National Aeronautics and Space Administration

Extreme Temperature Additively Manufactured GRX-810 Alloy Development and Hot-fire Testing for Liquid Rocket Engines

Paul Gradl, Darren Tinker, Ben Williams
NASA Marshall Space Flight Center

Tim Smith, Christopher Kantzos
NASA Glenn Research Center

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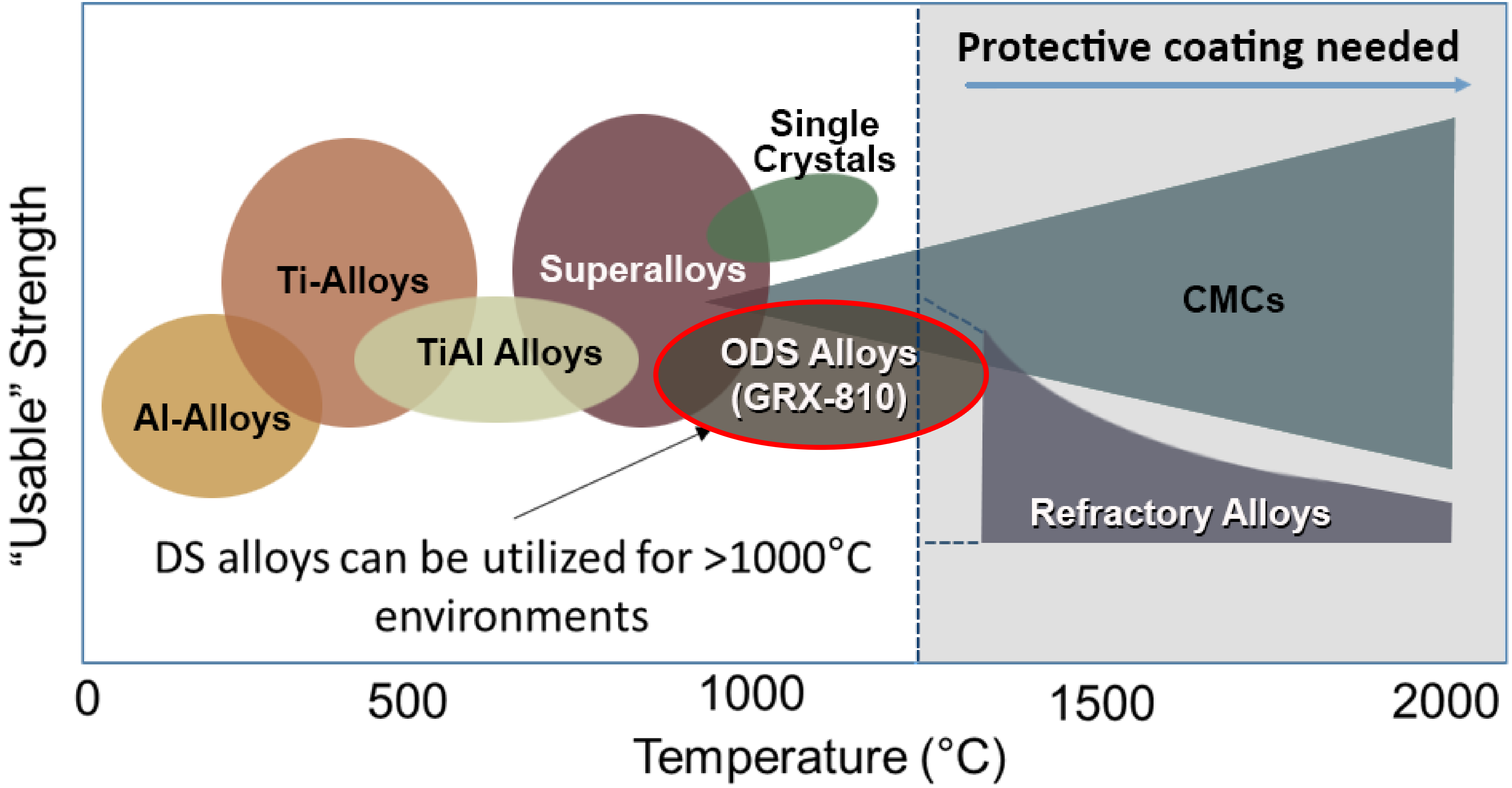
The need for novel extreme environment alloys

- Rocket engine components (injectors, nozzles, turbine static and rotating components, chambers) operate in extreme environments.
  - High pressure, high heat flux, high thermal gradients, long duty cycles, stress rupture (creep), oxidation
- Additive manufacturing (AM) has played a pivotal role in component development and production, but materials are still based on heritage metal alloys.
- New alloys using unique advantages of AM processing can provide a step change in properties to allow for higher performance.
- GRX-810 is an oxide dispersion strengthened (ODS) alloy for sustained use at 900-1200°C with high strength and 100x stress rupture capabilities.

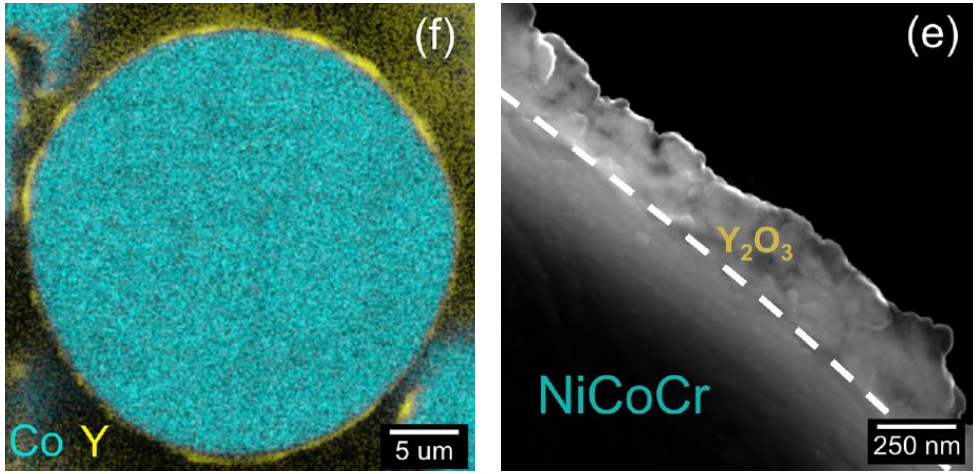
There is a need to advance metal alloys using additive manufacturing processes to enable higher performing components.

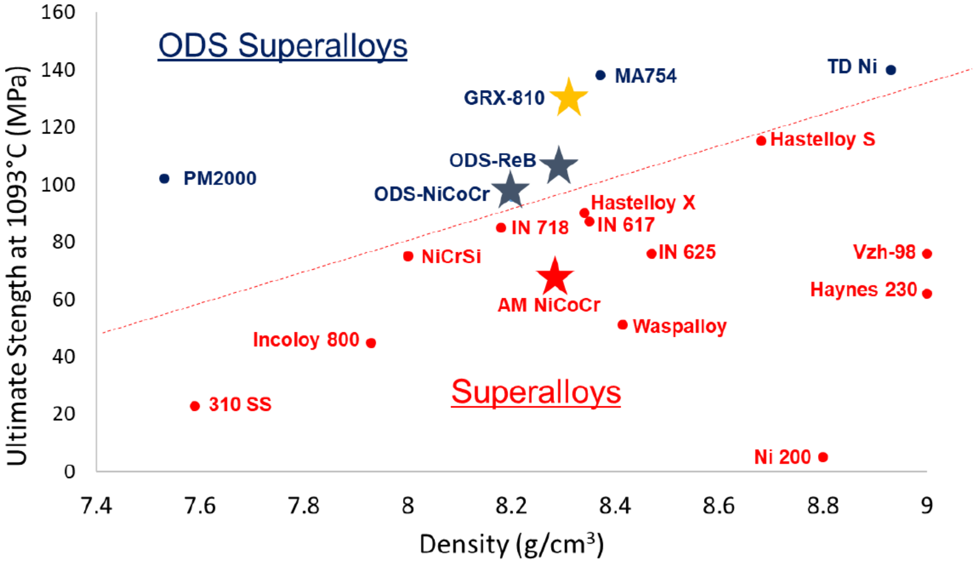
Landscape of Aerospace Materials and GRX-810



GRX-810 Overview

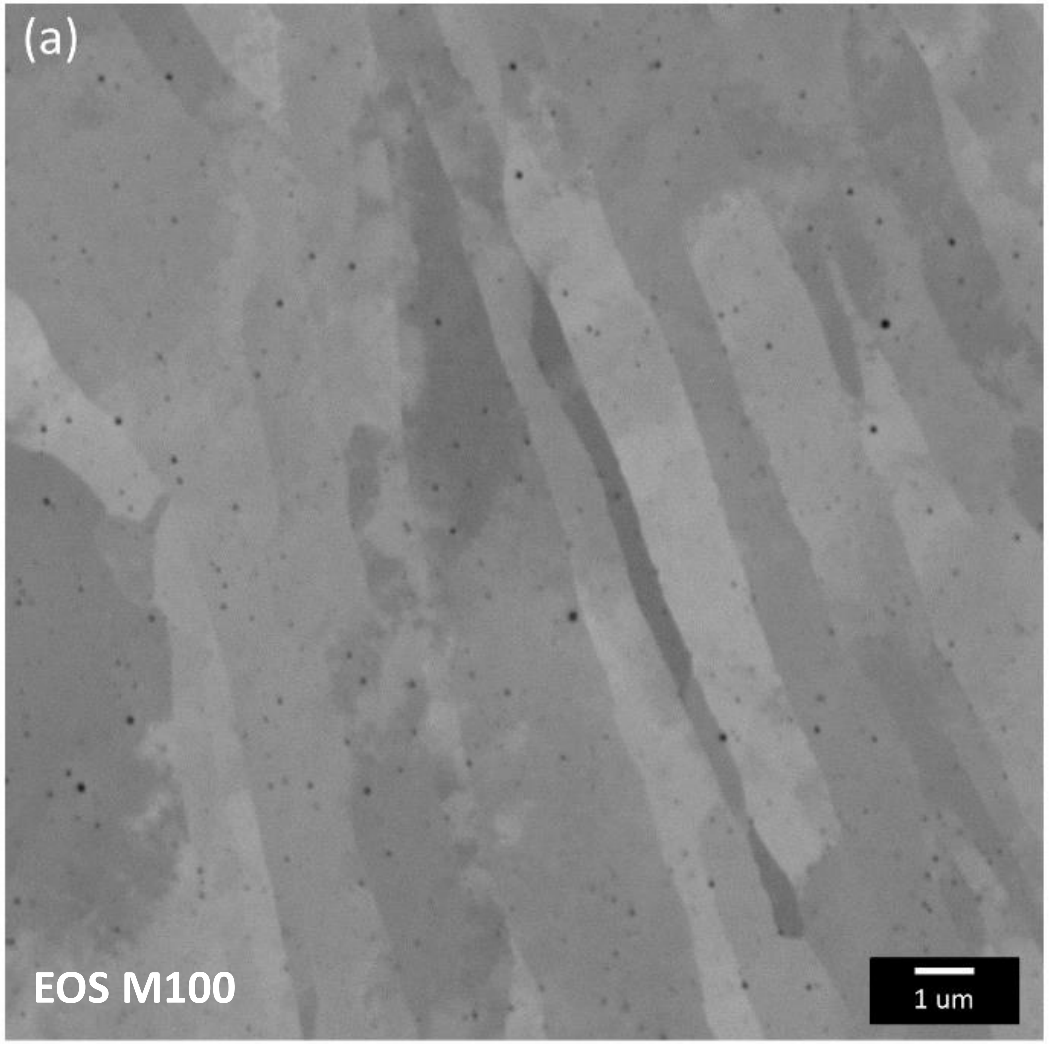
- **G**lenn **R**esearch Center e**X**treme temperature alloy (GRX-810) was developed using Integrated Computational Materials Engineering (ICME) – significantly reducing development time.
- Ni-Co-Cr medium entropy alloy using Laser Powder Bed Fusion (L-PBF).
- Uses unique ODS powder coating process with nano-scale Y_2O_3.
- Significantly improved properties:
  - 2x strength at elevated temperatures (1100°C)
  - 1,000x better creep rupture
  - 2x better resistance to oxidation
- Designed for simplified heat treatment – as-built or Hot Isostatic Pressing (HIP).

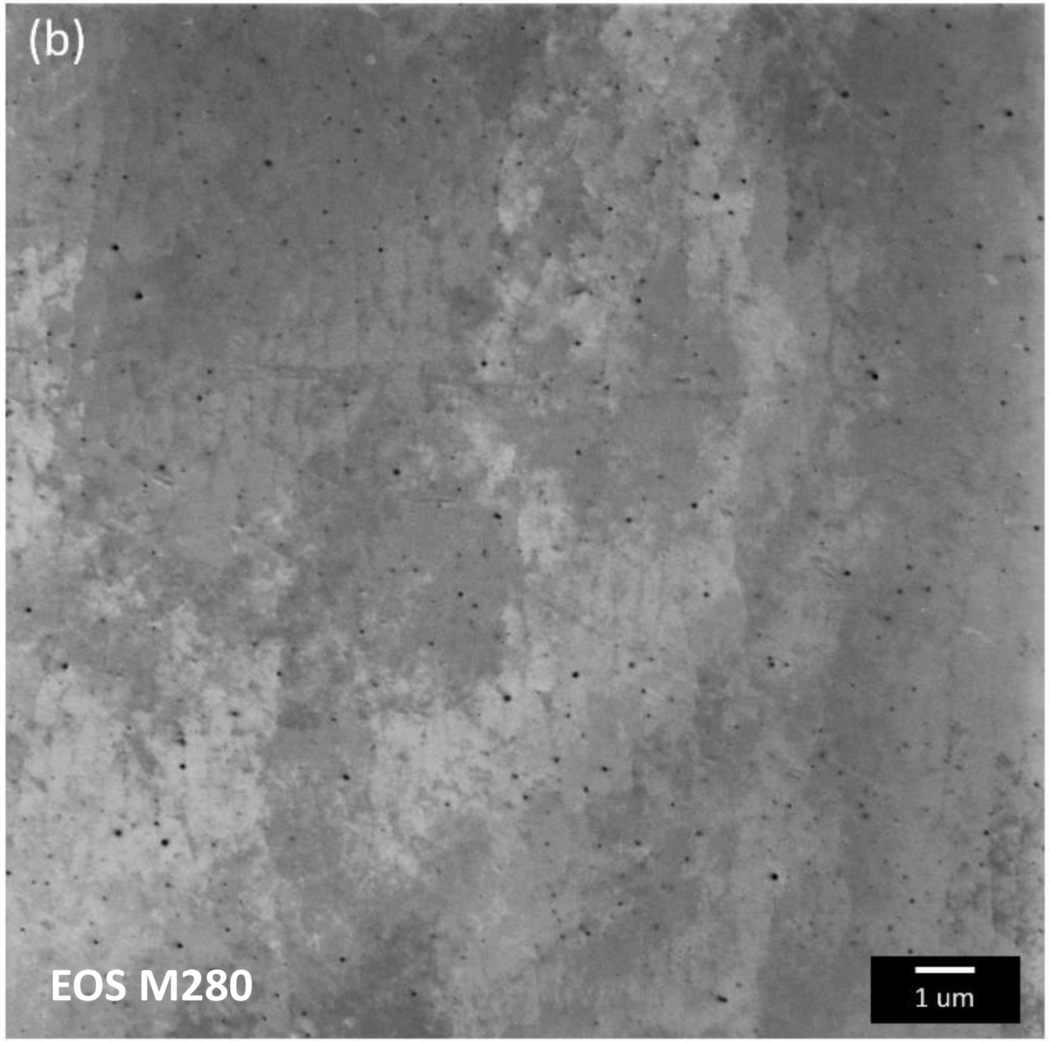




Smith, T.M., Thompson, A.C., Gabb, T.P., Bowman, C.L., Kantzos, C.A., 2020. Efficient production of a high-performance dispersion strengthened, multi-principal element alloy. Scientific Reports 2020 10:1 10, 1–9. https://doi.org/10.1038/s41598-020-66436-5

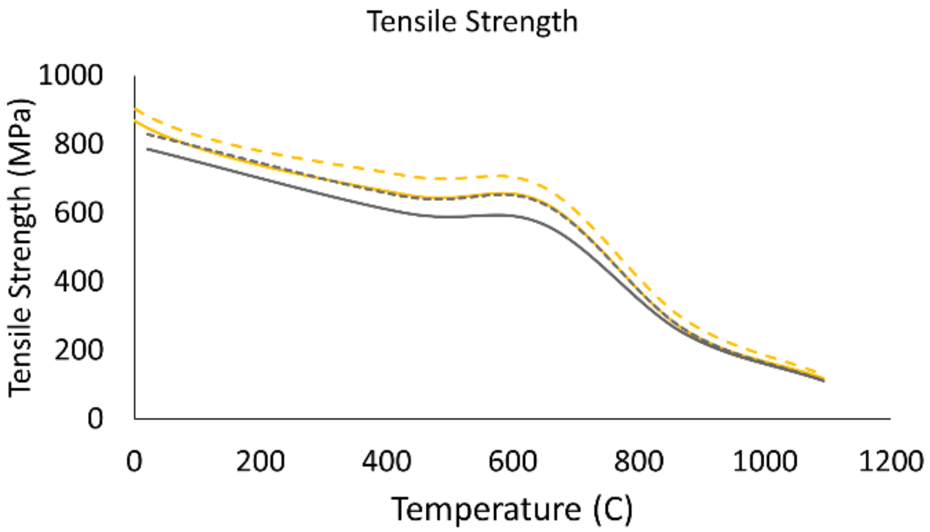
SEM Images of GRX-810 using L-PBF

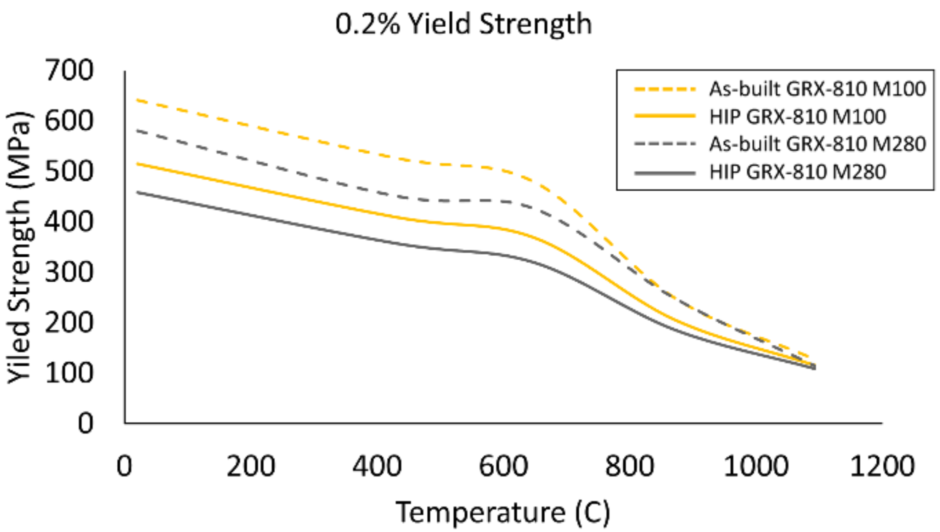




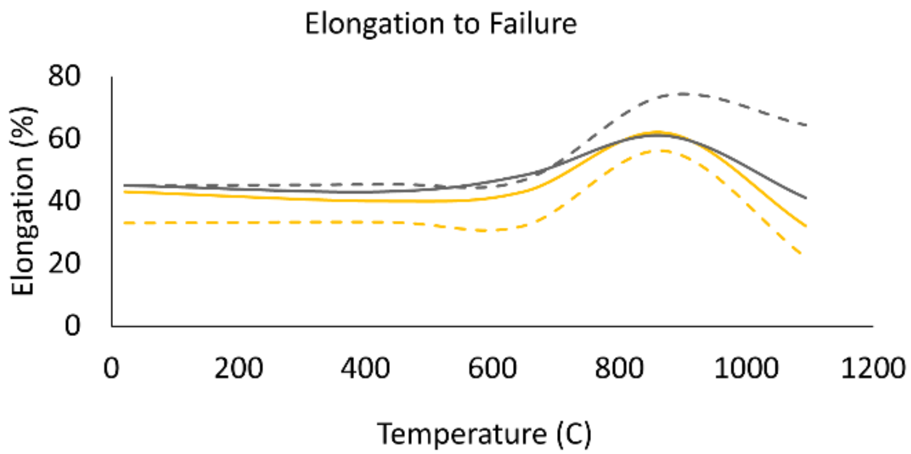
Secondary electron SEM micrographs of (a) Lot 1 GRX-810 produced using an EOS M100 and (b) Lot 2 GRX-810 produced using an EOS M280. The fine circular dark features are nano-scale Y_2O_3 particles.

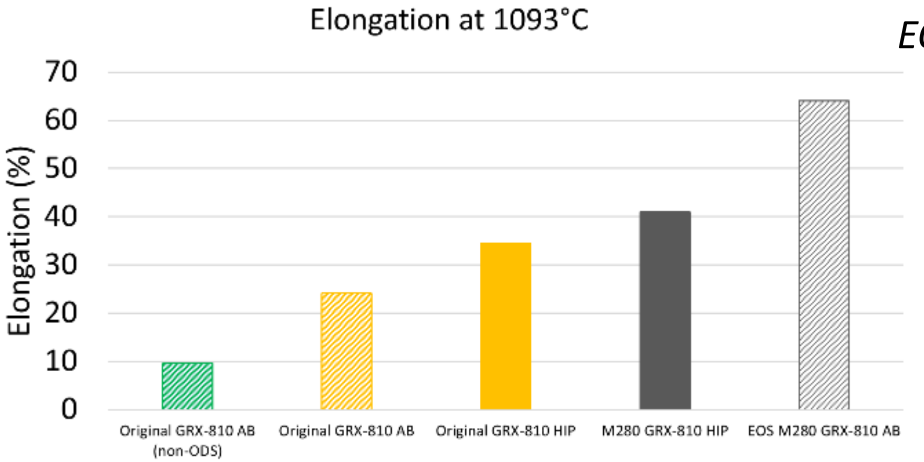
GRX-810 Mechanical Properties





EOS M100 (40 μm focus)
EOS M280 (100 μm focus)

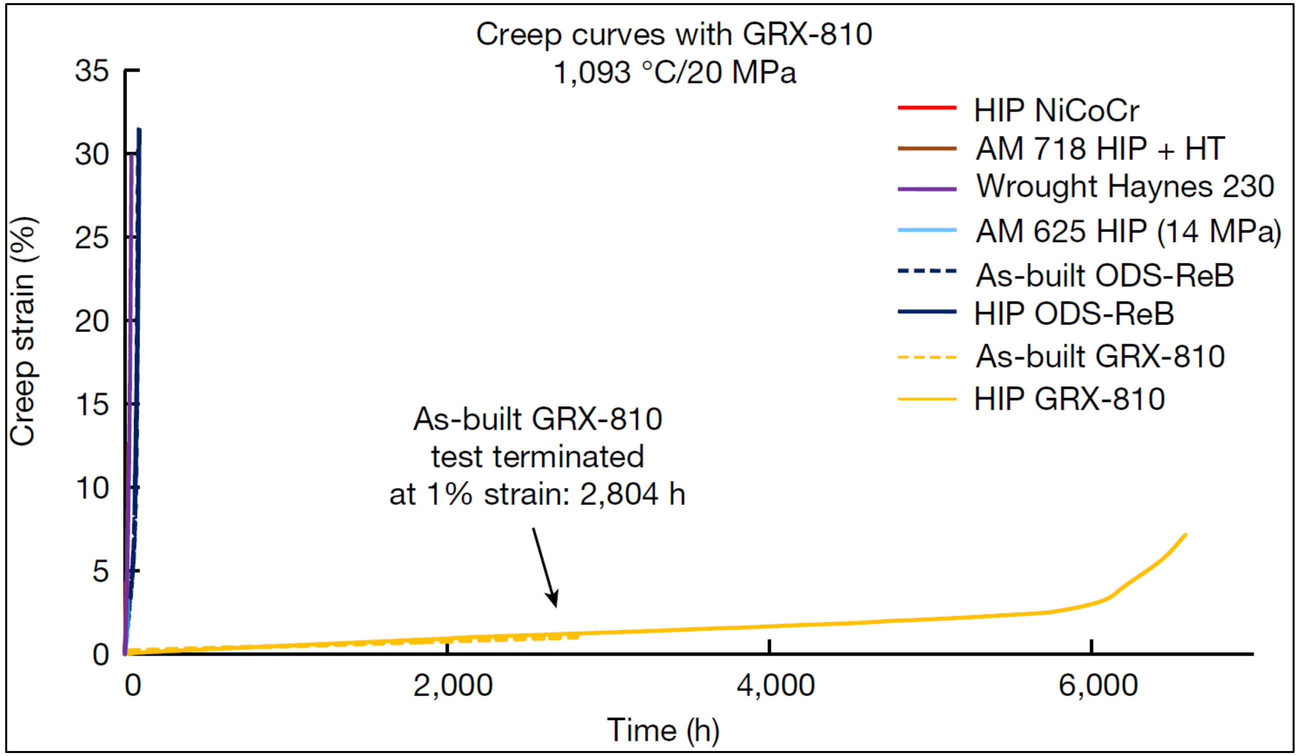




Tensile properties of GRX-810 produced using an EOS M100 and using an EOS M280. Notable differences in room temperature strength and high temperature elongation were observed between the different lots.

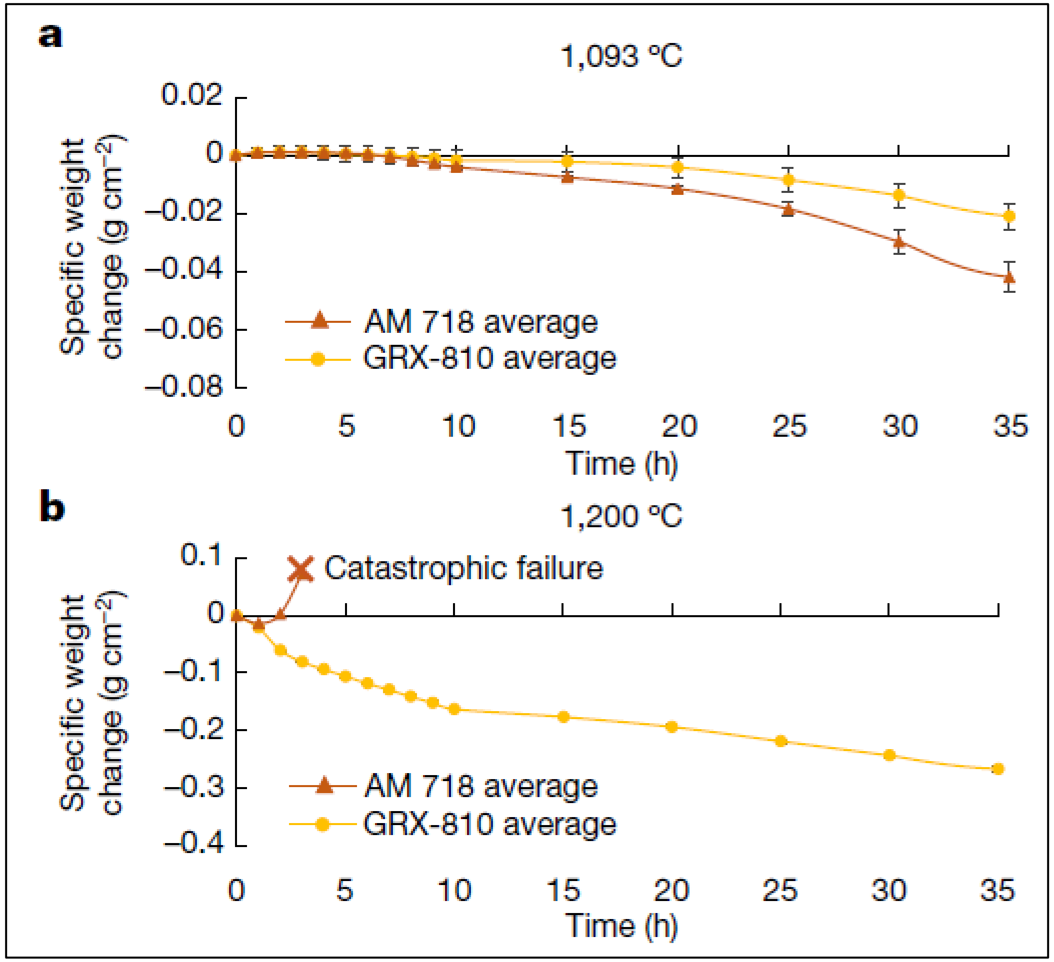
GRX-810 Stress Rupture and Oxidation

Stress rupture shows 100x improvement over typical Ni-based superalloys



Creep results from M100 and M280 showing similar trends, although M280 performing better

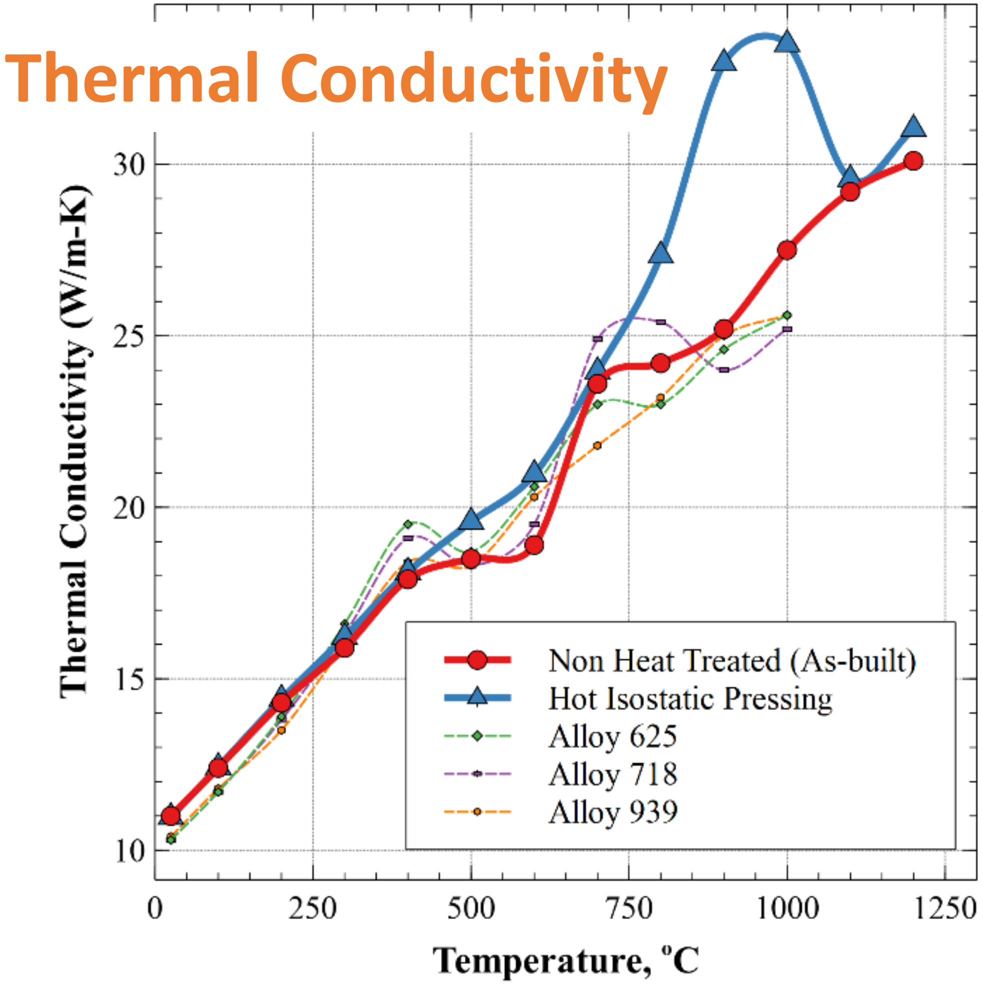
Cyclic oxidation at 1093°C and 1200°C

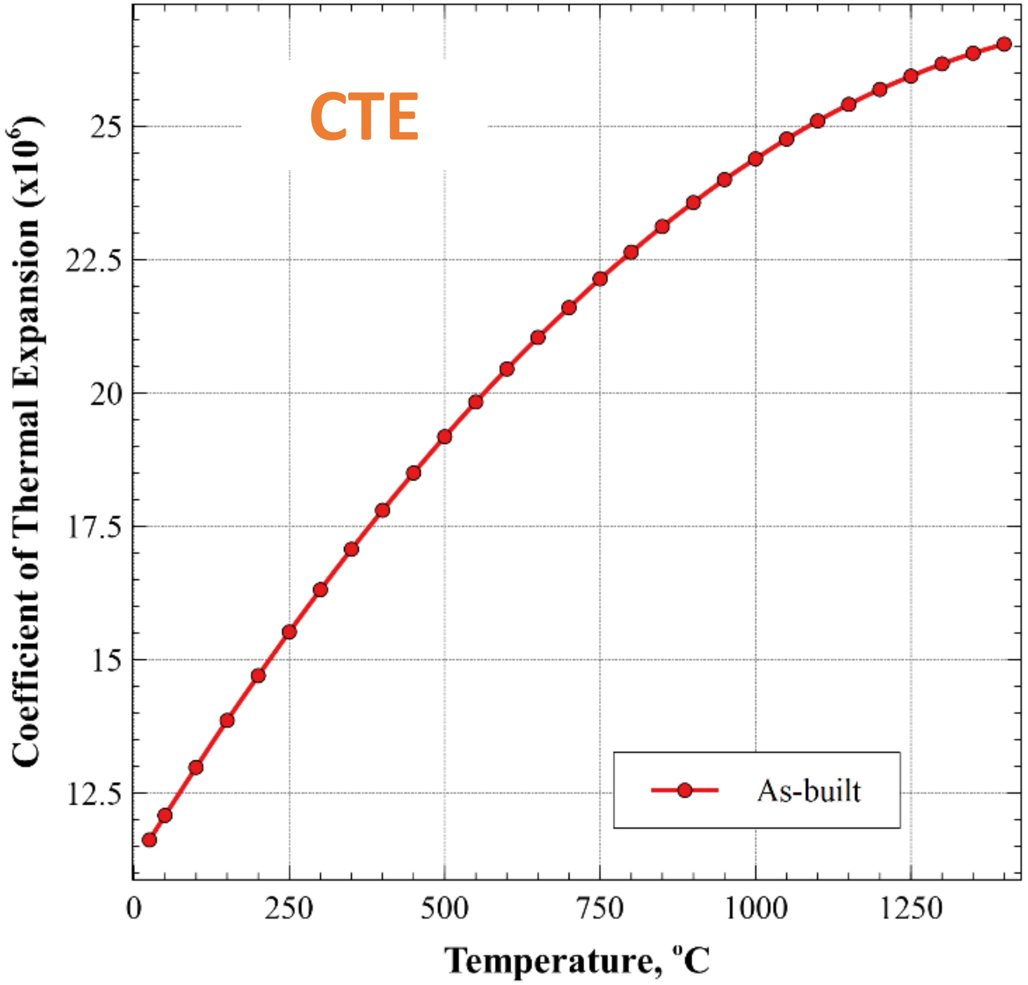


Smith, T.M., Kantzos, C.A., Zarkevich, N.A., Harder, B.J., Heczko, M., Gradl, P.R., Thompson, A.C., Mills, M.J., Gabb, T.P., Lawson, J.W., 2023. A 3D printable alloy designed for extreme environments. Nature. https://doi.org/10.1038/s41586-023-05893-0

GRX-810 Thermophysical Properties

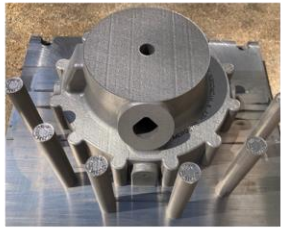
Thermal Conductivity and Coefficient Thermal Expansion (CTE) are similar to Ni-based superalloys





Successful Hot-fire Testing

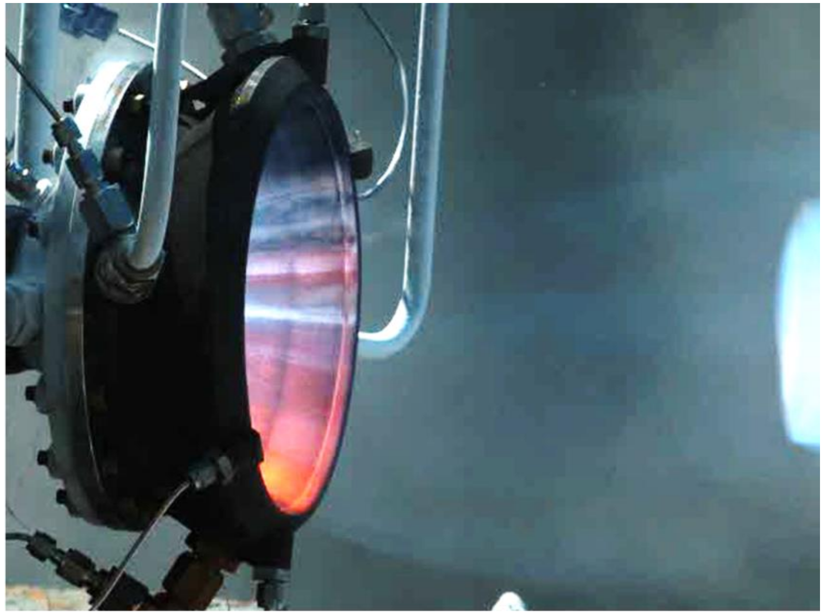
- Hot-fire testing of GRX-810 pentad injectors and channel-cooled nozzles using L-PBF GRX-810
- Propellants: LOX/LH2 and LOX/LCH4
  - Chamber Pressure ~750 psig (52 bar)
  - LOX/LH2 Mixture Ratio = 5.3 – 7.0
  - LOX/LCH4 Mixture Ratio = 2.7 – 3.6
- Demonstrate successful component fabrication process
- Challenge material at elevated temperatures at MSFC TS115
- Increase TRL from 3 → 5

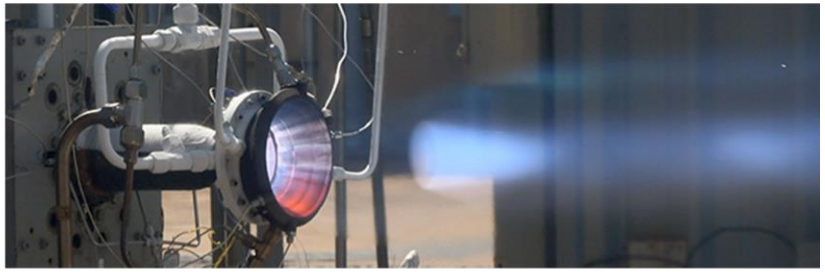


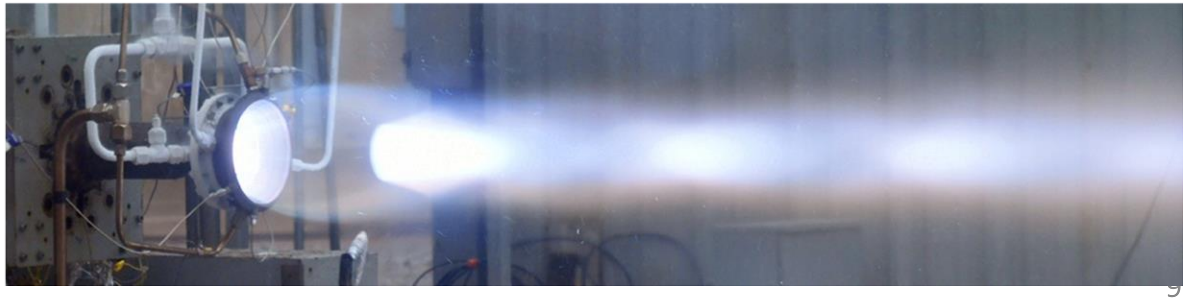
Injector

As-Built Nozzle

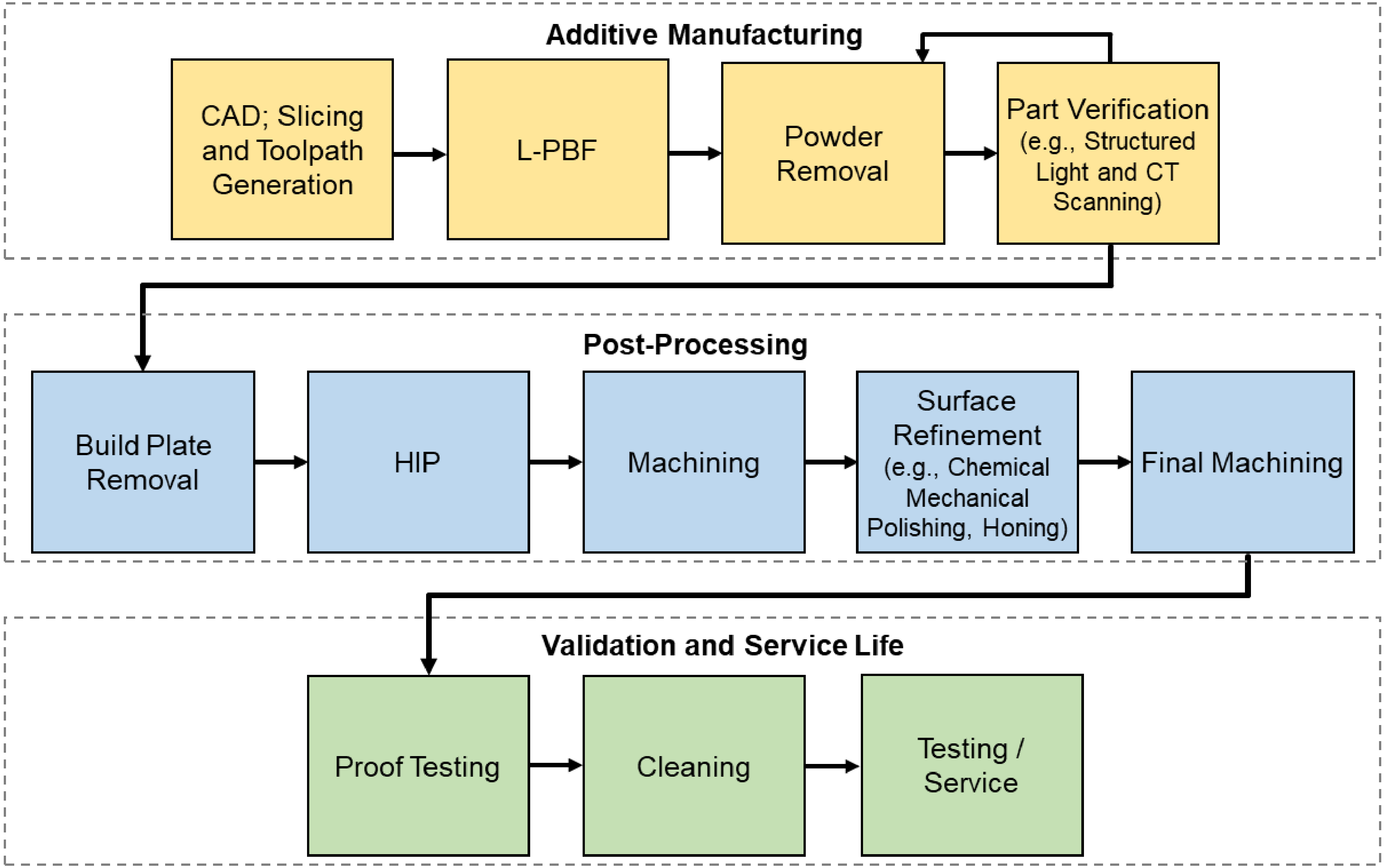
Post-HIP Nozzle



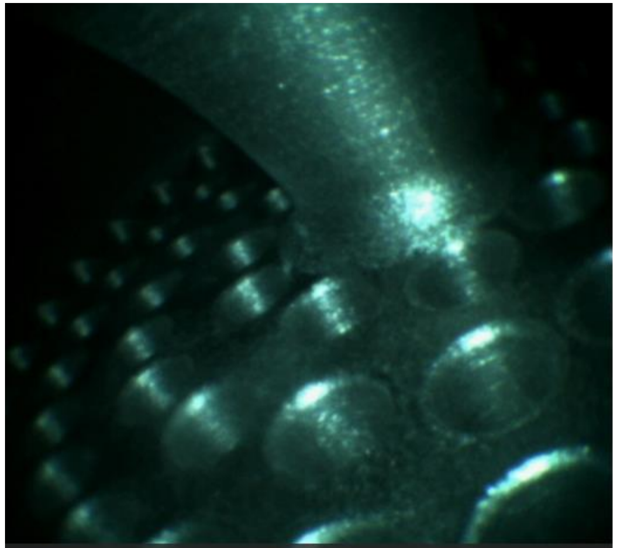




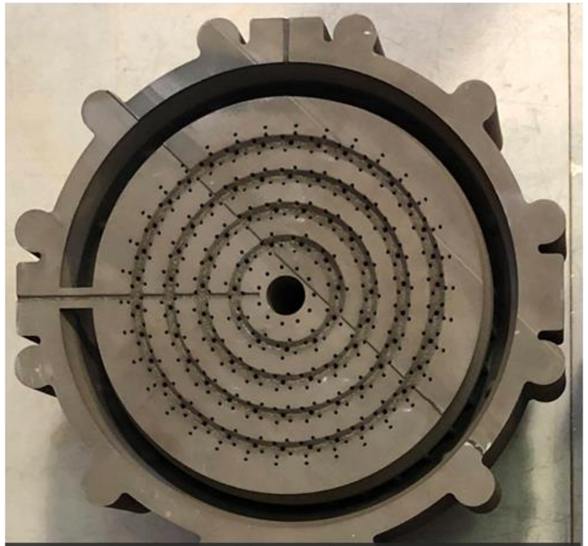
Typical Process Flow of GRX-810 Hardware



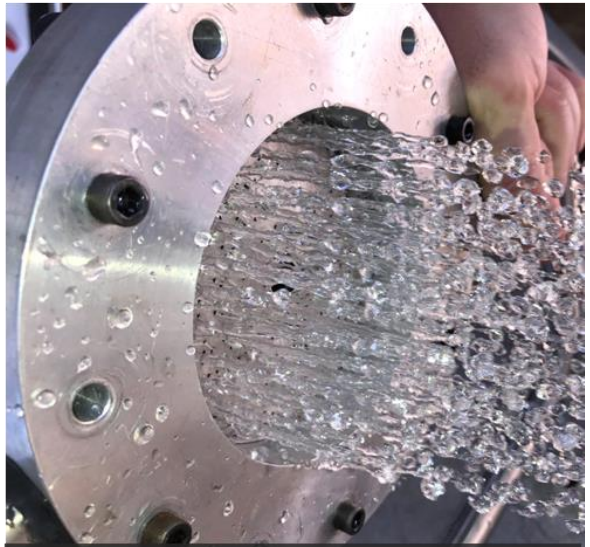
Typical Process Flow of GRX-810 Hardware



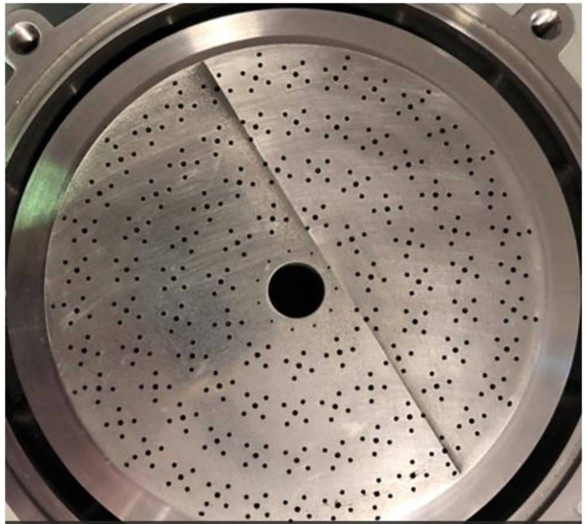
Powder Removal Inspection



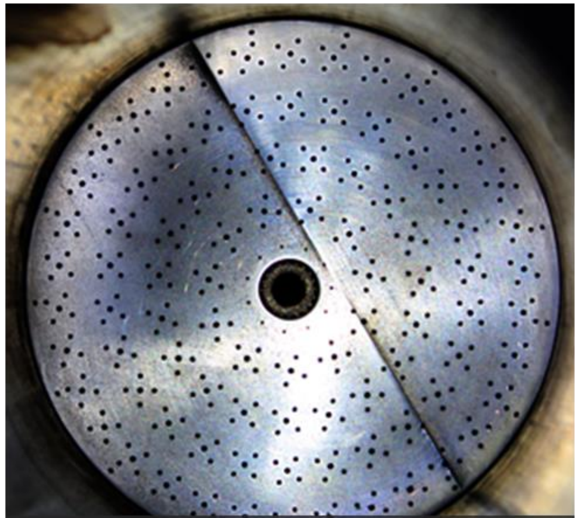
Post-HIP



Flow Testing

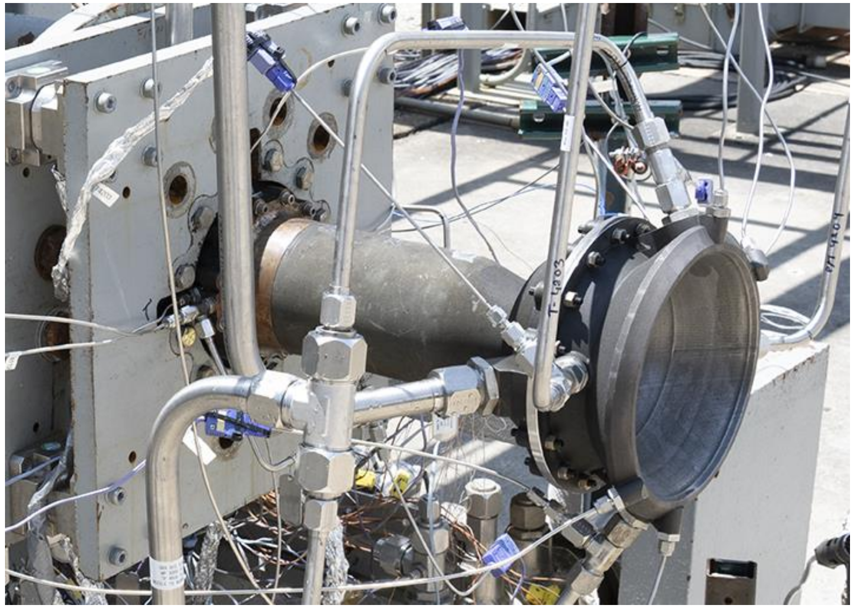


Face Polish



Installation

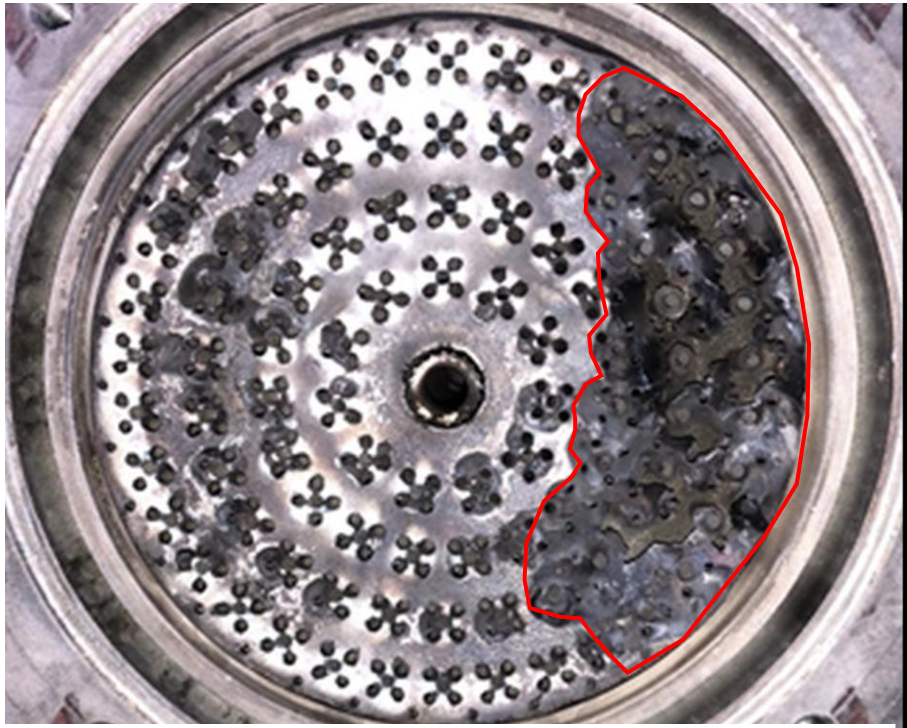
Hot-fire Testing of L-PBF GRX-810 Injector and Nozzle



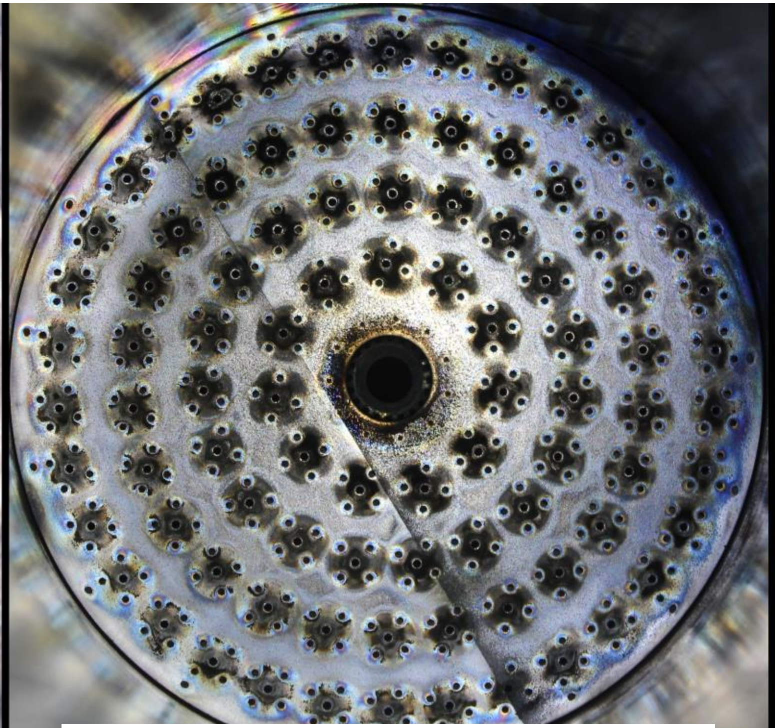
Component (-)		Starts (-)	Duration (s)	Pc (bar)	Pc (psia)	MR (-)
H2 Injector	SN01	9	302.8	49.5 - 57.2	718 - 829	5.33 - 7.02
CH4 Injector	SN02	29	586.5	37.4 - 52.4	542 - 760	3.03 - 3.65
CH4 Injector	SN03	84	2,227.9	43.2 - 52.1	626 - 756	2.68 - 3.19
Nozzle	SN04	91	2,309.4	37.4 - 52.1	542 - 756	2.68 - 3.11
Nozzle	SN05	8	149.1	49.0 - 50.5	711 - 732	3.00 - 3.19

Injector Test Results

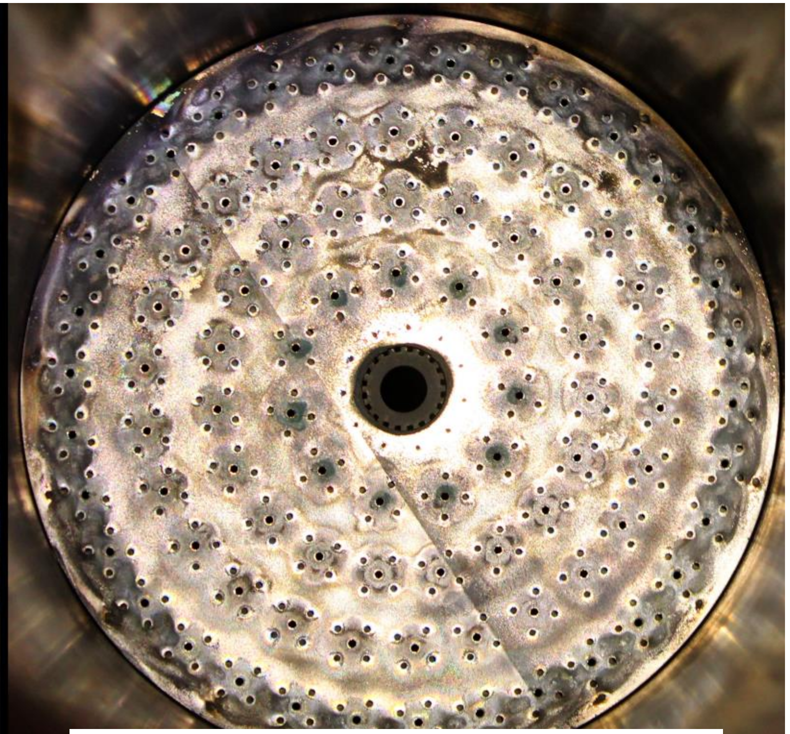
- GRX-810 Injector A achieved 84 starts and 2,228 sec (LOX/LCH4)
  - Demonstrated greater life than Inconel 625/718 equivalent
- GRX-810 Injector B achieved 30 starts and 591 sec (LOX/LCH4)
- GRX-810 Injector C achieved 9 starts and 303 sec (LOX/LH2)



Inconel 625 Injector after 10 starts (Erosion)



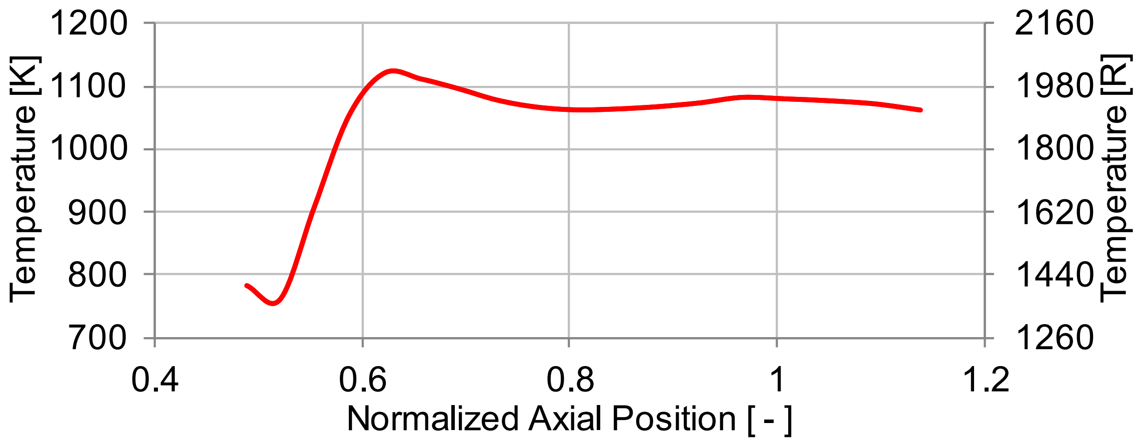
GRX-810, LOX/LCH4 – 13 starts

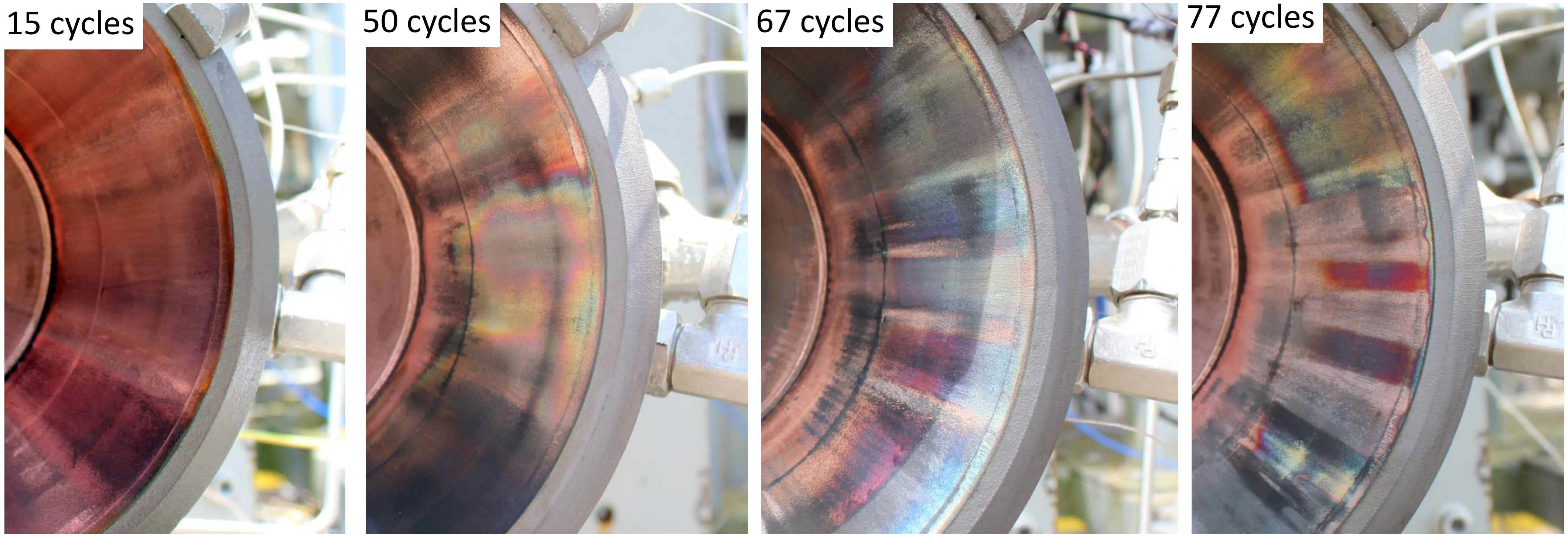


GRX-810, LOX/LCH4 – 84 starts

GRX-810 Nozzle Test Results

- Regeneratively-cooled (LCH4) nozzle accumulated 90 starts and 2,309 seconds.
- Local wall temperature >1,000°C





Hot-fire Testing

L-PBF GRX-810 Component Examples

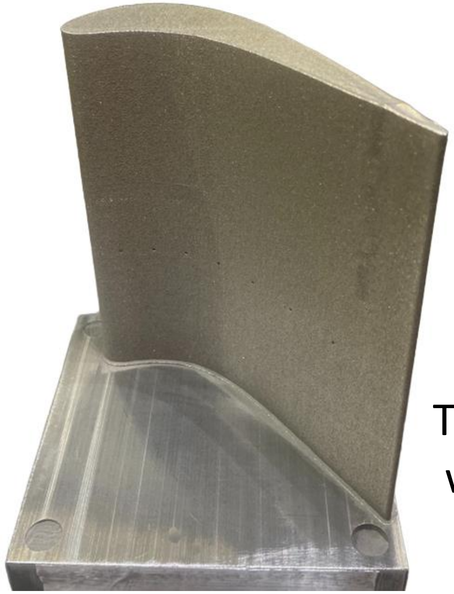
Turbine Blisk Demo

Inducer with flow passages

Pentad Injector

Regen Nozzle

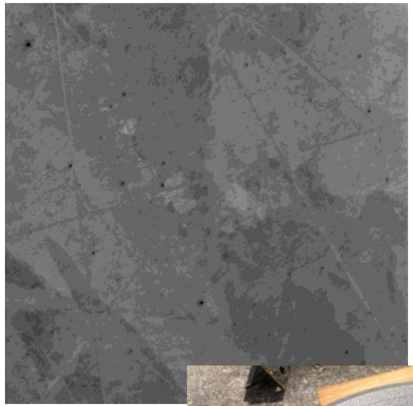
Shrouded Blisk



Turbine Blade with integral ports

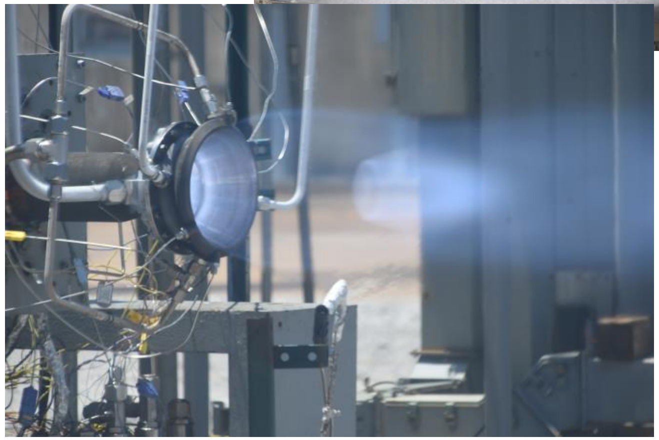
Summary and Future Work

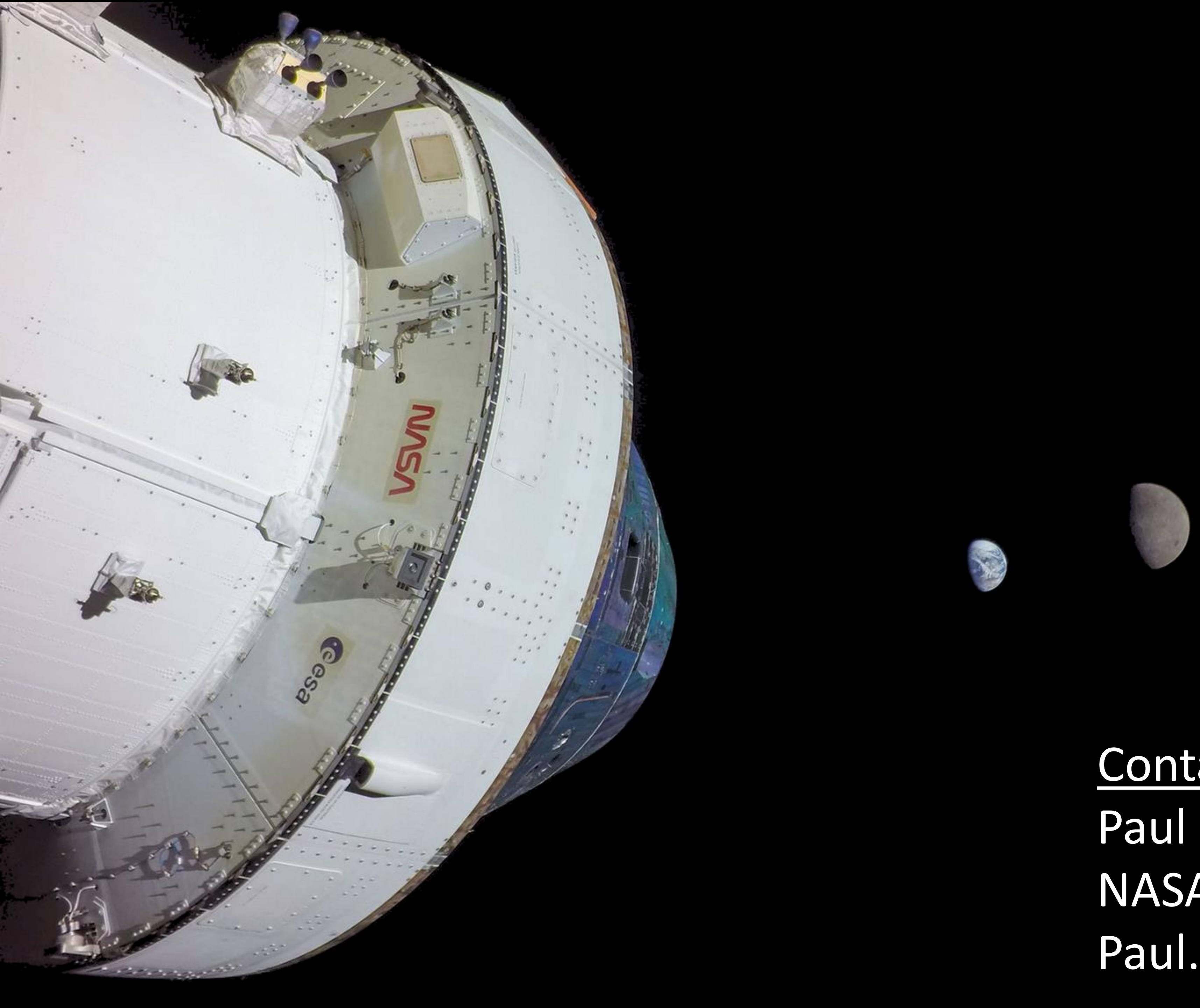
- Demonstrated successful formulation, powder processing and coating, microstructure characterization, mechanical properties, component development and hot-fire testing of GRX-810 alloy.
- Successful scale up from M100 to M280 platform and properties.
- Elevated temperature tensile (1100°C) is 2x Alloy 718.
- 1,000x improved creep rupture compared to Ni-based superalloys.
- Demonstrated successful injectors and nozzle L-PBF builds, processing, and hot-fire testing.
- Accumulated 221 starts across components, increased TRL = 5



<u>Ongoing Development</u>

- Commercialization of the powder processing and coating.
- Continued mechanical testing and characterization ongoing.
- Scale up to M400 and larger machine platforms (L-PBF, DED).
- Properties and data will be available to industry partners.





<u>Contact:</u>
Paul Gradl
NASA MSFC
Paul.R.Gradl@nasa.gov

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- Optimized and Repeatable Components using Additive (ORCA) Project
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