High Temperature Alloy Development

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The Importance of Materials

- Materials have defined human history
  - Stone Age: Before 3300 BCE
  - Bronze Age: 3300-1200 BCE
  - Iron Age: 1200 BCE – 1 AD (Western Europe)
  - Industrial Age (Steel): 1760-1970
  - Information Age (Silicon): 1970-Present

Stone Tool

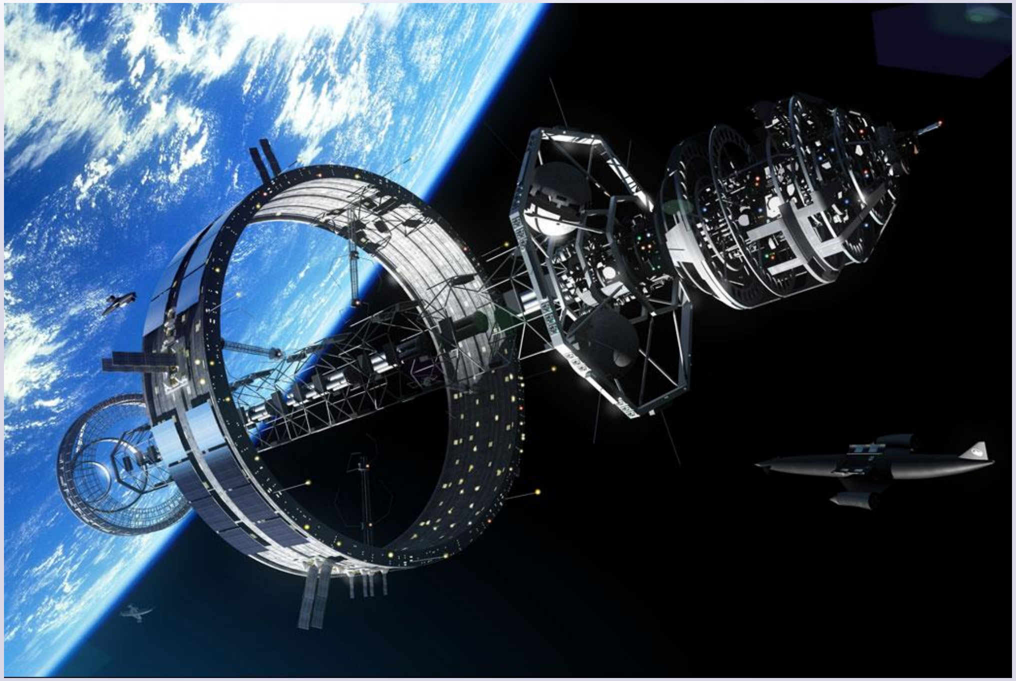
Bronze Tools

Iron Tool

Many Technology Challenges are Material Challenges

- Climate Crisis:
  - Fusion energy
  - Fission energy (fast thorium reactors)
  - Battery technology
  - Solar panel efficiency

- Travel:
  - Propulsion
  - Space radiation protection
  - Strength vs. weight
  - Engine efficiency

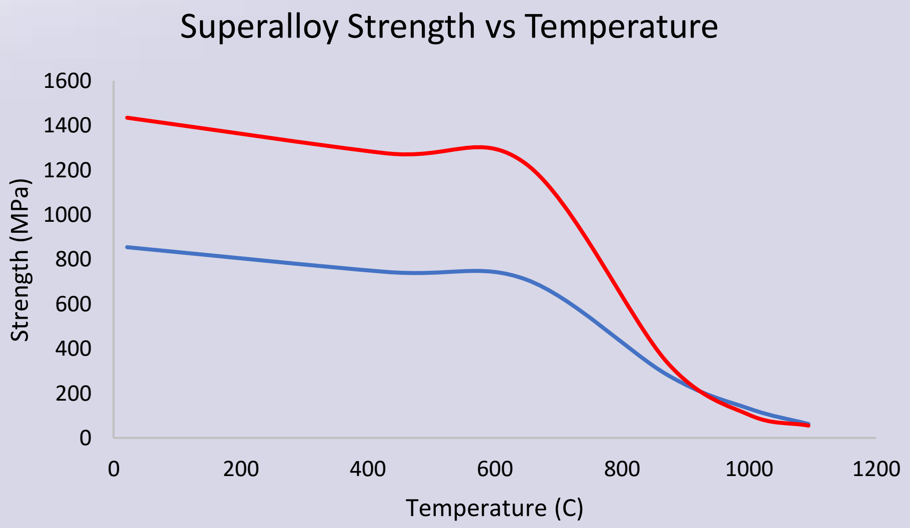


Material Problems at High temperature

- All metals are negatively impacted at high temperature long before they melt.
  - Reduction in Strength
  - Creep
  - Increased Oxidation / Corrosion
  - Increased crack growth

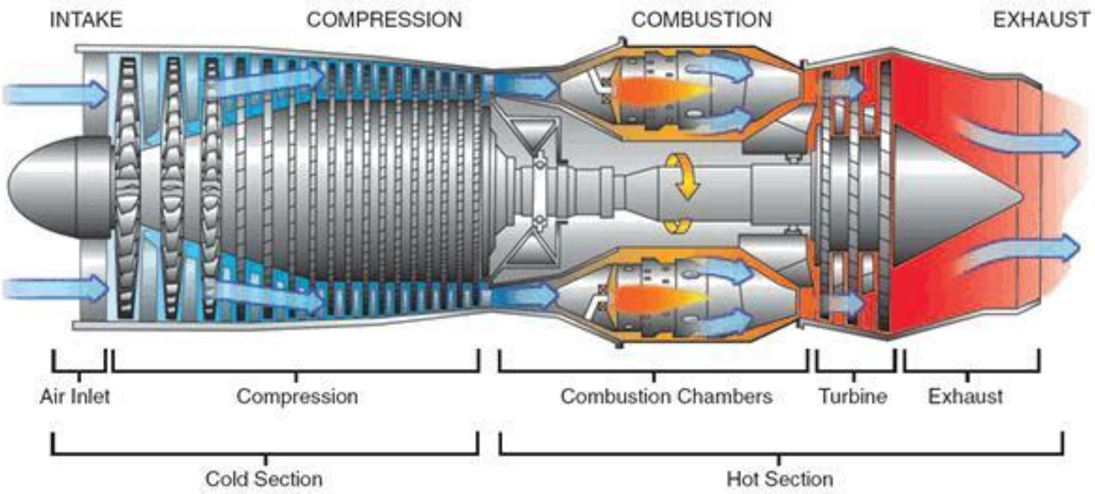
- Superalloys: Class of alloys that can operate at a high fraction of its melting point.

Right: Strength vs temperature for Ni-base Superalloy 625 and 718. Both melt around 1430°C.



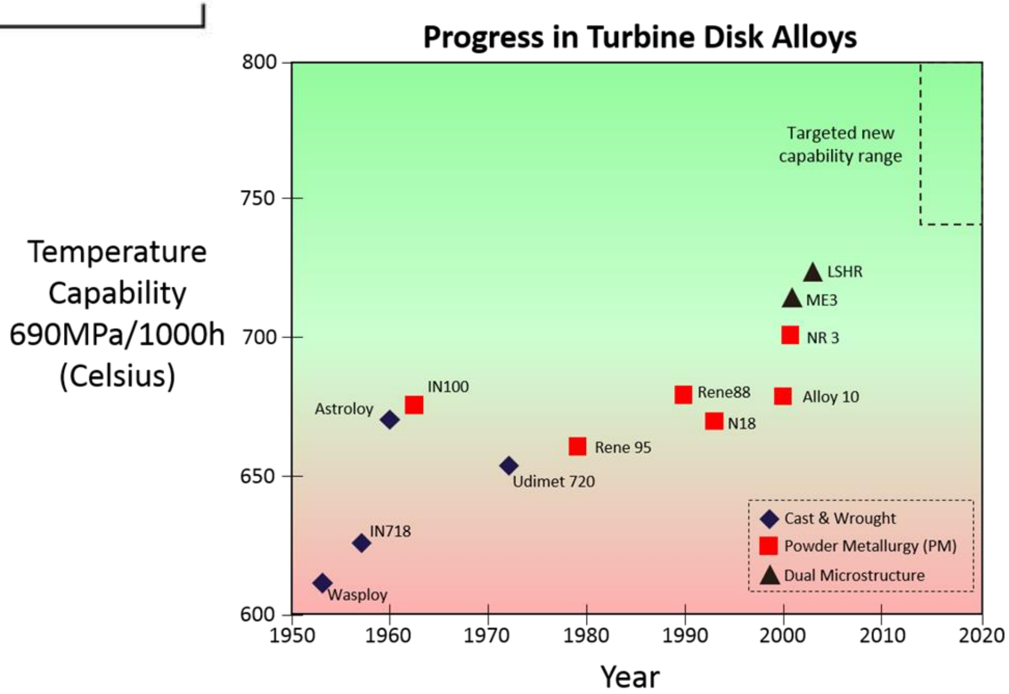
National Aeronautics and Space Administration

Example 1: Ni-Base Superalloy Development



Material advancements are required to accommodate the higher compressor exit temperatures in jet turbine engines (>700°C near the rotor rim) for improved efficiency and pollution reduction.

New understanding and materials will be needed for future advancements



Motivation for Improving Superalloy Performance

An increase of only 25°C in temperature capability of disk alloys (HPC)

↓

Approx. 1% increase in aircraft engine efficiency

↓

Billions $ in operating cost for a fleet over their service life

↓

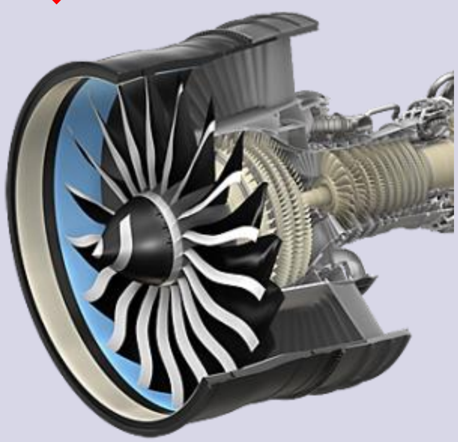
Beneficial environmental impact by reducing carbon emissions

GE90-115B (777)

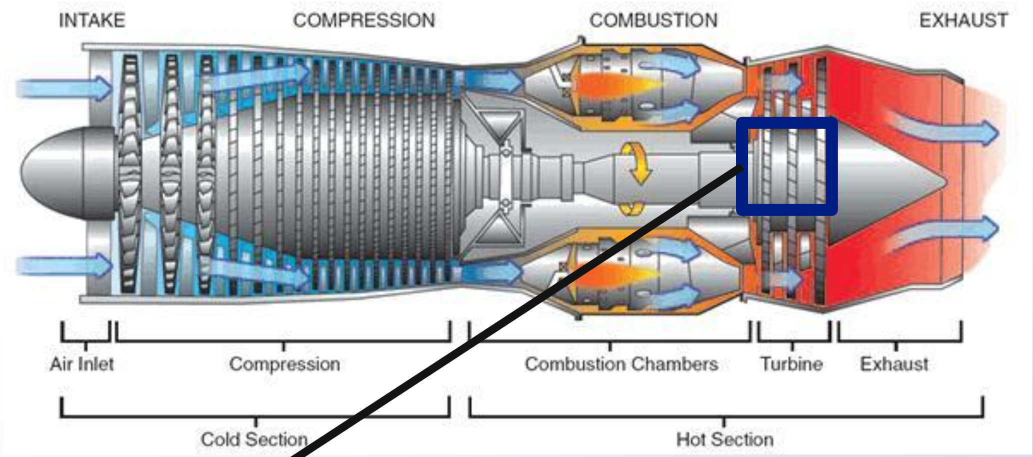
↓

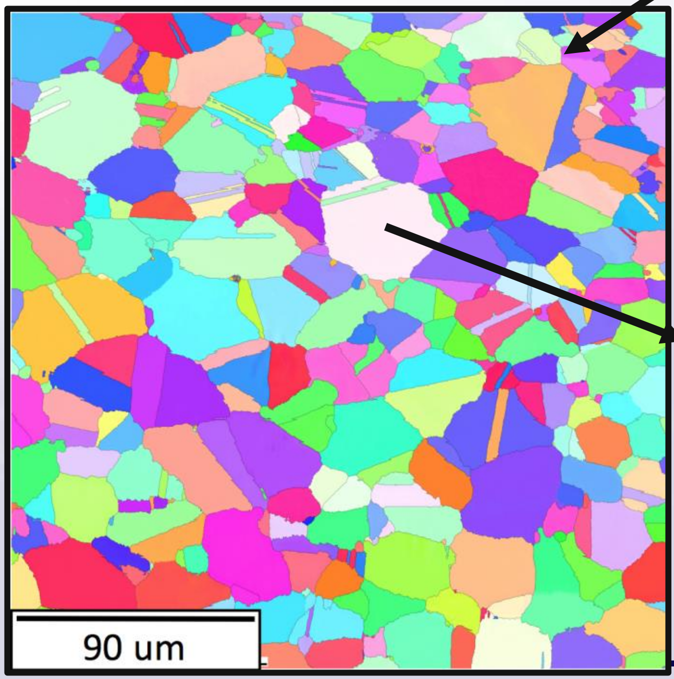
GEnx™

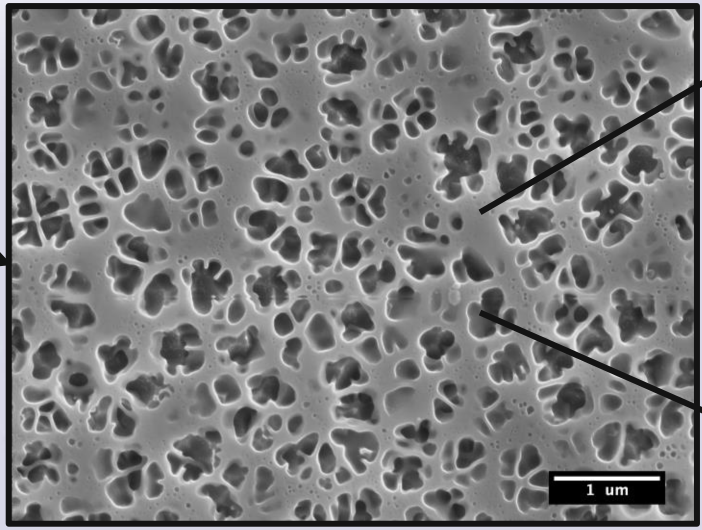
787, 747-8



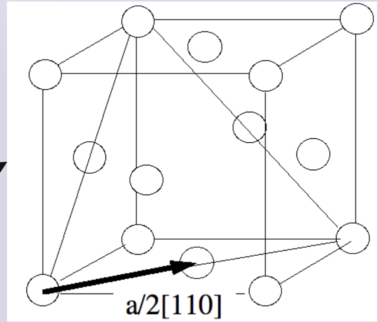
What is a Ni-Base Disk Superalloy?



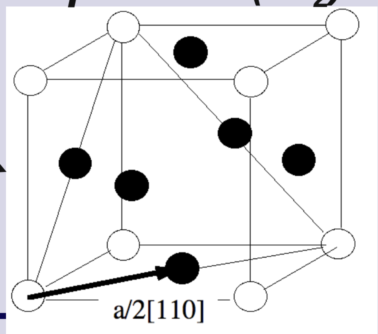




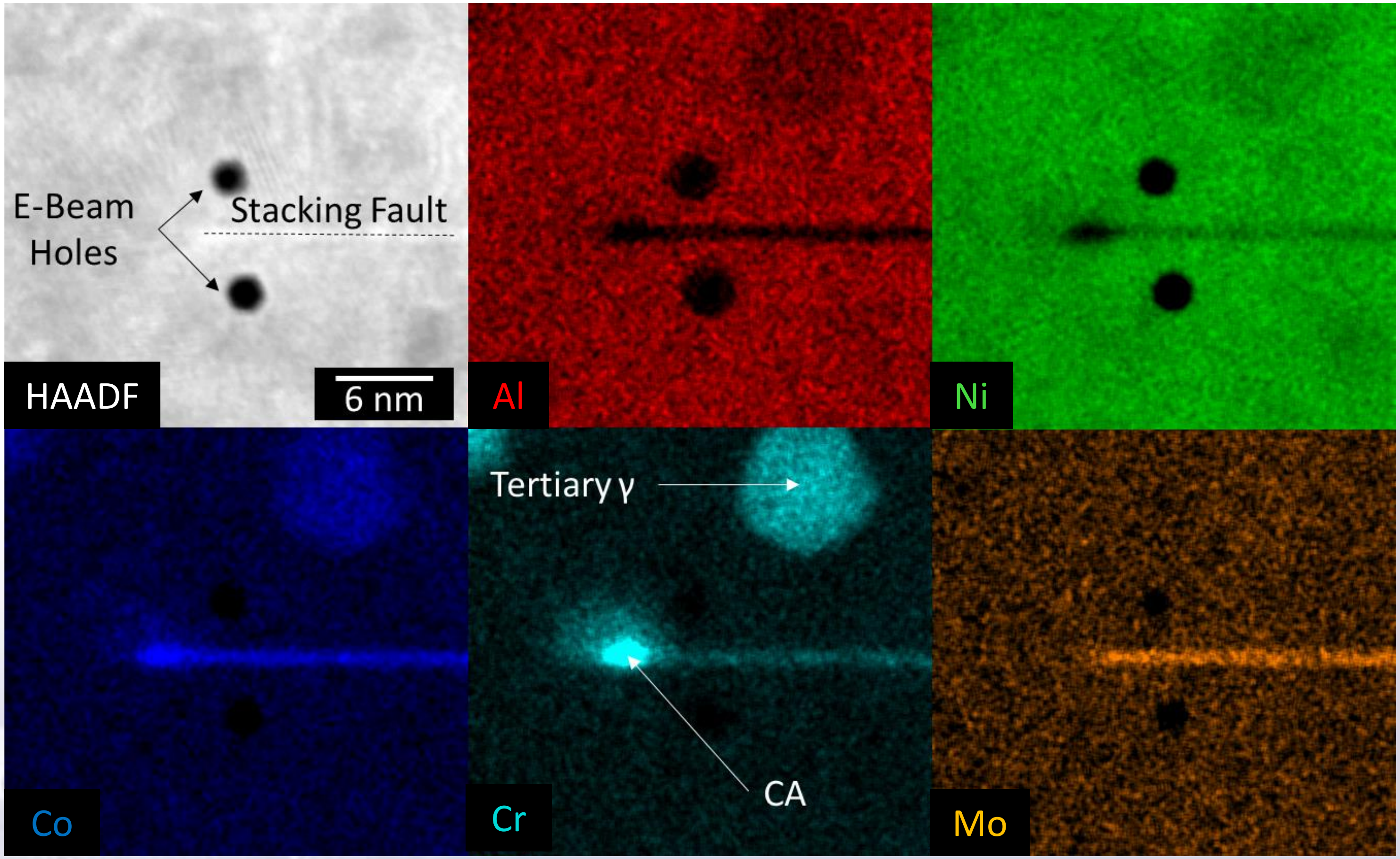
γ Phase (FCC)



γ' Phase ($L1_2$)



How do Superalloys Deform?



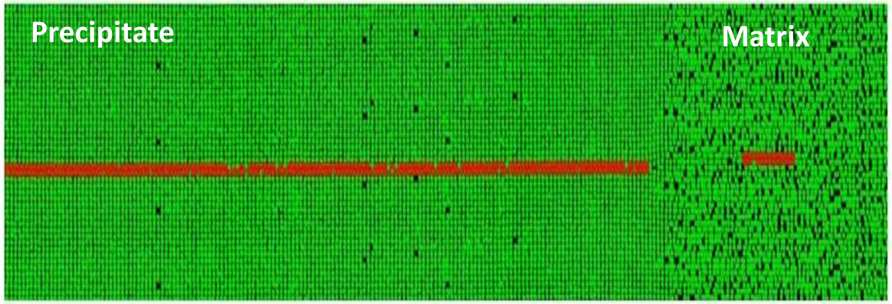
γ Phase elements: Ni, Co, Cr, Mo

γ' Phase elements: Ni, Al, Ti, Nb, Ta

New Alloy Class Created – Phase Transformation Strengthened NASA Alloy

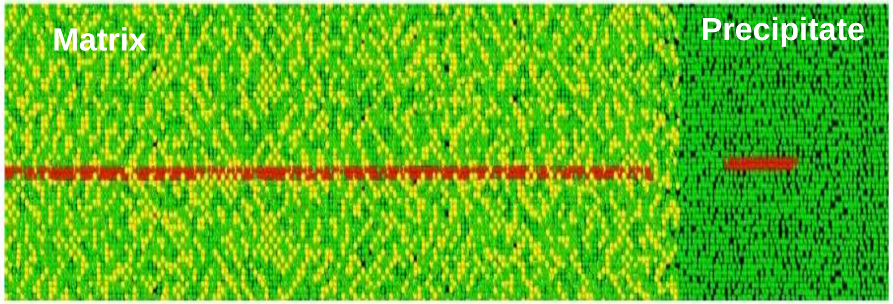
Low Nb

High Creep

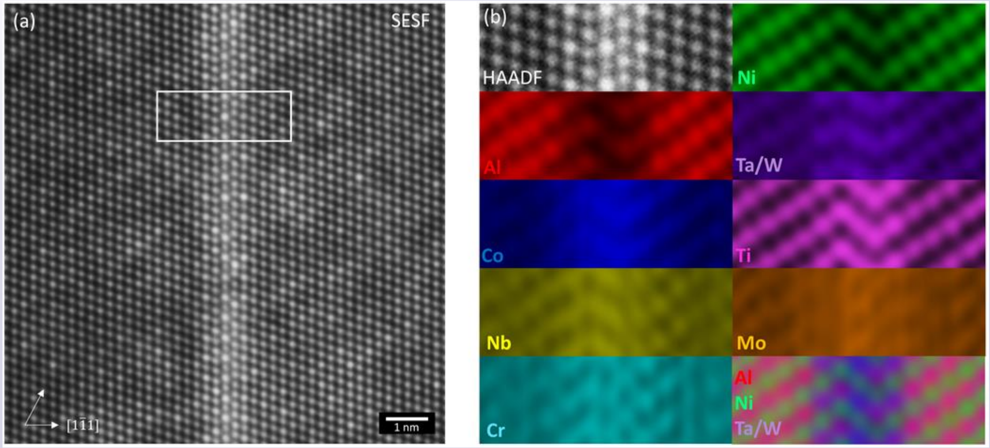


High Nb

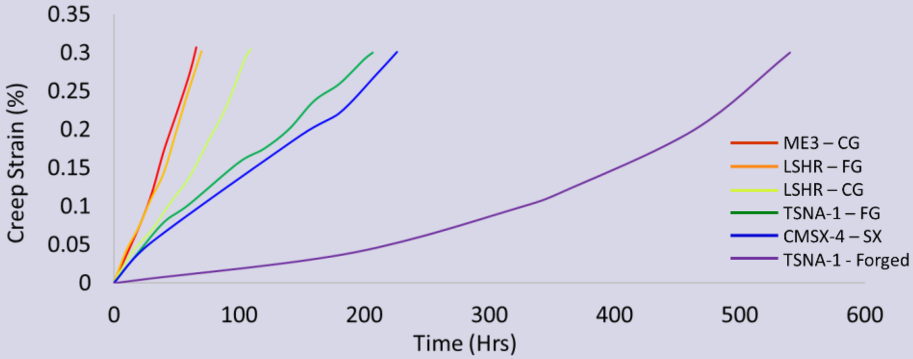
Low Creep



Atomic-scale Characterization of Strengthened Defects



10X Improvement in High Temperature Properties

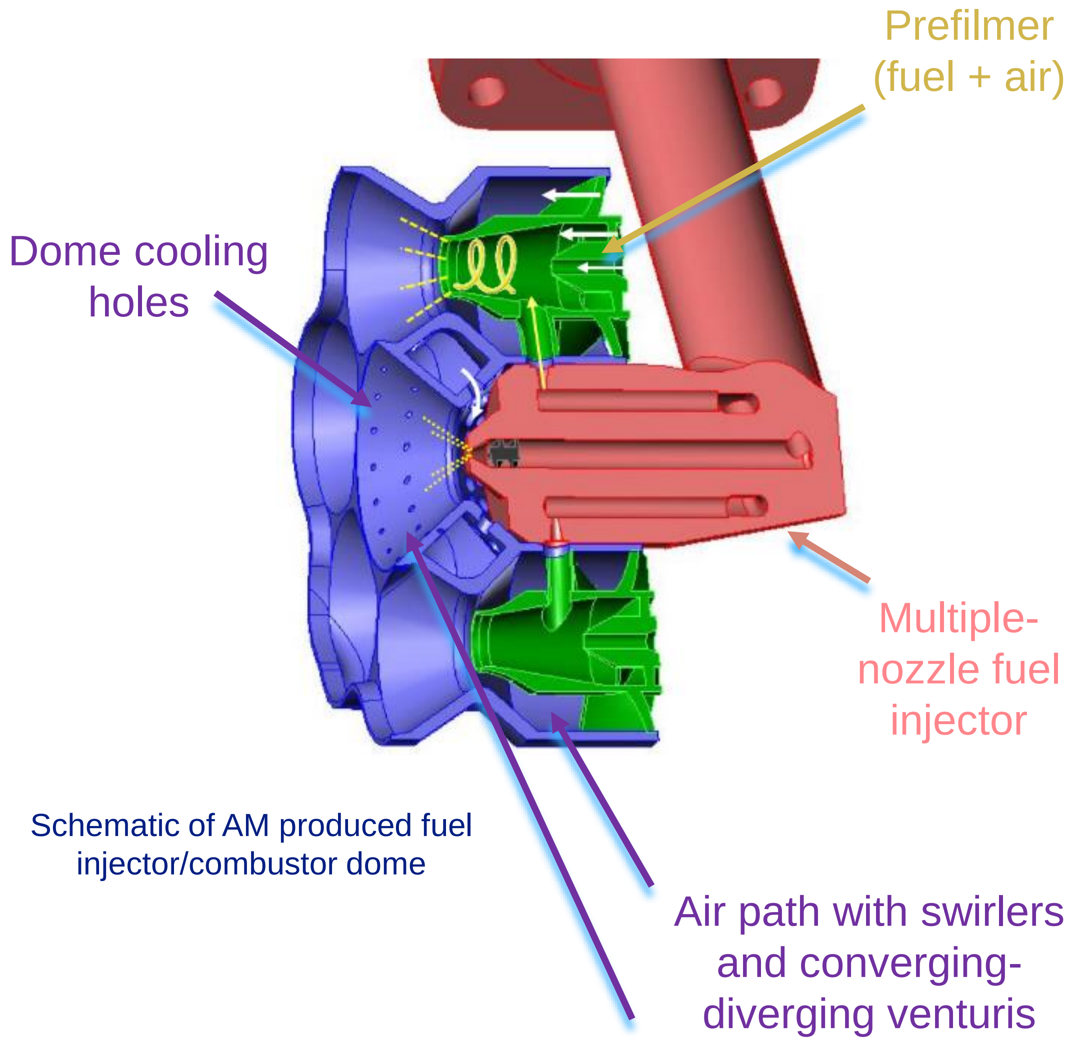


Example 2 – 3D Printed High Temperature Components

Problem: Conventional materials and processing techniques limit the design of combustor domes used in jet turbine engines.

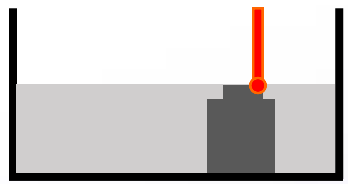
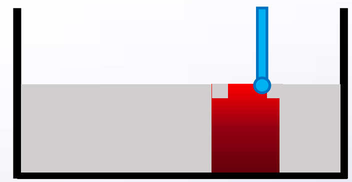
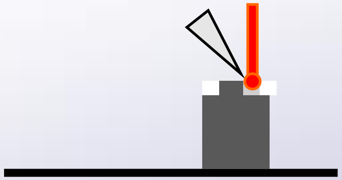
Proposed Solution: Develop a high ductility, high temperature material for an additively-manufactured (AM) combustor fuel nozzle and dome for supersonic aircraft (>1093°C (2000°F) operating temperature).

- Lead to several improvements to the turbine combustor design ultimately reducing NOx pollution and lowering weight.
- May enable lean-front-end small-core combustors.



Schematic of AM produced fuel injector/combustor dome

Metallic Additive Manufacturing

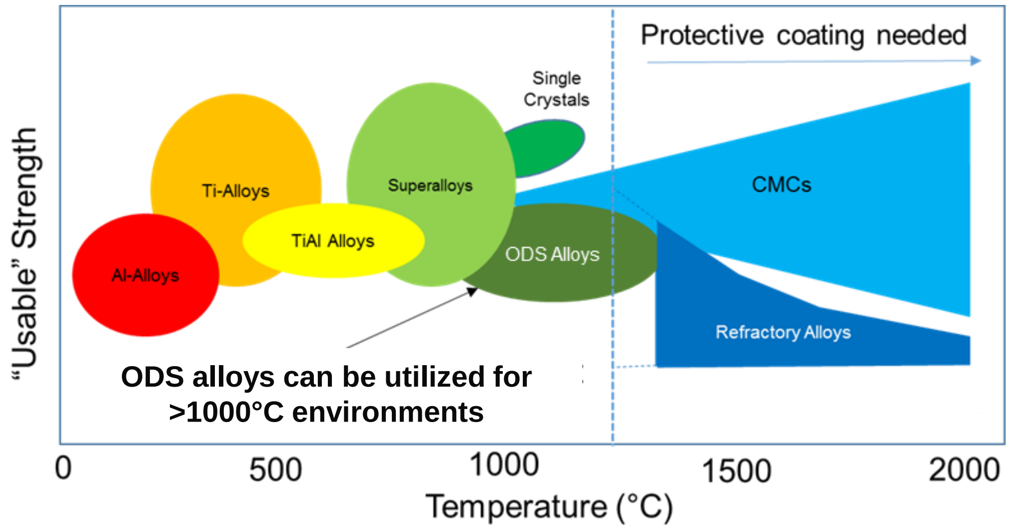
Process	Laser Powder Bed Fusion (L-PBF) 	Electron Beam Powder Bed Fusion 	Direct Energy Deposition (DED) 
Energy Source	Laser	E-Beam	Laser or E-Beam
Powder Bed	Yes	Yes	No
Power (W or kV)	50-1000 W	**30-60kV**	100-2000 W
Max Build Size (mm)	500 x 280 x 320	500 x 280 x 320	**2000 x 1500 x 750**
Material	Metallic Powder	Metallic Powder	Metallic Powder or Wire
Dimensional Accuracy	**<0.04 mm**	0.04-0.2 mm	0.5 mm (powder) 1.0 mm (wire)

- 3D printing or additive manufacturing (AM) has shown promise in realizing a new design space for aerospace applications.
- Each AM technique has a set of pros and cons associated with them.
- Instead of producing well known cast and wrought alloys with AM. We should look at AM as a new opportunity to produce materials that are currently difficult to create.
- For this study, L-PBF is used due to its superior dimensional accuracy.

High Temperature AM Compatible Materials

High Temperature Materials:

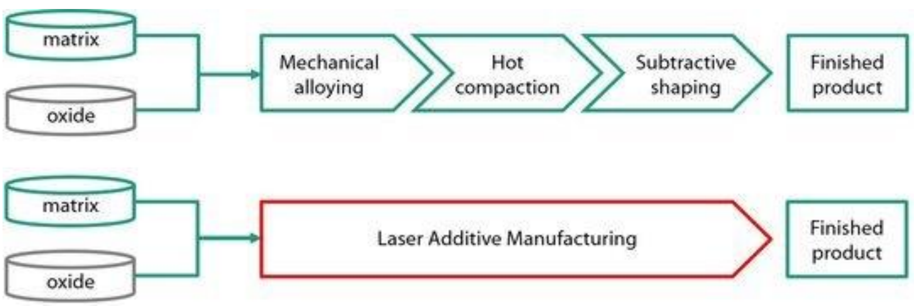
- Refractory metals
- Carbon-Carbon composites
- CMC's
- Ni-base superalloys
- **Oxide Dispersion strengthened (ODS) alloys**



Inspired by Andy Jones. ODS alloy Development.

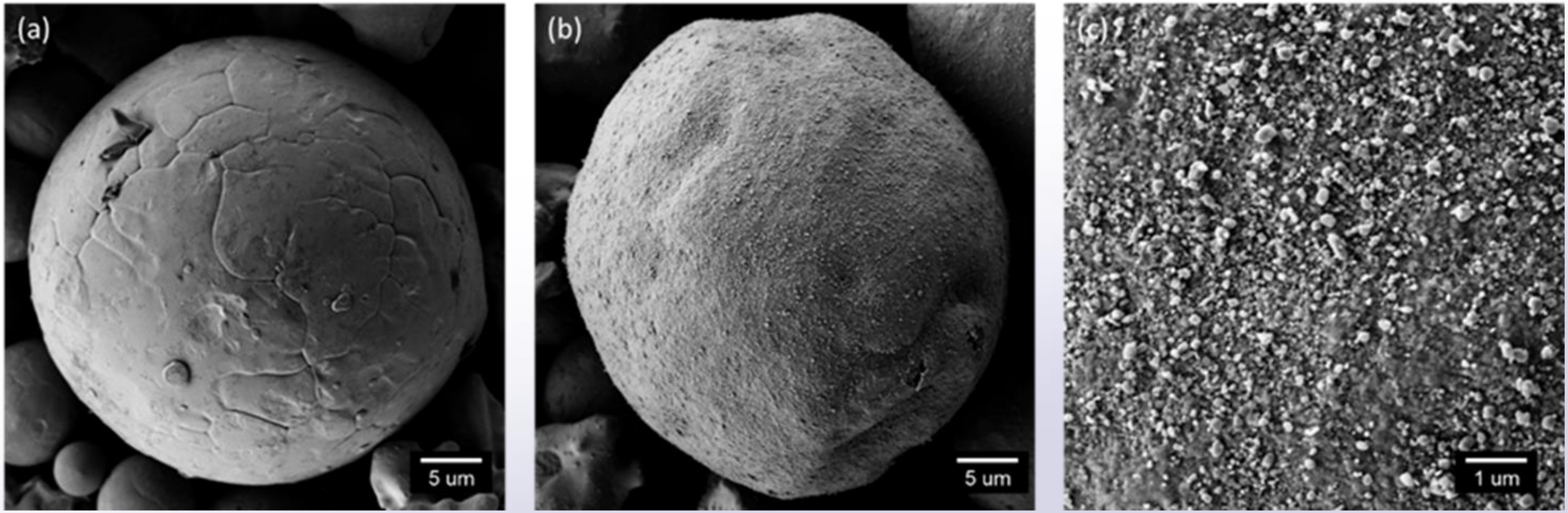
(ODS) alloys offer higher temperature capabilities compared to Ni-base superalloys. However, it has been a challenge to produce ODS alloys through conventional manufacturing methods. **Therefore, they have not been widely embraced by industry.**

Conventional Manufacturing vs AM



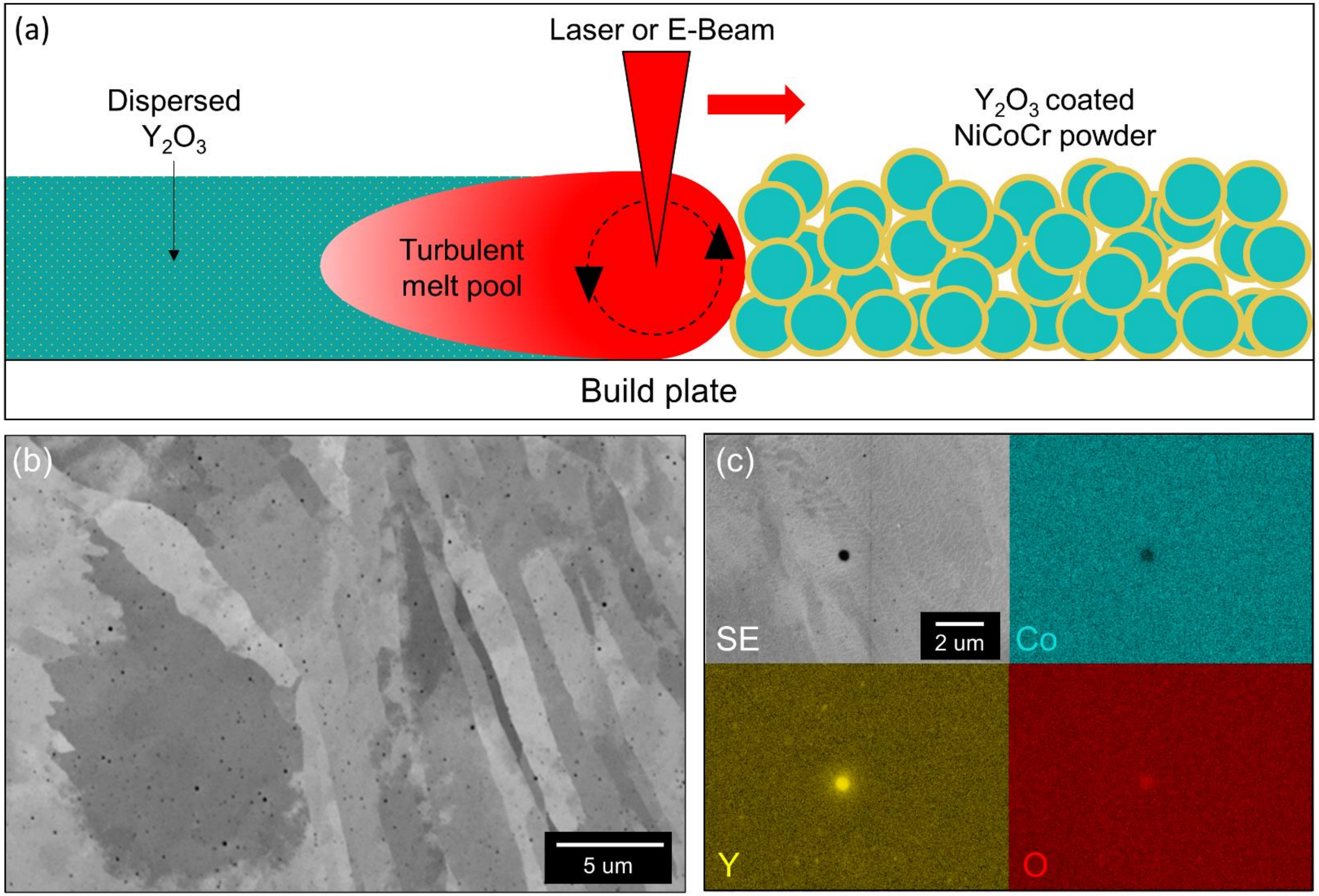
Can AM improve ODS alloy manufacturability?

Novel Powder Coating Technique



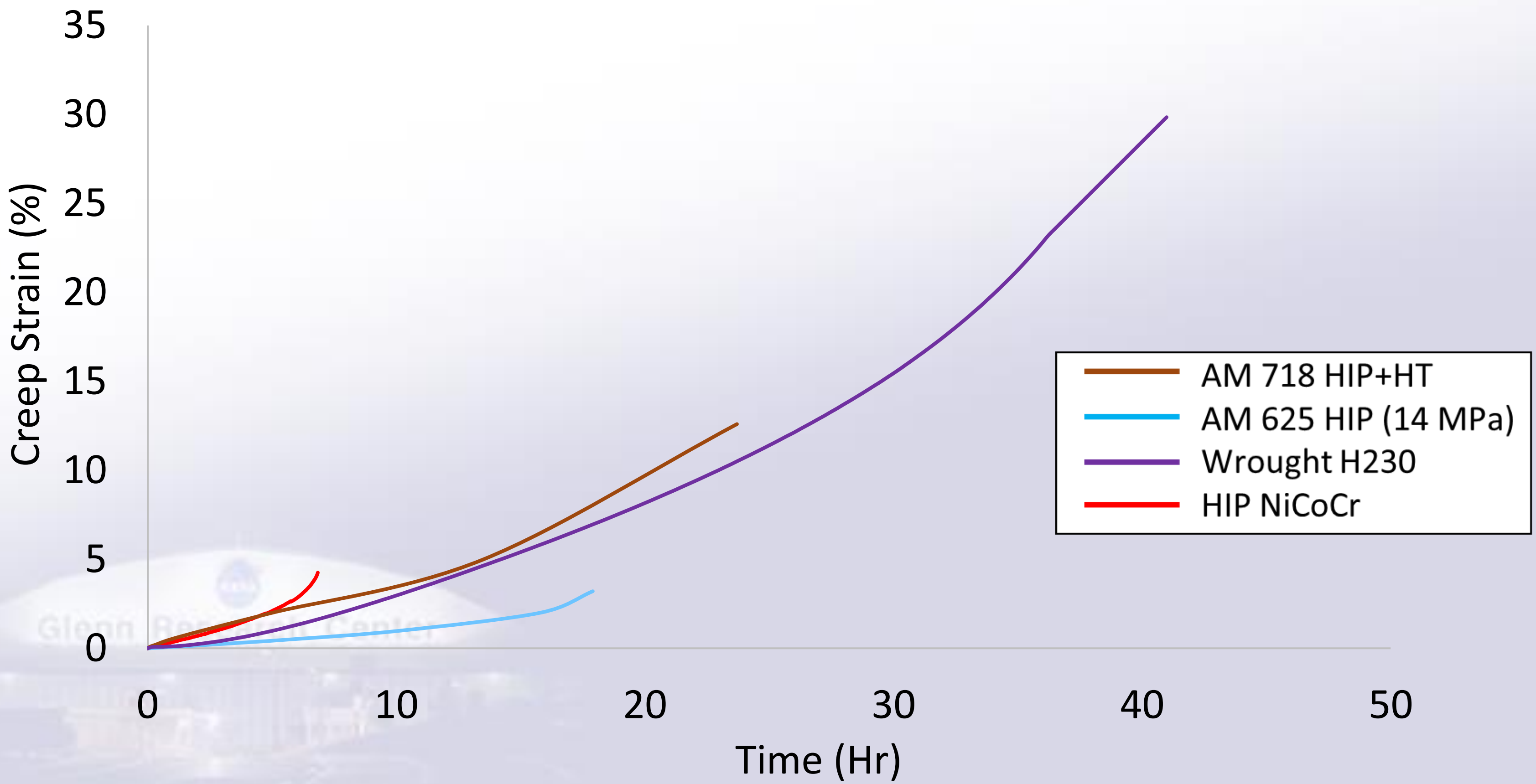
- The advanced dispersion coating (ADC) technique did not deform the metallic powder.
- The ADC technique fully coats the metallic powders with nano-scale oxides
- Both uncoated and coated powders qualitatively passed the Hall flow test.
- The technique does not affect the printability of the powder lot.

Leveraging L-PBF to Produce Oxide Dispersion Strengthened Alloys



L-PBF successfully disperses the nano-scale Y_2O_3 particles throughout the AM build

Mechanical Results – 1093°C/20MPa Creep Rupture



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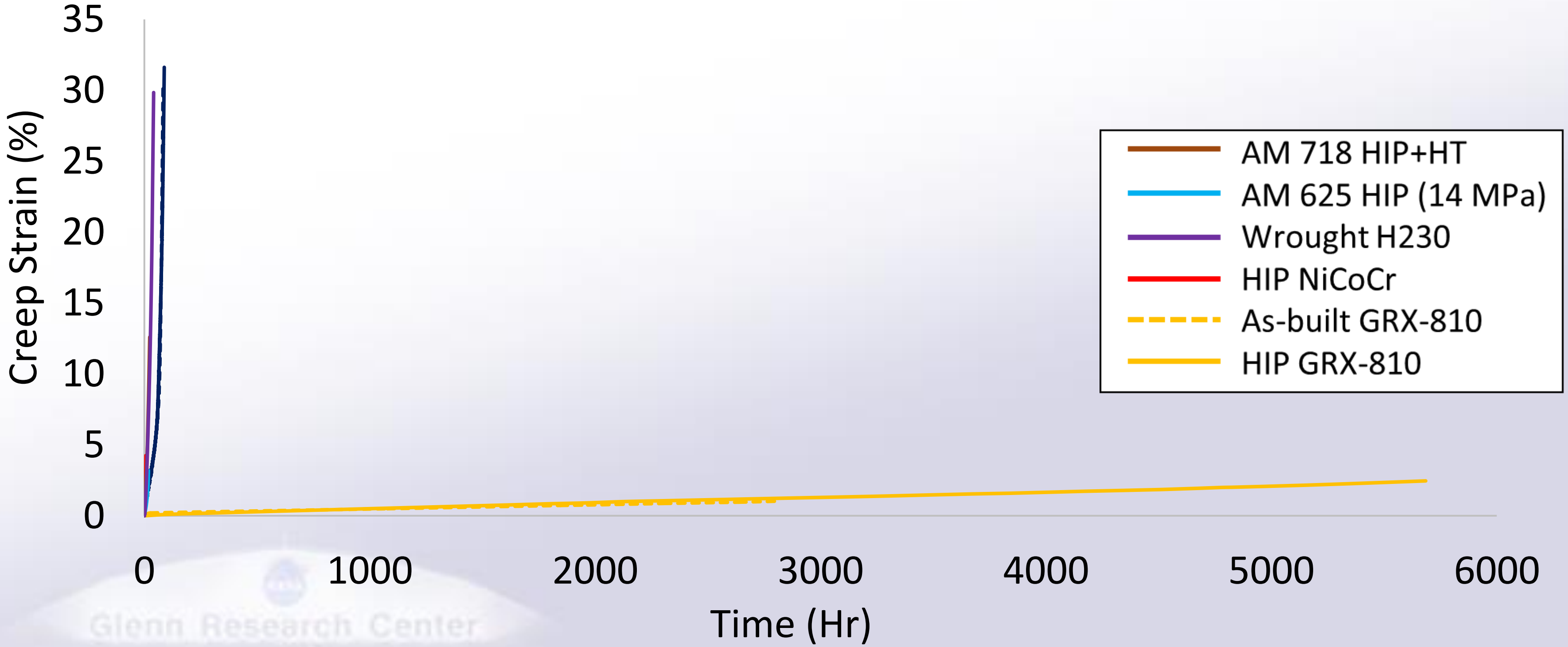
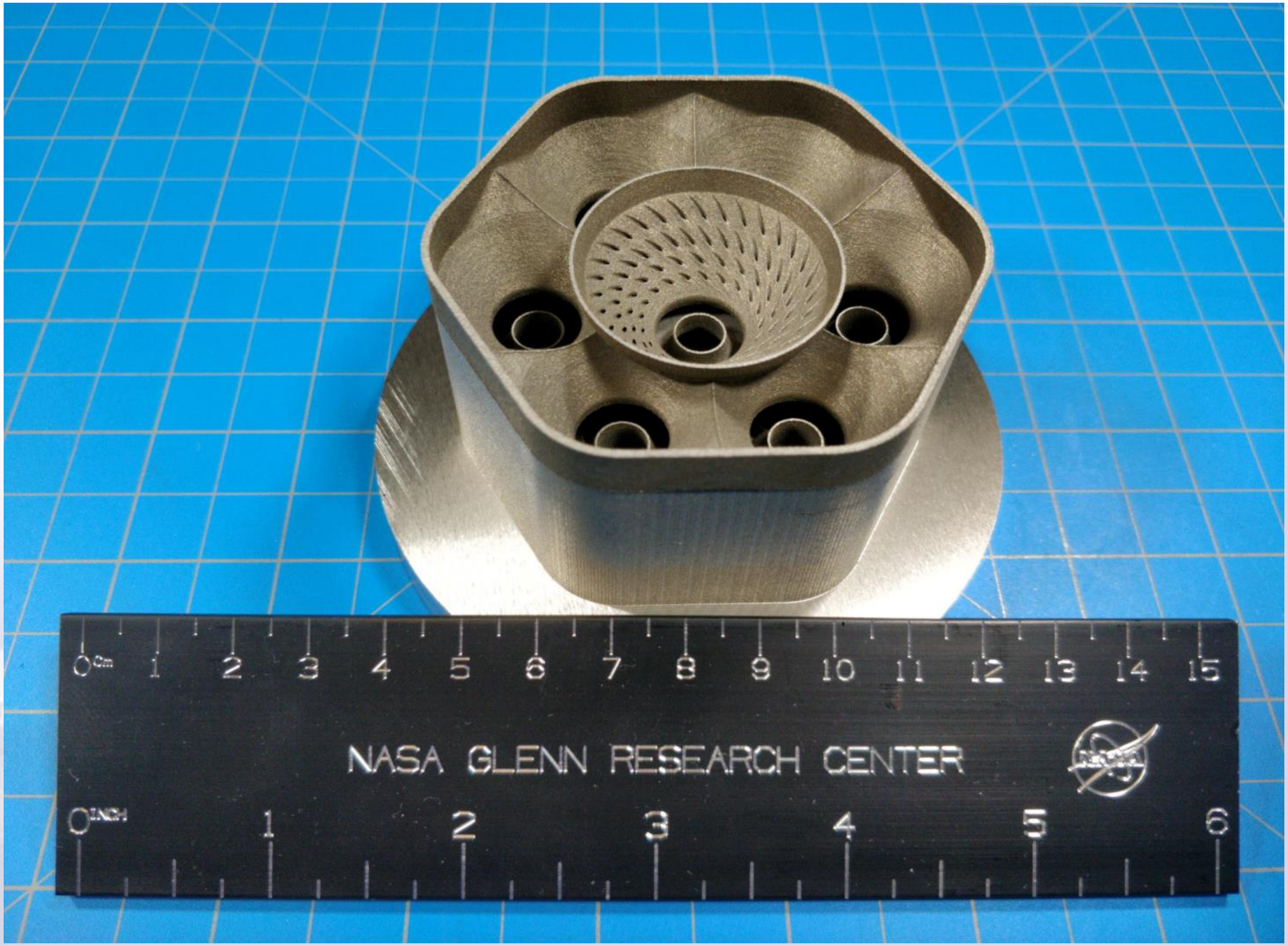
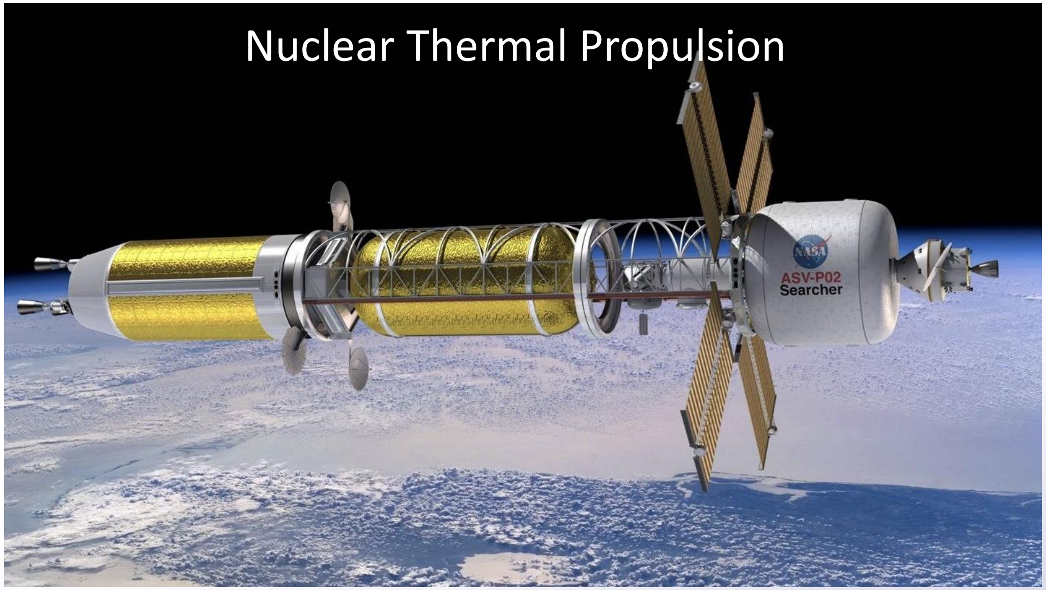


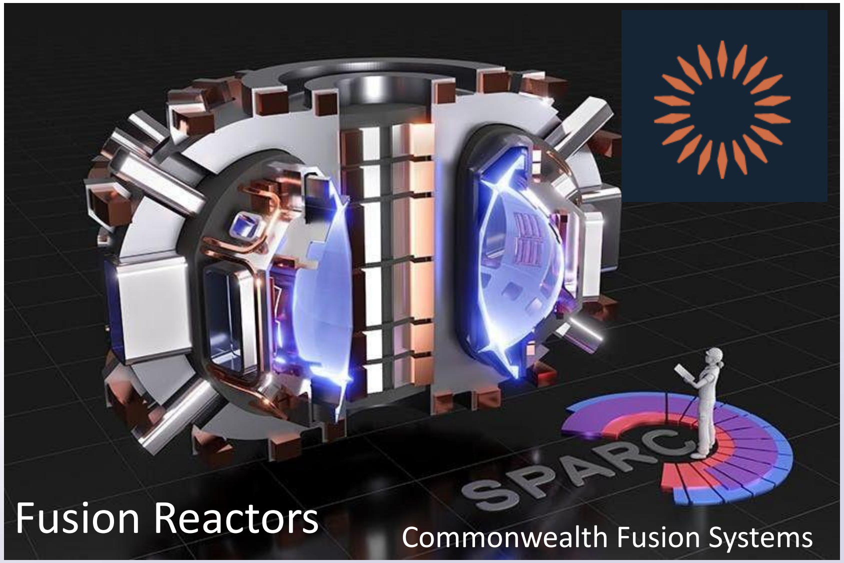
- **GRX-810 ODS tests are still running ATM (2% strain currently).**
- ODS alloys provide orders of magnitude improvements in creep rupture life at 1093°C compared to conventional superalloys 718 and 625.
- AM 718/625 built and tested by Henry DeGroh and Chris Kantzos.

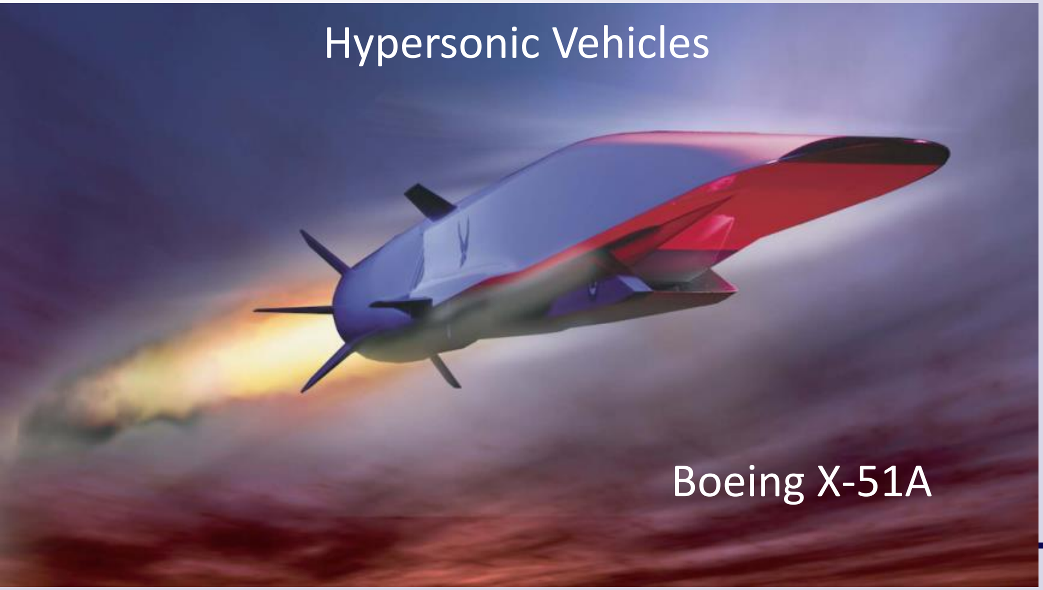
3D printed Oxide Dispersion Strengthened Combustor Dome



Promoting ODS alloys in Industry







Candidate applications and components using this new technology are currently in discussion

To make it a reality... My recommendations

1. Understand your materials
2. Form the right team/skills. You can’t do everything yourself.
3. Always look for ways to optimize your process.
4. Failures only occur if you don’t learn from them.
5. Documentation is very important – I’ve been burned on this one.
6. Communication is important
7. Have fun

Questions?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