Laser Additive Manufacturing & Applications in GE

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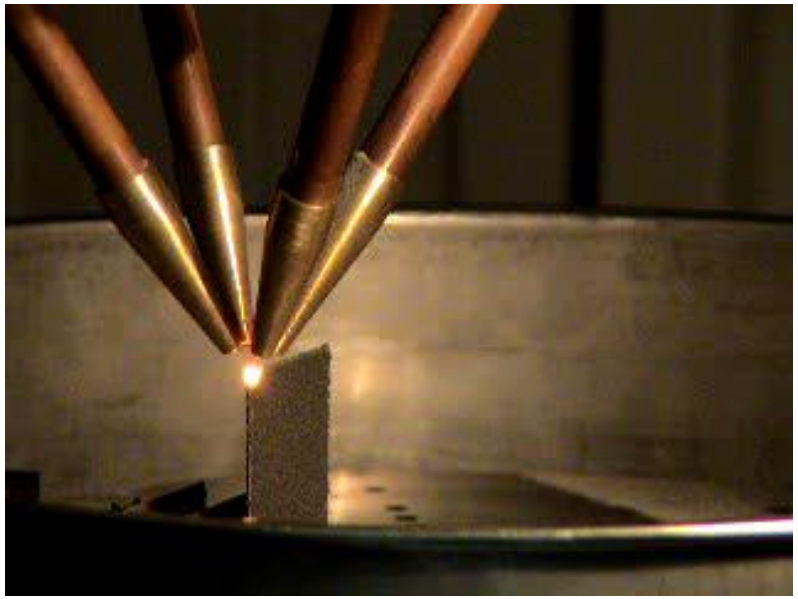
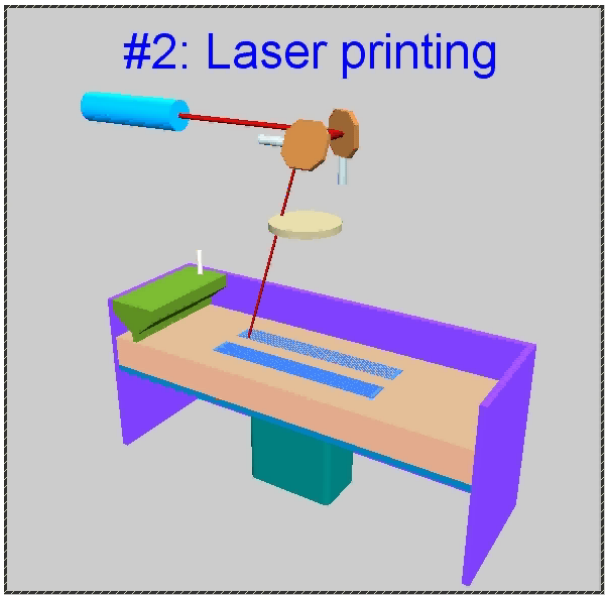
Laser Additive Manufacturing of Metal Parts



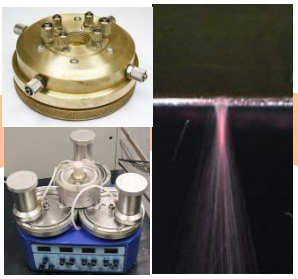
Powder Deposition



DMLS(M)

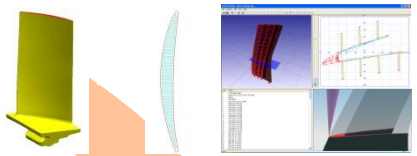
Laser Net Shape Manufacturing (LNSM)

Powder Processing

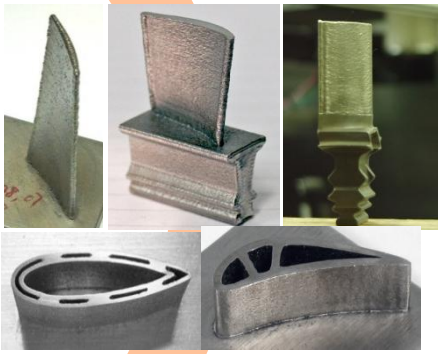


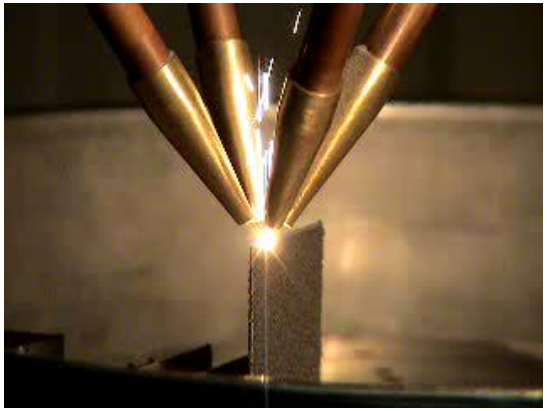
Systems Integration

Geometry Modeling

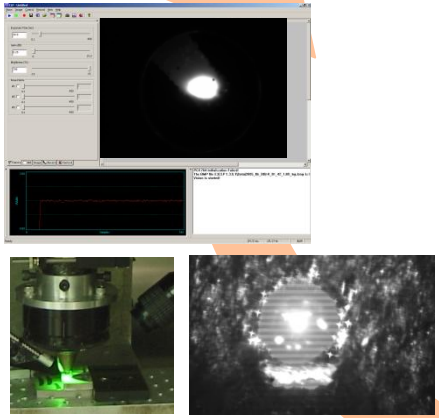


Laser Processing

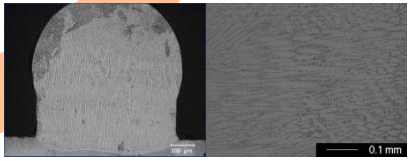




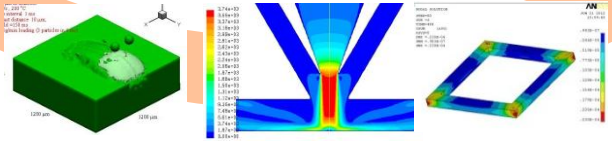
Sensors/Metrology



Materials



Process Modeling



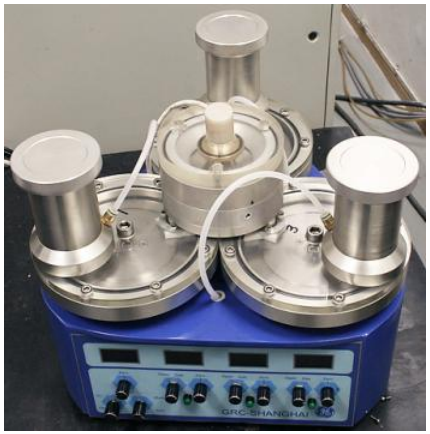
imagination at work

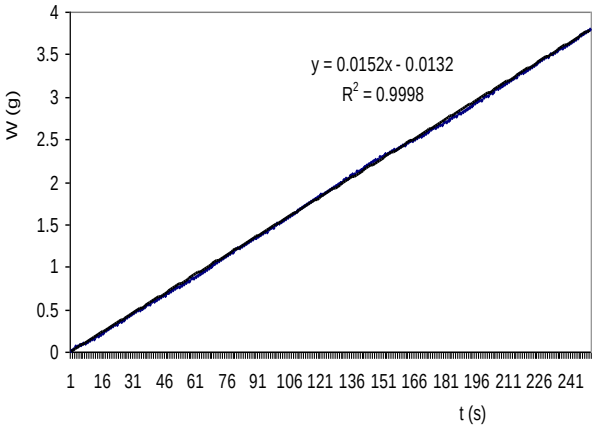
GE General Public

Key System Component Development

Accurate powder feeder

- High consistent under small powder feeding rate (<1g/min)
- Multi-hopper feeder with separate control – change powder composition during deposition





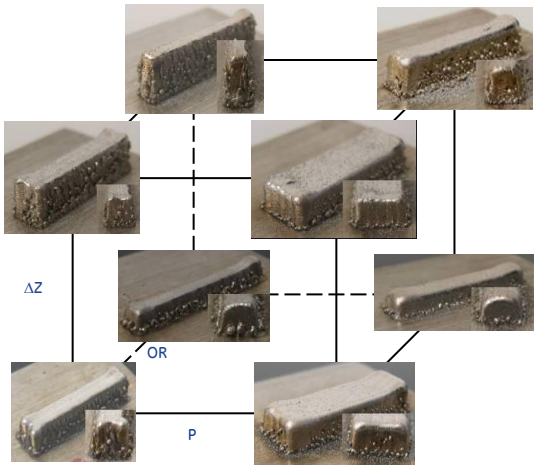
Patented Nozzle

- Good protection in air
- Good powder stream focus – smooth surface of deposition

Process Understanding

- Develop process window through DoEs
- Develop special treatment for different geometry features – smooth surface and defect free microstructure

DoE for process window



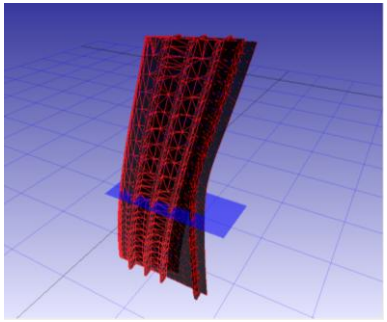
Special treatment for different geometry features

Single path T shape	zigzag	Step wall	Solid path T shape	Sharp corner	Overlapped double wall
					
					

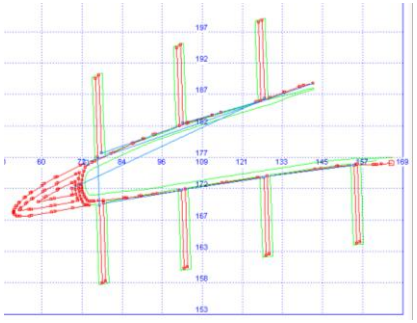
LNSM Toolpath Generation

New make toolpath

CAD model



Slicing



Toolpath generation

Repair toolpath

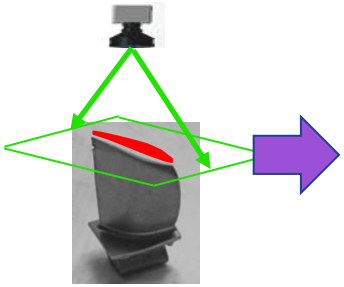
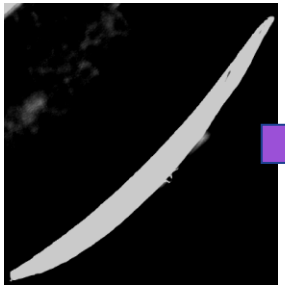
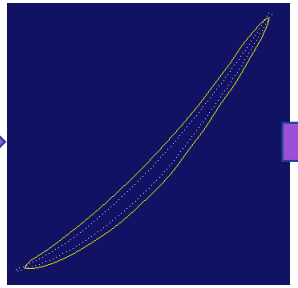


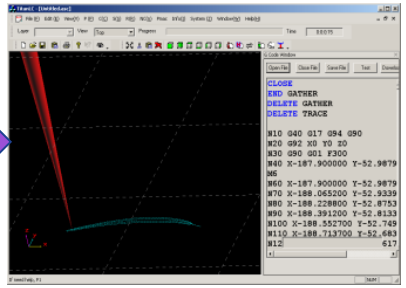
Image capture



High contrast Image



Tip contour finding

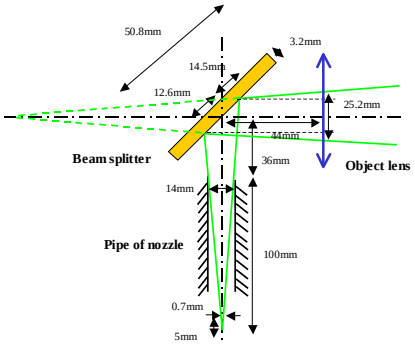


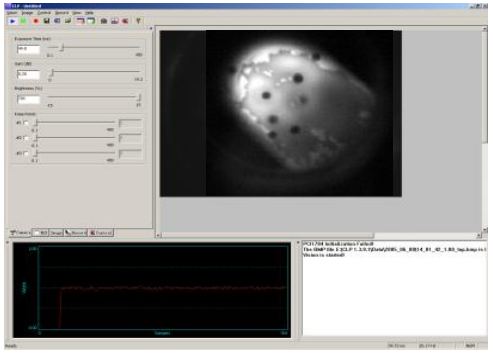
3D Toolpath generation

Closed-loop Processing (CLP)

Online sensors (optic, thermal, etc.) to monitor weld pool and adjust parameters to keep stable process

- Better geometry accuracy
- Eliminate defects
- Automation

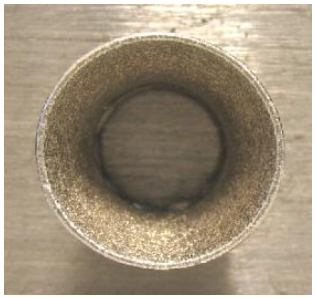




CLP Module

OL

CL



Results compare between OL & CL

CLP – Process Stability

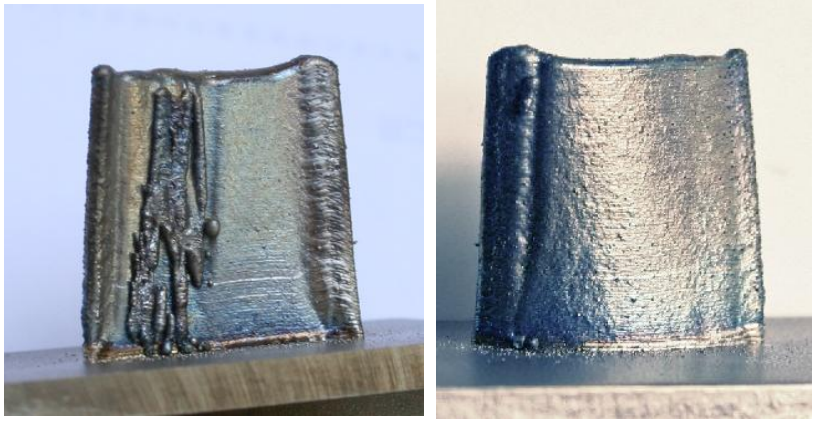


Fig.1 Airfoil w/o CLP

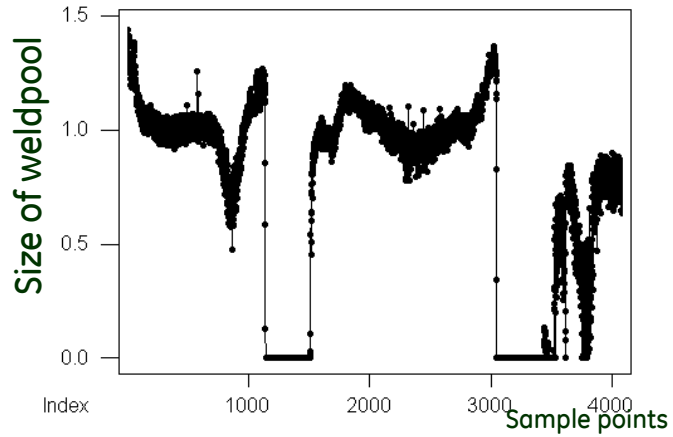


Fig.2 On-line data w/o CLP

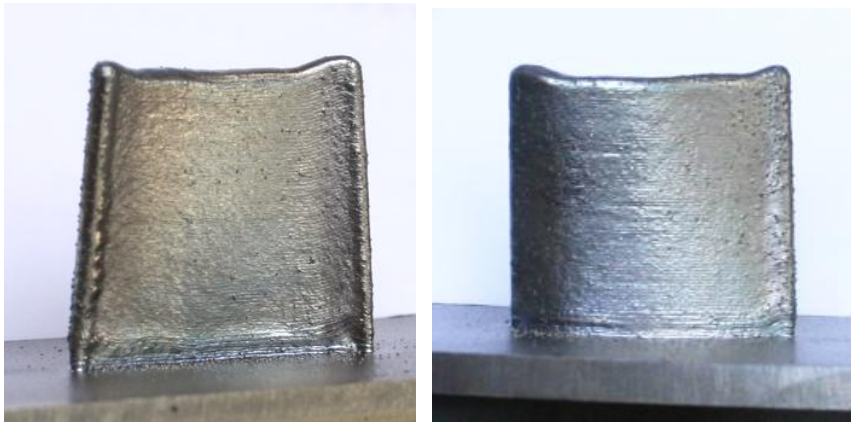


Fig.3 Airfoil w/ CLP

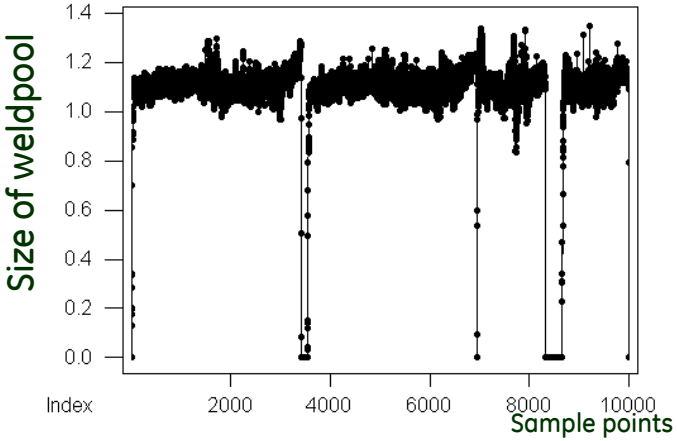
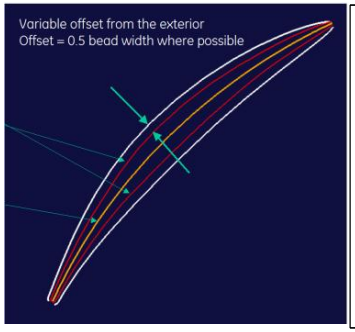


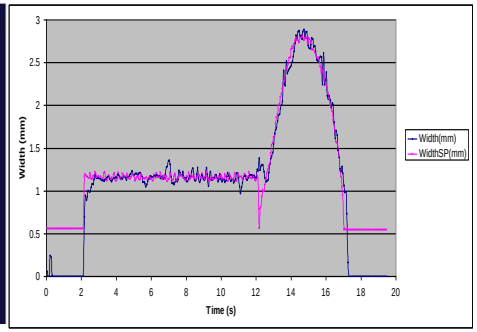
Fig.4 On-line data w CLP

CLP – Geometry Accuracy Improvement

Regular toolpath

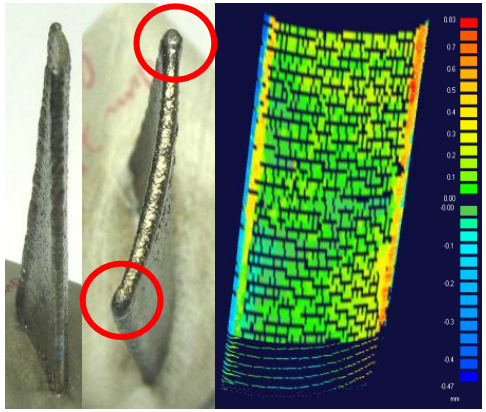
Adaptive toolpath



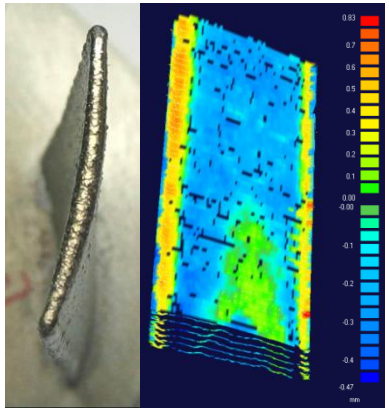


30% improvement

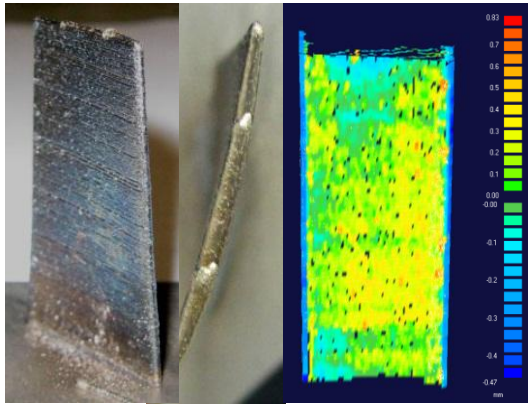
20% improvement



Deposition w/o CLP



Deposition w/ CLP



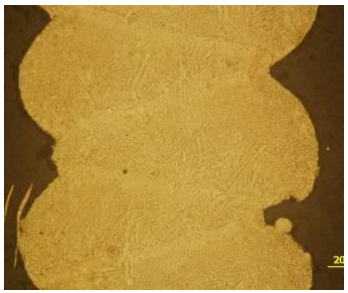
Adaptive toolpath w/ CLP

CLP – Defect Eliminate

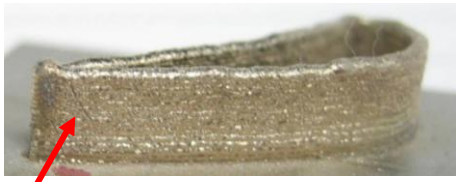
- Improve process stability
- Energy input control to eliminate / minimize cracks

Cold deposition + CLP

Microstructure at TE (XY)

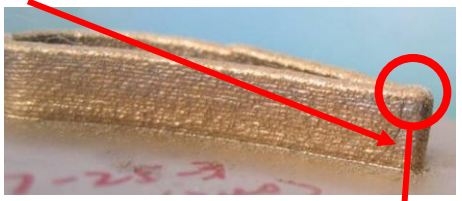


Microstructure at TE (XZ)



Crack

(a)



(b)

Macro cracks in samples

Micro cracks at TE

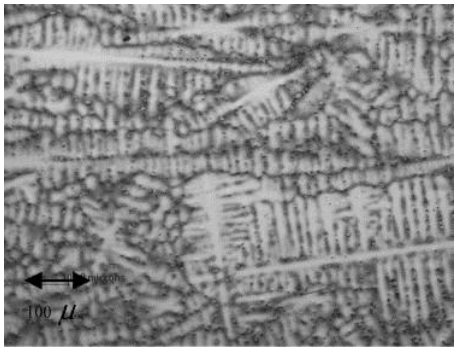
Filler Materials / Base Alloys Combinations

- Shafts/Rotors
  - IN718/Forged IN718
- Frames
  - IN718/IN718
  - Ti-6Al-4V/ Ti-6Al-4V
  - IN718/Cast IN718
- Cases
  - HS188/Waspalloy
  - Ti-6Al-4V/ Ti-6Al-4V
- Seals
  - IN718 on A286
  - Marage 250/Marage 250
- Miscellaneous Hardware
  - IN718/Forged IN718
  - Ti-6Al-4V on Ti-6Al-4V
  - Stellite 694/IN738 & Udimet 700
- Turbine Blades & Vanes - OEM
  - IN738/Rene Base Materials
  - HS188/Rene Base Materials
- Turbine Blades & Vanes - Repair
  - IN625, Rene Alloys/ Rene Base Materials
- Compressor Blades - Repair
  - IN625, IN718, Ti-6Al-4V/IN718, A286, Ti-6Al-4V

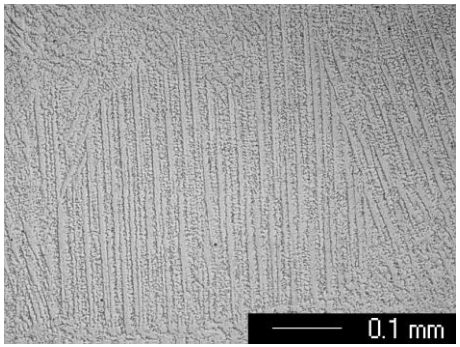
Materials & Microstructure

IN718, IN625, Ti-6-4, HS188 — Rene 80 — Rene N5, Rene 195

Insensitive — Cracking sensitivity — Sensitive

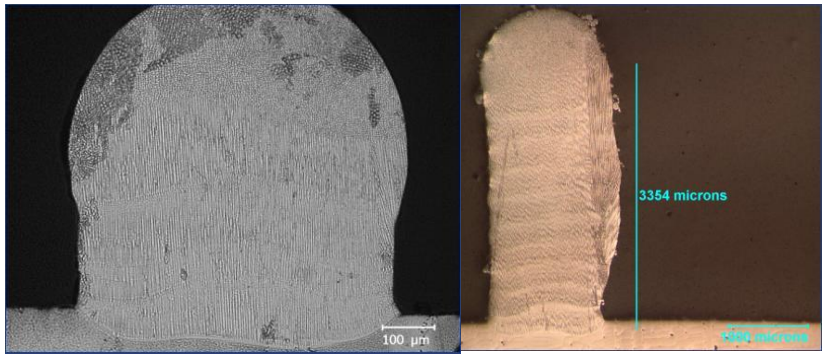


Casting

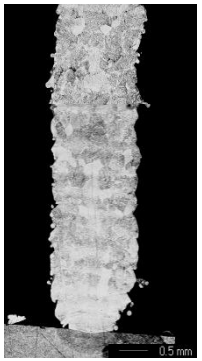


LNSM

Microstructure of Rene 80

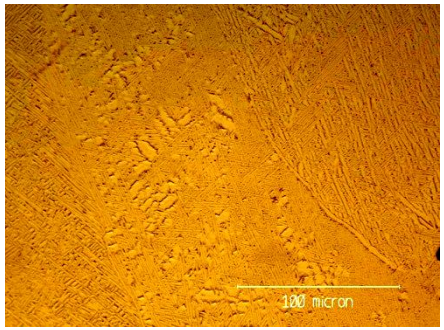


Single Crystal Microstructure

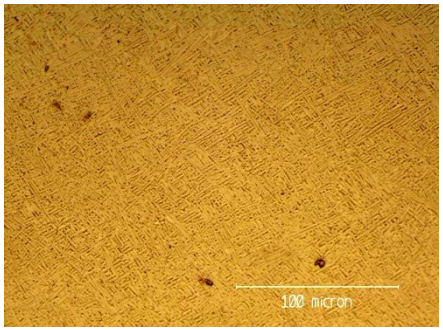


Cellular arowth — Equiaxial arowth

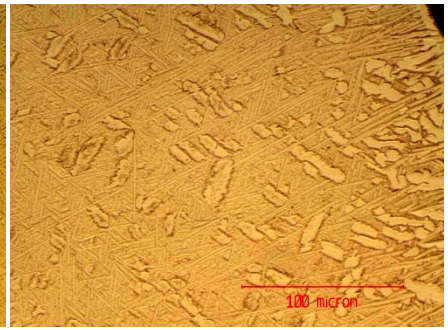
Microstructure of LNSM Ti-6Al-4V



Stress relief



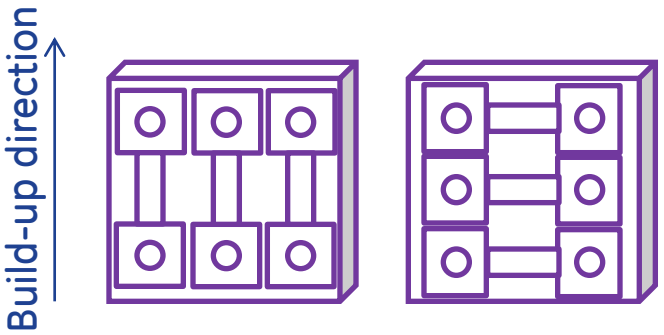
Annealed



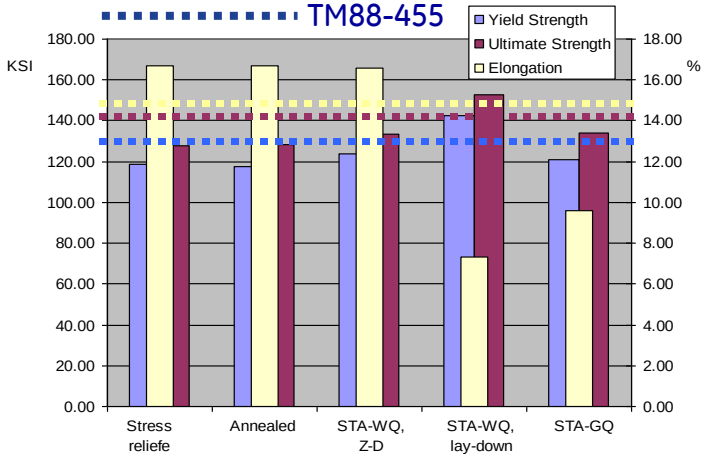
STA – water quench

Microstructure of LNSM Ti-6Al-4V with different heat treatment

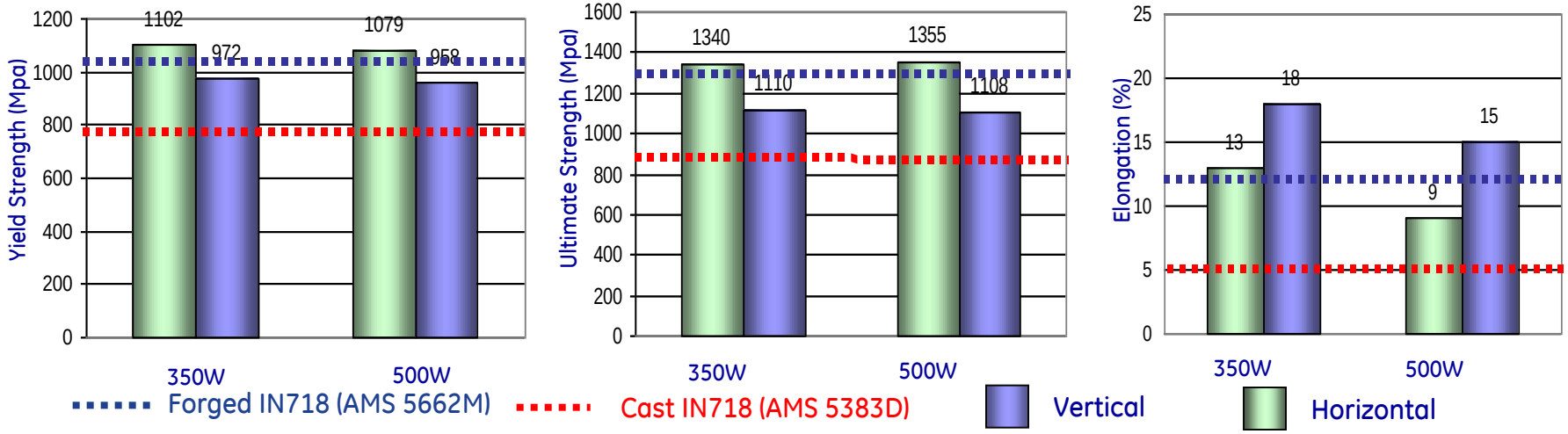
Mechanical Properties



Tensile samples and test



Tensile test results of LNSM Ti-6Al-4V



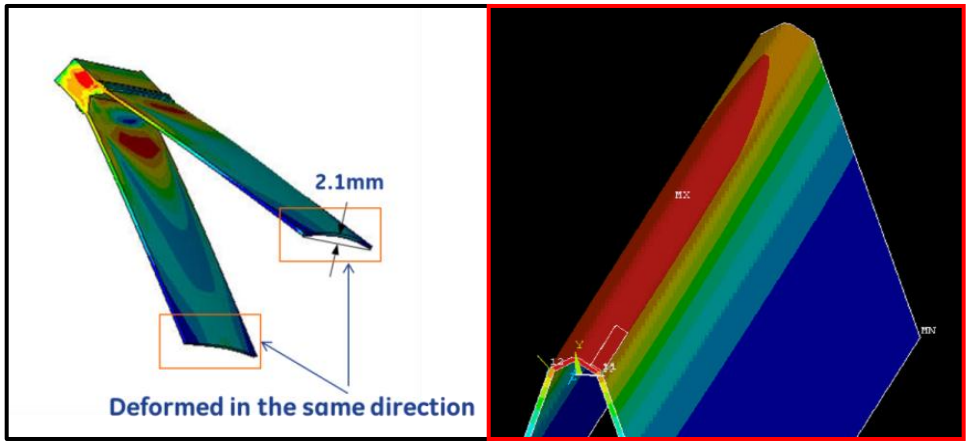
Tensile test results of LNSM IN718 parts

imagination at work

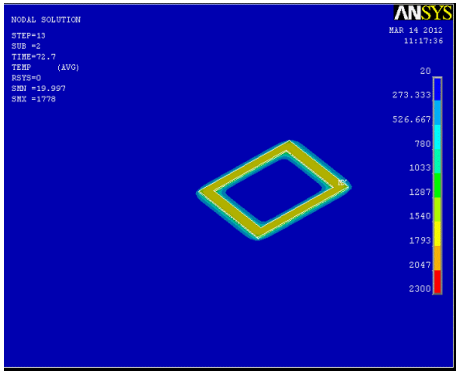
Comparable to forging data

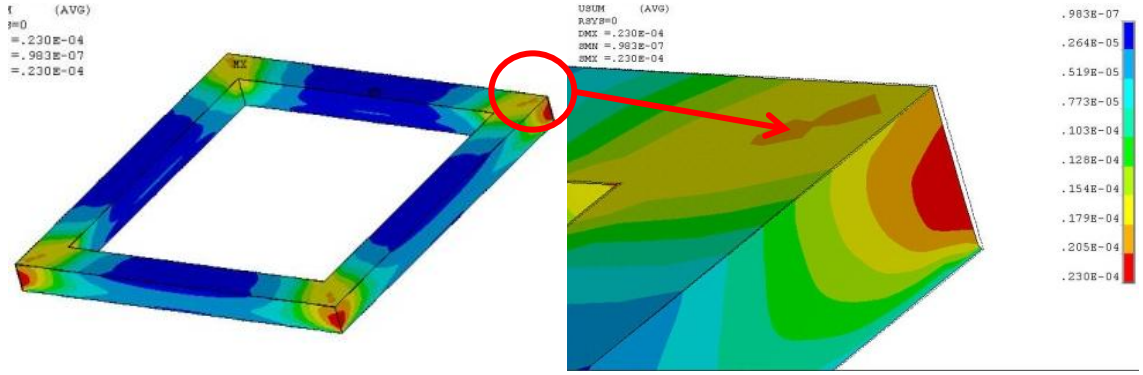
LNSM Process Simulation

- Temperature and distortion analysis
- Distortion control and compensation



Powder deposition simulation

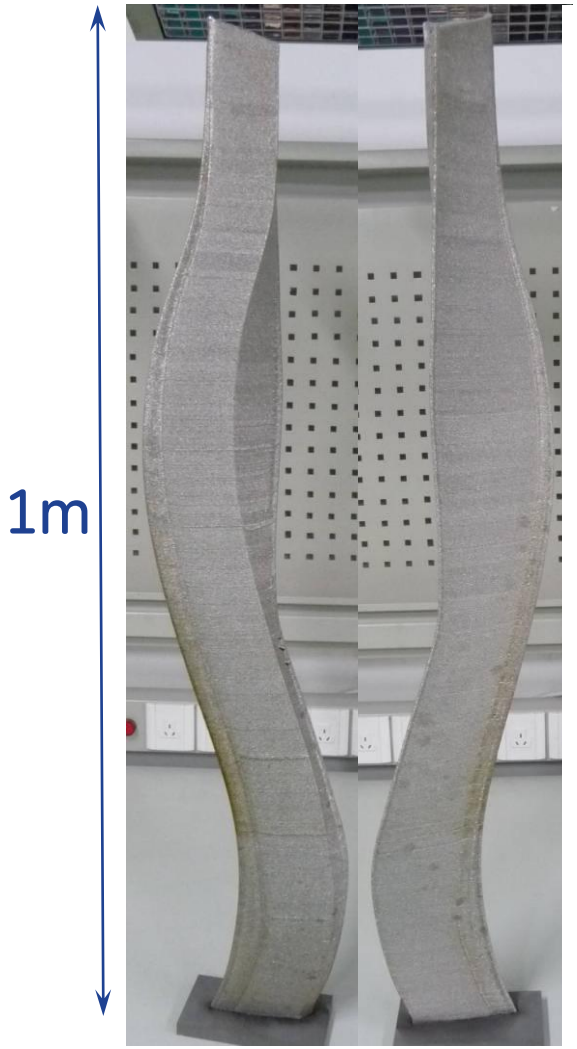




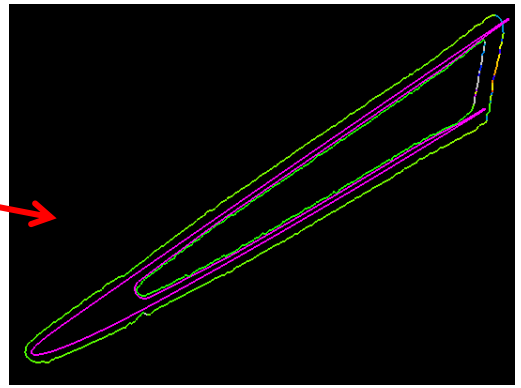
Powder bed simulation

Applications – NPI

- Ti-6Al-4V component
- Significant time and cost saving vs. current process



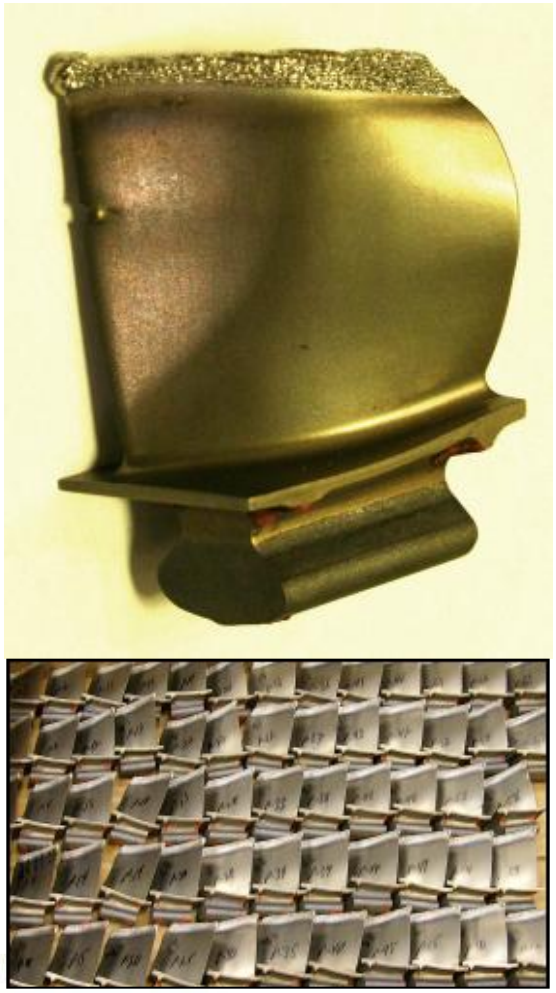
Application



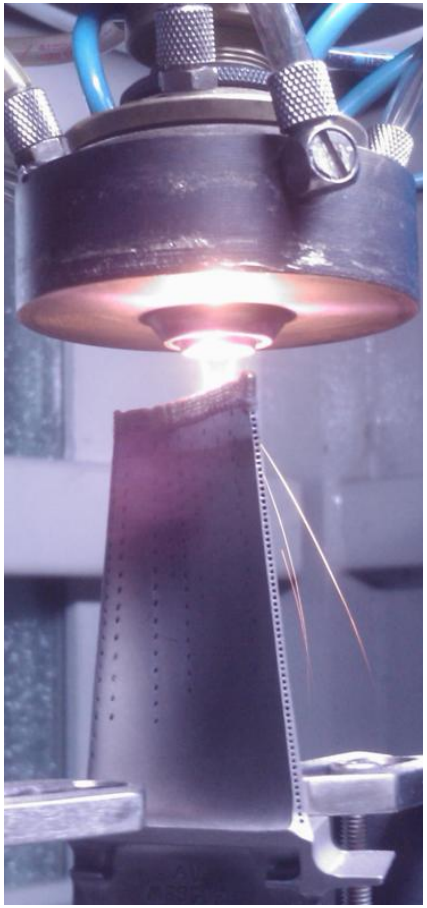
Initial distortion

Applications – Blade Tip Repair

HPC Blade repair

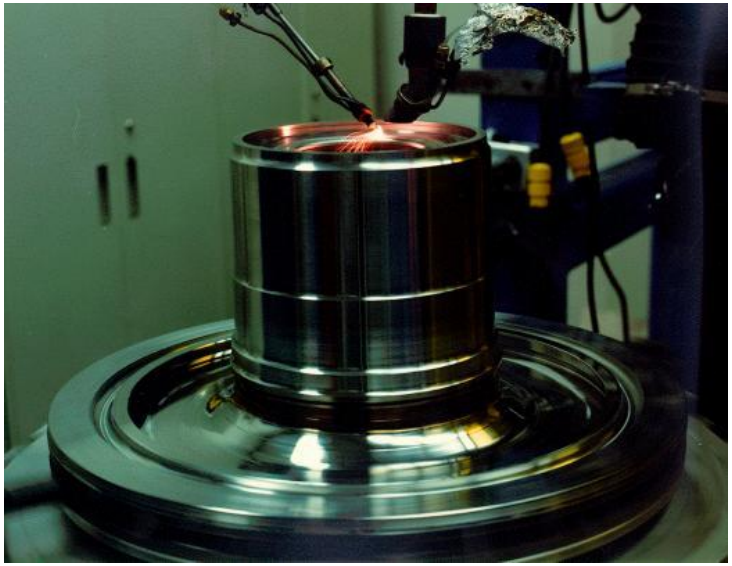


HPT Blade Tip deposition/repair

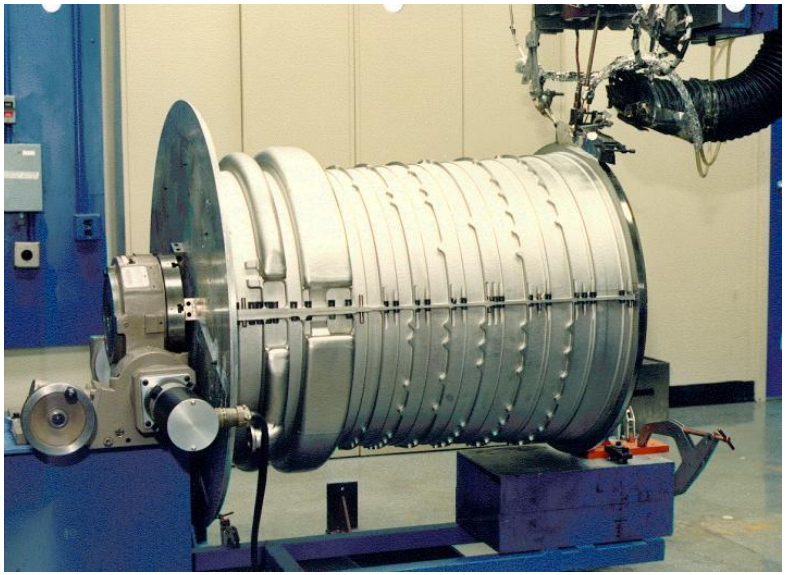


Applications – Components Repair

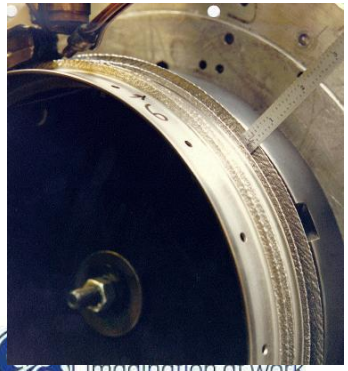
LPT Rotor



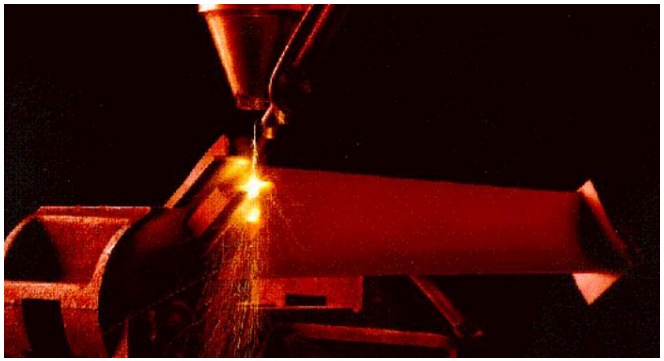
Front Compressor Case



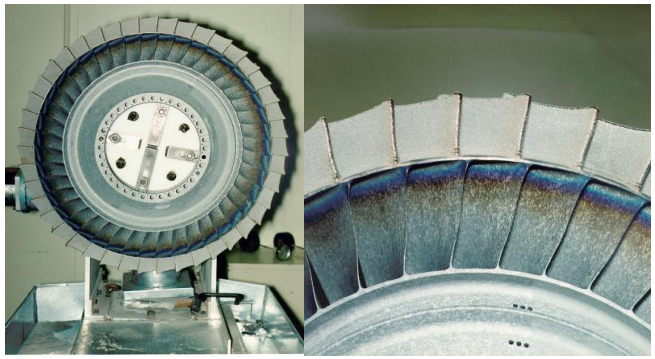
Knife Edge Seal



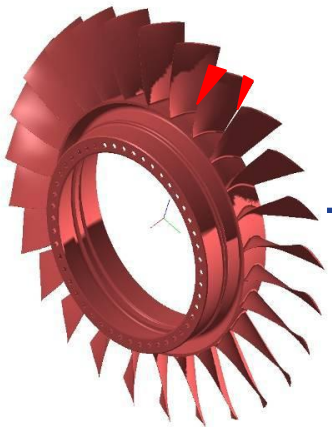
Turbine Interlocks



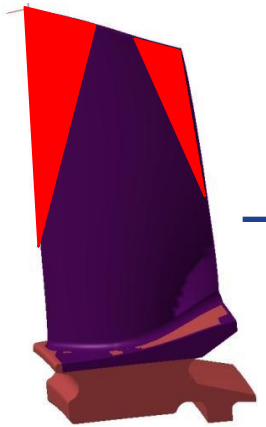
Blisk



Applications – Blisk Repair Demonstration

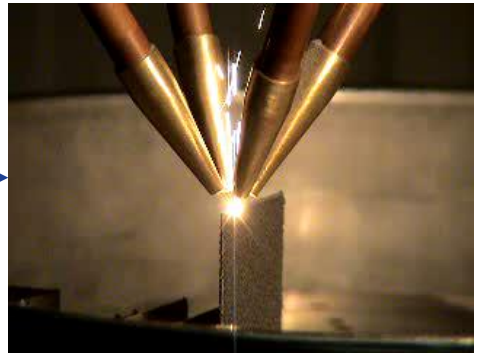


Blisk

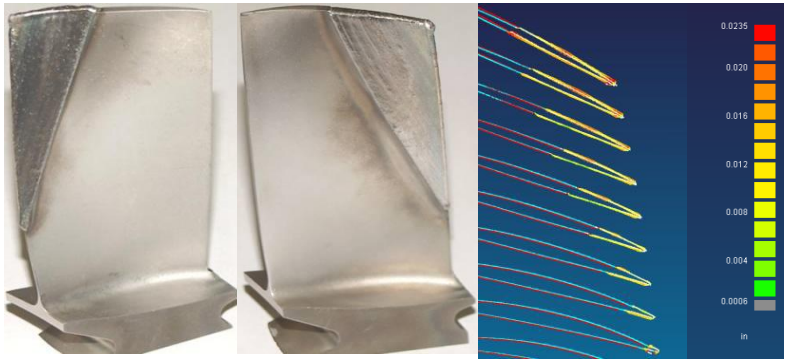


Repair zones on cut-out blade

Toolpath generation

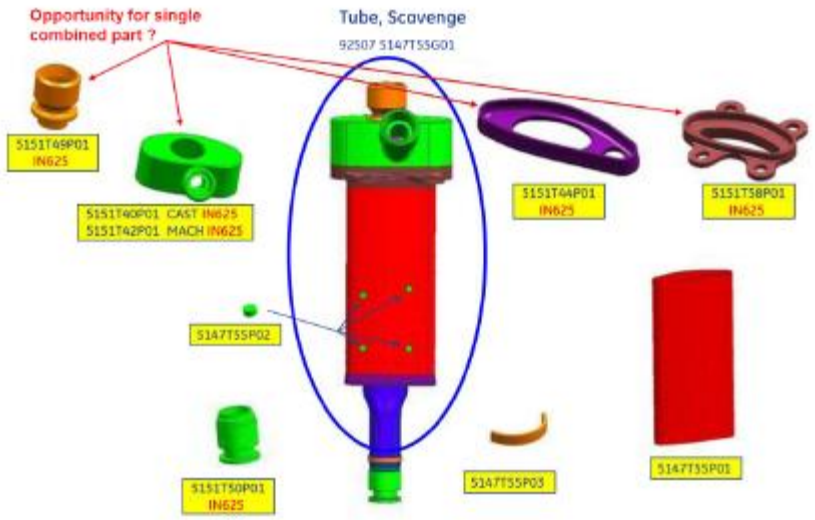


Deposition



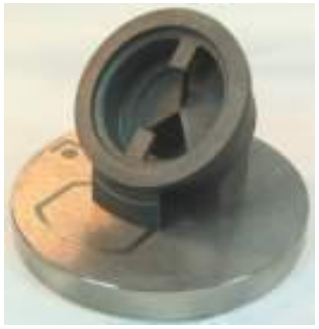
- Average deviation: +10.5 mils
- Max error: +23.5 mils
- Std. Deviation: 4 mils

Direct Metal Laser Sintering (DMLS)



- GE efforts began in ’05
- Commercial equipment + external vendors
- Focus – alloys not offered by system providers
- First commercial application in 2013

DMLS Parts

	Air Venturi	Tube Coupling Flange	Flame Check Valve Flange
Unigraphics Solid Model			
Casting Geometry			
Machined Geometry			

Summary & Looking Forward

- Additive Manufacturing will play a key role in future development/production
  - Shorten cycle & saving cost
  - Enable new design
  - Reduce buy-to-fly ratio
- Challenges to be overcome
  - Size limitation
  - Surface roughness
  - Speed for high volume production
  - Material properties database
  - Limited design tools

Thank You!