



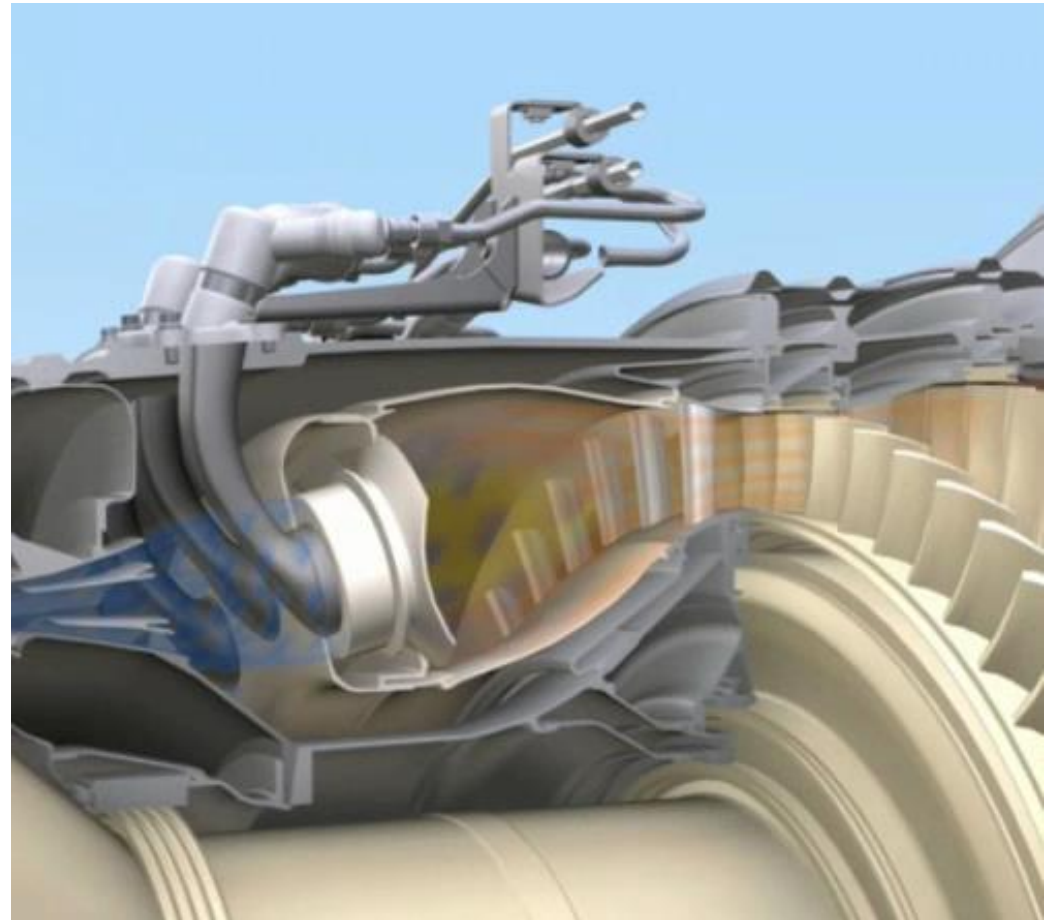
The Power of Flight

High Volume Production with Additive Manufacturing

29 September 2016

**Export Classification: NLR
(DoC Jurisdiction, 9E991)**

LEAP Fuel Nozzle ... overview



Direct Metal Laser Melting (DMLM)



Best Feature Resolution

Laser in powder bed provides the best control of the weld pool.

Best Material Properties

Laser in powder bed provides isotropic small grain structure with lowest surface roughness

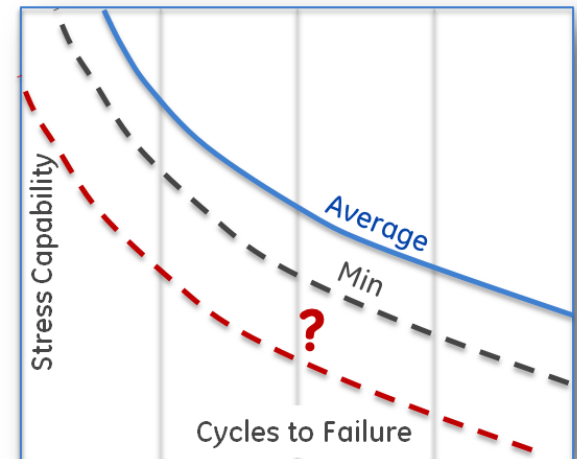
Longest Commercial Experience

20 years of producing parts

Starting Point: Material Uncertainty & Variation



- Material variation between and within machines...
- Raw Material Control
- Chemistry, size, distribution
- Machine Control
- Laser parameters, calibration, environment
- Part Control
- Location, orientation
- Thermal Processing
- HIP, Solution
- Performance Measures
- Surface Finish, Tensile, Fatigue, Grain Size
- Manufacturing & Operating Environment
- Temperature, Corrosion



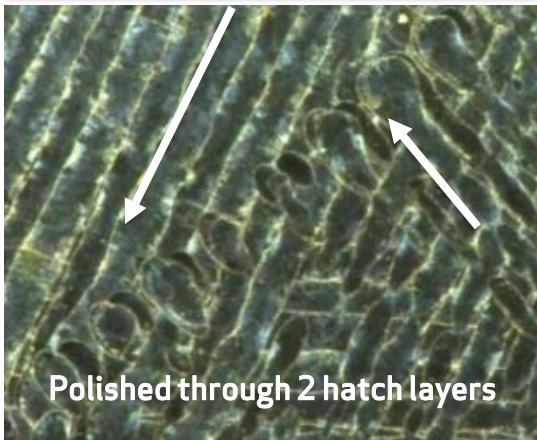
Design Allowables must account for all sources of variation and debits

Microstructure Evolution

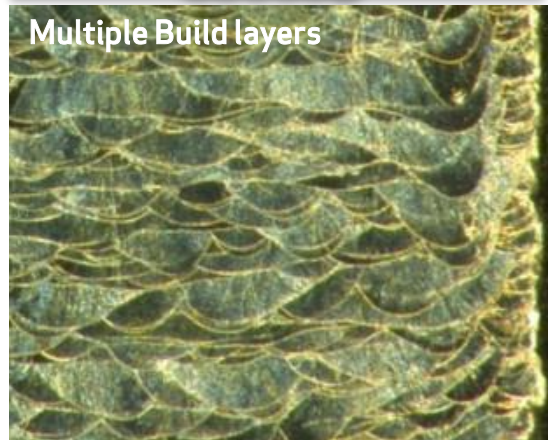
Stress Relief ... Required to eliminate residual thermal stresses left during build process

Hot Isostatic Press ... High temperature, high pressure thermal cycle to eliminate sub-surface porosity (*if necessary*)

Solution Heat Treatment ... Completes conversion of material to near wrought, isotropic structure

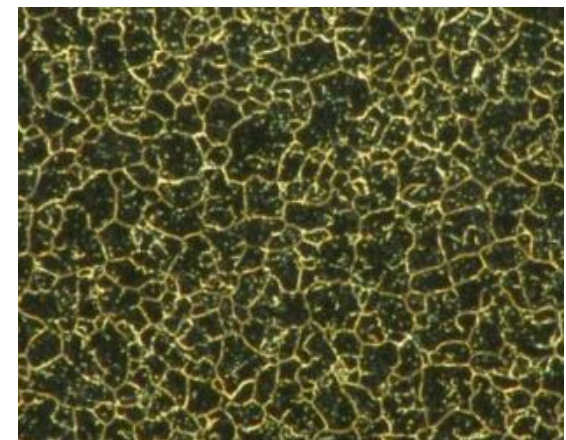


**Pre-Solution
(Top View)**



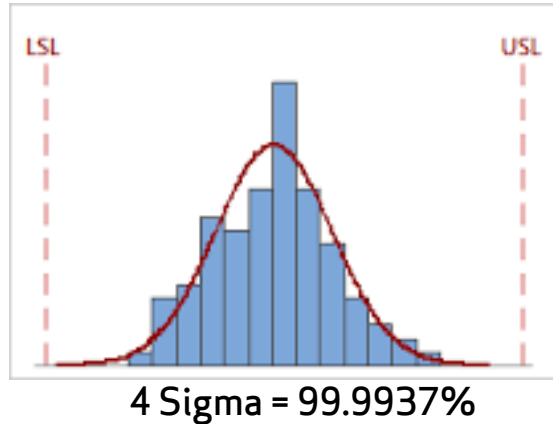
**Pre-Solution
(Side View)**

- Full conversion to fine grain structure
- Fully isotropic structure & properties



**Heat Treated
(All directions)**

Part Dimensional Qualification



**Demonstrate Dimensional:
Process Capability**



Dimensional Qualification

- ✓ *Dimensional conformity*
- ✓ *Process control over multiple builds*
- ✓ *Machine variation*
- ✓ *Position variation*
- ✓ *Quality plan (cut-up and NDT)*
- ✓ *NDT probability of detection studies*

Part Functional Qualification



Fuel Nozzle Spec

Functional Qualification

- ✓ *Component level testing*
- ✓ *Critical-to-quality performance tests*
 - ✓ *Pressure test*
 - ✓ *Flow test*
 - ✓ *Spray test*
 - ✓ *Aerodynamic test*
- ✓ *Part Spec/Drawing Requirements*
 - ✓ *Pressure test*
 - ✓ *Flow test*
 - ✓ *Spray test*
 - ✓ *Surface finish*

Component to Product Level Certification



High Volume Production

