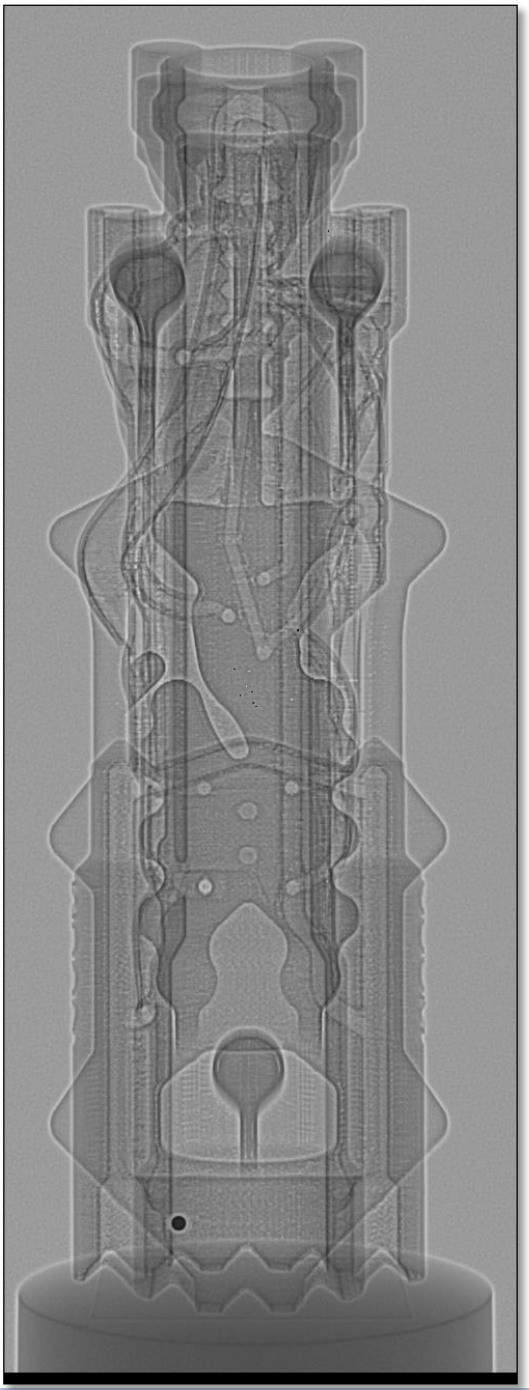
Hardness Tester

Bore Scope

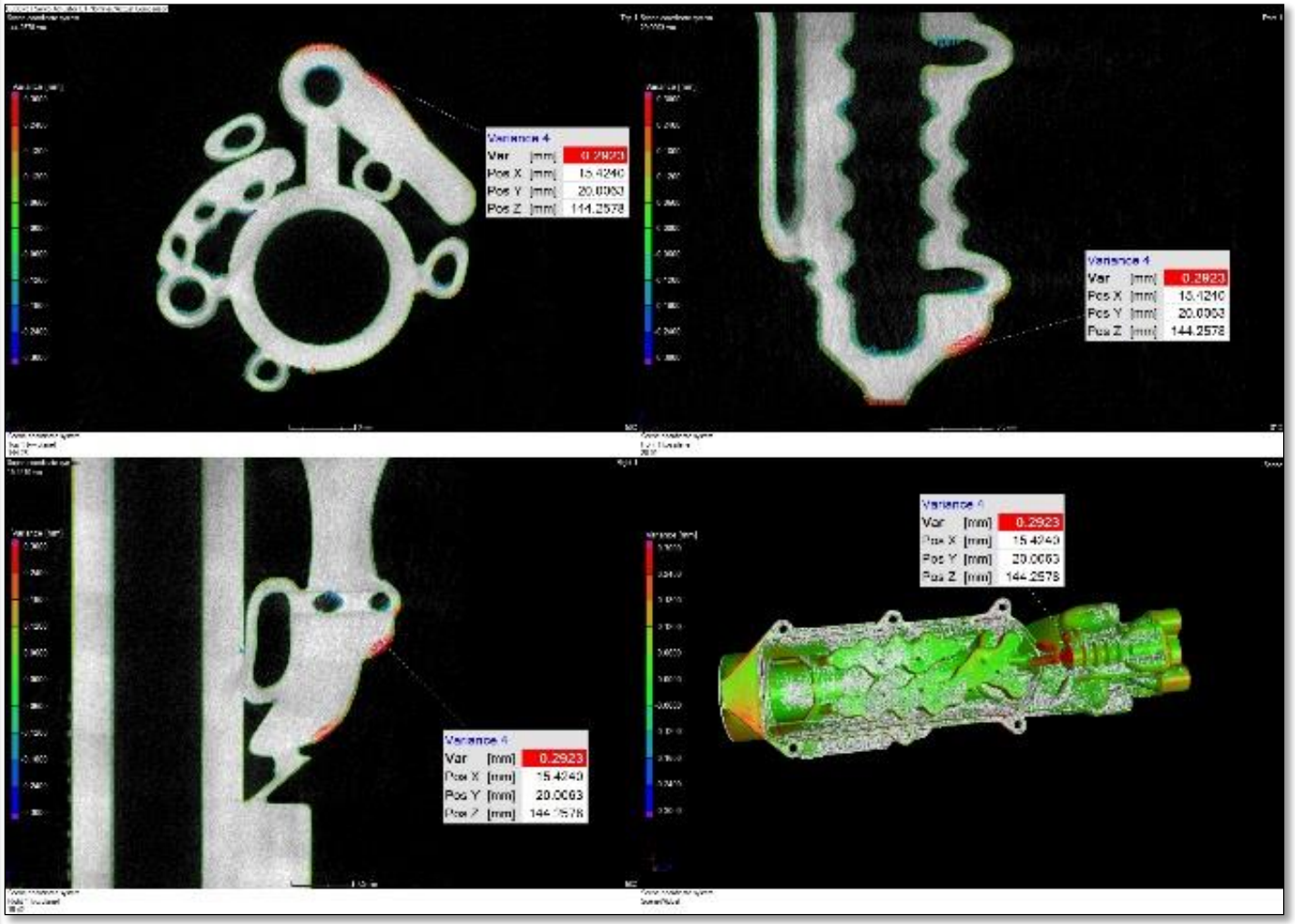


FTIR & GC/MS

Inspection



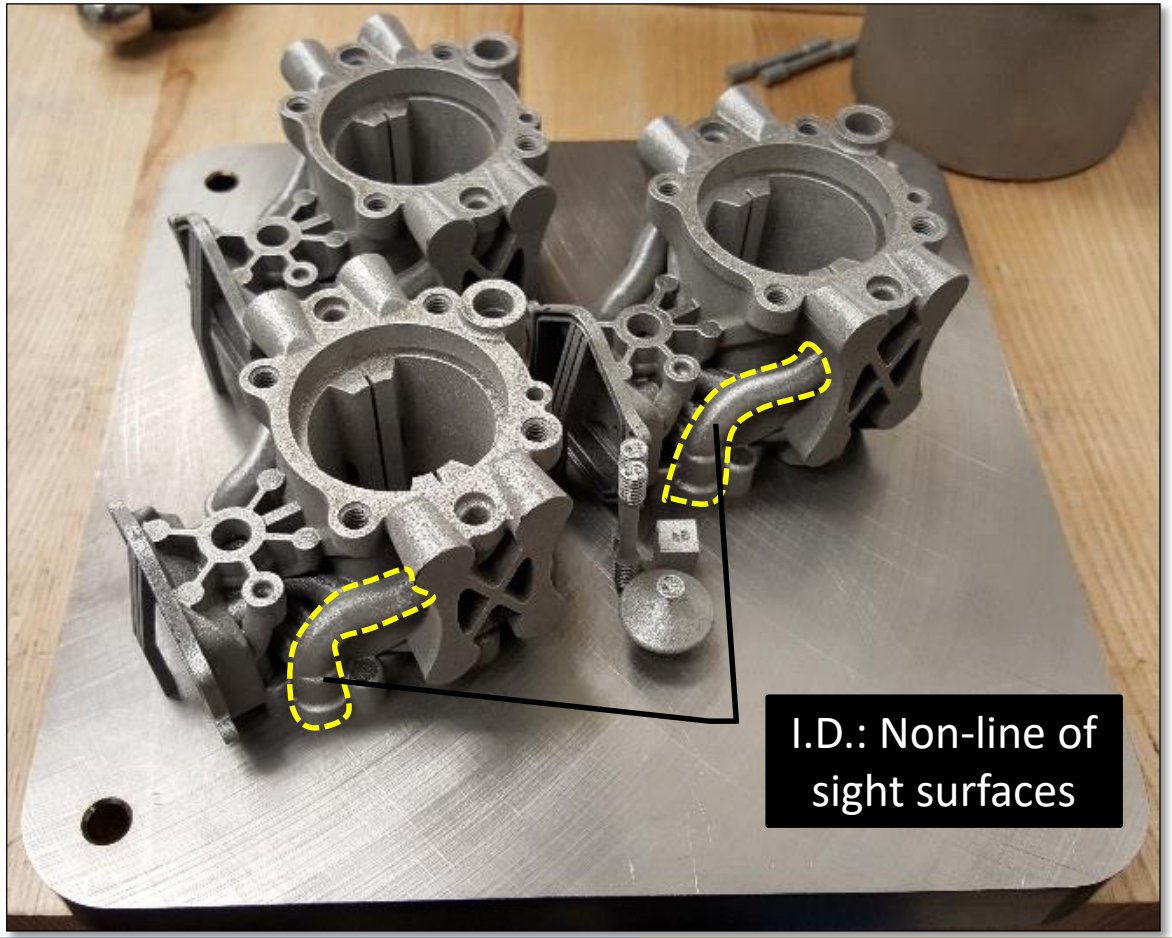
- Radiography: CT Scan

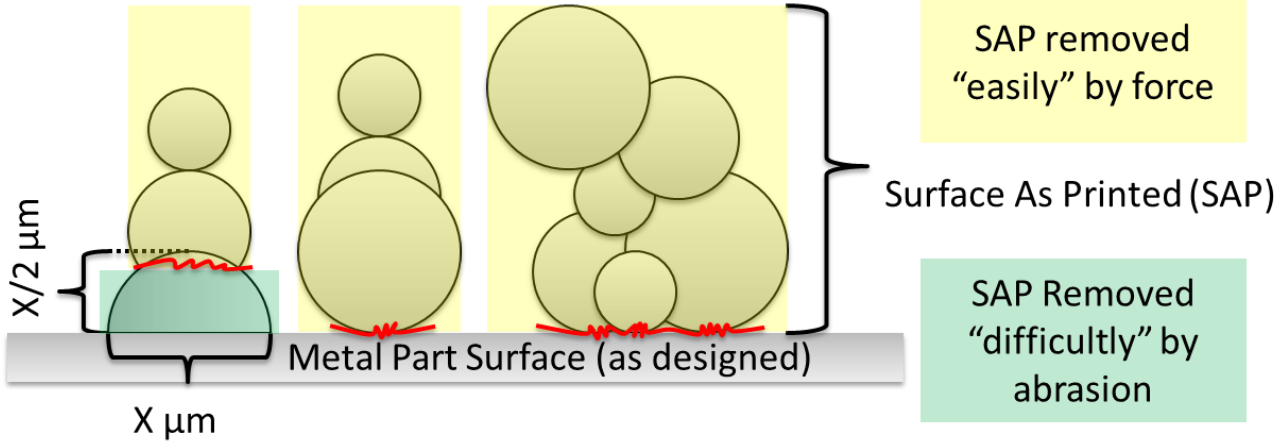


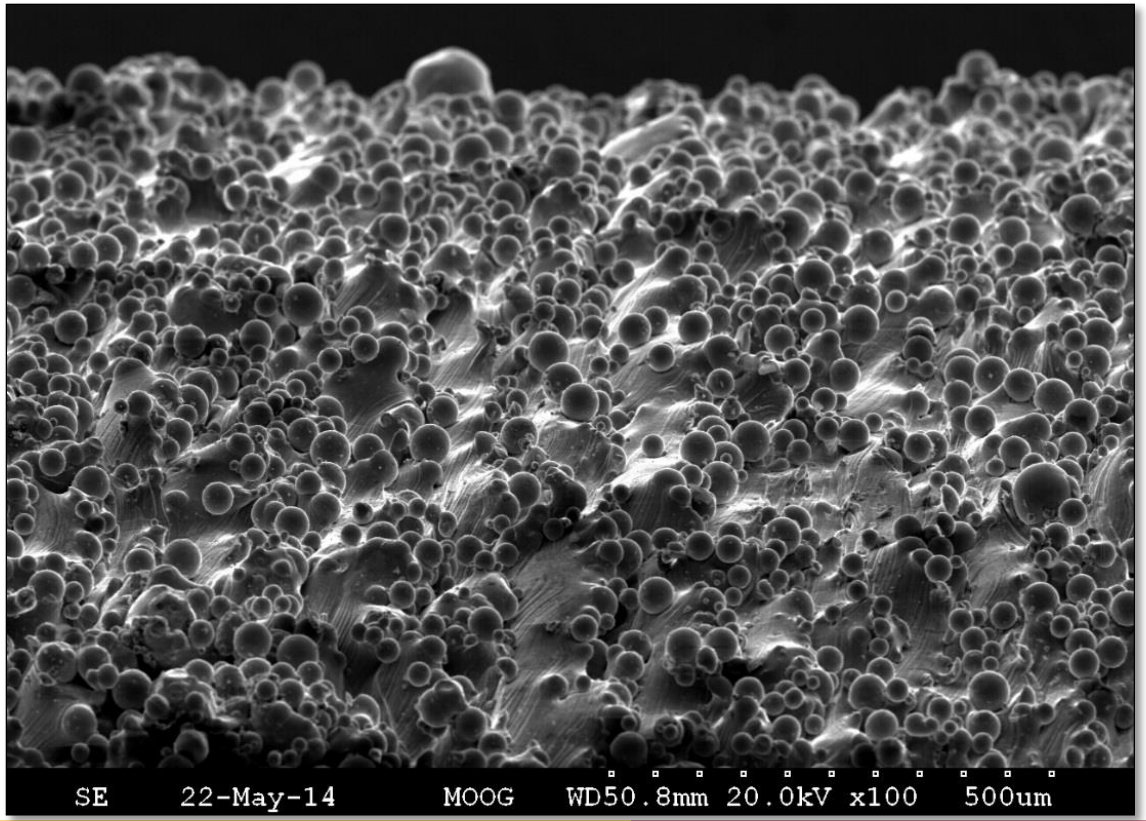
Surface of Powder Based AM Processes

Laser/EB Powder Bed Fusion

Surface As Printed (SAP)



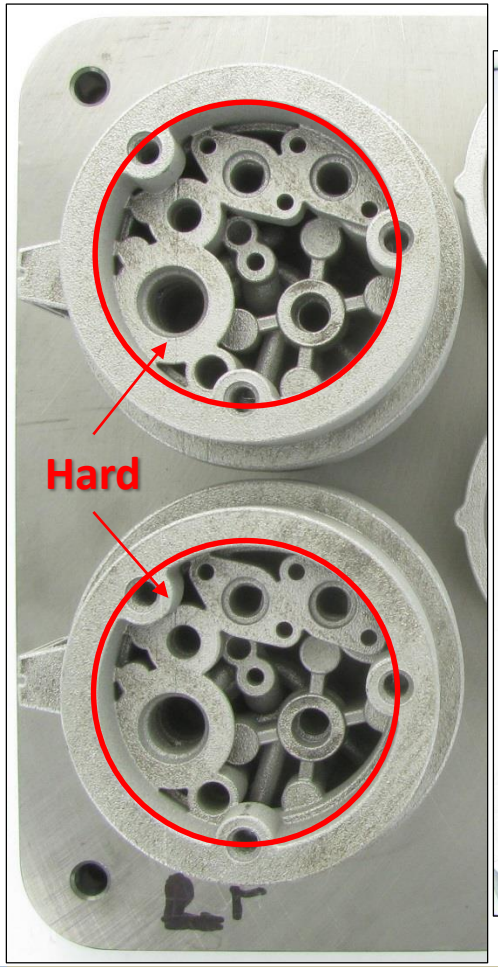


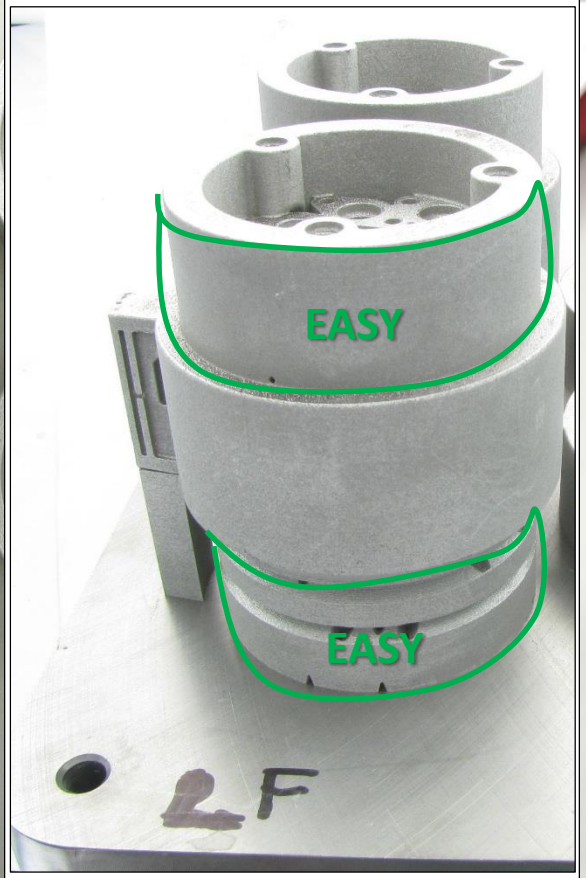


Current Challenge: Machining Complex Parts

- **Material:** Ti-6Al-4V
- **Product Description:** Hydraulic robotics
- **Problem:** Setting datum and machining to print

Datum/ Machining Pads

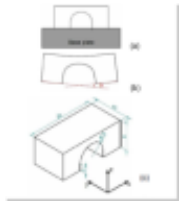




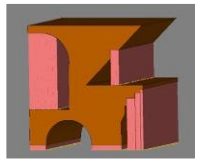
AM is more than just the AM Machine:

Includes: Specification, Sieving, reuse, handling, filling, removal

Powder Management



Build Stresses



Supports

Recoater direction

Build Direction

Build Plate Design

Data Control and Verification

AM Design freedom/ constraints

Machining allowances

AM Design rules 2.0

AM part Selection (Suitability criteria/ assessment)

AM Machine Parameters

AM Machine Control strategies

Build Verification

Micro Machining

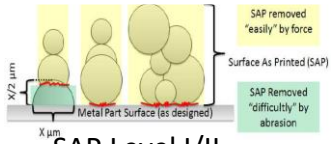
3D scanning

CT scan

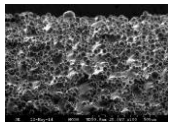
Honing

Stress relieve

EDM



SAP Level I/II removal



Contamination Control

Heat Treat

Polishing

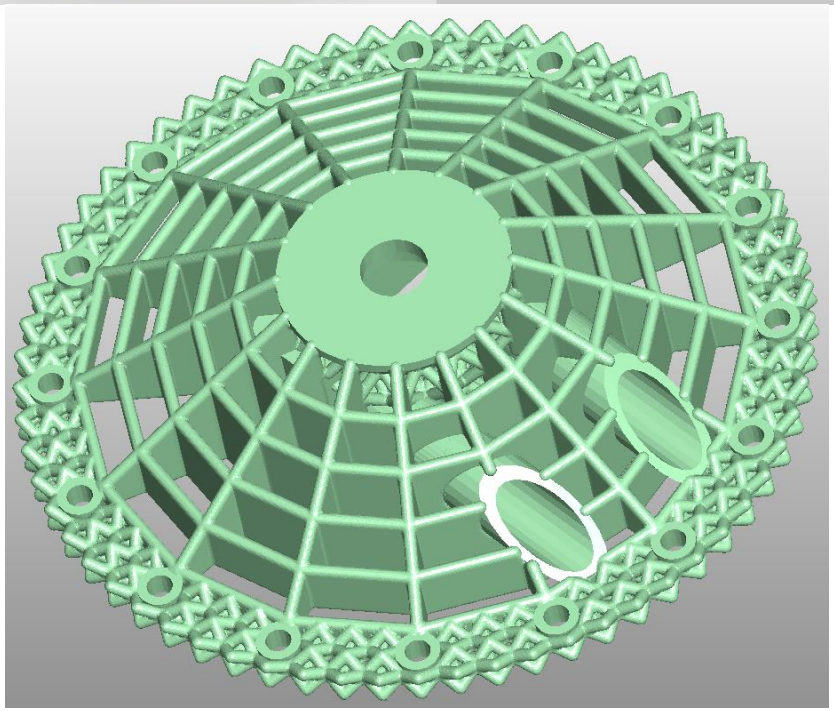
AM part Costing

Moog Hexapod: Spider Part

HX-M350 SPIDER

Actuator Component

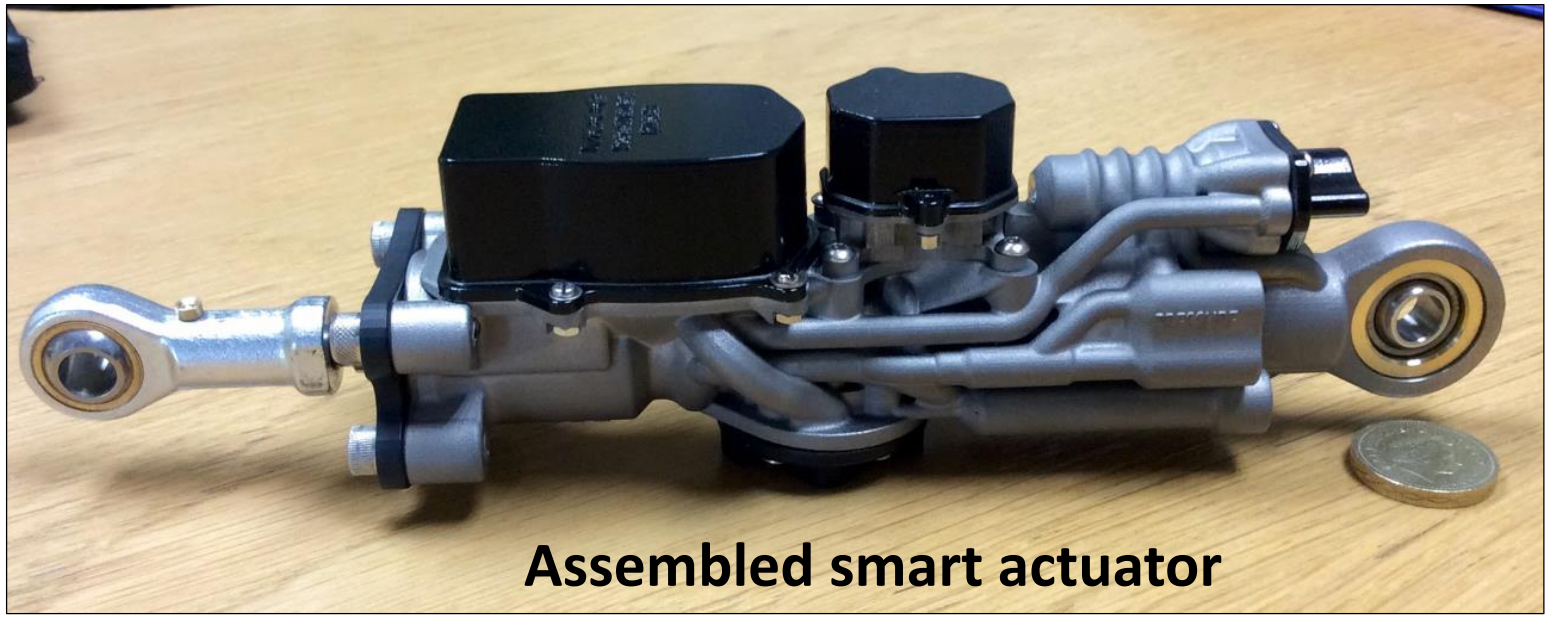
- Lighter Weight Means Less Inertia
- Ti-6AI-4V Makes for a stronger material compared to Aluminum
- Higher Maximum Axial Load vs. Aluminum



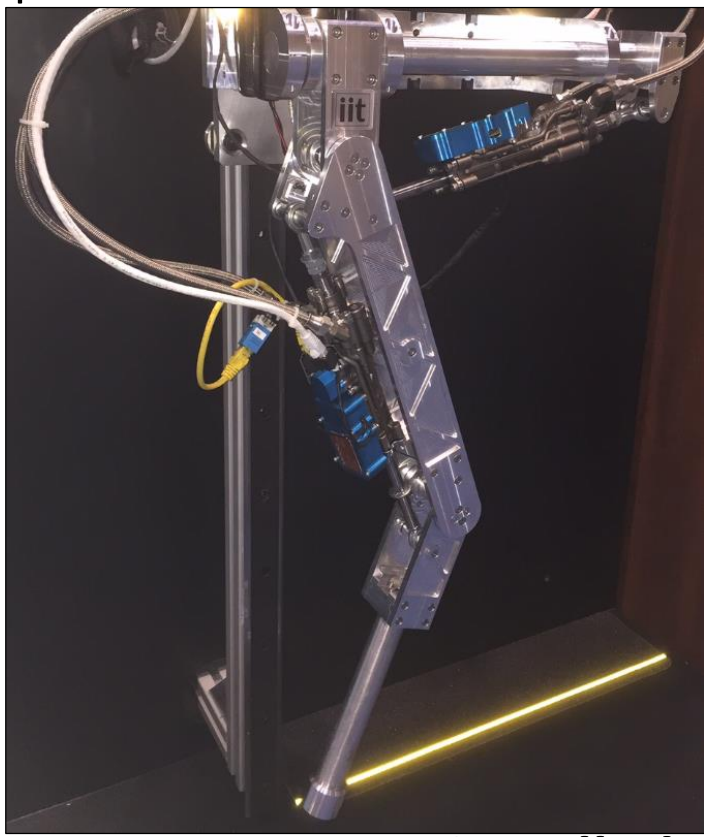
Robotic Hydraulic Actuator

- **Challenge:** Speed integration and system development for robotics engineers to easily connect high energy density motion control axes
- **Solution:** Moog produced a highly integrated hydraulic actuator with onboard closed loop position and force control
- **Benefit:** Quick turnaround, customized, fully integrated Ti-6Al-4V actuator produced in weeks

As printed smart actuator body

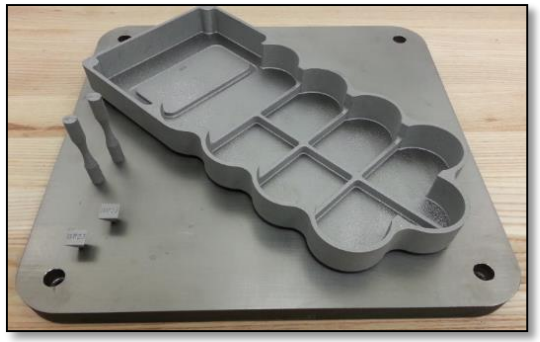


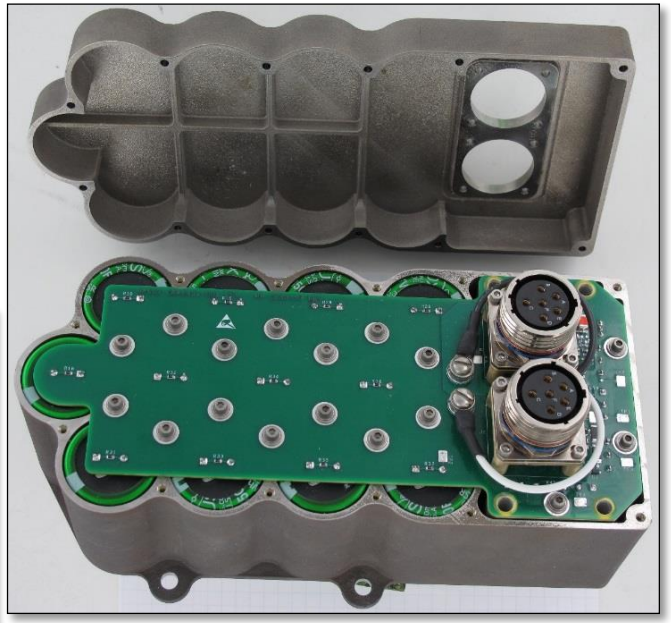
Assembled smart actuator



Smart actuator installed on robot leg

AM Example - Li-Ion Energy Storage Module



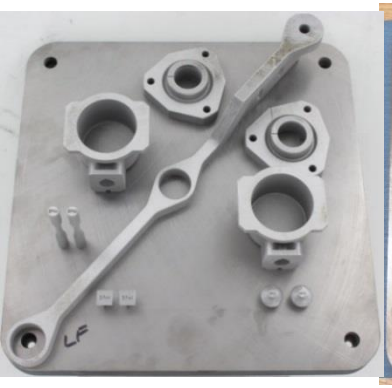


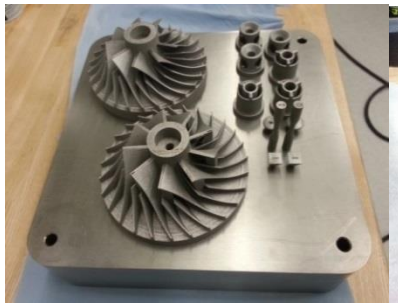
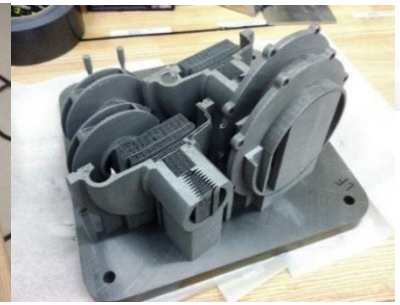
CHALLENGE:

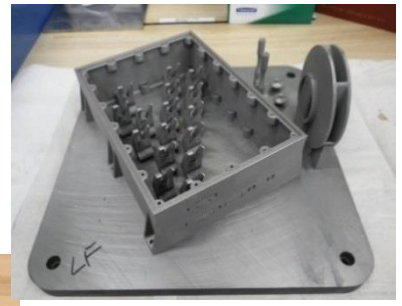
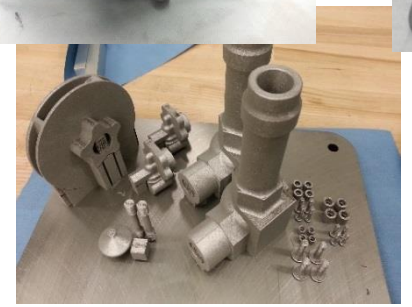
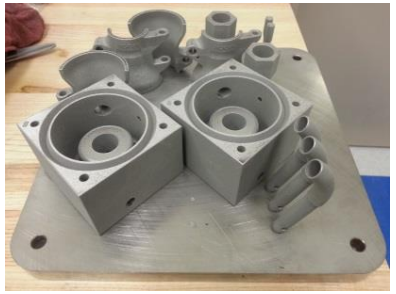
- Produce a light weight modular electronic power system (MEPS) suitable for launch vehicles which utilize electronic thrust vector control systems.

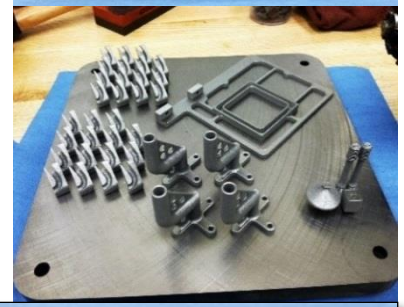
MOOG SOLUTION:

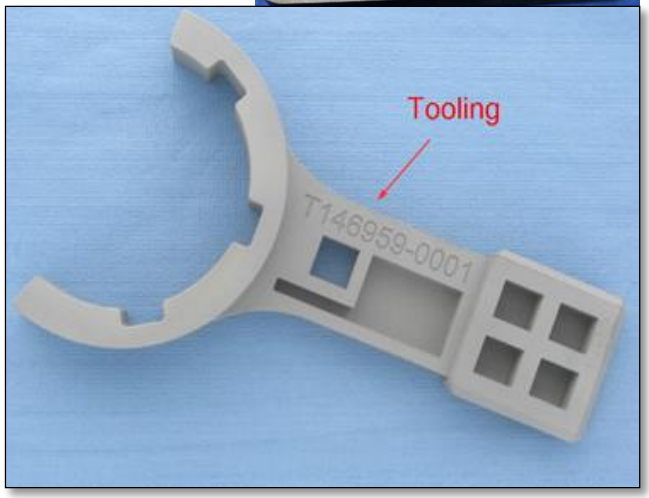
- Printed box was produced in a few days, no casting house/lead times. Finish machine ops were reduced to skim cuts on top and bottom surfaces, threaded holes.
- Lead time savings allowed for rapid bid with functional hardware.



Thank You!

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