Additive Manufacturing Activities at NASA Glenn Research Center

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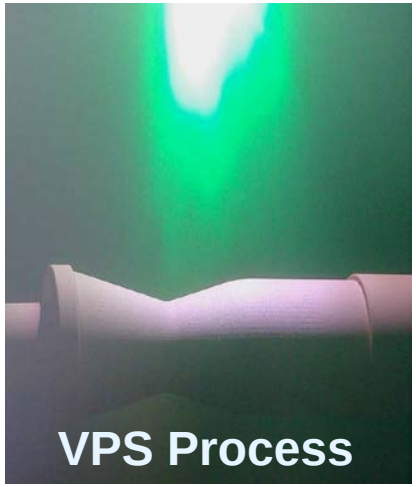
Overview

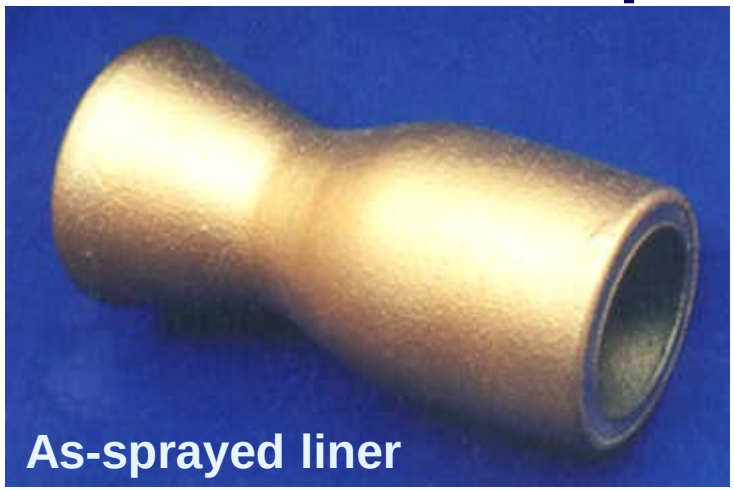
- **NASA has been involved in a variety of efforts to decrease weight on aircraft and rockets for decades**
  - One pound saved on a rocket is one pound more payload
  - One pound saved on an airplane engine can be several pounds more cargo
- **NASA has also been working on new processing methods developed both in-house and by industry**
- **Additive manufacturing is only the most recent area investigated by NASA**
- **This talk will deal with additive manufacturing of rocket engine components**

The Past: Reusable Launch Vehicle – Second Generation Program

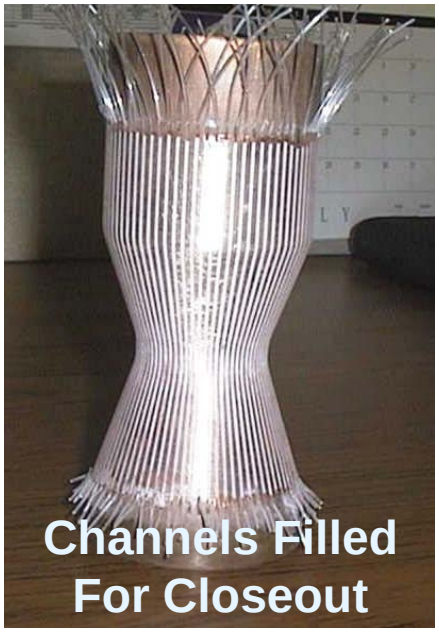
Additive Manufacturing Before There Was Additive Manufacturing

Vacuum Plasma Spray (VPS)


VPS Process


As-sprayed liner

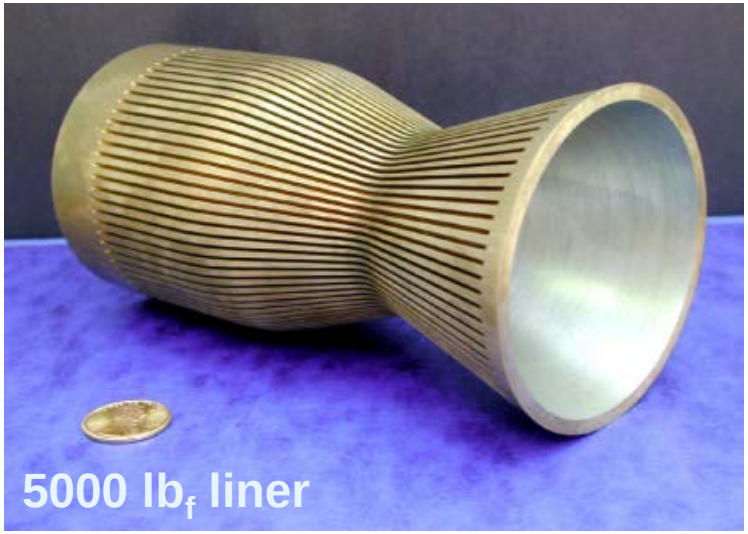

Liner With Channels

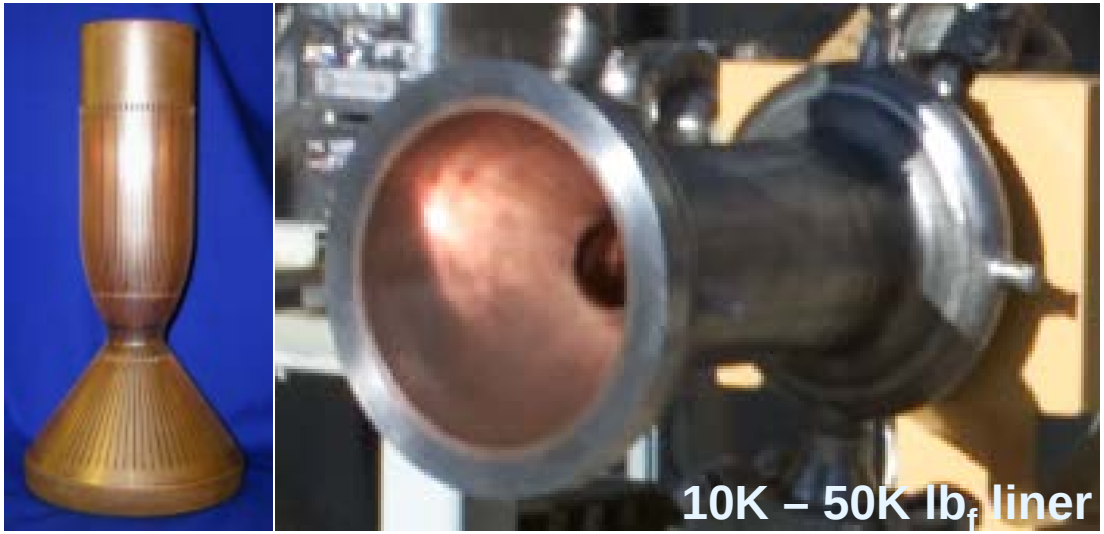

Channels Filled For Closeout


VPS Closeout


Manifolds and PMC Jacket

Examples Of Vacuum Plasma Sprayed Liners



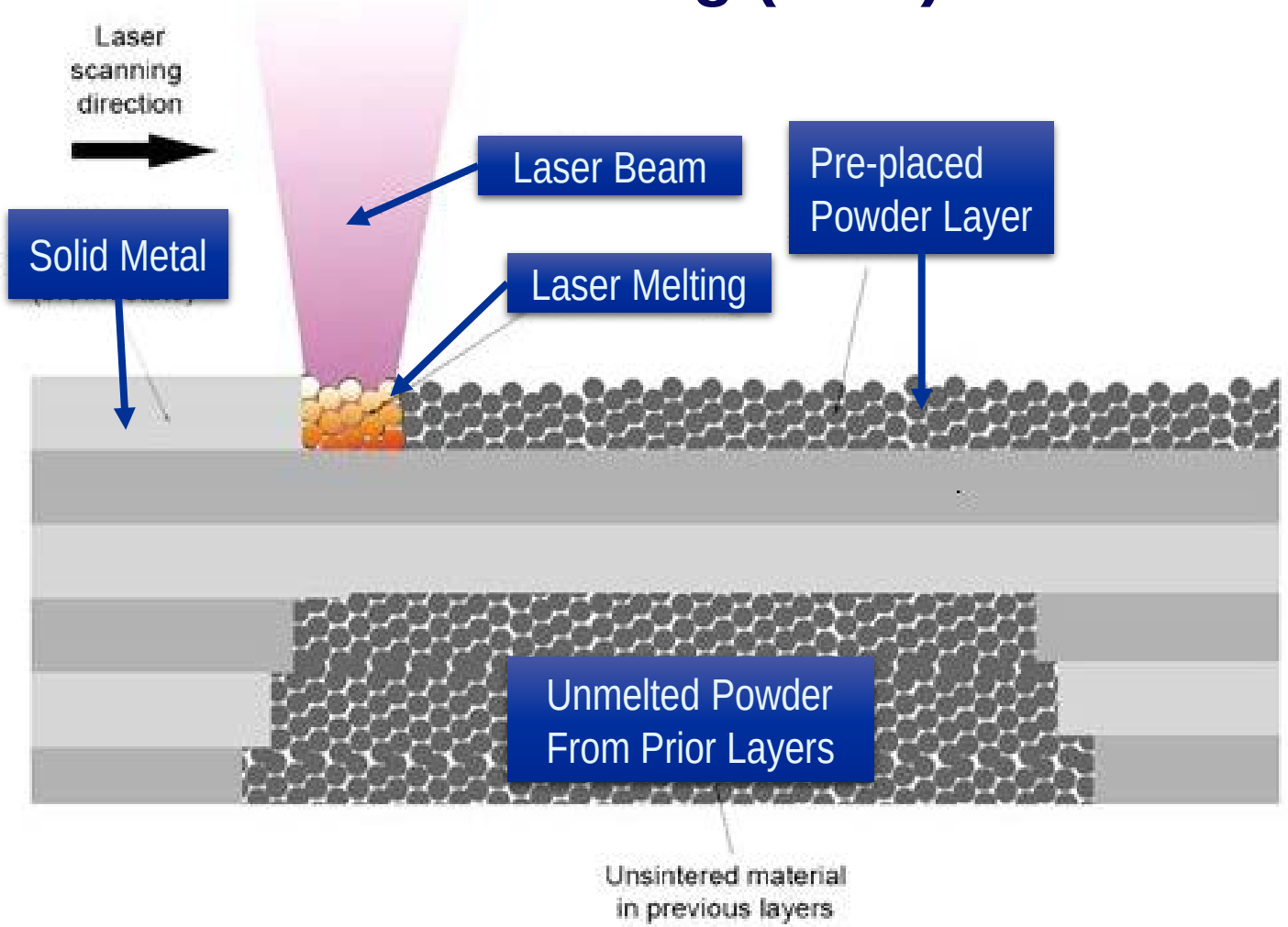


Hot Fire Testing Of 40K lb_f VPS Liner

The Present:
Low Cost Upper Stage Program

Modern Powder Bed And Electron Beam Additive Manufacturing Of Liners And Jackets

Selective Laser Melting (SLM) Processing

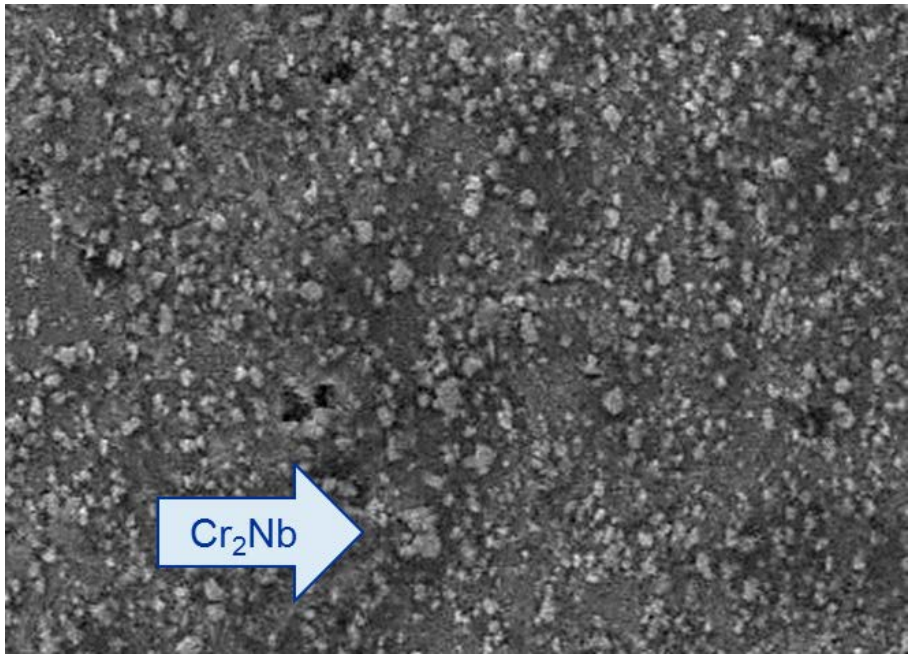


Unlike Selective Laser Sintering (SLS), SLM involves melting and resolidifying the powder-

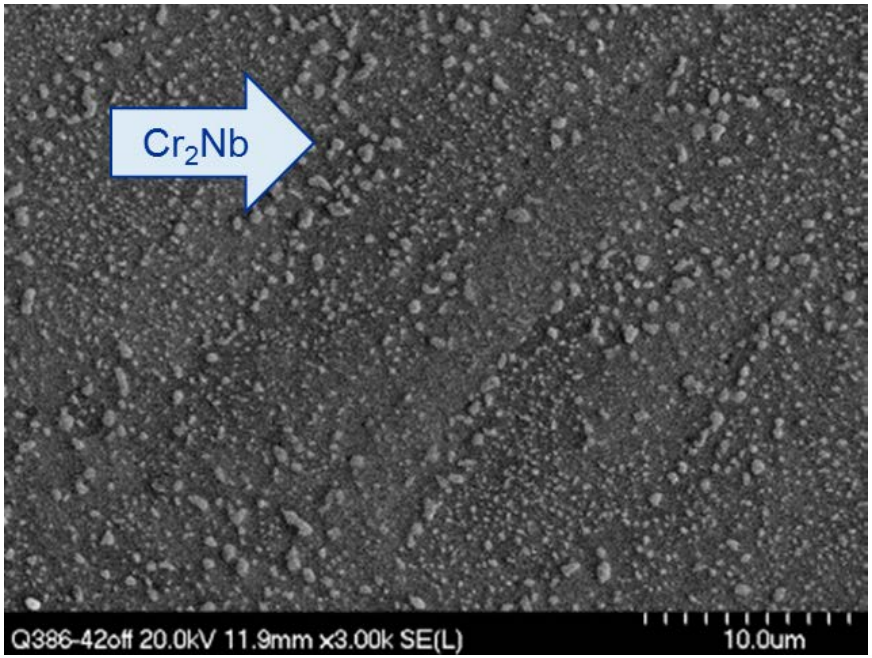
Concept Laser M2 Machine: Selective Laser Melting (SLM) Additive Manufacturing

SLM GRCop-84 Rocket Engine Liner And Mechanical Test Samples

SLM Processing Led To Unexpected Refinement Of GRCop-84 Microstructure



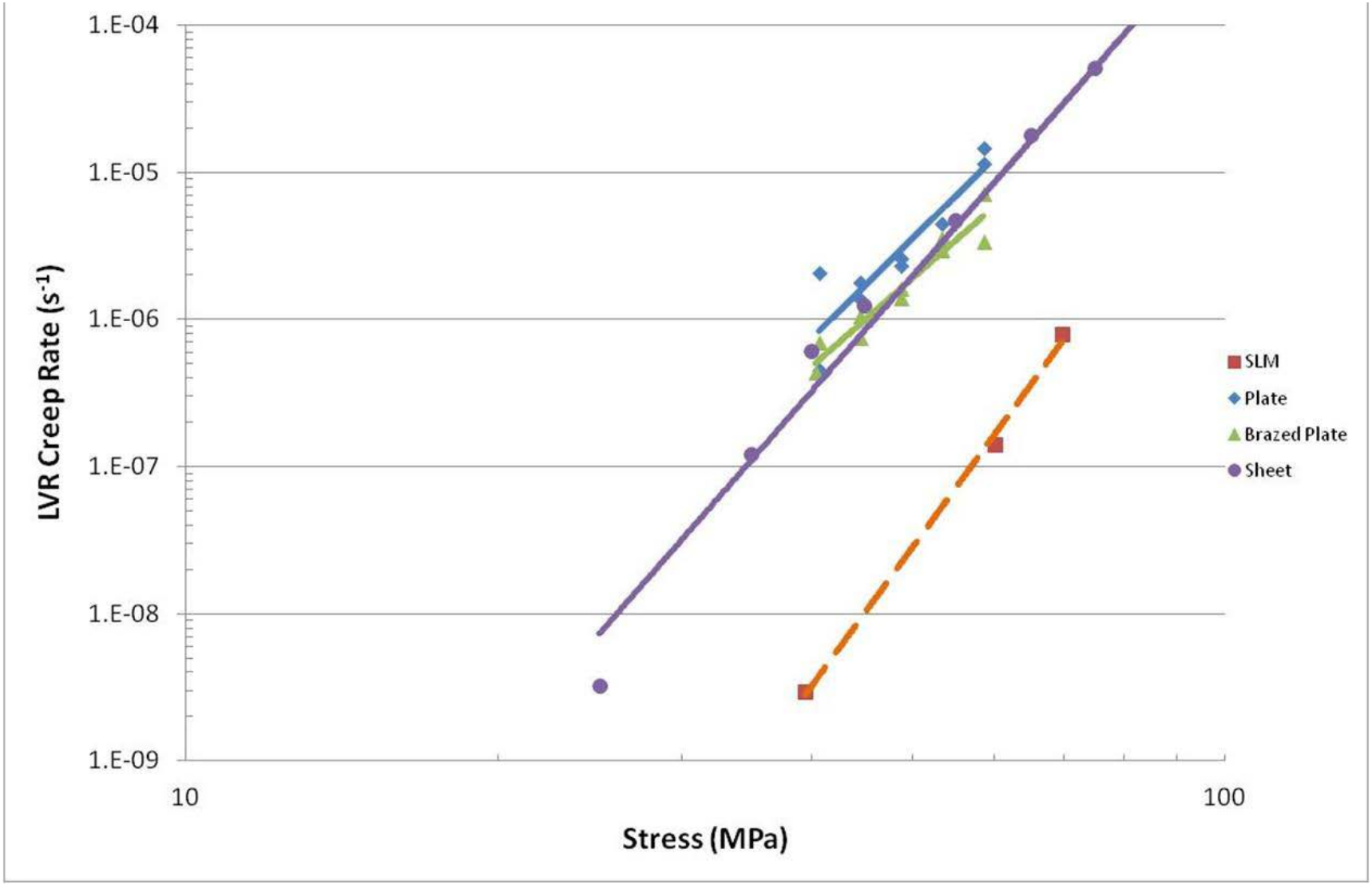
(a) As-Extruded GRCop-84



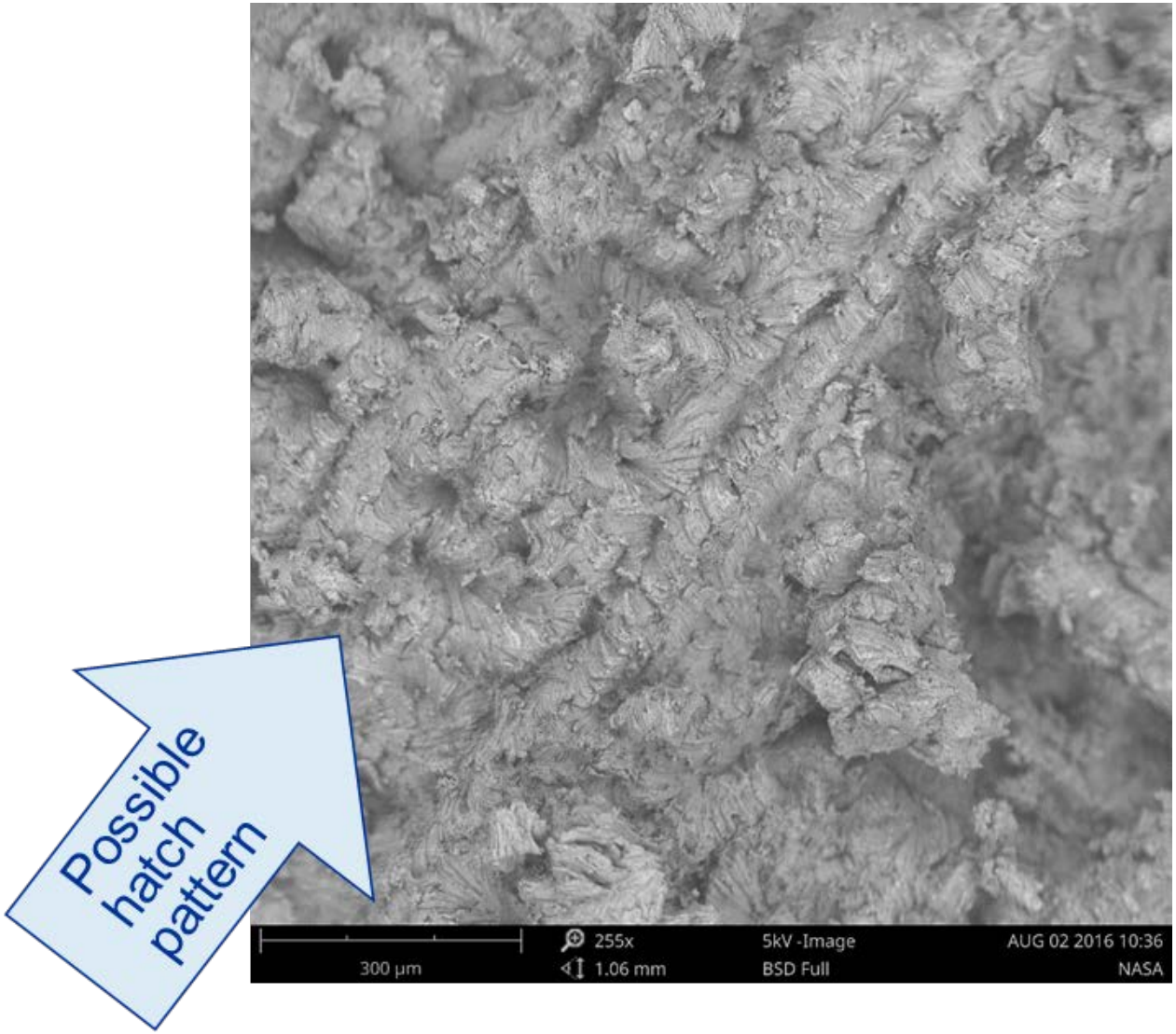
(b) SLM GRCop-84

Finer microstructures generally have better properties

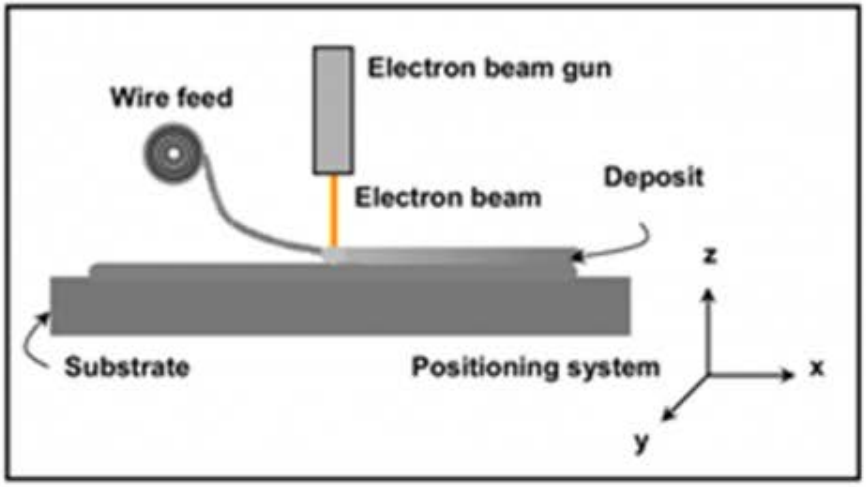
SLM Led Directly To Improved GRCop-84 Mechanical Properties

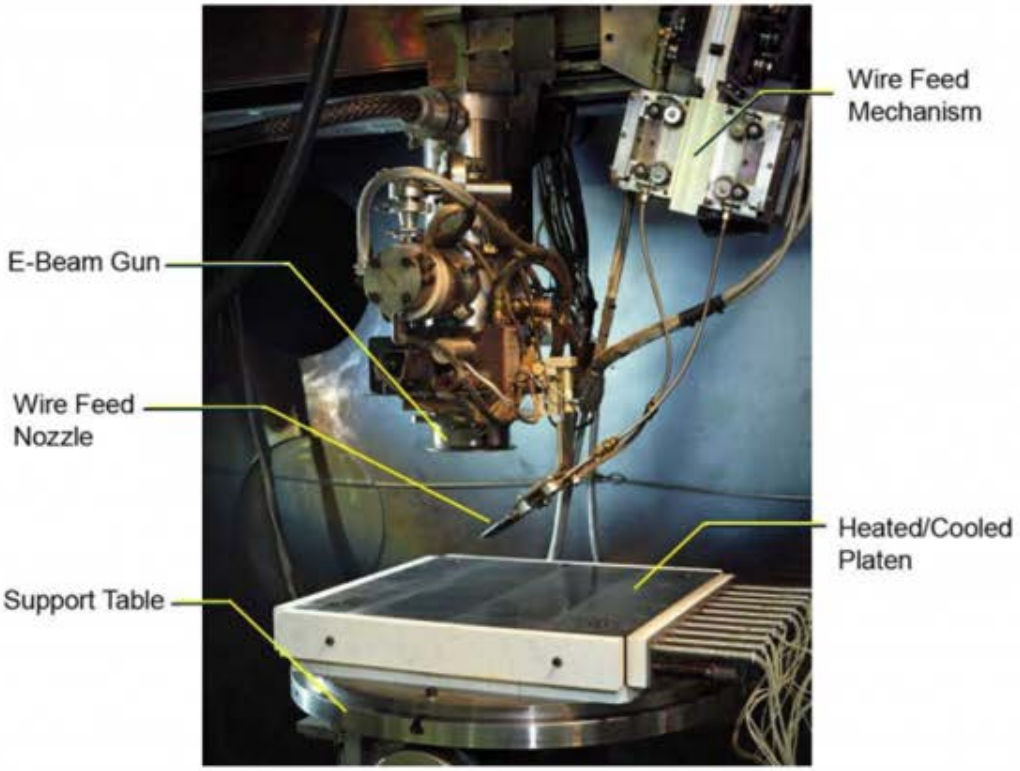


Additive Manufacturing May Affect Failure Mode Of AM Parts



Electron Beam Free Form Fabrication (EBF^3)





Jacketed SLM Liner

- EBF^3 used to deposit Alloy 625 (commercial Ni-based superalloy) onto liner
- Allowed deposition of manifolds at the same time as the jacket
- EBF^3 allowed very fast deposition (pounds per hour) on a fairly complex geometry

The Near Future 1: Rapid Analysis and Manufacturing Propulsion Technology Program

Fully Additive Liners, Jackets, Manifolds And Nozzles

The Problem: Make Bigger Parts

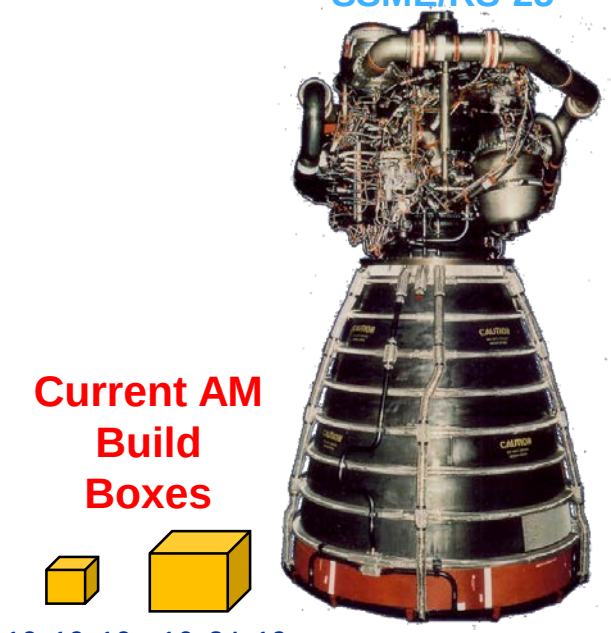
SSME/RS-25

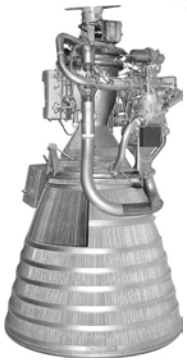
RL-10A-4

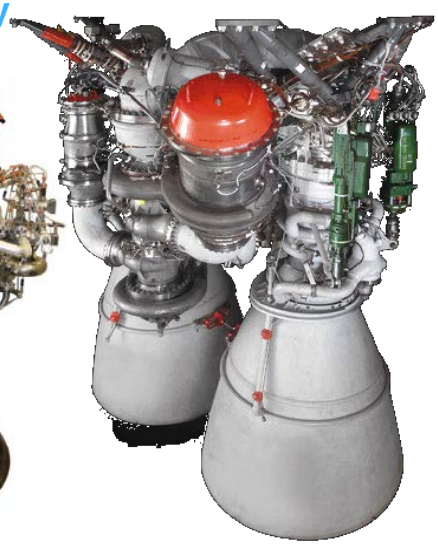
J-2X, Regen Only

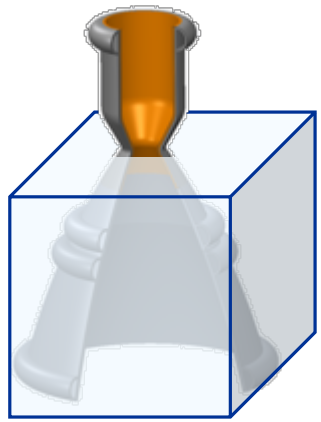
RD-180

RAMPT









90”

46”

70”

Nozzle Exit Dia.

56”

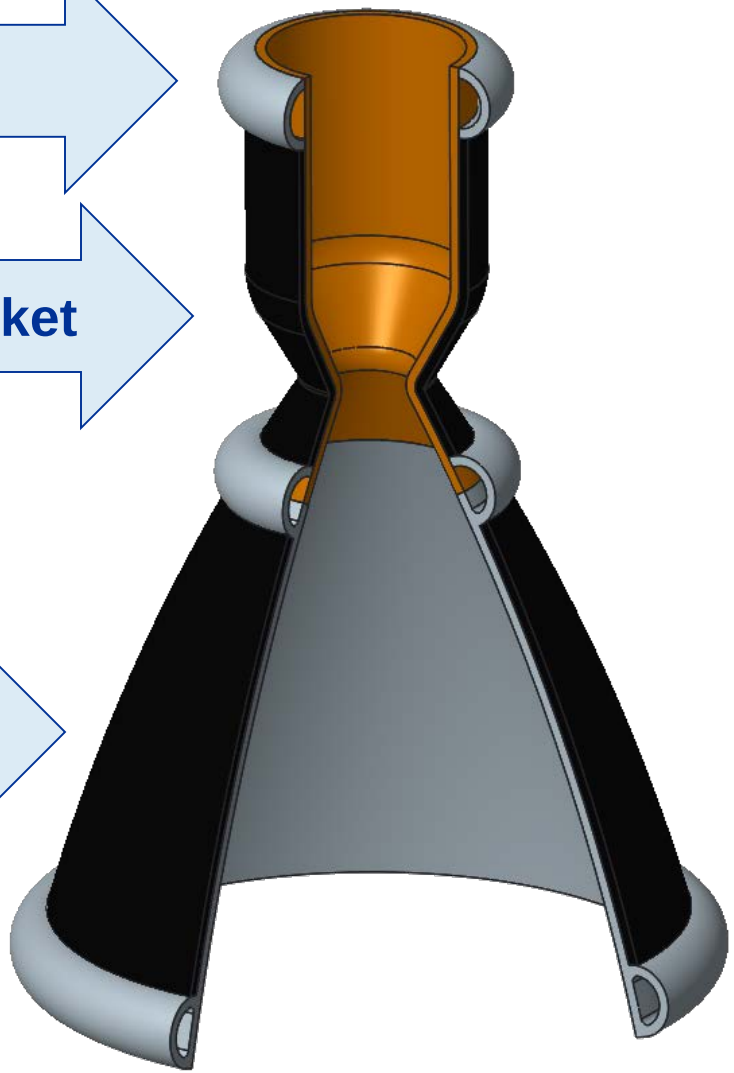
Addresses longest lead, highest cost and heaviest component in engine

Areas Of Interest

Manifolds

Lightweight Jacket

Nozzle



Joints And Joining Present Major Challenges

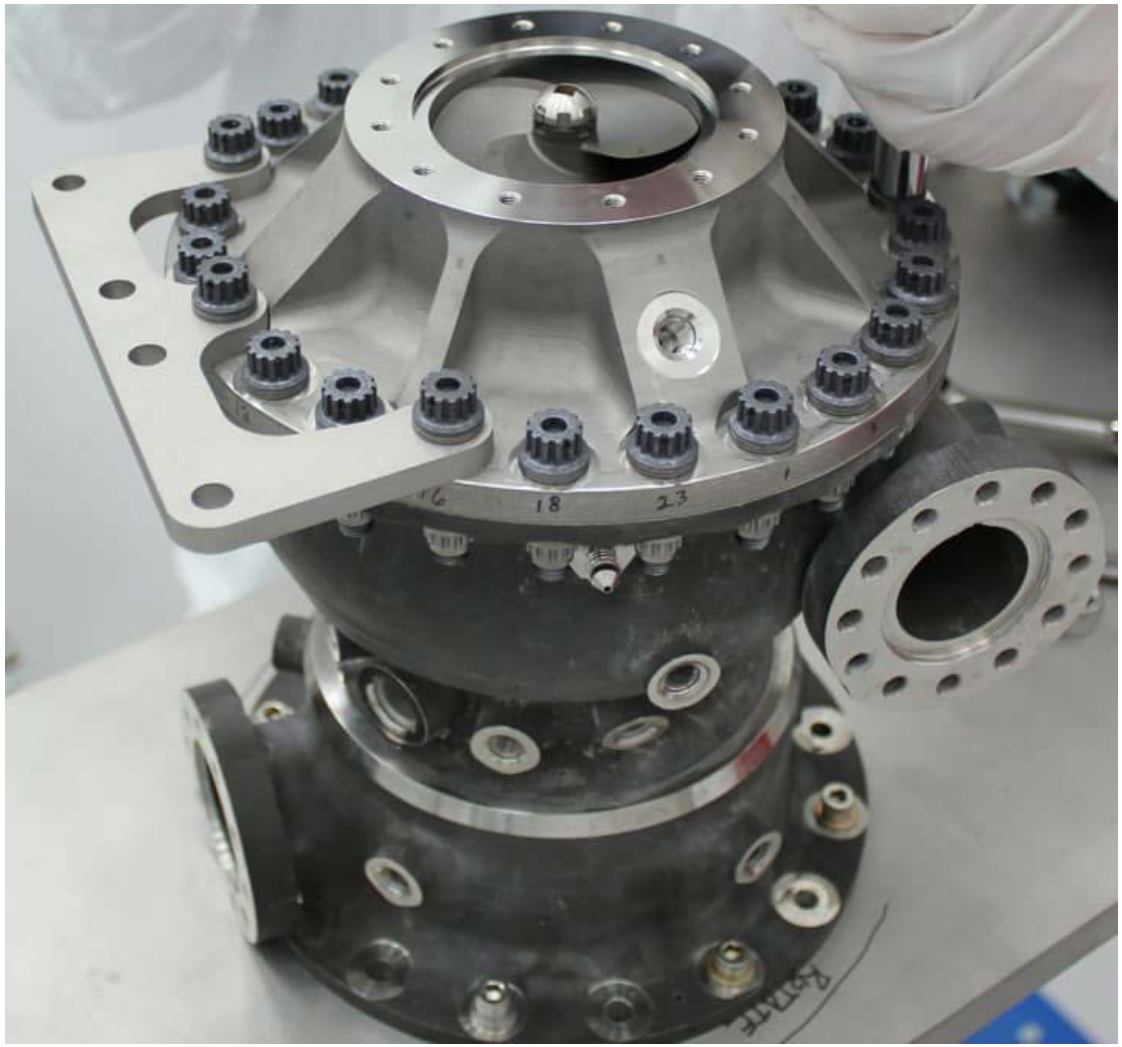
The Near Future 2: Additive Manufacturing Structural Integrity Initiative Program

Are All Powders For Superalloy Parts For Rocket Engines The Same?

Space Launch System And RS-25E Rocket Engine

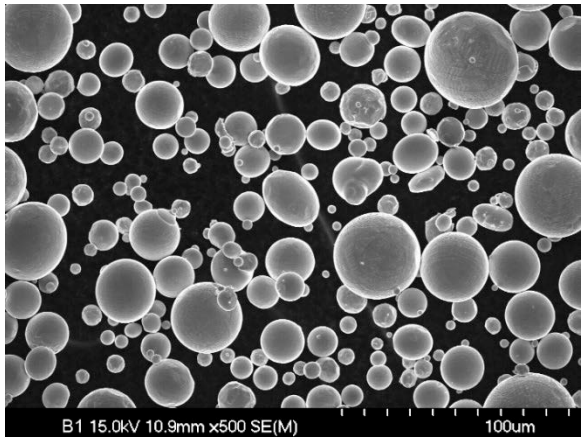
- Additive manufacturing can reduce part count and decrease weight by eliminating joints and flanges
- Alloy 718 can be used for ducts, housings, turbomachinery, and other applications

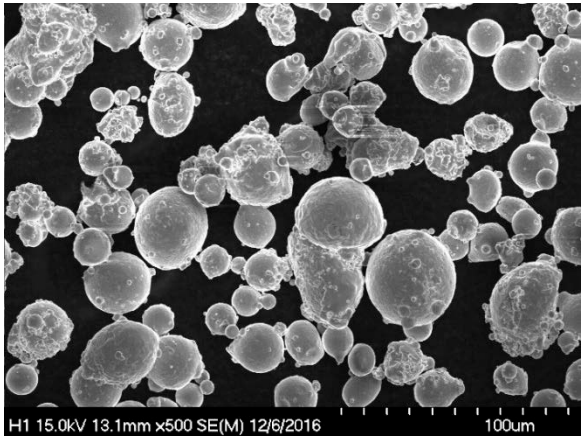
3D Printed Rocket Components Are Already A Reality



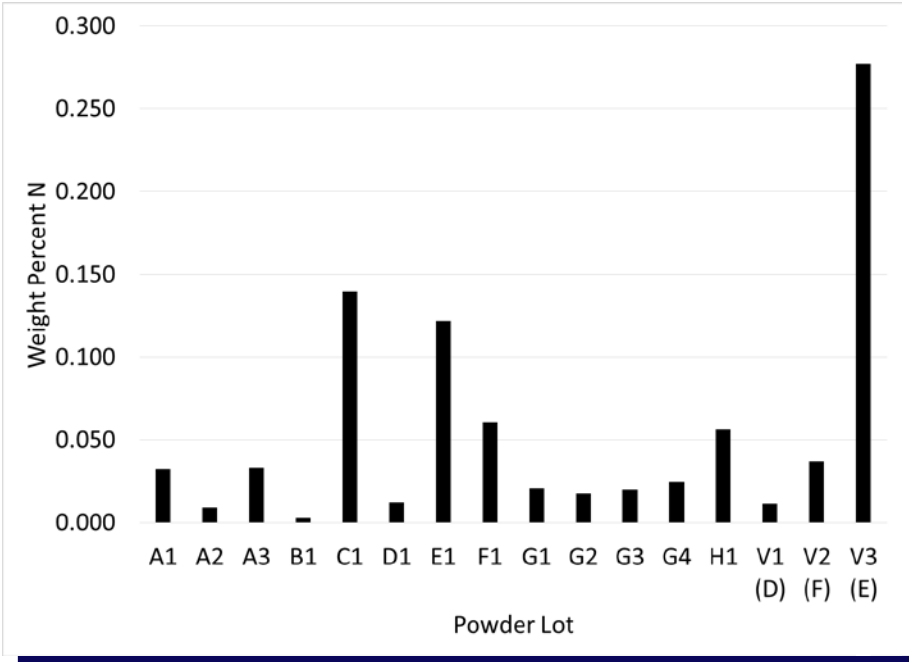
- **Fuel Turbopump for 30,000 lb_f class rocket engine**
  - Suitable for upper stage engine
- **90,000 RPM disk speed**
- **45% fewer parts than SSME FTP**
- **Tested under actual service conditions in July 2015 at NASA MSFC**

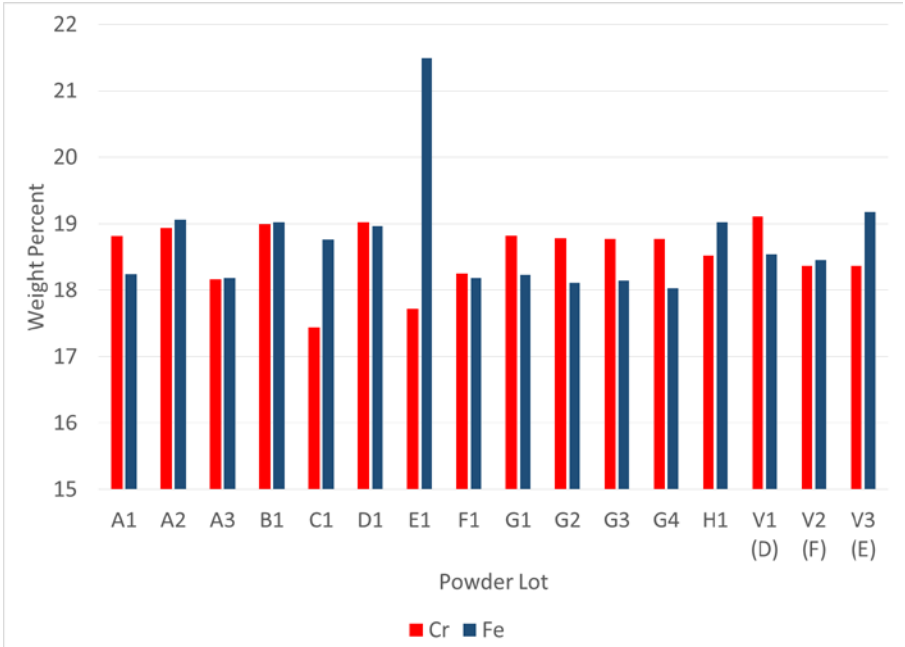
All Alloy 718 Powders Are Not The Same





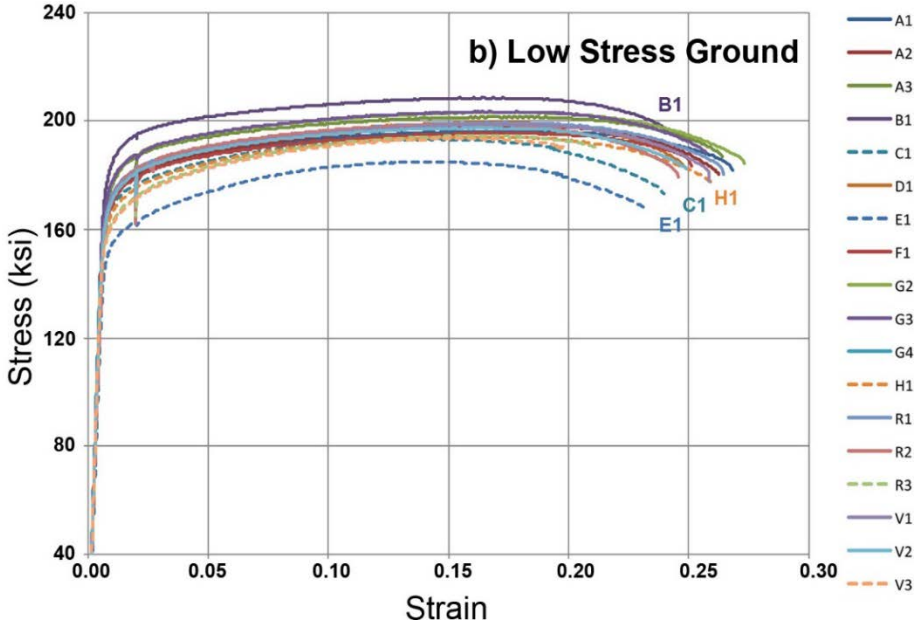
Powders can have widely varying sizes and chemistries and still meet specifications



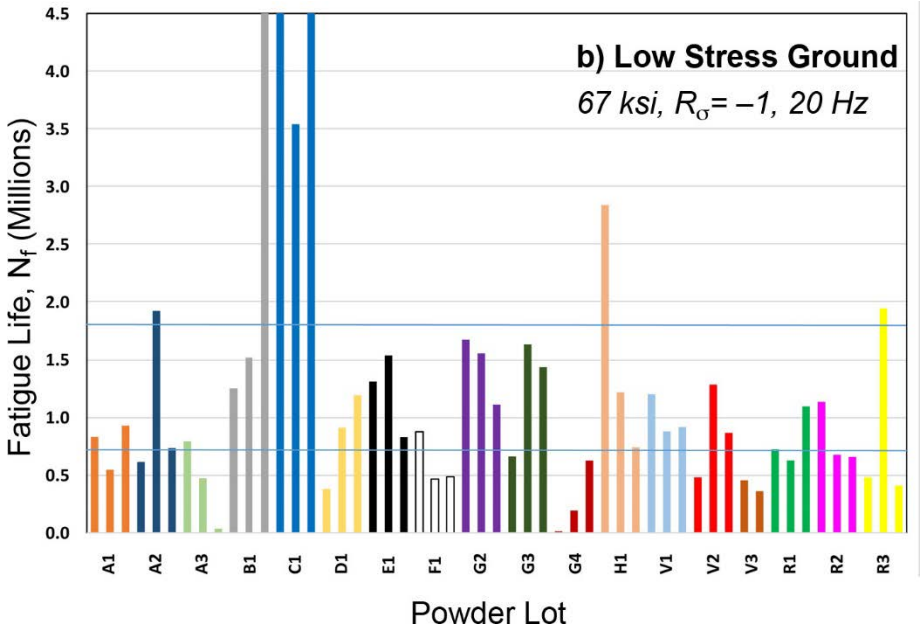


Differences In Powder Translate To Differences In Properties

RT Tensile Strength



RT Low Cycle Fatigue



- **Varying powder chemistry and morphology affects the build and the mechanical properties**

Summary

- **Current work is showing that additive manufacturing is a viable process for making rocket engine components**
- **Examination of the feed stock reveals wide variability even when the powder meets the specifications**
  - NASA is working on defining what should be specified and controlled for SLS and other applications
- **Additive manufacturing is producing materials that can be very different from traditional cast, wrought and powder metallurgy parts**
- **There appears to be significant gains that can be made using additive manufacturing**