National Aeronautics and Space Administration

Optimization of Rocket Engine Components using Multi-Metallic Additive Manufacturing

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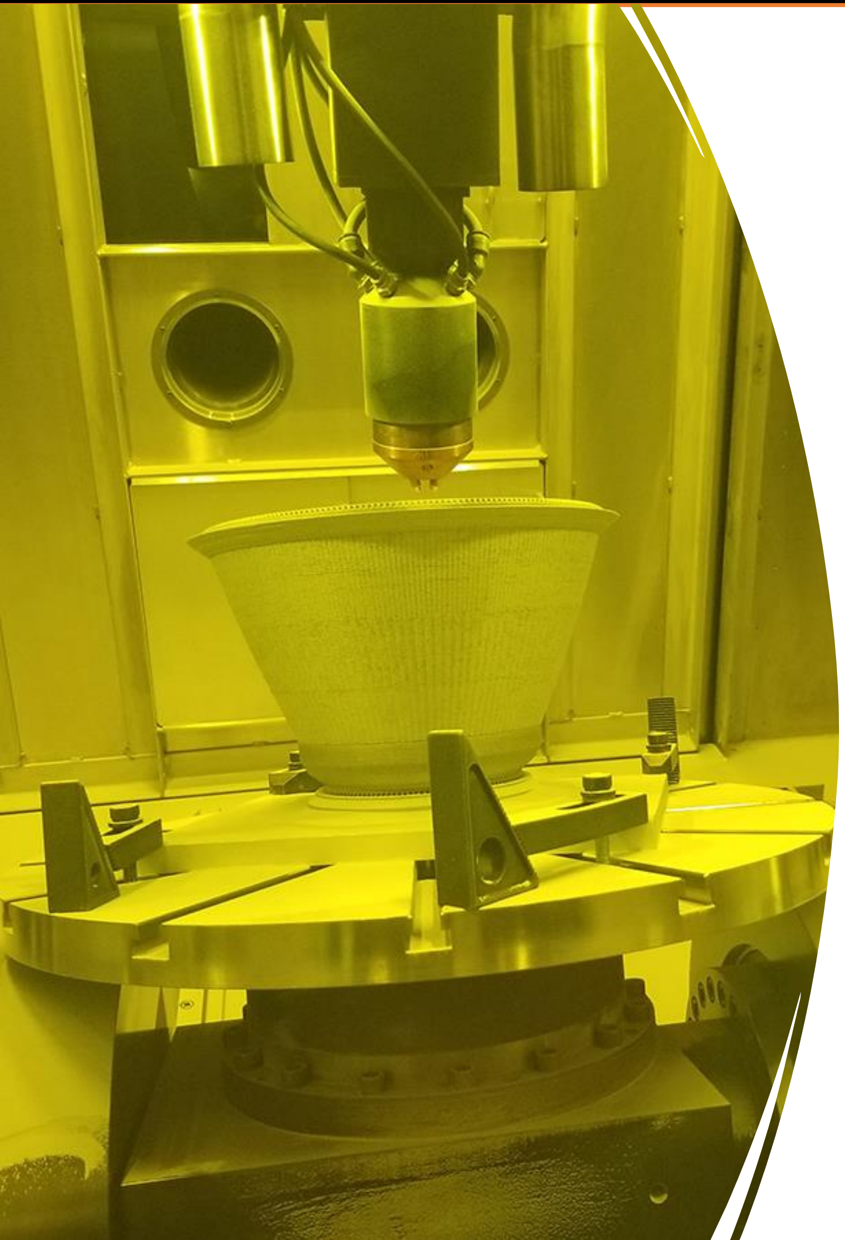
Introduction



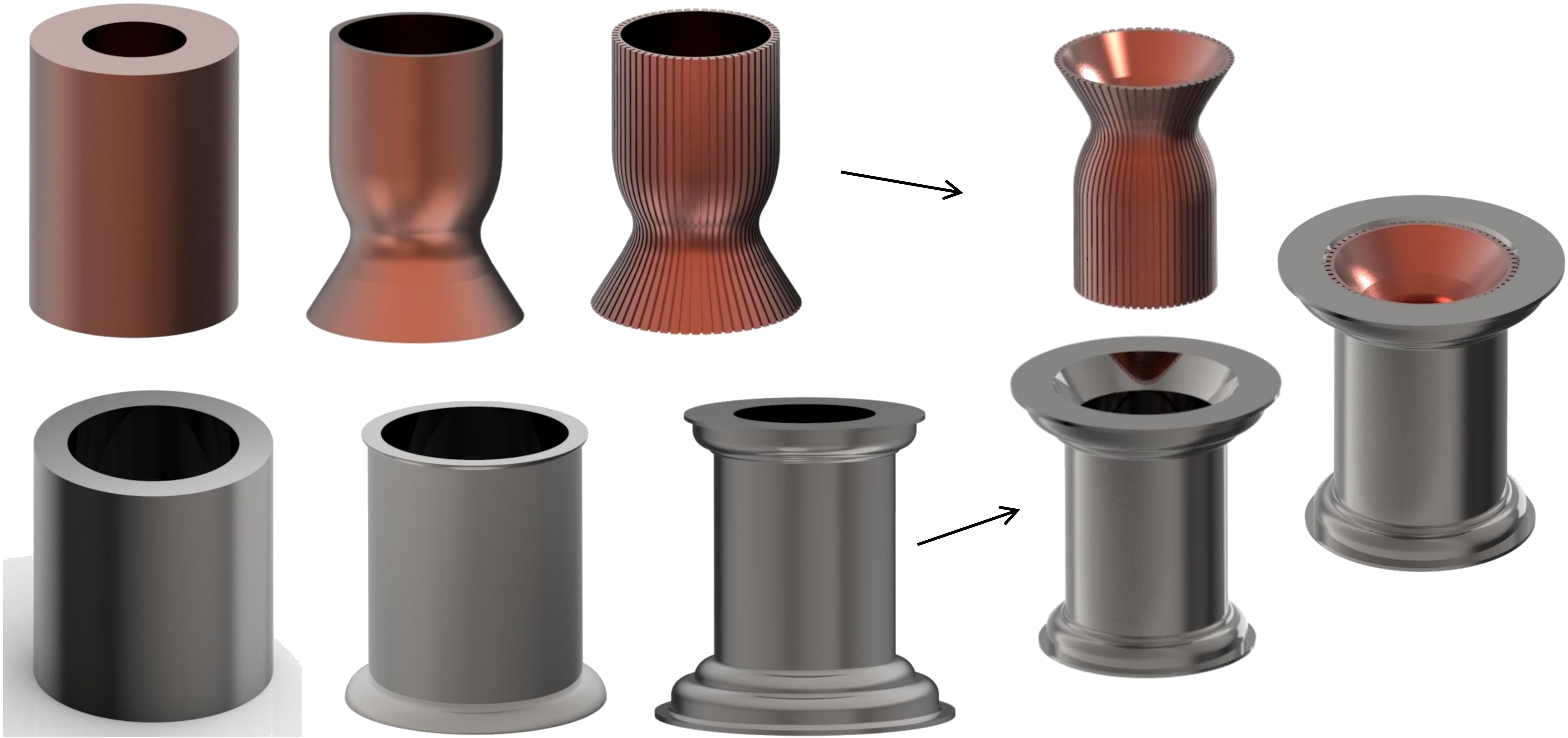
- Objectives and Project Overview
- Why bimetallic and multi-alloy AM?
- Process Development
- Hardware Development
- Hot-fire and Component Testing
- Summary

Why use multi-metallic joints and AM?

- Additive manufacturing (AM) is advancing component fabrication for liquid rocket engines allowing for reduced cost, reduced lead time, and performance opportunities over traditional manufacturing.
- Much of AM is focused on single alloys, where further opportunities exist to optimize performance.
  - Weight reduction (higher strength to weight).
  - Use of materials as required locally based on various properties.
- Copper-based alloys, such as GRCop-42 and GRCop-84 are used for high conductivity, such as regenerative-cooling for combustion chambers.
  - Although have high strength, better metal alloys (superalloys) available to react pressure, thermal, and thrust loads (↑ strength to weight).

There is a need to advance bimetallic and multi-alloy components using additive manufacturing processes

Traditional Manufacturing…Forging to final assembly



A rocket combustion chamber case study for AM

*Low volume production

Category	Traditional Manufacturing	Initial AM Development	Evolving AM Development
Design and Manufacturing Approach	Multiple forgings, machining, slotting, and joining operations to complete a final multi-alloy chamber assembly	Four-piece assembly using multiple AM processes; limited by AM machine size. Two-piece L-PBF GRCop-84 liner and EBW-DED Inconel 625 jacket	Three-piece assembly with AM machine size restrictions reduced and industrialized. Multi-alloy processing; one-piece L-PBF GRCop-42 liner and Inconel 625 LP-DED jacket
Schedule (Reduction)	18 months	8 months (56%)	5 months (72%)
Cost (Reduction)	$310,000	$200,000 (35%)	$125,000 (60%)

As AM process technologies evolve using multi-materials and processes, additional design and programmatic advantages are being discovered

Bimetallic AM Process Overview

A variety of AM processes are used to build a base material and then deposit/apply a secondary material to create a bimetallic component

Base Component

- Laser Powder Bed Fusion (L-PBF) — GRCop-42, GRCop-84

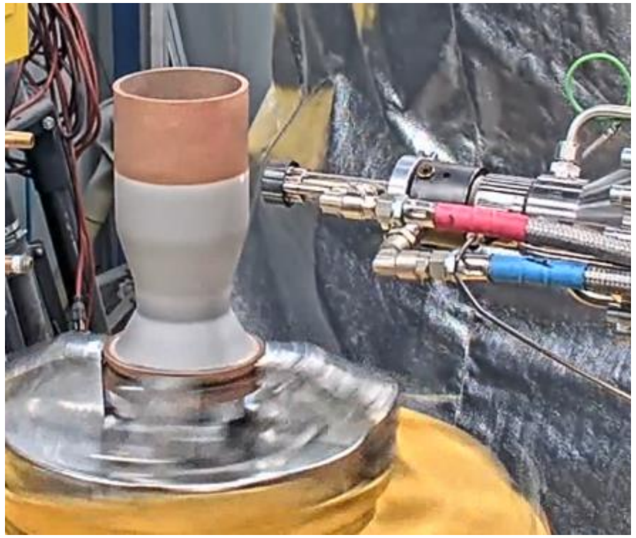
Secondary AM Operation

- Laser Powder Bed Fusion (L-PBF) — Inconel 625
- Laser Powder Directed Energy Deposition (LP-DED) — Inconel 625, NASA HR-1
- Electron Beam Wire Directed Energy Deposition (EBW-DED) — Inconel 625
- Arc Wire Directed Energy Deposition (AW-DED) — Inconel 625
- Gas Coldspray — NASA HR-1

AM Processes evaluated for bimetallic joints

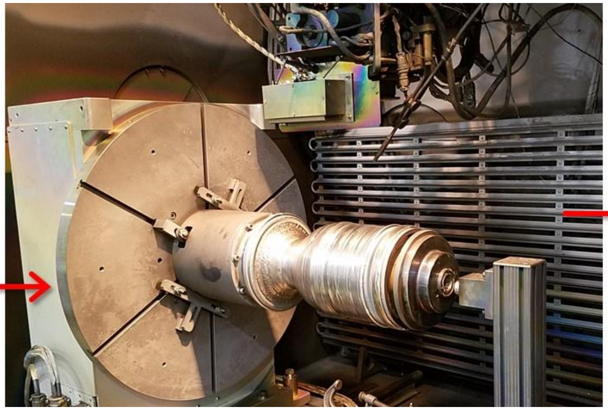
Laser Powder Bed Fusion

Cold spray

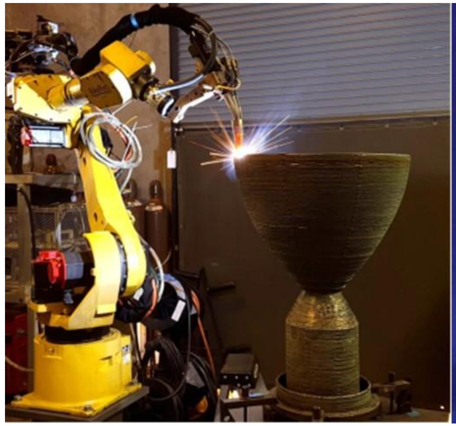


Laser Powder Directed Energy Deposition


Electron Beam Wire Directed Energy Deposition

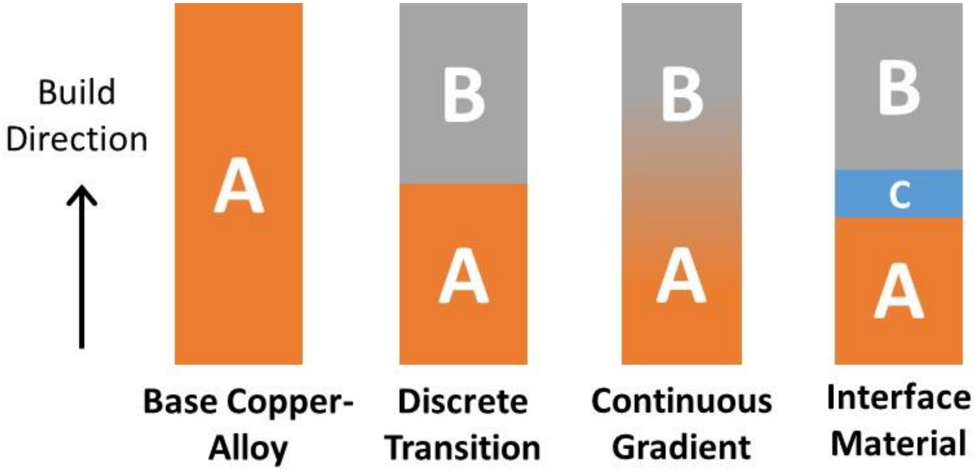



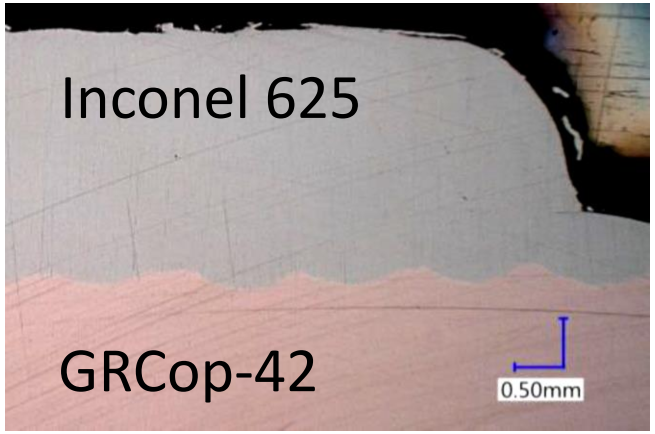

Arc Wire Directed Energy Deposition

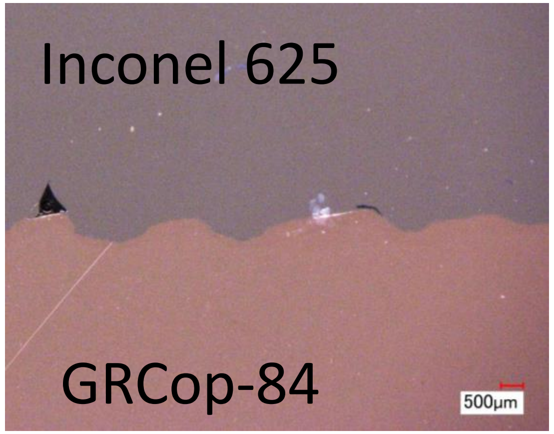


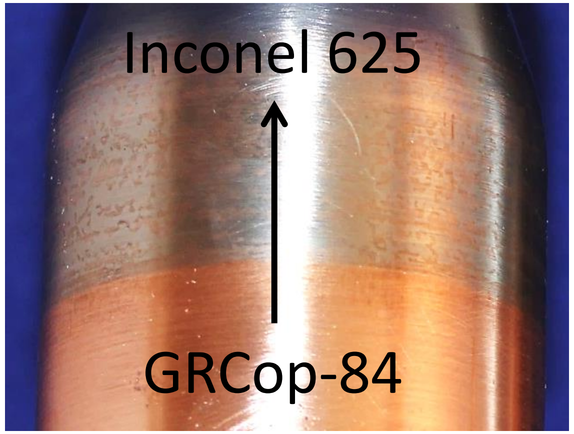
AM bimetallic provides various joint options

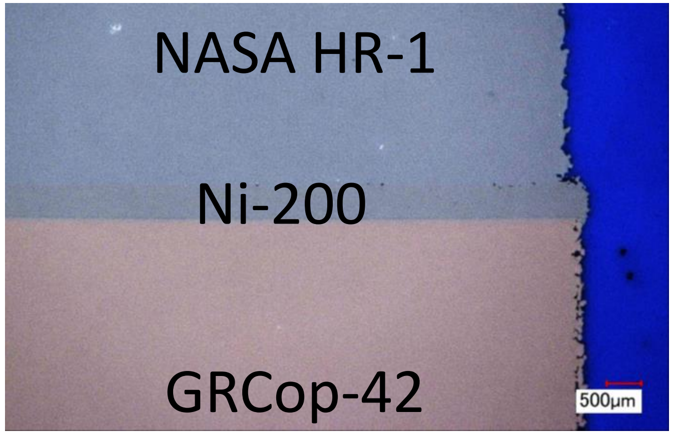
- AM provides a variety of options for bimetallic and multi-alloy joints.
- The type of joint design is highly dependent on the end use and component loads.
- NASA is investigating several types of joints to mature the AM process technology.





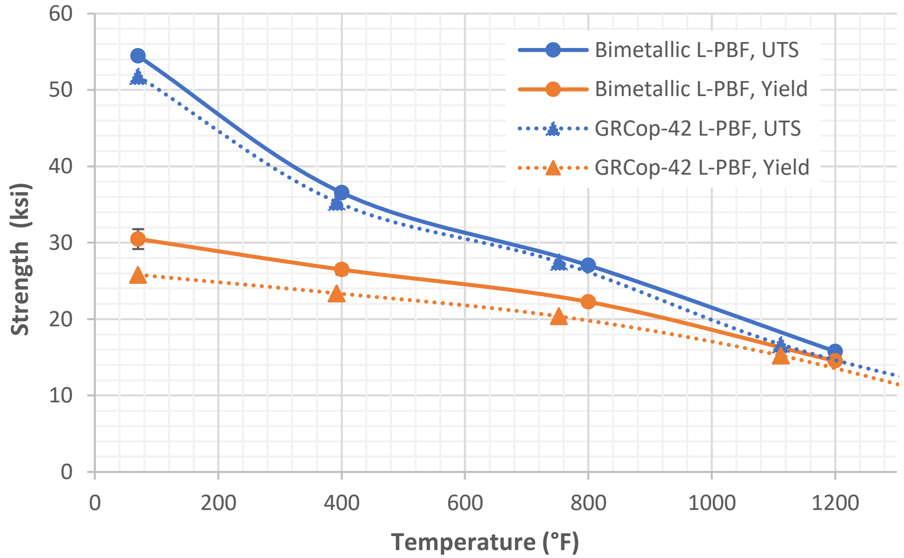


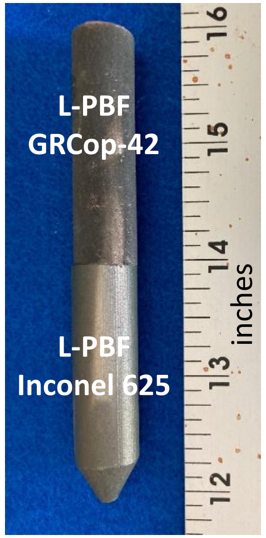


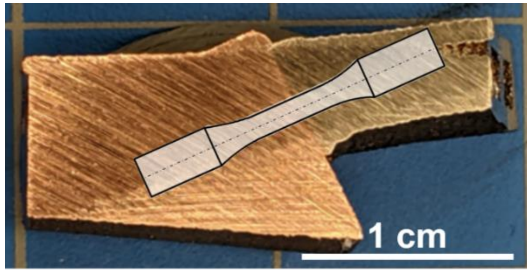


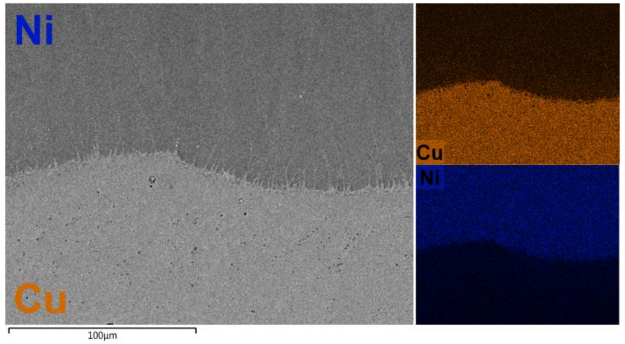
Joint Characterization and Lessons learned from bimetallic L-PBF AM

- Residual stresses can be very high and cause significant shrinkage
- Material modeling to aid with selection using CALPHAD
- High bond strength can be achieved with proper thermal control from deposition parameters
- Intermediate metal alloys may be required to avoid deleterious phases
- Microtensile testing provides a method to characterize joints directly on hardware



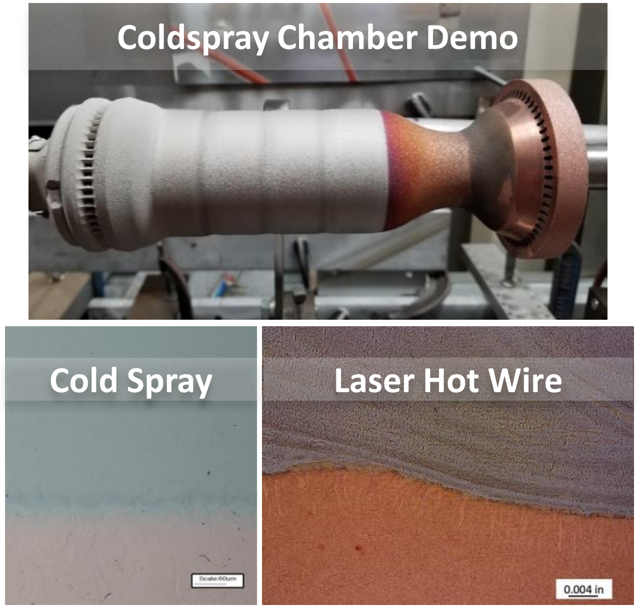


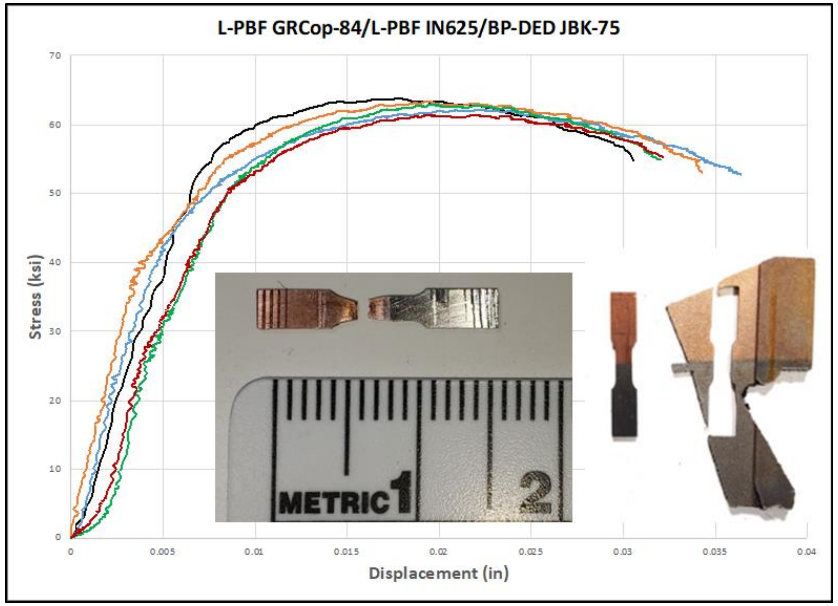




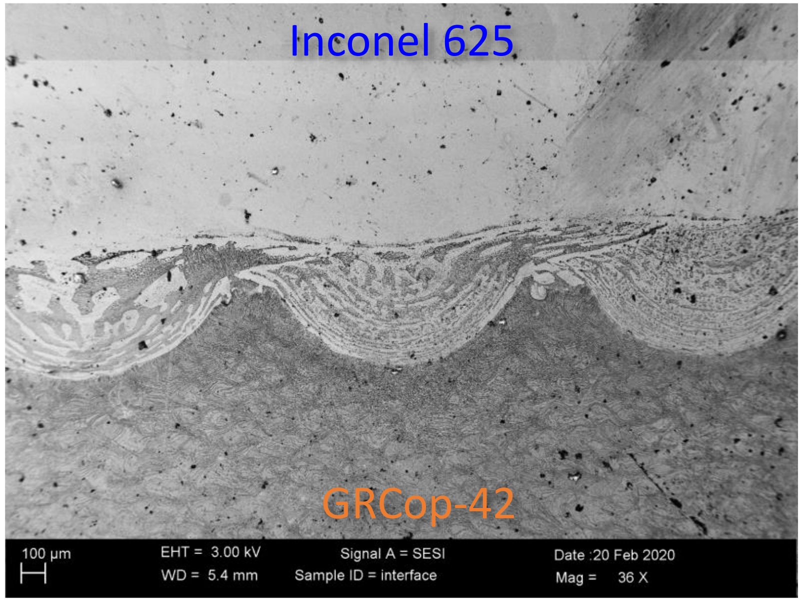
Bimetallic and Multi-metallic Additive Manufacturing for Thrust Chambers

- Bimetallic and multi-metallic joints necessary to join various alloys to optimize strength-to-weight materials by using materials locally based on component requirements
  - Locations include for joining manifolds on the chamber and axial joint between chamber and nozzle
  - Eliminates bolted interfaces
  - Nickel interface layers allow for material transition
- Evaluation various processes including Cold Spray, Laser Hot Wire, and Blown Powder DED



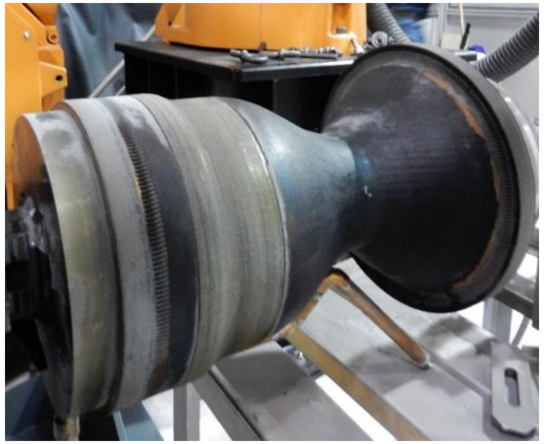


Microtensile testing of Bimetallic/Multi-metallic Joints

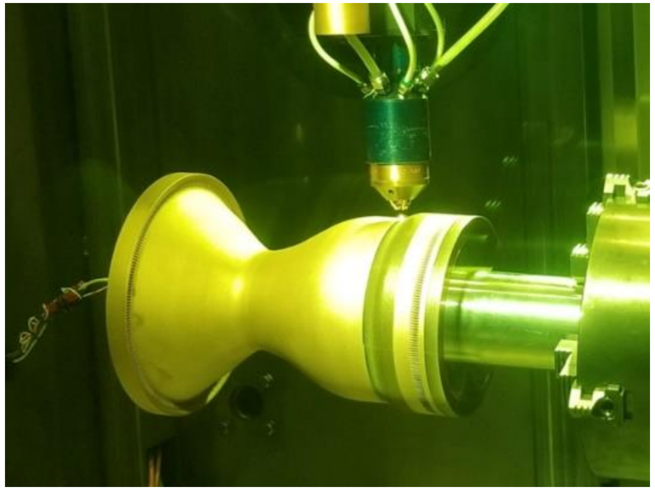


Examples of Component Fabrication

40K-lbf LP-DED Chambers

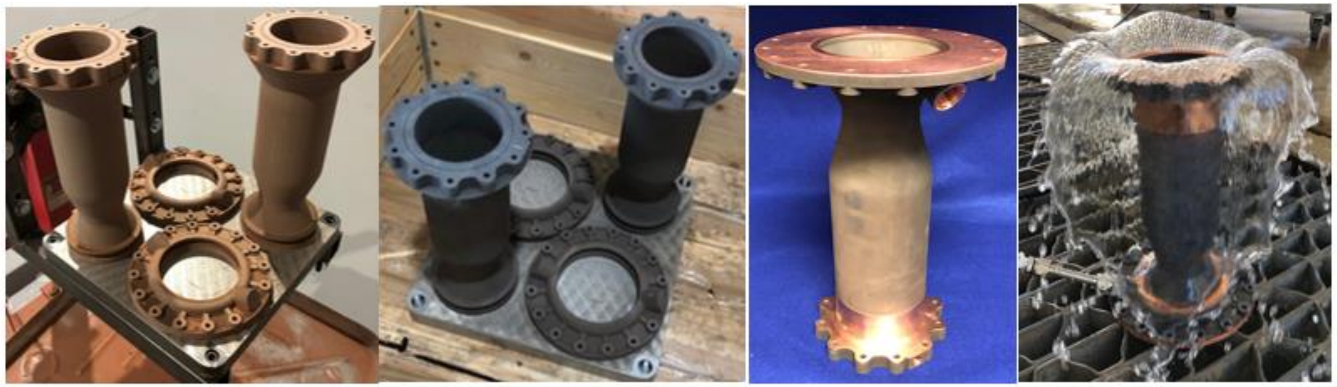



L-PBF GRCop-42 to LP-DED Inconel 625



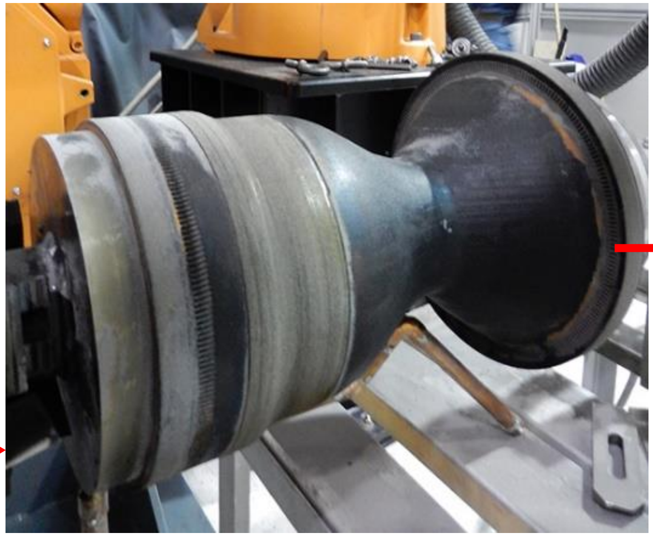

L-PBF GRCop-42 to LP-DED NASA HR-1

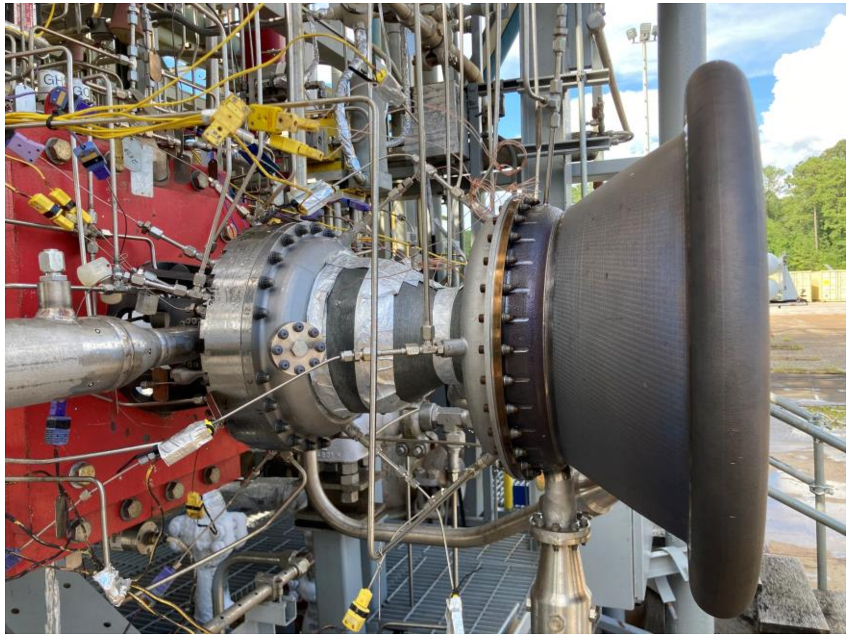
7K-lbf L-PBF GRCop-42 to NASA HR-1 Cold spray Chamber



Post-Build → HIP → Final Machining, Weld, Flow Test → Cold Spray → Final Testing

Hot-fire Testing of Bimetallic AM Chambers





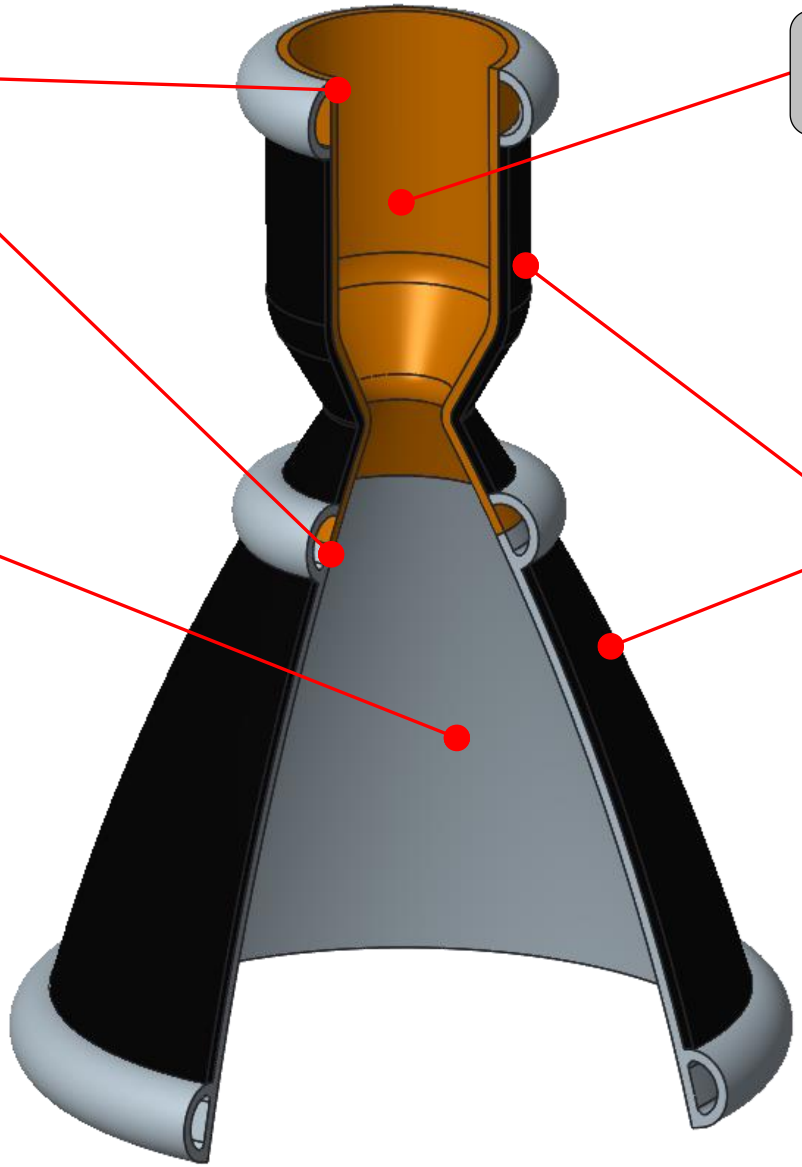
Multi-metallic Additive Manufacturing under RAMPT Project

Bimetallic Deposited Manifolds and Nozzle Interface

- Develops commercial supply chain
- Optimizes weight based on selective material deposition
- Reduces costs
- Evaluating DED and solid-state AM processes

Integrated Large Scale DED Freeform Manufacturing Deposition Regen-Cooled Nozzle

- Selected Laser Powder Directed Energy Deposition (LP-DED)
- Demonstrate integral channels using DED process
- Demonstrate coupled chamber and nozzle configuration to reduce weight
- Reduces complexity
- Significantly increases scale for AM processes for regen-cooled components



L-PBF AM Copper Chamber

- Based on prior LCUSP development
- Proven Technology for GRCop alloys
- Expand to GRCop-42
- Advances and expands commercial supply chain

Composite Overwrap

- Significantly reduces weight for high chamber pressure TCA's
- Reduces distortions caused by bimetallic cladding
- Reduces overall cost and fabrication schedules
- Builds upon prior composite overwrap pressure vessel (COPV) technology

Technology Overview of RAMPT

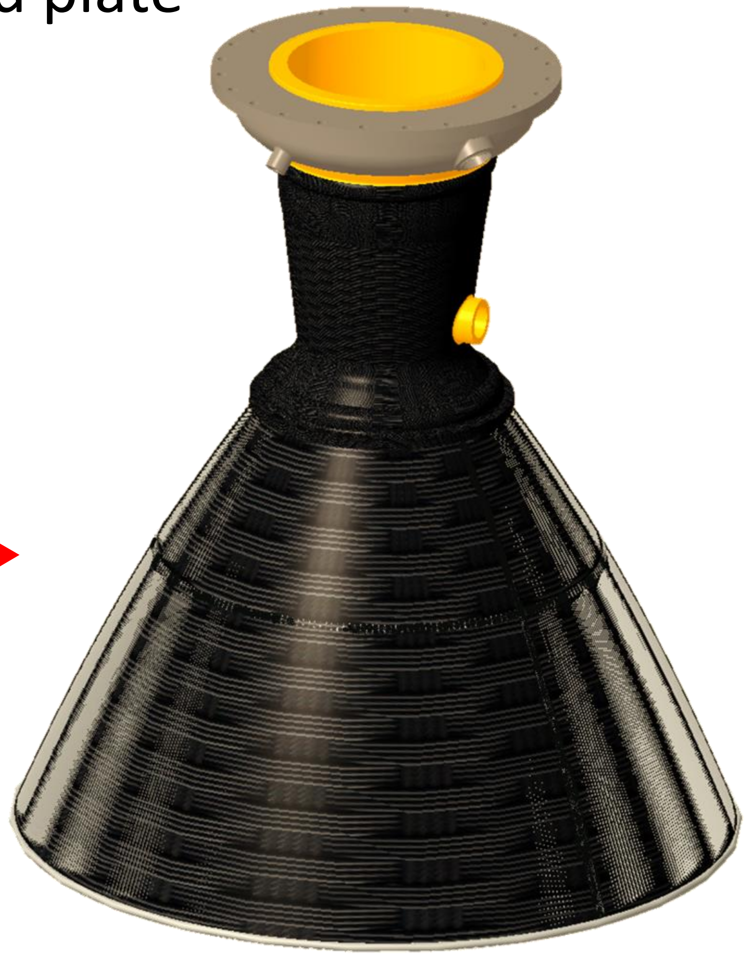
Combining key technologies into an integrated thrust chamber assembly using:

1. GRCop-42 L-PBF chamber as central component and “build plate”
2. Large scale laser powder directed energy deposition
3. Bimetallic and multi-alloys for joints
4. Composite overwrap jacket

L-PBF GRCop-42 Chamber Liner

Manifolds applied using bimetallic AM DED

Laser Powder DED of Regen-nozzle directly on chamber



Composite Overwrap of TCA

RAMPT Hardware Overview

- Decoupled versions built and tested during development
- Technology improvements made continuously throughout project

10 inches

2k-lb$_f$ Coupled Chamber

7k-lb$_f$ Coupled Chamber

40k-lb$_f$ Coupled Chamber

RAMPT Multi-alloy Radial and Axial Hardware


L-PBF Chamber

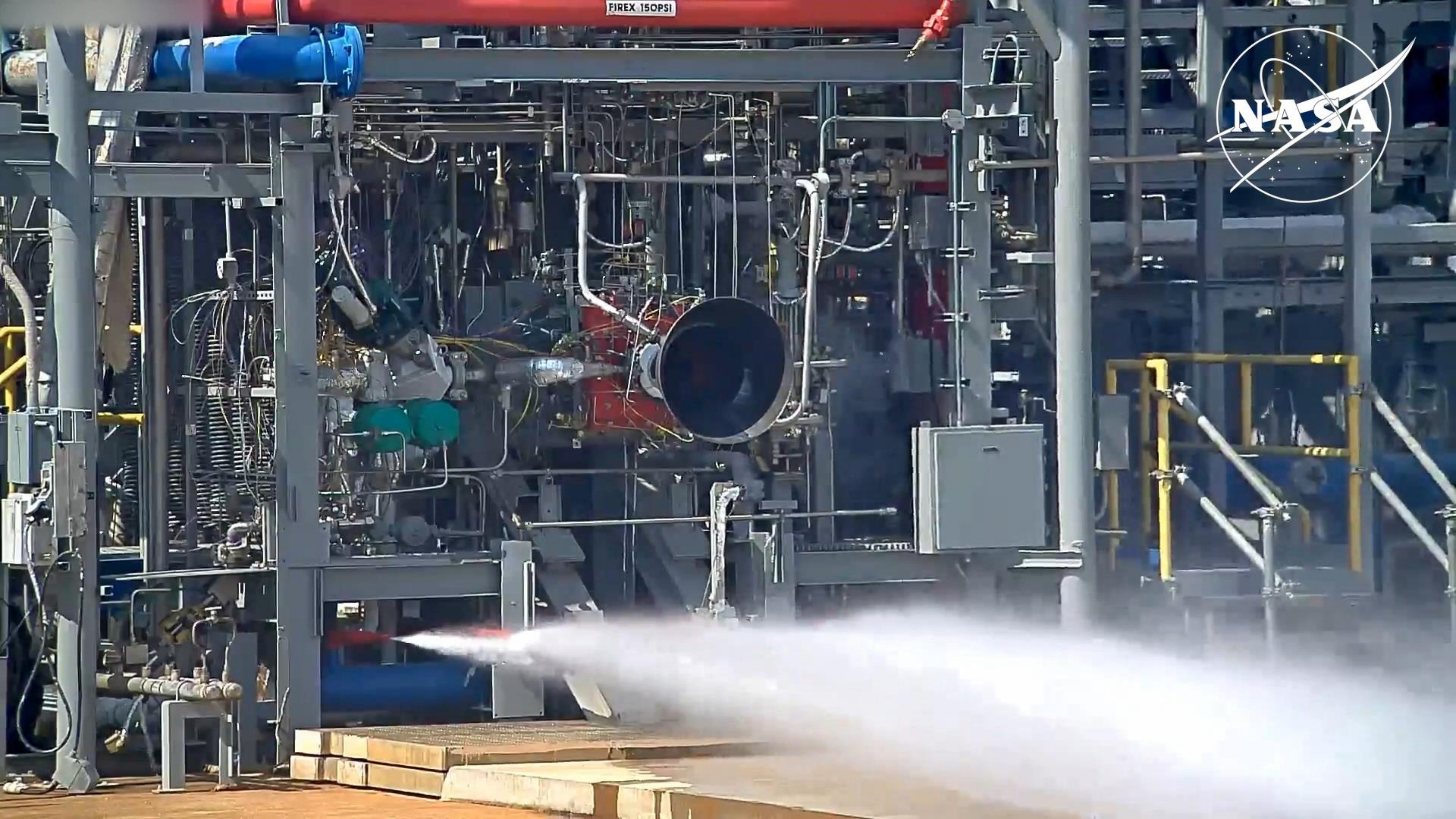

Manifold Prep LP-DED Setup


Radial LP-DED


Manifold EB Welded


Axial LP-DED Nozzle


Final Machining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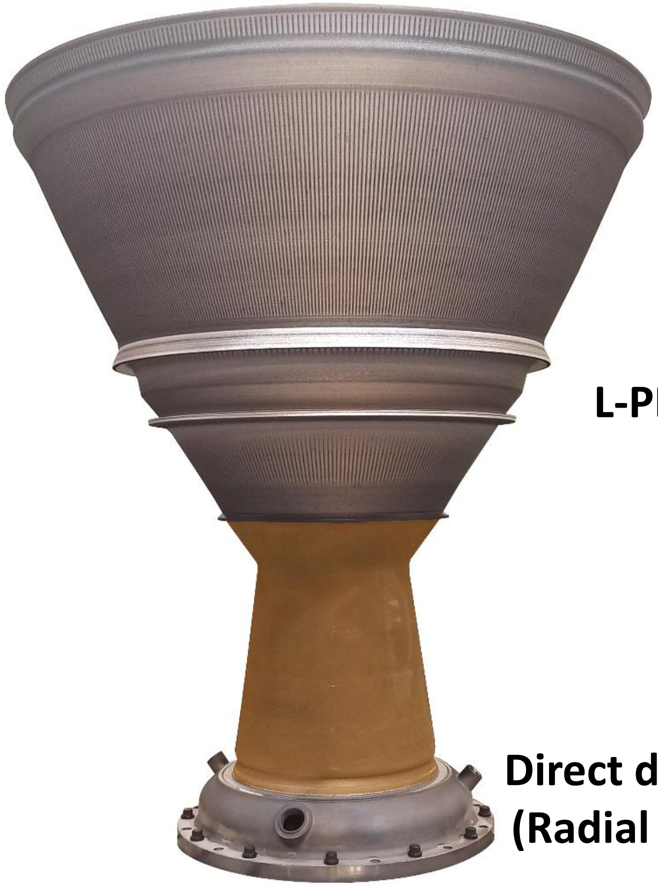
Multi-metallic and multi-process hardware development

Credit: RPMI

L-PBF Liner / LP-DED Jacket

L-PBF Liner / Coldspray Jacket



Direct deposit LP-DED nozzle (Radial and Axial Bimetallic)

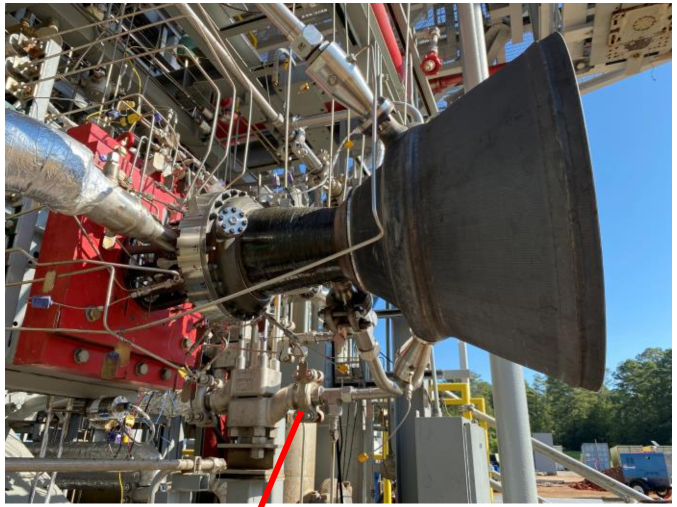
L-PBF Liner / EBW-DED Jacket

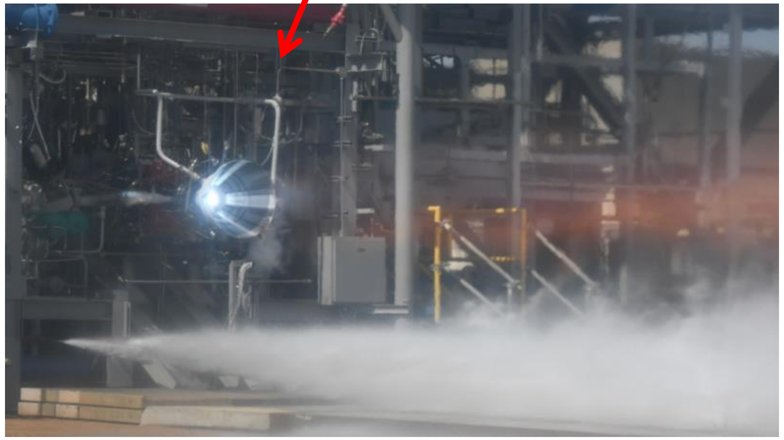
L-PBF GRCop-42 to Inco 625

Hot-fire Testing of Bimetallic Chambers

- Completed various test programs from 2k to 40k-lbf in LOX/H2, LOX/RP-1, and LOX/CH4
- Hot-fire tested using various bimetallic AM processes

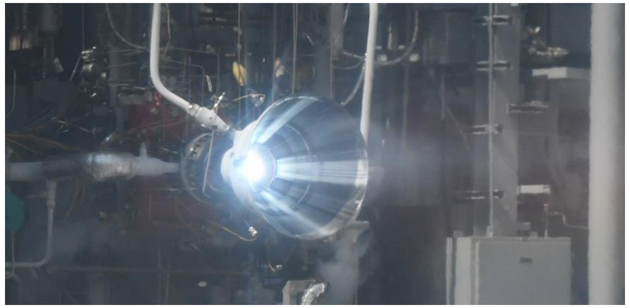
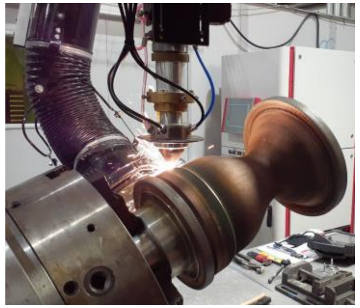
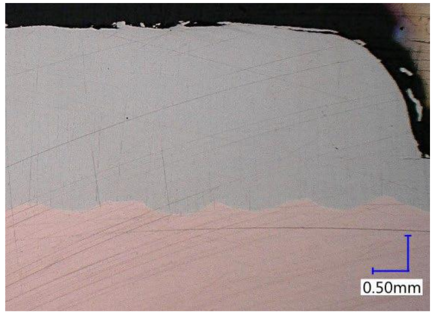
Project	Propellants	Thrust (lb_f)	Metal Alloys	Multi-Alloy Process	Starts	Seconds
PF086	LOX/LH2	30,000	GRCop-84 / Inconel 625	EB-DED	9	147
PJ024	LOX/RP-1	2,400	GRCop-84 / Inconel 625	LP-DED	11	475
PJ024	LOX/RP-1	2,000	C-18150 / Inconel 625	LP-DED	9	405
PI043	LOX/LCH4	2,200	GRCop-84 / Inconel 625	LP-DED	6	76
PK076	LOX/LCH4	7,000	GRCop-42 / NASA HR-1	Coldspray	6	356
PJ051	LOX/LH2	35,000	GRCop-42 / Inconel 625 GRCop-42 / NASA HR-1	LP-DED	12	404
PJ129	LOX/LH2	2,000	GRCop-42 / NASA HR-1	LP-DED	9	321
PK165	LOX/LH2	40,000	GRCop-42 / NASA HR-1	LP-DED	11	328
				TOTAL	**73**	**2,512**





Conclusions / Summary

- NASA has advanced state-of-the-art bimetallic and multi-alloy GRCop-alloy to superalloy AM for liquid rocket engine components.
- Advancements were made through evaluations of various multi-alloy AM processes, material characterization, and successful component manufacturing and hot-fire testing for various combustion devices.
- Manufactured 2K-lbf through 40K-lbf bimetallic chambers and have hot-fire tested various configurations using both radial and axial multi-metallic joints
  - Accumulated 73 starts and 2,512 seconds of hot-fire time across multi-alloy AM chambers
- NASA continuing to develop the bimetallic AM techniques
  - Investigating modeling, characterization, and improvements for bimetallic joints
  - Mechanical and hot-fire data available to industry partners

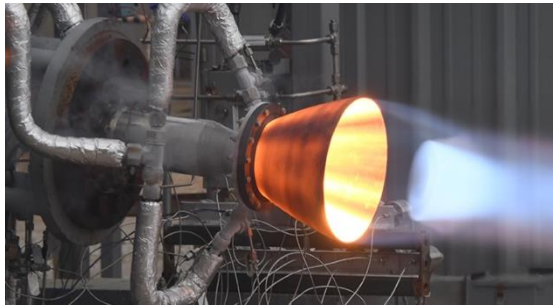



Photo: NASA/Ben Smegelsky

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- Tyler Blumenthal
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- MSFC TS116 crew
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- ProCAM
- PTR Precision
- Pressure Technology
- PAC
- DM3D
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