Additively Manufactured RCS for Small Satellites and Landers

SSC22-X-03

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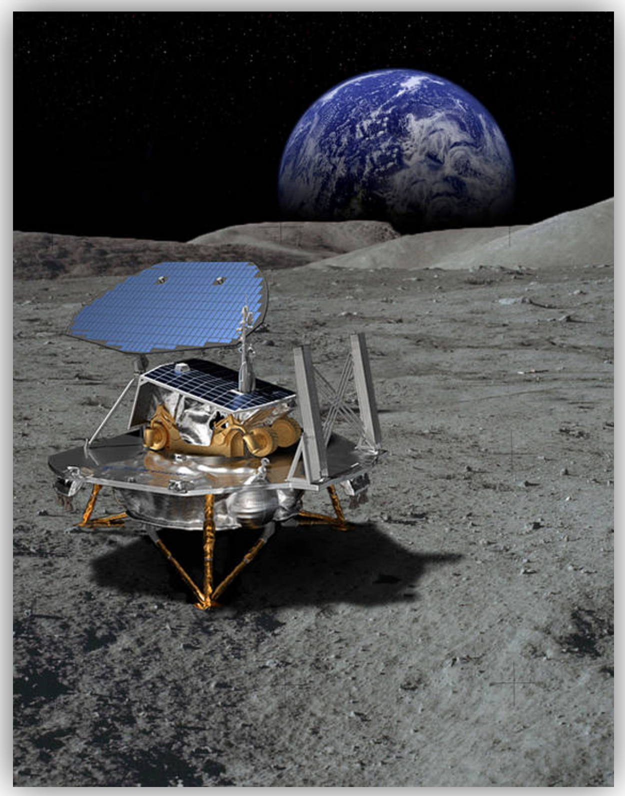
Introduction

- New interest in long term utilization of the moon is driving opportunities for small satellites and landers
  - Artemis Program, Commercial Lunar Payload Services (CLPS)
  - Regular resupply of logistics: food, cargo, and science
- Storable propulsion technology enables a rapid, reliable, and low cost approach for delivering logistics to the lunar surface
  - NASA NextSTEP-2 Appendix E studies / Apollo Program
- Long term sustainability of any exploration effort is enabled by affordability
  - Where can 50 years of advancements in computer aided design, propulsion technology, and manufacturing be leveraged?

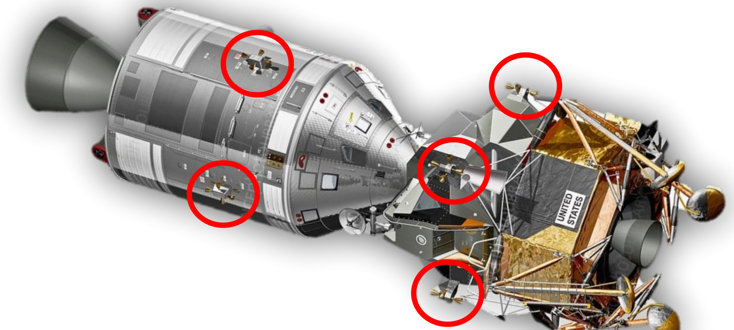


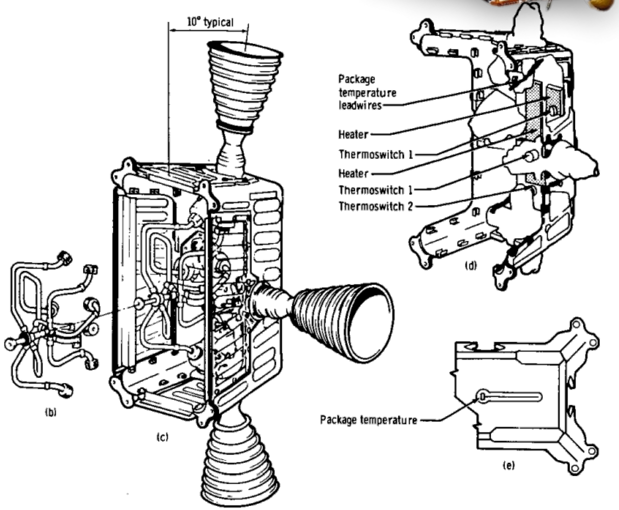
Lockheed Martin's Small CLPS Lander *McCandless*

(Image credit: NASA.gov)

Reaction Control System (RCS)

- Bipropellant RCS used for attitude control during fast-acting maneuvers
  - EDL, Proximity Operations
- 50 years ago: Apollo Lunar & Service Modules
  - Four 100 lbf R-4D thrusters integrated into “quads”
  - 650+ produced to support the 12 manned missions and 6 landings
- Today: The development of modern RCS systems
  - Reduce the complexity of the Apollo era design using Additive Manufacturing (AM)
  - Incorporate advances in bipropellant technology to improve cost/schedule/reliability

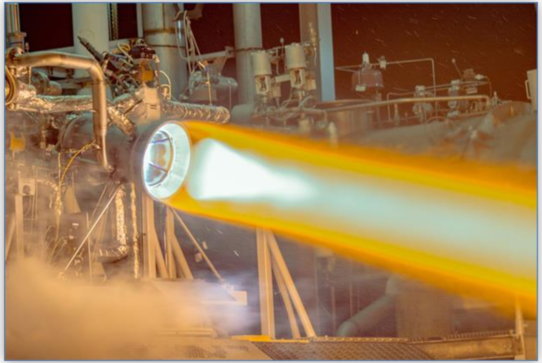




(ref: Taeuber, Ralph J., and Dwayne P. Weary. 1973.)

Additive Manufacturing Processes

- Laser powder bed fusion (L-PBF)
  - Metal powder is selectively melted layer-by-layer
  - AR development: nickel, titanium, aluminum, and copper alloys across four L-PBF platforms
  - Supports over 100 printed parts used in AR liquid rocket engines
- Cold spray
  - Robotic deposition technology that imparts fine powder particles on a substrate using a high velocity compressed gas stream
  - The powder is able to mechanically (diffusion) bond together to create a layer

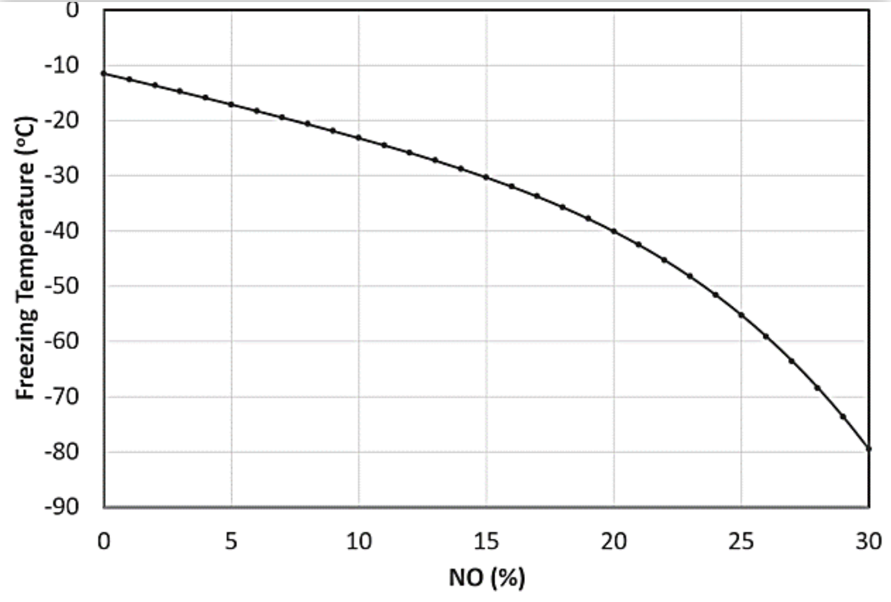


RL10C-X Upper Stage Liquid Rocket Engine with AM Copper Thrust Chamber

C-103 thrust chamber cold spray geometry demonstration

MON-25 Background

- MMH and MON-25 Propellants
  - Hypergolic (reliable restart)
  - Storable (long duration applications)
- MON-25
  - NTO with 25% Nitric Oxide = Lower freezing point (-55 °C)
  - Reduces heater power and associated mass required by the vehicle to prevent freezing in the tank and line
  - <u>Combustion instabilities associated with higher vapor pressure of the oxidizer</u>



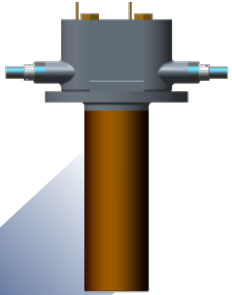
Freezing Temperature Reduction of MON with increase of NO in the mixture

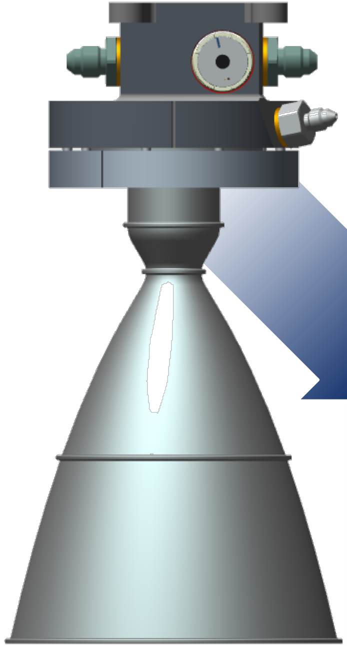
(ref: Trinh, Huu P., Christopher Burnside, and Hunter Williams. 2019)

Point-of-Departure Designs

ISE-5

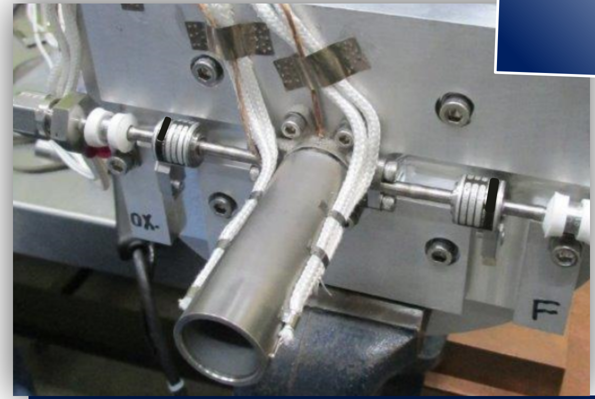
- MON-25 / MMH
- 5 lbf thrust
- 275+ seconds vacuum I_{SP}
- 1.25 Mixture Ratio
- Early development testing

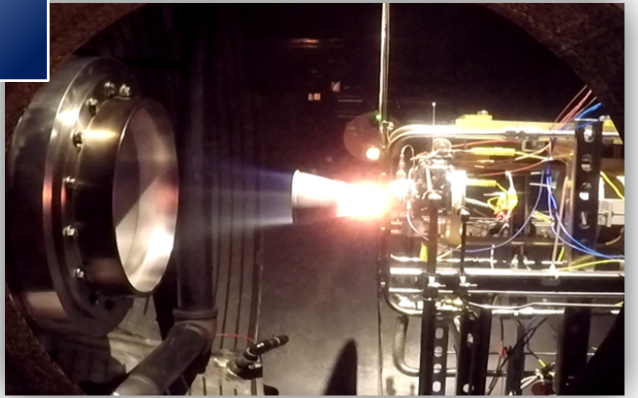




ISE-100

- MON-25 / MMH
- 100 lbf thrust
- 314+ seconds vacuum I_{SP}
- 1.59 Mixture Ratio
- Development testing complete

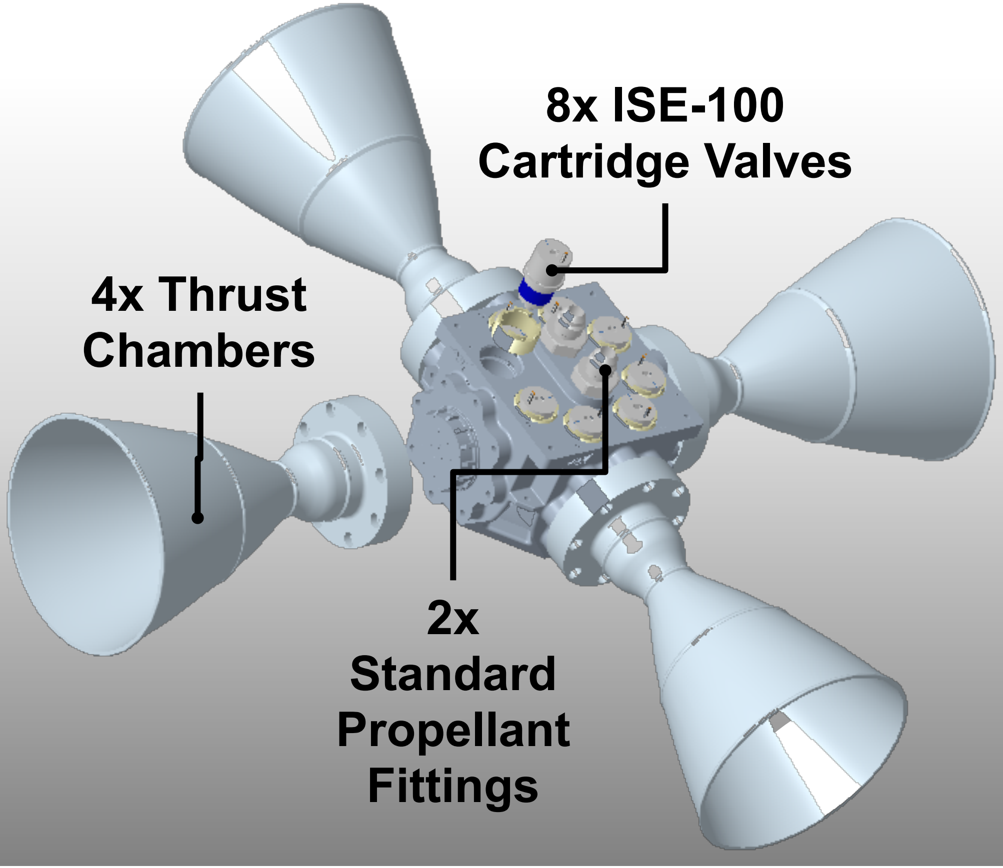




AM designs that stably combust MON-25:

1/5 the mass, 1/2 the size, and 1/3 the cost of its nearest space-based competitors

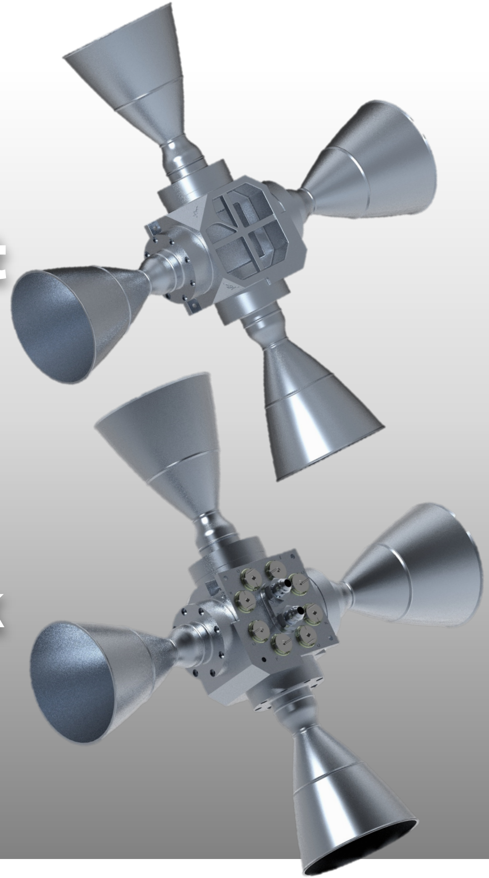
Integrated AM RCS: *ISE-100 Based*



8x ISE-100 Cartridge Valves

4x Thrust Chambers

2x Standard Propellant Fittings



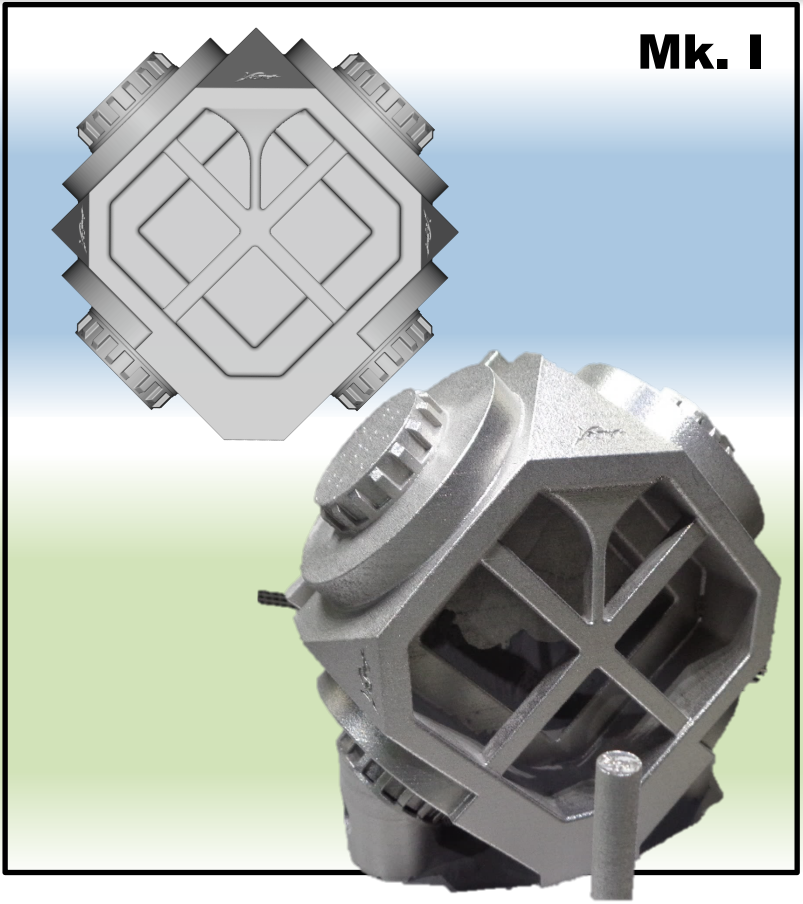
Front

Back

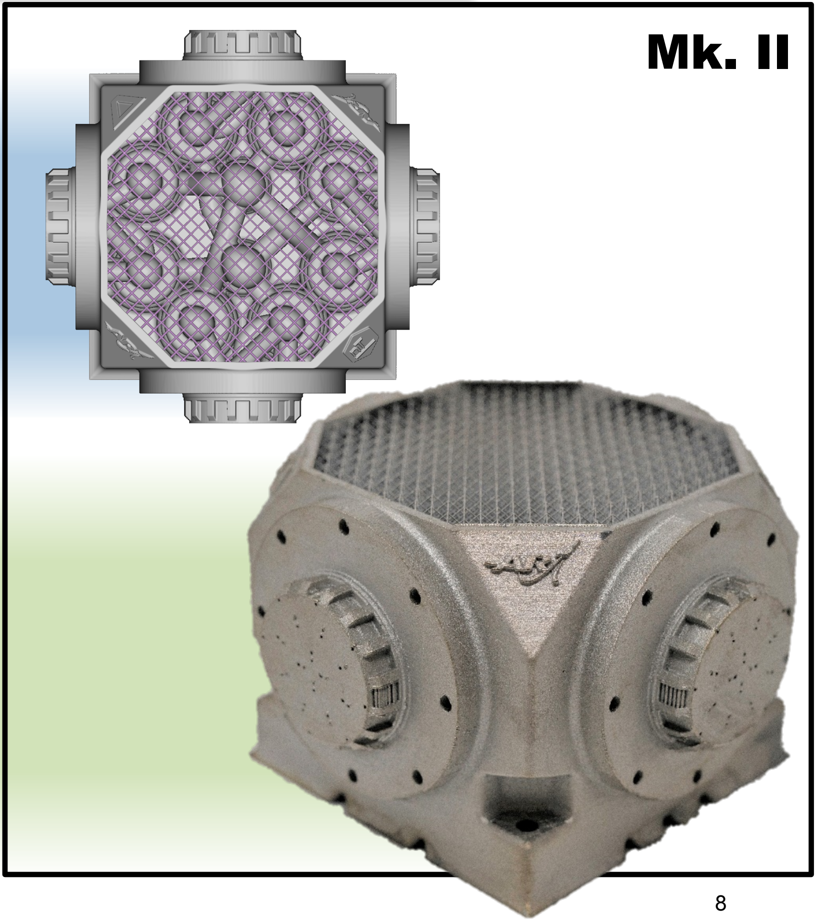
Reduction to practice

CAD Design

As Printed

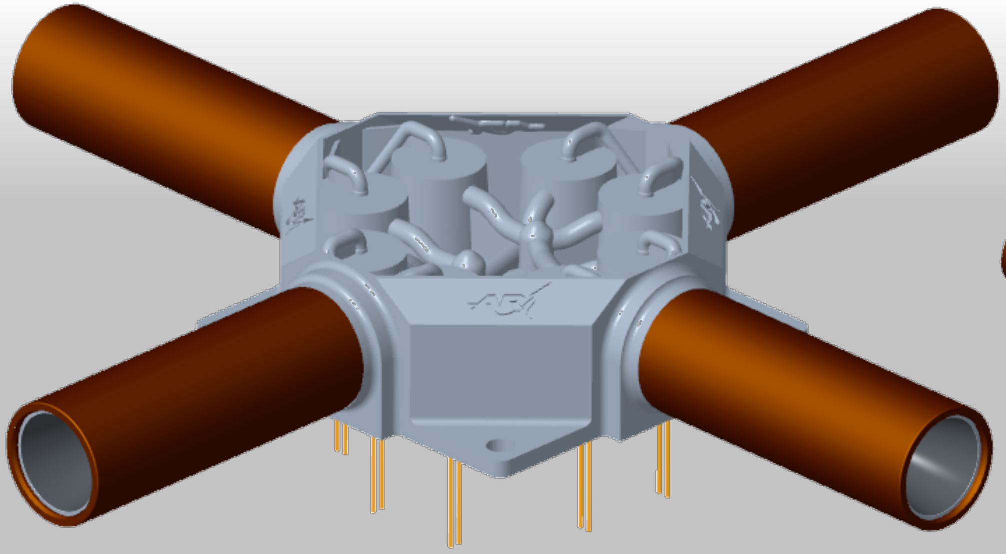


Mk. I



Mk. II

Integrated AM RCS: *ISE-5 Based*



Front

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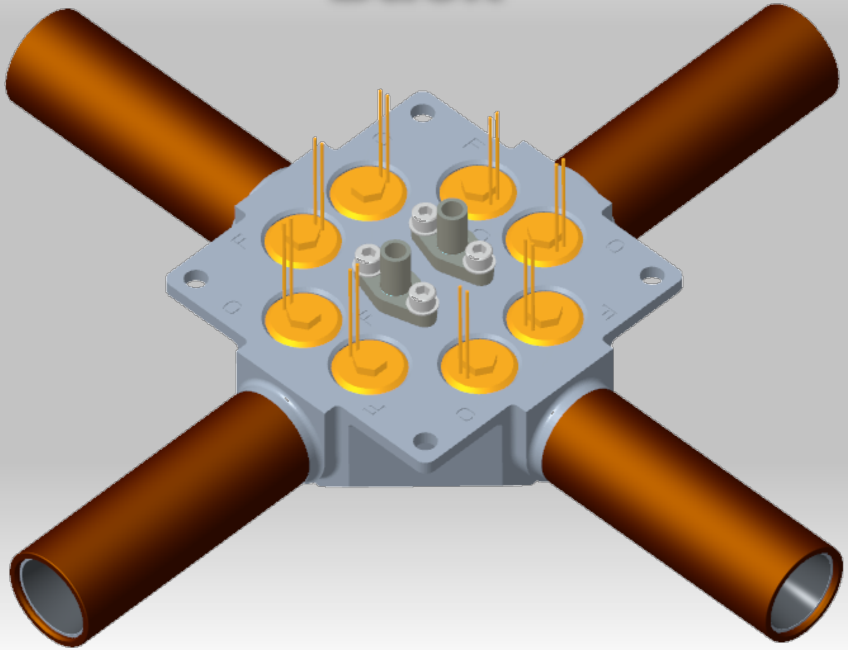

Conclusion

- For 60+ years, storable propulsion has been a proven & reliable technology to explore the solar system
- Leveraging recent advancements in computer-aided optimization and manufacturing, spacecraft subsystems can be built at a fraction of the traditional cost while still improving upon the performance
    - Affordability of the product helps ensure sustainability of any future effort to explore the Moon, Mars, and beyond
- AR has reduced to practice a fully integrated AM RCS subsystem that takes advantage of recent developments in bipropellant technology

(Image credit: NASA.gov)