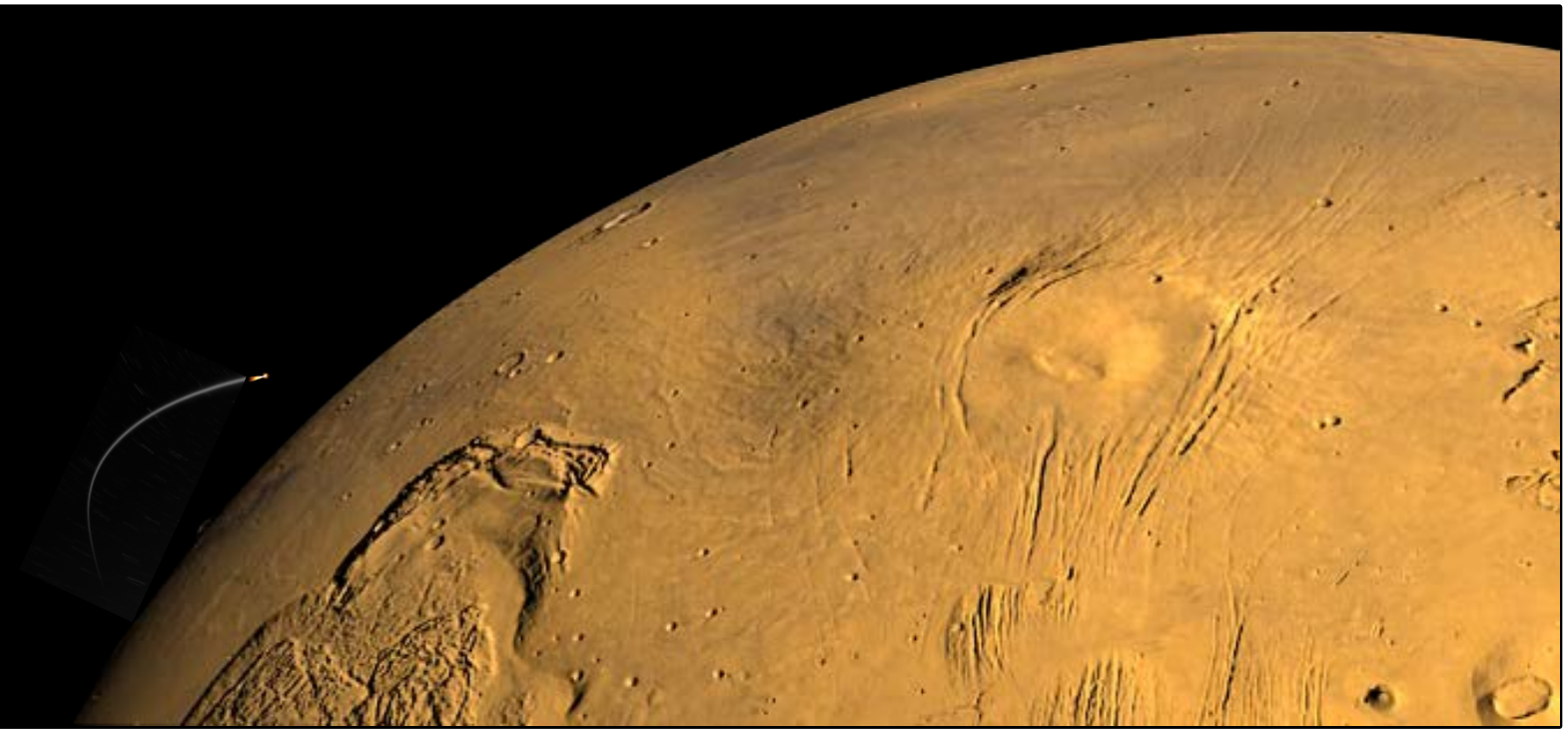
Mars Ascent Vehicle



Jet Propulsion Laboratory
California Institute of Technology

MARSHALL
SPACE FLIGHT CENTER

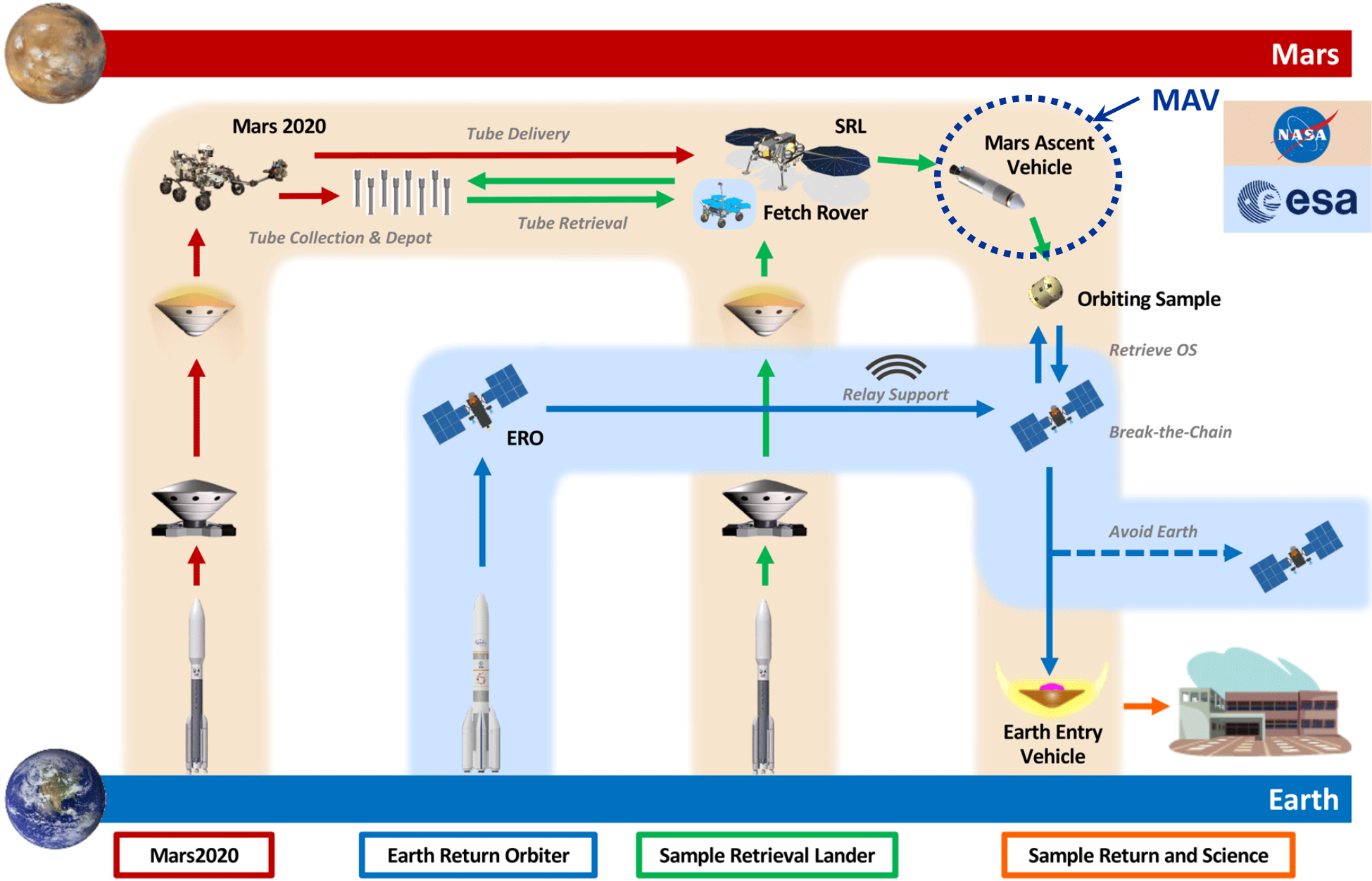
Mars Ascent Vehicle Hybrid Propulsion Configuration

Darius Yaghoubi

March 12, 2020
IEEE Aerospace Conference

Mars Sample Return and MAV

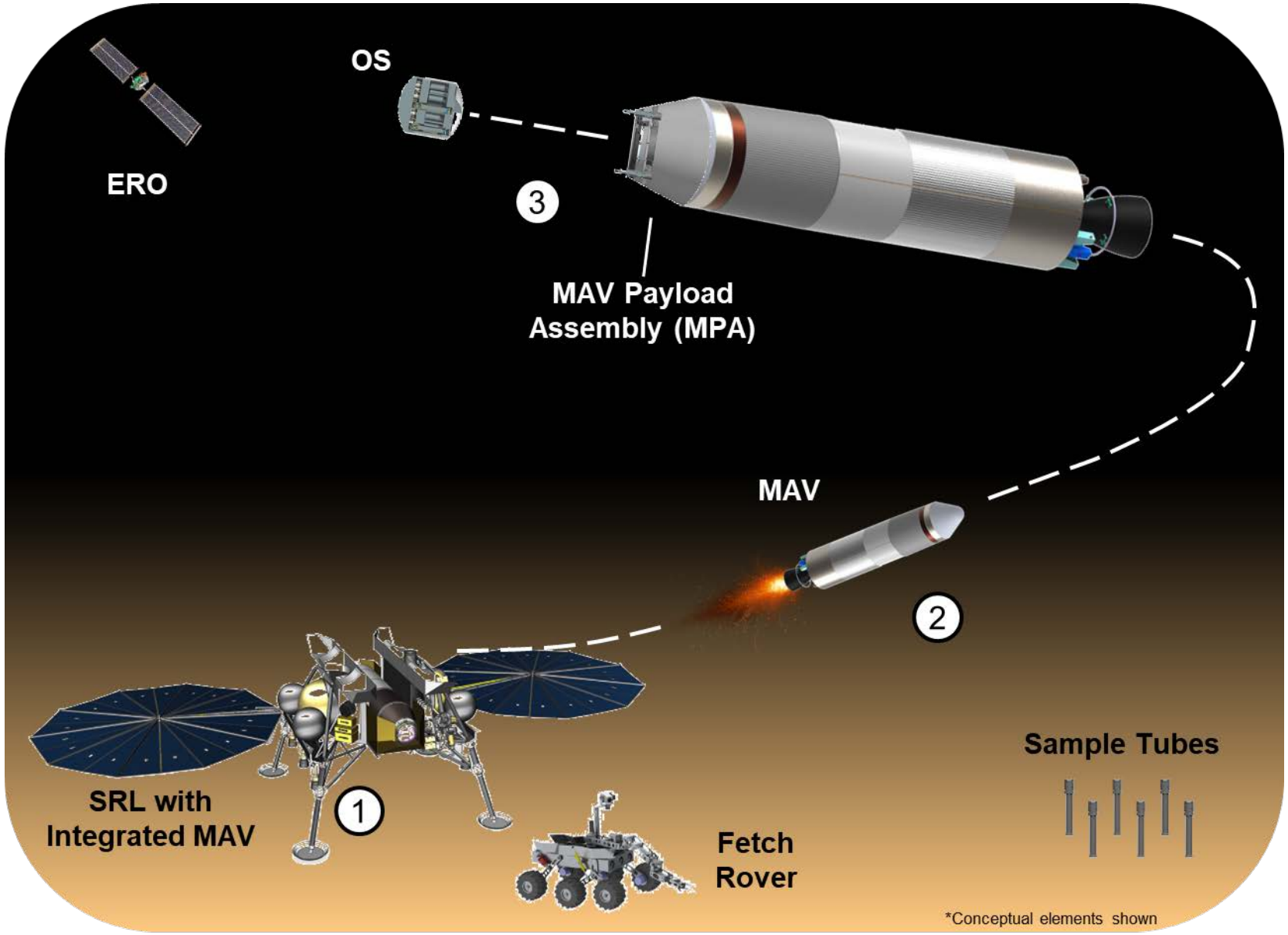
National Aeronautics and Space Administration
Jet Propulsion Laboratory / Marshall Space Flight Center
Mars Ascent Vehicle Study



Pre-decisional. For planning and discussion purposes only.

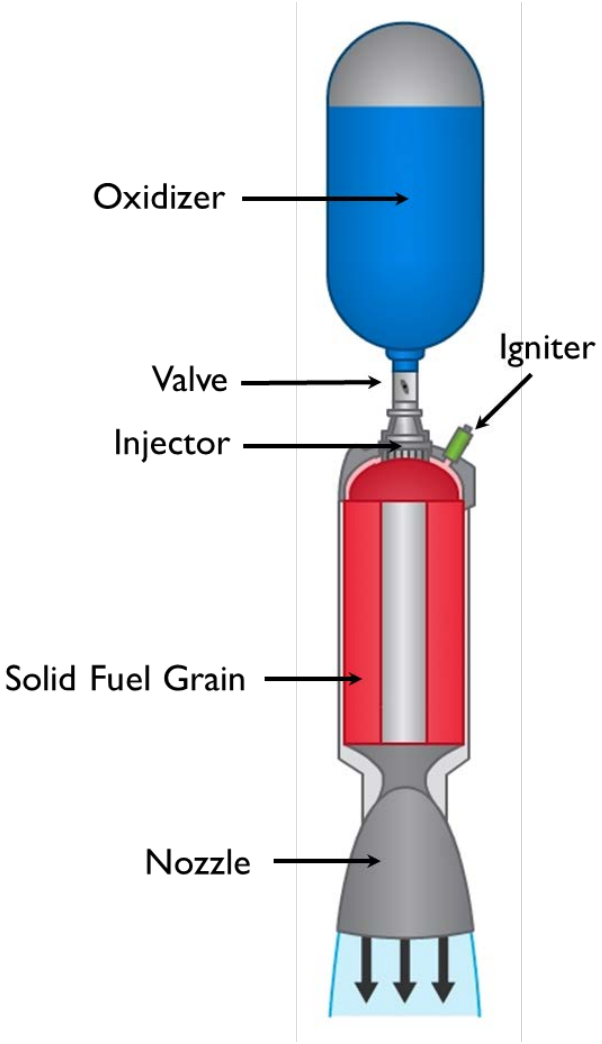
MAV Mission Objectives

1. Receive sample tubes inside Orbiting Sample (OS) on Mars surface.
2. Launch OS to predefined Mars orbit.
3. Release OS in Mars orbit for pickup by Earth Return Orbiter (ERO).



Preliminary Architecture Assessment

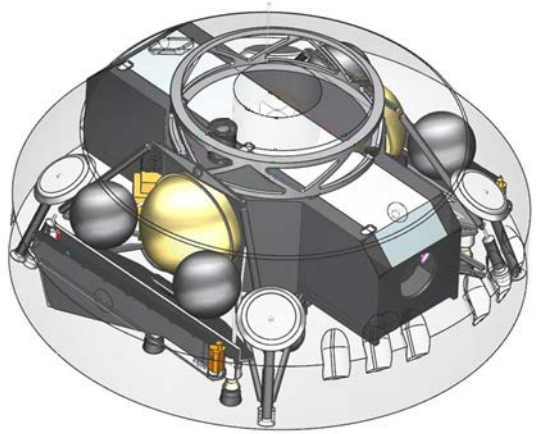
- From January-July 2019, PAA was performed to mature the designs for two MAV concepts: MAV-Hybrid and MAV-Solid. This presentation will focus on the **MAV-Hybrid** design. Decision made in December 2019.
- Analysis focused on **discriminators** between two designs
- Hybrid Propulsion Overview
  - Liquid oxidizer with solid fuel
  - Capable of active shut down and throttling
  - Higher Isp than solid counterparts, lower than liquid
  - Flexibility with hypergolic ignition options
  - Performance in cold environments
  - Significant hazards avoided
  - Added complexity
  - Relatively low Technology Readiness Level (TRL) compared to solids/liquids

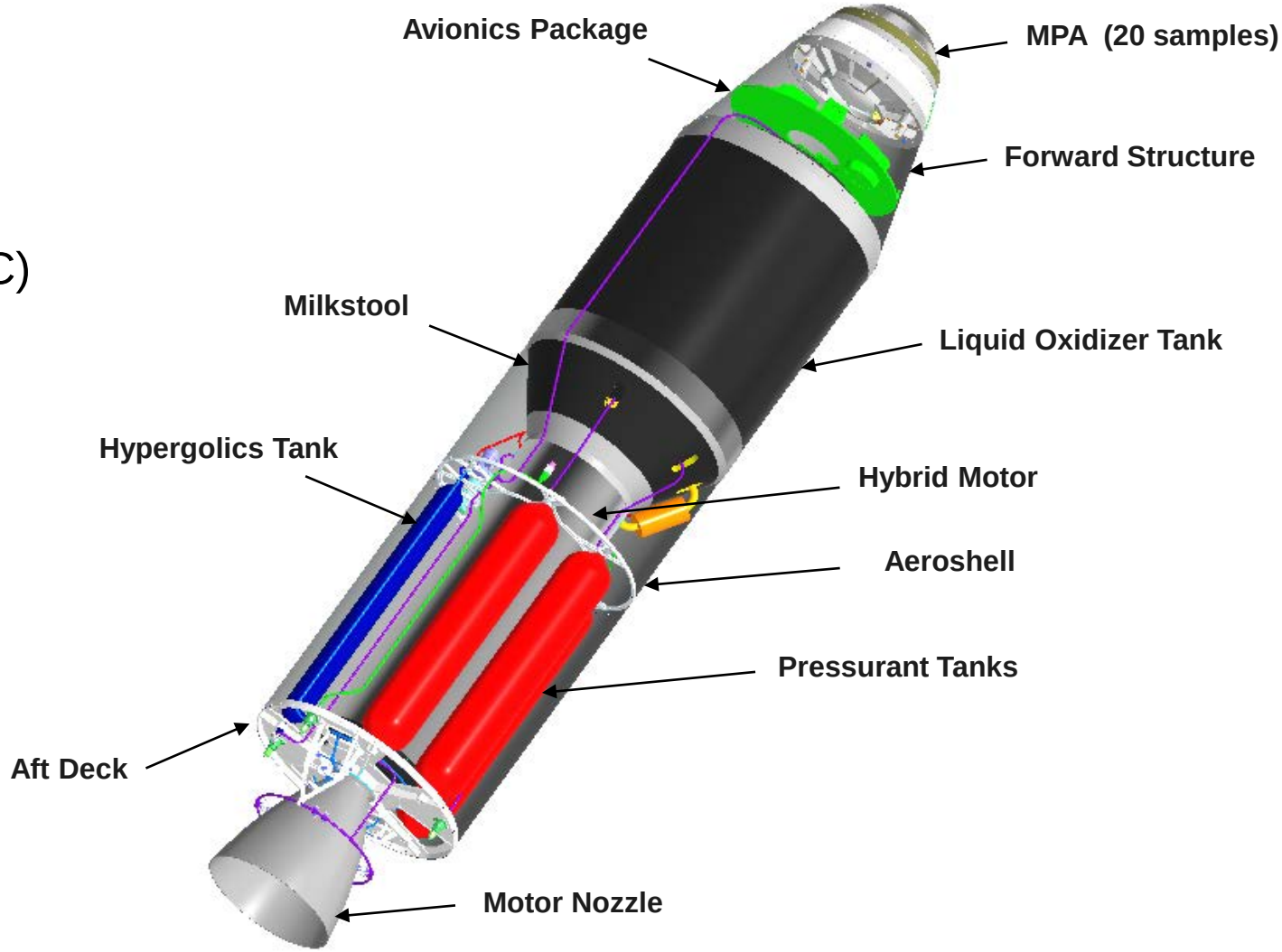


PAA Hybrid Configuration

Single-Stage Hybrid Motor Vehicle

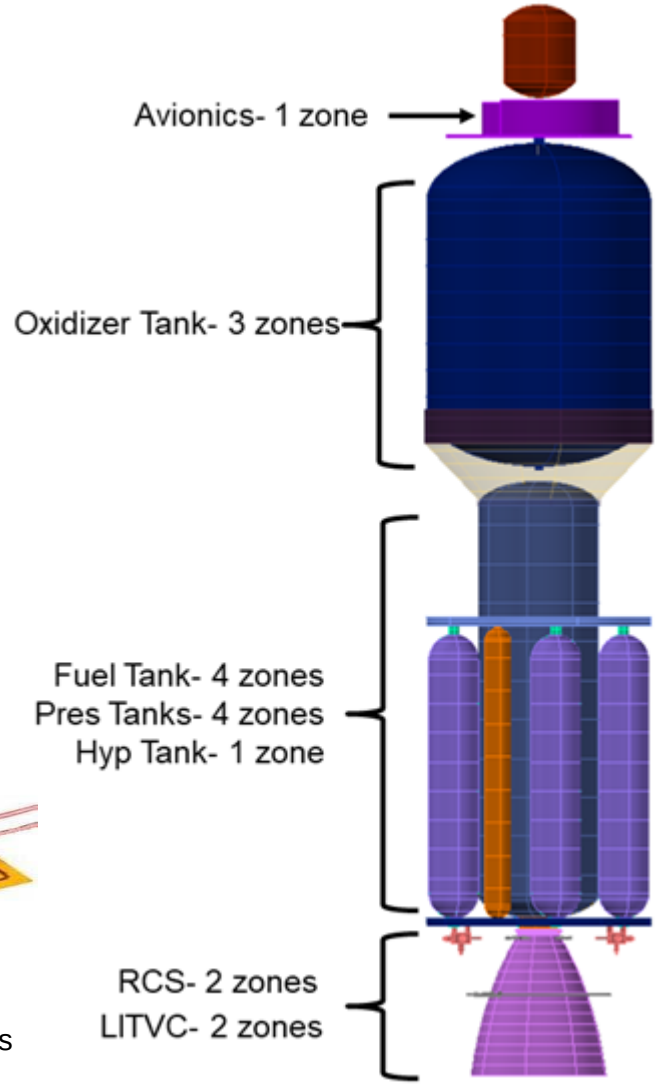
- Designed to deliver 14kg payload to circular orbit of 343km @ 25º inclination
- Storable, pressure-fed liquid oxidizer
- Solid fuel
- Liquid Injection Thrust Vector Control (LITVC)
- Cold-gas Roll Control System (RCS)
- Hypergolic ignition
- **Note: Some systems have changed dramatically since the conclusion of the PAA.**





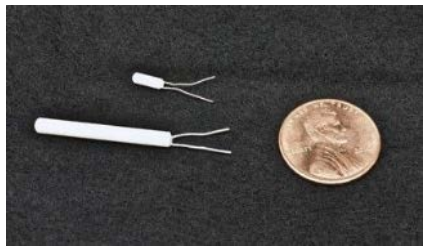
Thermal Design

- MAV stored within Sample Retrieval Lander (SRL) during cruise to Mars and on surface.
- SRL provides a layer of thermal protection, onboard heaters keep systems at specified temperatures beyond that.
- Vehicle makes use of 17 individual heater zones, with each zone including a specific number of heaters controlled by a Platinum Resistant Thermometer (PRT).
- Additional thermal insulation in the form of thermal blankets, aluminized polyimide tape, low emissivity Kapton film.





Aluminized Polyimide is used on Hubble Space Telescope



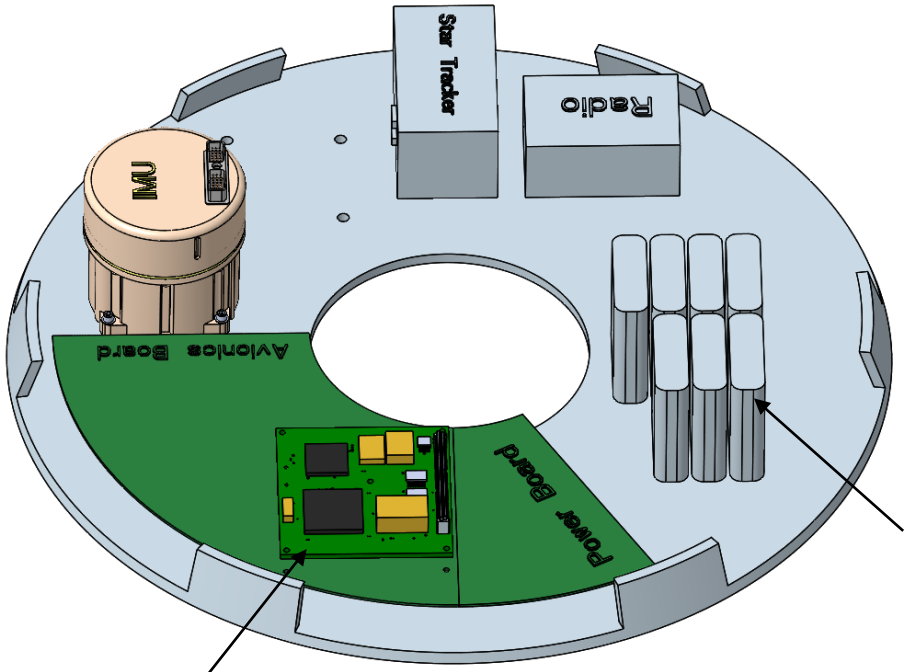
PRT Sensors



Single Element Polyimide Patch/Strip Heaters

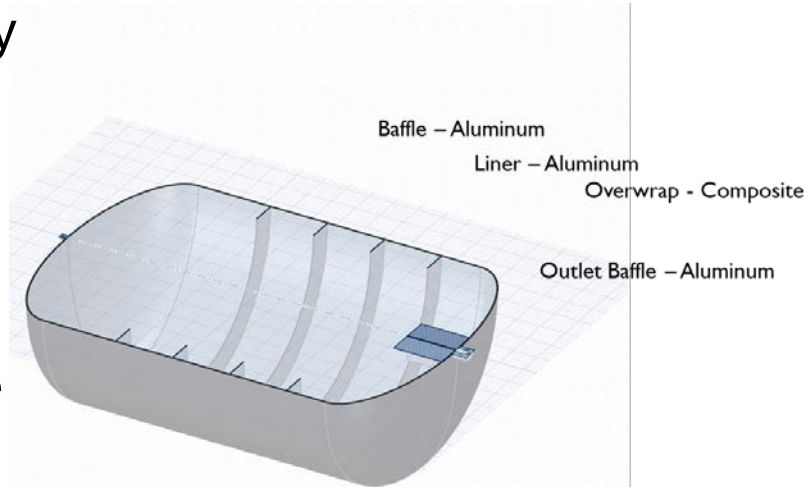
Avionics Design

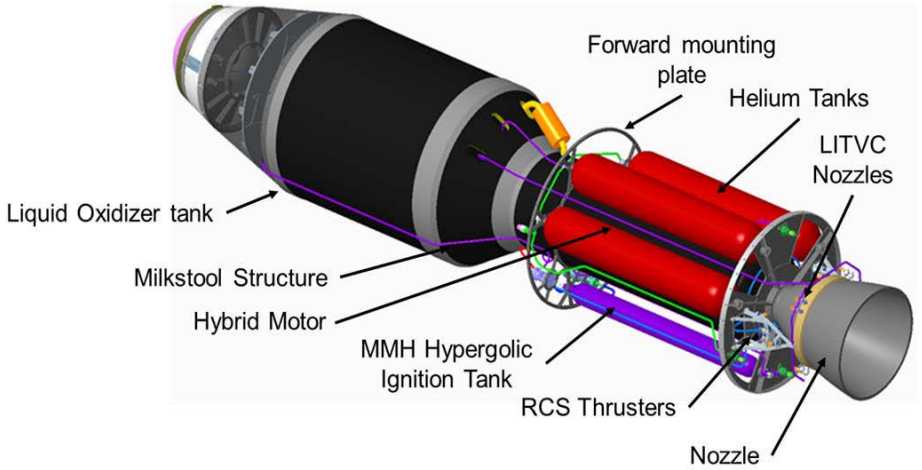
- Avionics responsible for three primary functions: Command and Data Handling (CDH), communication, and power.
- CDH carried out by flight computer, star tracker and IMU.
- Communications managed by transceiver, antenna, and navigational beacon.
- Power managed by batteries, power distribution board, and cabling.
- All avionics have to operate in extremely cold and radiation heavy environments.

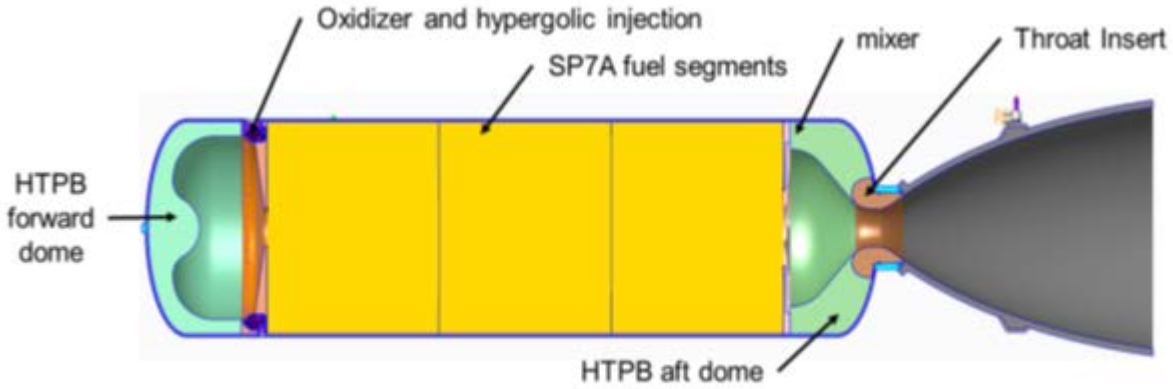


Propulsion Design

- Initial sizing driven by mass and physical size constraints
- Hybrid propulsion offers versatility and performance at extremely low temperatures. Orbital quality not a large concern.
- MON-25 liquid oxidizer with SP7A wax-based solid fuel. SP7A has a high coefficient of thermal expansion.
- Helium pressurant injects oxidizer and hypergolic MMH* into hybrid motor HTPB** forward dome for ignition.
- Slosh analysis not included in PAA, however, slosh baffles were included in tank design to account for additional mass.
- Fixed design motor nozzle that must survive two burns. Throat erosion a cause for concern, requiring more testing.



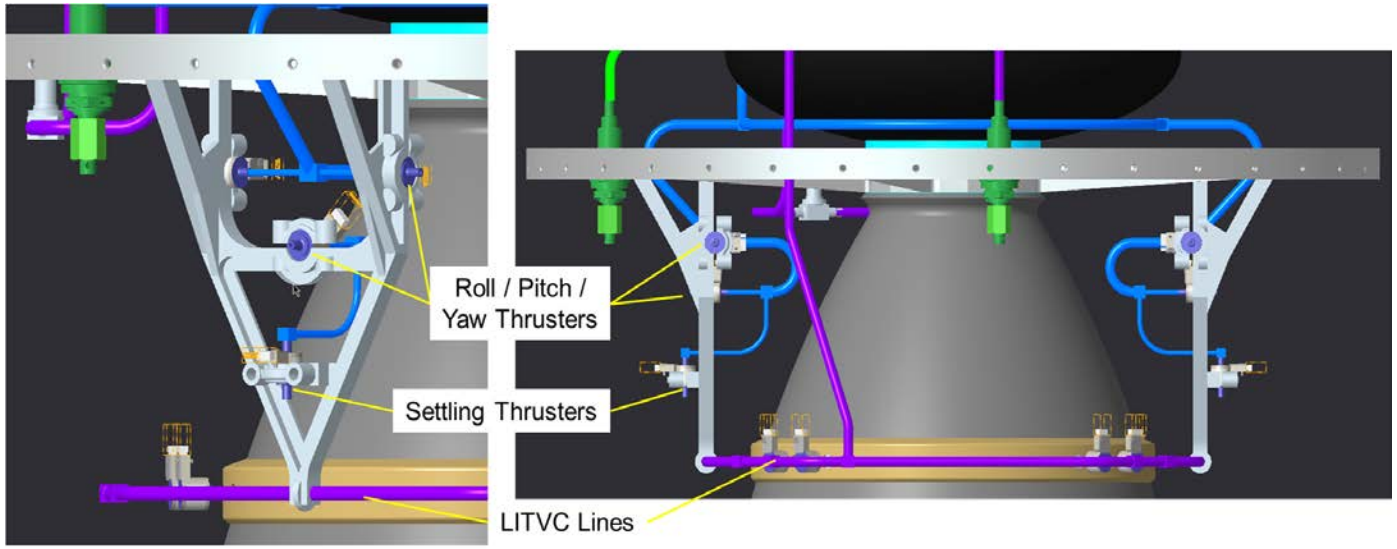




*MMH = Monomethylhydrazine
**HTPB = Hydroxyl-Terminated PolyButadiene

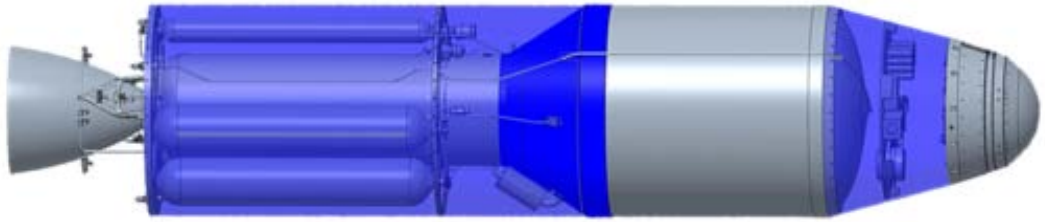
RCS/TVC Design

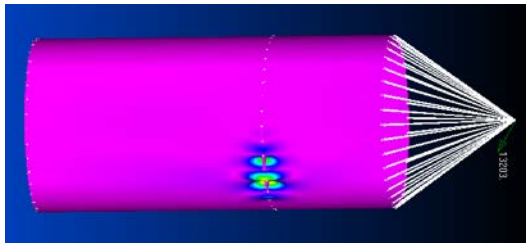
- Reaction Control System (RCS) provides roll control during engine burn and full control during coast. Liquid Injected Thrust Vector Control (LITVC) provides pitch and yaw control during burn.
- RCS consists of a helium cold gas system.
  - Helium already used as an oxidizer pressurant.
  - Six independent thrusters to provide attitude control and two thrusters for settling
- LITVC deflects flow at specific injection points within motor nozzle, allowing pitch and yaw control without the need for traditional external actuators.
  - Shares oxidizer and pressurant tanks with main motor
  - Eight valves, similar in design to RCS

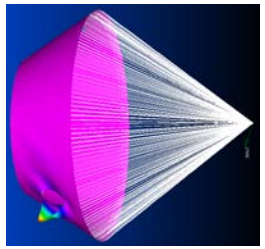


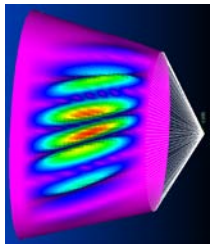
Structures Design

- Unique structural design challenge as vehicle must survive approximately 15g lateral loads during Mars Entry/Descent/Landing (EDL)
- Center of Gravity (CG) drives SRL performance in addition to MAV performance
- Monocoque construction make SRL attach a significant design point. Primary load path travels through oxidizer tank.
- Additional induced loads such as aeroacoustics found that the thin Martian atmosphere has no significant impact on the vehicle.



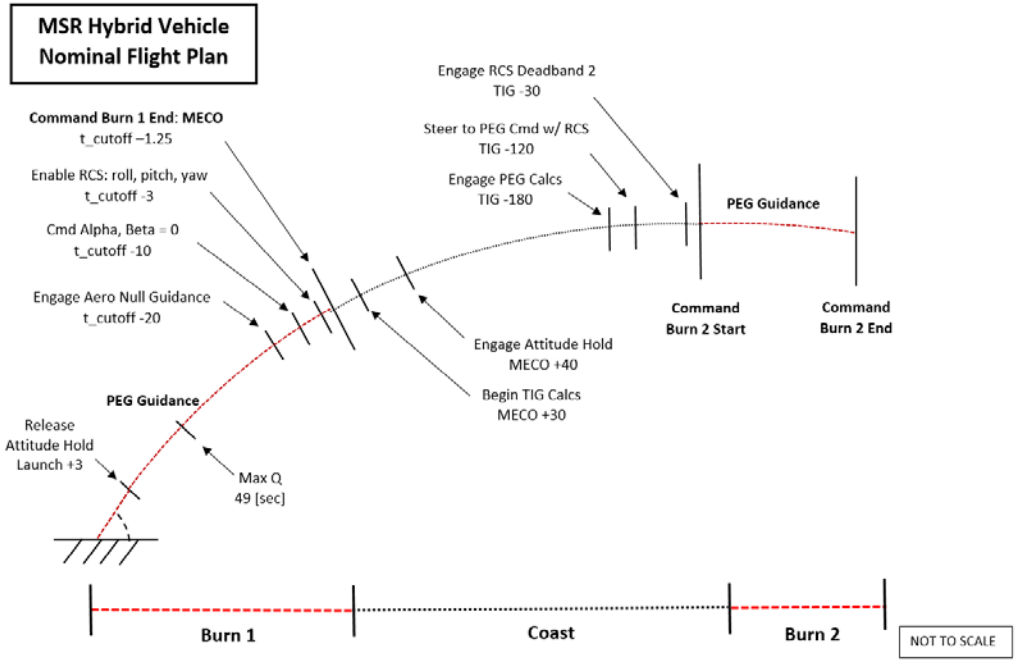


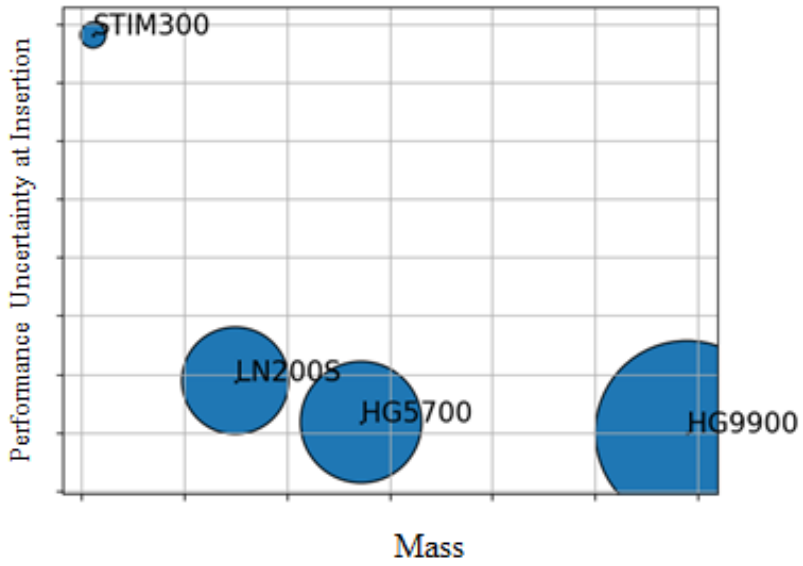




Guidance, Navigation, and Control Design

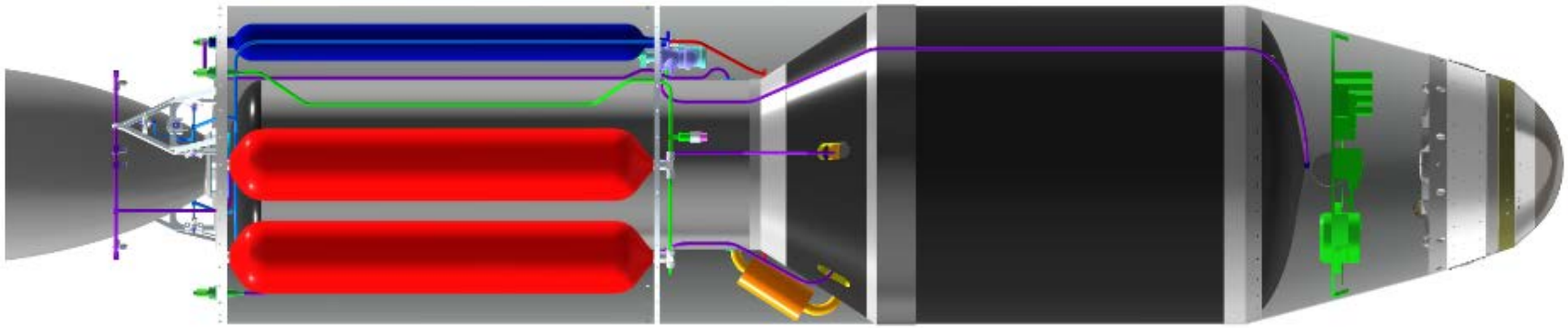
- Vehicle designed to deliver 14kg payload to 343km @ 25º inclination.
- Initial 3 Degree of Freedom (3DOF) trajectory analysis determined necessary thrust/flow rates, followed by 6DOF to determine capability of LITVC and RCS. Dispersed analysis also performed on a number of systems.
- Inherent design of hybrid vehicle results in CG moving aft as propellant is burned, reducing stability. Closed loop Powered Explicit Guidance (PEG) used to reduce undesirable attitude motion. Orbital accuracy is a strong point of hybrids.
- Unique mission environment resulted in need for highly specialized Inertial Measurement Unit (IMU) that can accurately perform on Mars.





Decision Package for MAV

- Hybrid configuration was found to successfully deliver 14kg payload of an expected 20 sample tubes to Martian orbit, meeting all size and mass constraints
- This design featured versatility in ability to meet mission design constraints through hybrid propulsion technology; orbital accuracy can be attained
- Largest downside to hybrid vehicle is lower TRL, presenting a significant risk in MSR campaign
- Decision Package Review held at NASA MSFC in November 2019. Ultimately, solid vehicle design was chosen going forward



Questions?



Mars Jezero Crater, future MAV landing/liftoff site of MAV