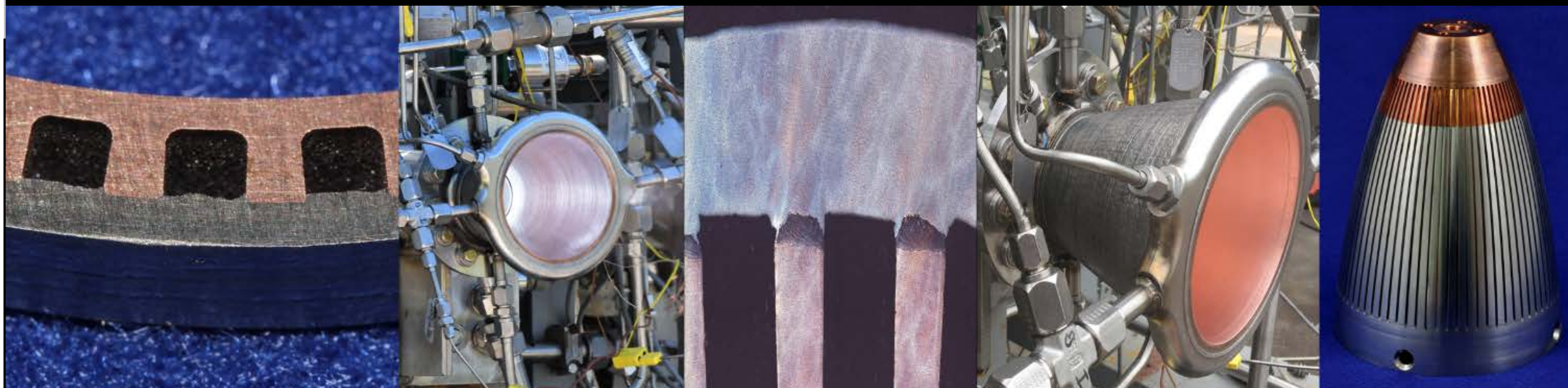

Bimetallic Channel Wall Nozzle Development and Hot-fire Testing using Additively Manufactured Laser Wire Direct Closeout Technology

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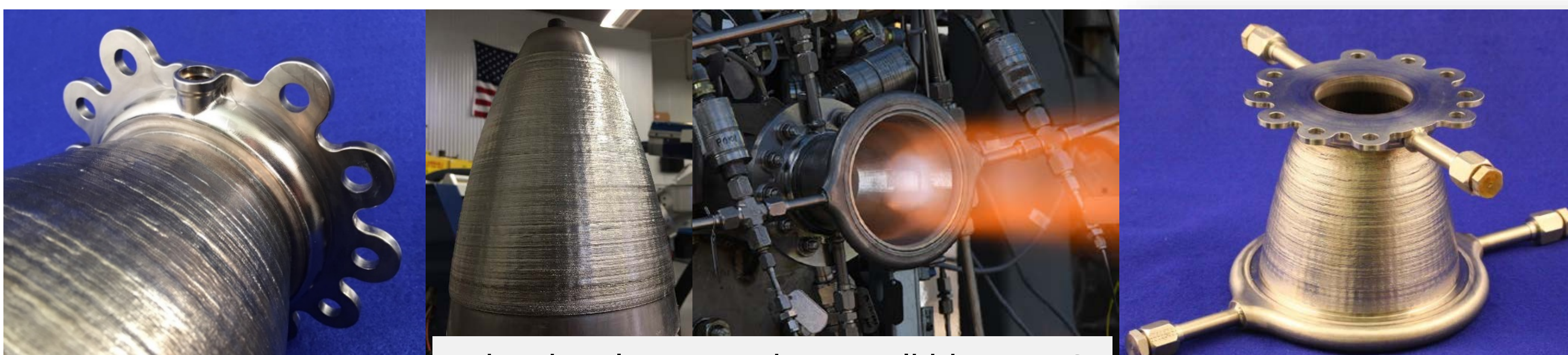
Background and Overview

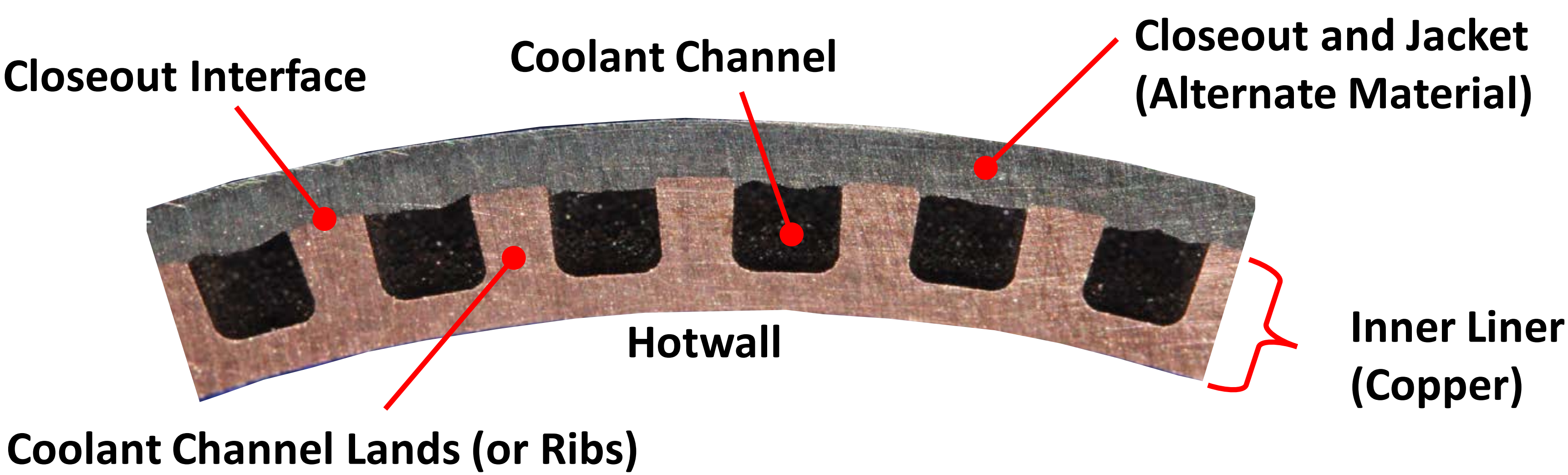
- NASA has been investigating a variety of advanced manufacturing techniques for channel wall nozzle (CWN) fabrication
- A leading technique that has been evaluated and demonstrated is the Laser Wire Direct Closeout (LWDC) technology
  - Prior manufacturing and hot-fire demonstrations were completed using monolithic materials (SS347, Inco 625, Haynes 230)
  - Ref: *Gradl, et al. "Channel Wall Nozzle Manufacturing and Hot-Fire Testing using a Laser Wire Direct Closeout Technique for Liquid Rocket Engines" AIAA 2018*
- **Current research is being conducted demonstrating bimetallic and multi-alloy fabrication using the LWDC technology**



Prior developments in monolithic LWDC

Bimetallic Nozzle Overview

- Typical material selection for channel wall nozzles use stainless or Inconel-based alloys for simplicity of fabrication (joining)
- Bimetallic or multi-alloy configuration uses a copper-alloy liner for reduced hotwall temperatures in higher heat flux environments
  - Closeout and/or jacket uses an alloy other than copper (Stainless, Inconel)
  - Copper liner also reduces some manufacturing complexities such as tolerances during slotting



Bimetallic and Multi-alloys configurations

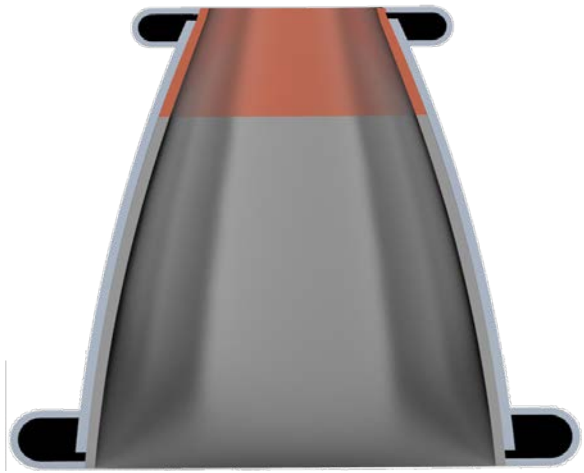
- Copper is higher density than superalloys and requires thicker hotwalls due to reduced strength
- Motivation to develop LWDC technology using bimetallic and multi-alloy configuration is to better optimize for weight
  - Optimizes materials in the radial and axial directions

Radial Bimetallic Nozzle

- Applies 2nd material in **radial direction** for closeout
- Uses copper as liner and non-copper material for channel closeout/jacket to optimize weight

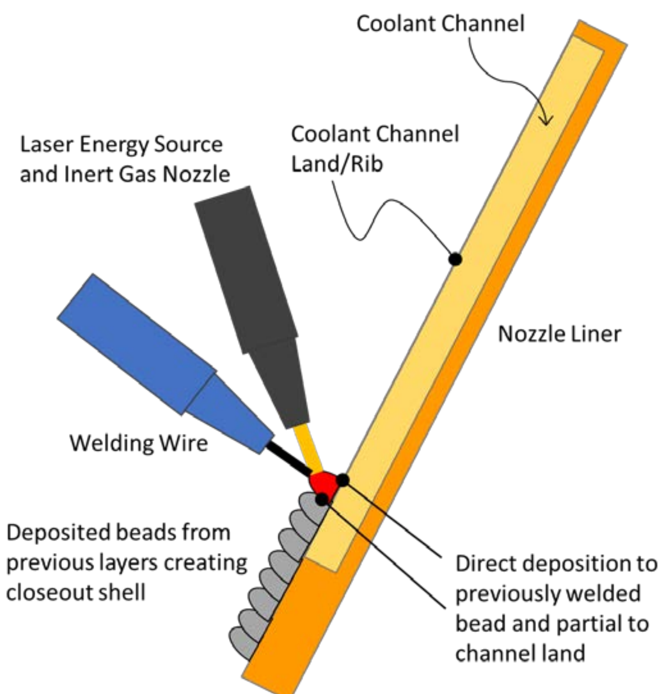
Axial Multi-alloy Nozzle

- Uses varying materials along length of hotwall to optimize for weight
  - Copper for high heat flux region
- 2nd or 3rd material used for channel closeout (high strength jacket)



Overview of LWDC Process

- Laser Wire Direct Closeout (LWDC) is an additive manufacturing technique that locally welds filler wire to the channel ribs and provides a structural jacket fabricated “in place”
  - Freeform welding process without need for filler within the channels
- Uses laser energy source and off-axis wire filler material
- Complete bond at ribs and previously deposited layers
- No material “drop-thru” into channels



Test Hardware Configuration

- Radial bimetallic structure with a full C-18150 (Cu-Cr-Zr) liner with Monel 400 LWDC and structural jacket
  1. **Direct** LWDC of the C-18150 liner
  2. Multi-metallic **intermediate** alloy LWDC of the C-18150 liner
- **Axial split multi-metallic** (or multi-alloy) liner with C-18150 at forward end and SS347 continued jacket. Closeout using Monel 400 for the jacket

Unit	Configuration	Liner	LWDC Closeout	Heat Treatment
Nozzle #6	Radial Bimetallic, Intermediate Alloy	C-18150	Monel 400	Solution and Age
Nozzle #7	Axial Multi-alloy	C-18150 / CRES 347	Monel 400	Solution and Age
Nozzle #8	Radial Bimetallic, Direct	C-18150	Monel 400	Solution and Age
Nozzle #9	Radial Bimetallic, Direct	C-18150	Monel 400	None

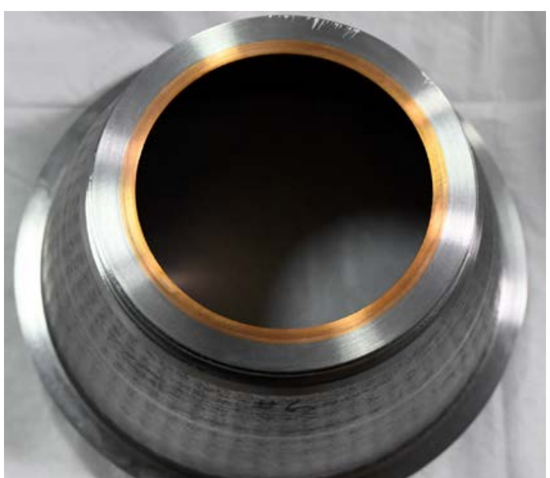
Radial LWDC, Nozzle #6, 8, 9

Nozzle #6 – LWDC with Intermediate alloy

Monel 400

Inconel 625

C-18150



Nozzle #8,9 – Direct LWDC

Monel 400

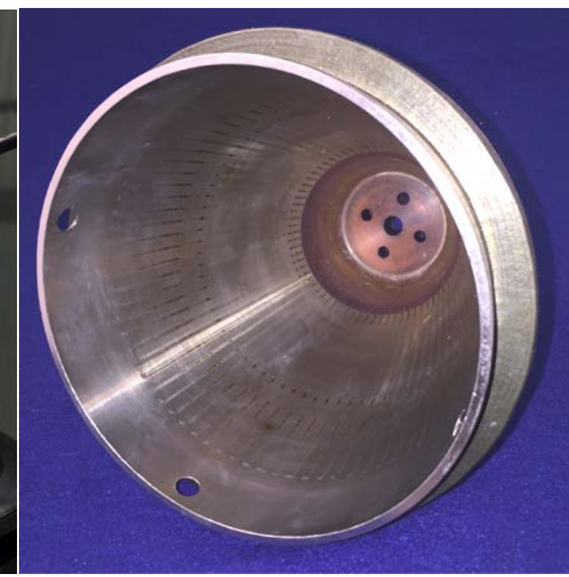
C-18150

Multi-alloy LWDC – Nozzle #7

- Nozzle #7 used an explosive bonding technique to form the axial bimetallic joint followed by closeout and jacket using LWDC

Explosive Bonding for axial bimetallic split C-18150 / SS347 → Final Machining of Liner → Closeout using LWDC, 3rd alloy



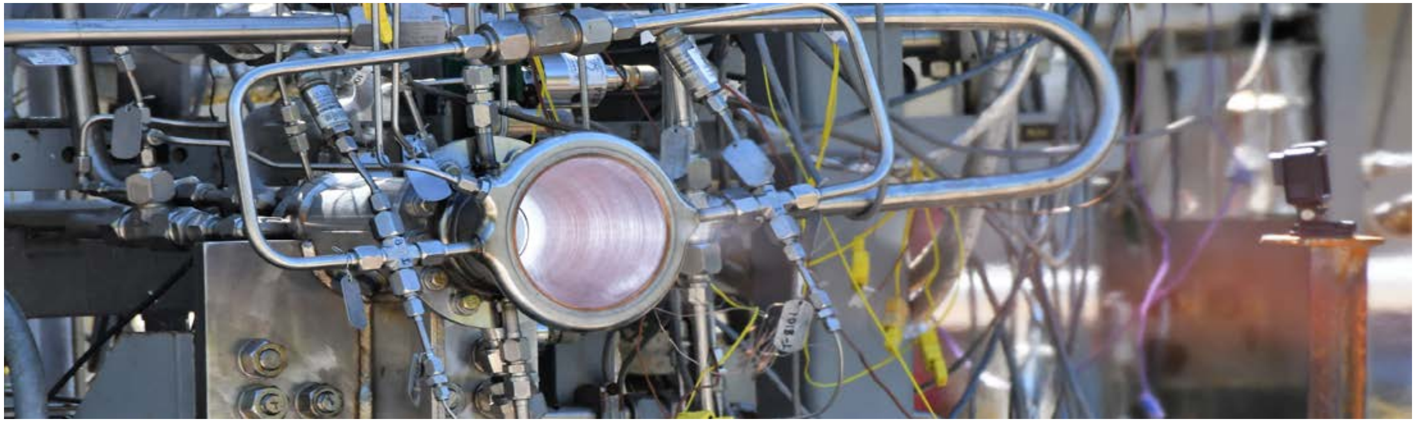



- Experienced leak at forward end due to some thin regions that caused leaks and did not move forward with testing this configuration

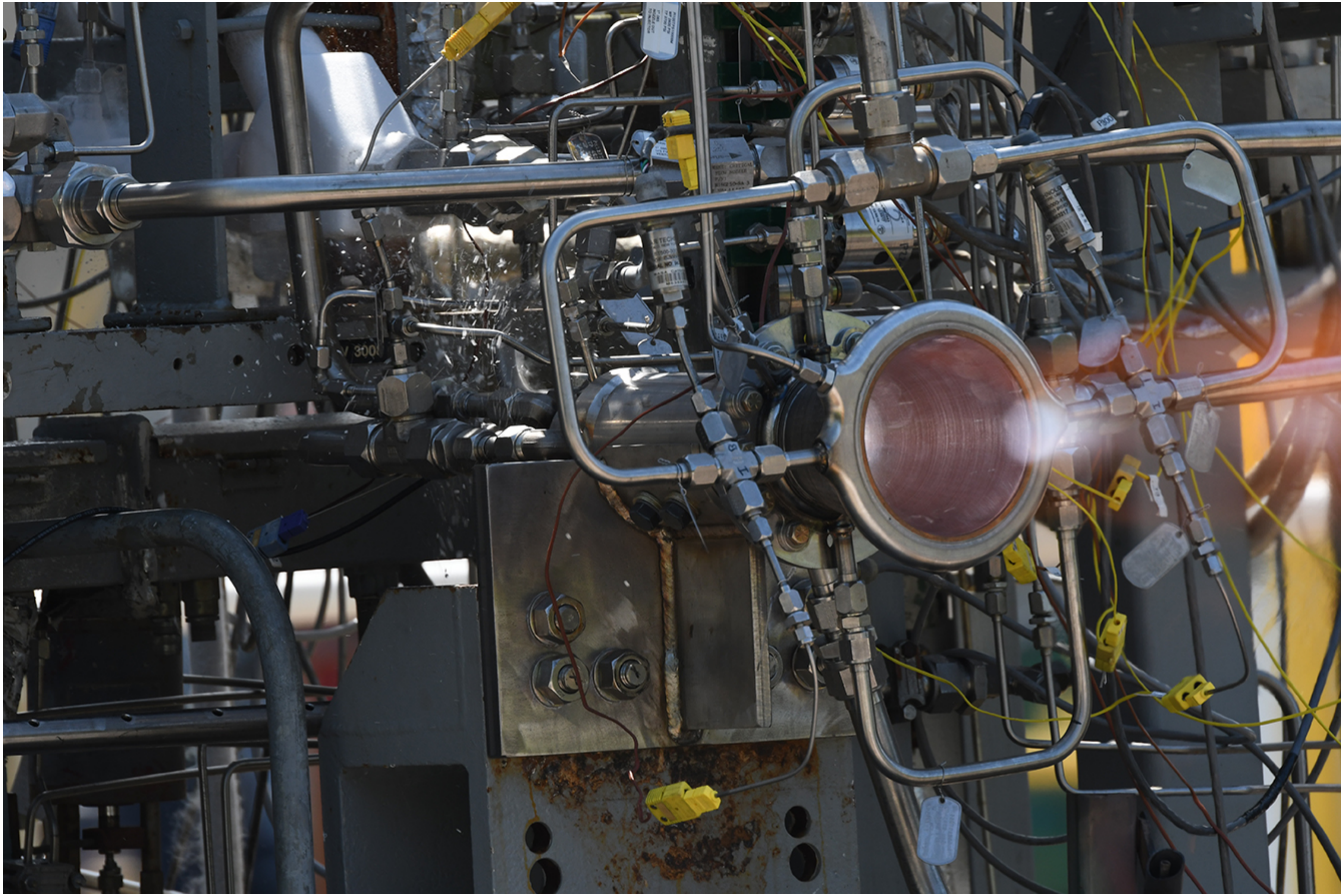
Hot-fire Testing of Nozzles

- Completed hot-fire testing at MSFC Test Stand 115
  - Conducted from April-June 2019
- LOX/GH2 and GH2-cooling of nozzle (initially water to characterize)
- Pc = 1,225 psig and MR = up to 8.0 max (Thrust ~2,100 lb_f)
- Additive GRCop-42 combustion chamber and additive coaxial injector

Nozzle	Configuration	Coolant	Peak Chamber Pressure (psig)	Peak MR	Starts	Accumulated Time (sec)
Nozzle #6	Radial Bimetallic, Intermediate Alloy	GH2	1,122	6.2	3	540
Nozzle #8	Radial Bimetallic, Direct	GH2	1,139	6.2 - 8.0	60	1,830
Nozzle #9	Radial Bimetallic, Direct	Water / GH2	1,225	6.2	9	1,130

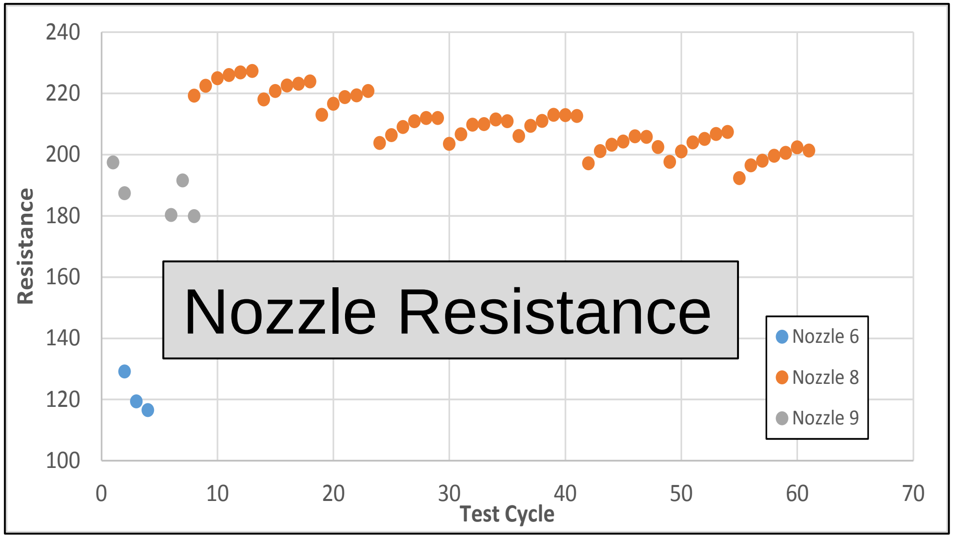


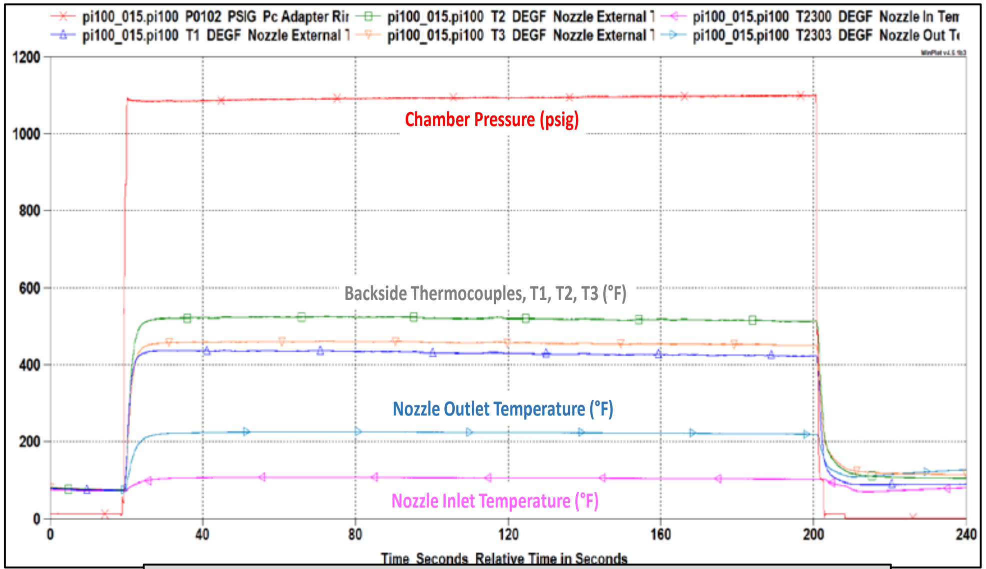
Hot-fire Test Series



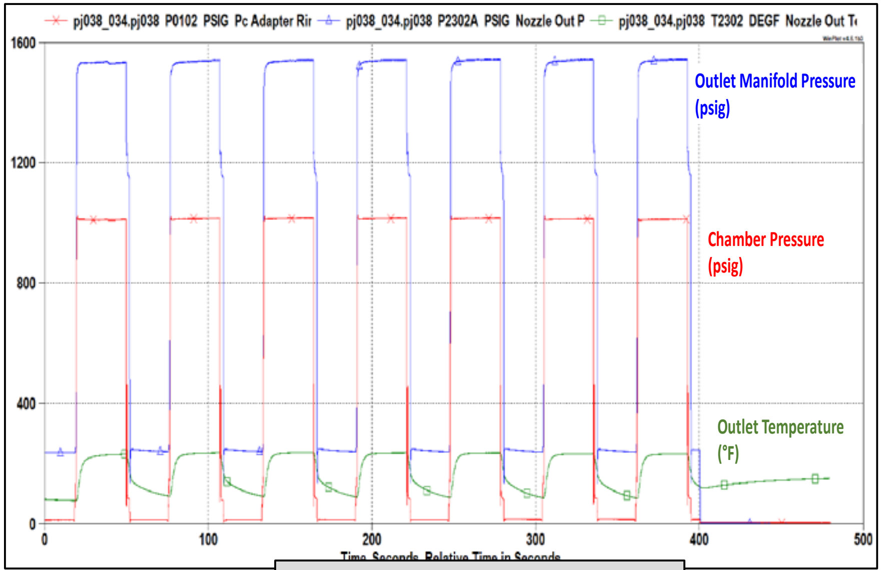
Results from Hot-fire Testing

- Observed differences between resistance of nozzles
- Repeatable data during long duration and cycle testing
- Constant conditions tested with excursion testing completed (high mixture ratio)





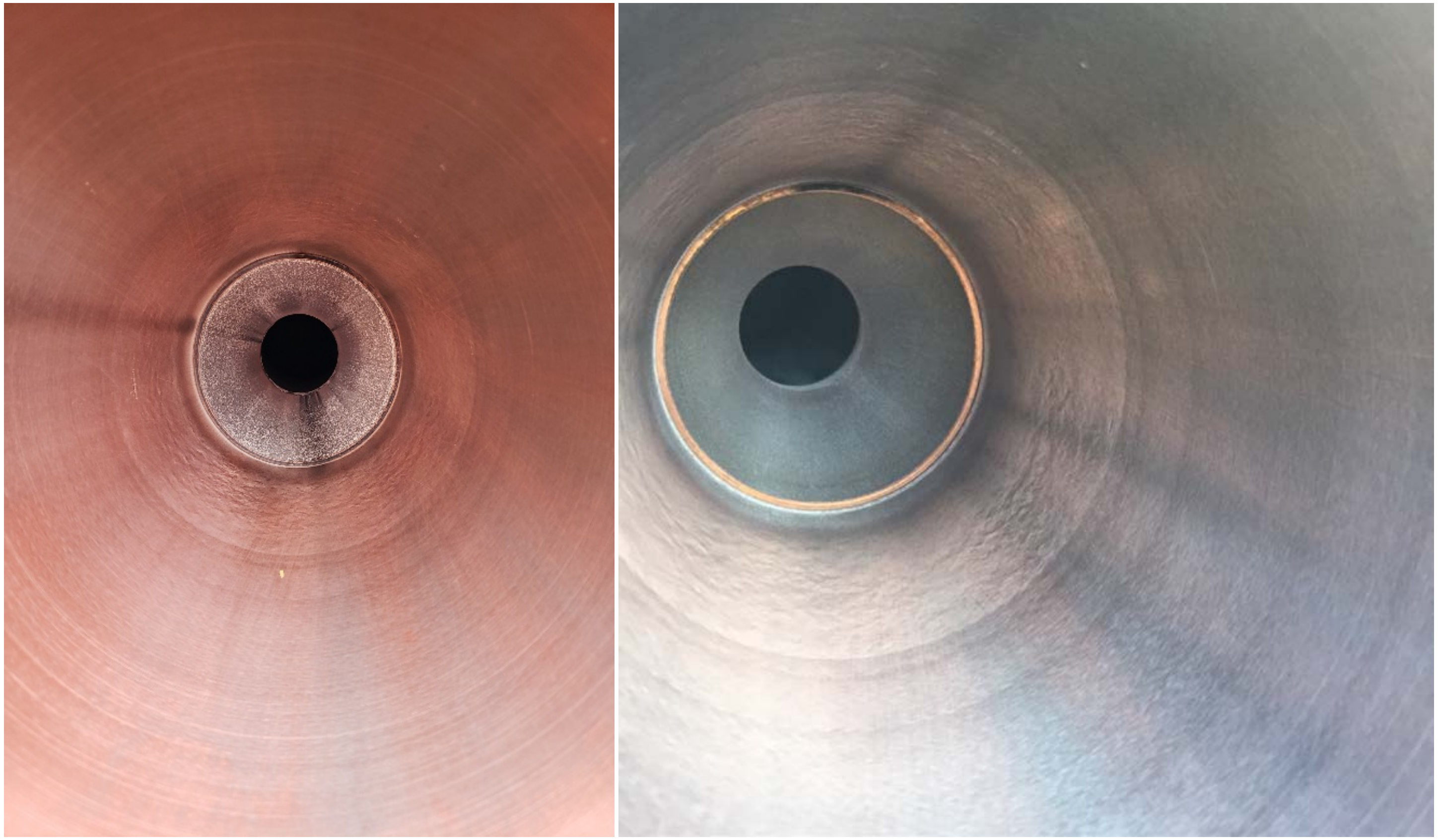
Long duration single-test



Cycle testing

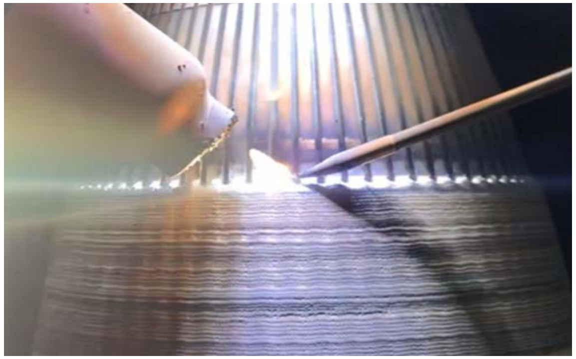
Nozzle hardware inspection results

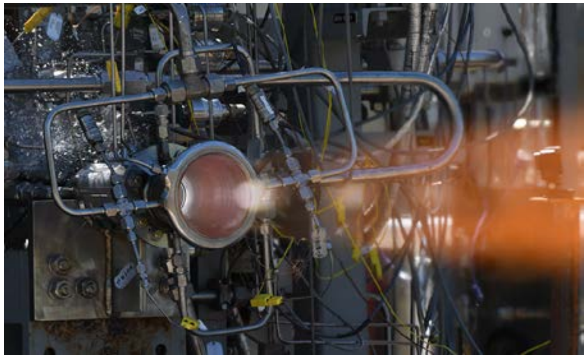
- Nozzle #8 completed 60 hot-fire tests and 1,830 accumulated sec
- Remained in good condition and repeatable data
- After hot-fire testing completed, sections nozzles to evaluate joints
  - LWDC closeout could use some improvement in surface finish on backside



Conclusions

- Completed process development and hardware fabrication using LWDC process with bimetallic configuration
  - Copper-alloy (C-18150) liner and Monel 400 closeout
- Evaluated various methods to optimize closeout including intermediate alloy and direct LWDC
- Completed hot-fire testing and accumulated 72 starts and >3,500 seconds at Pc up to 1,225 psig and MR=8.0
- The LWDC process is continuing to be scaled up and larger hardware being developed for hot-fire testing
- Development data and vendors available to industry partners





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