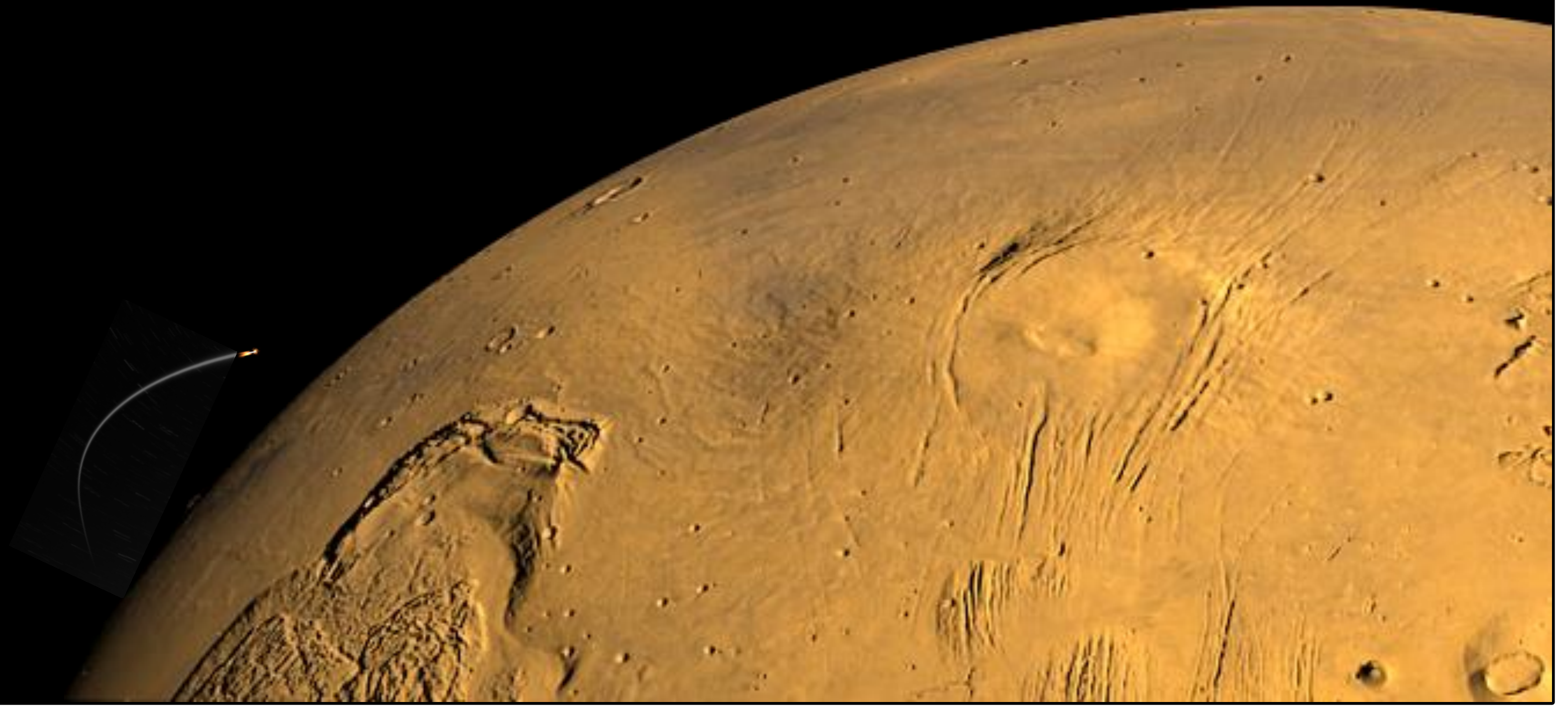
Mars Ascent Vehicle



Jet Propulsion Laboratory
California Institute of Technology

MARSHALL
SPACE FLIGHT CENTER

Mars Ascent Vehicle
Solid Propulsion Configuration

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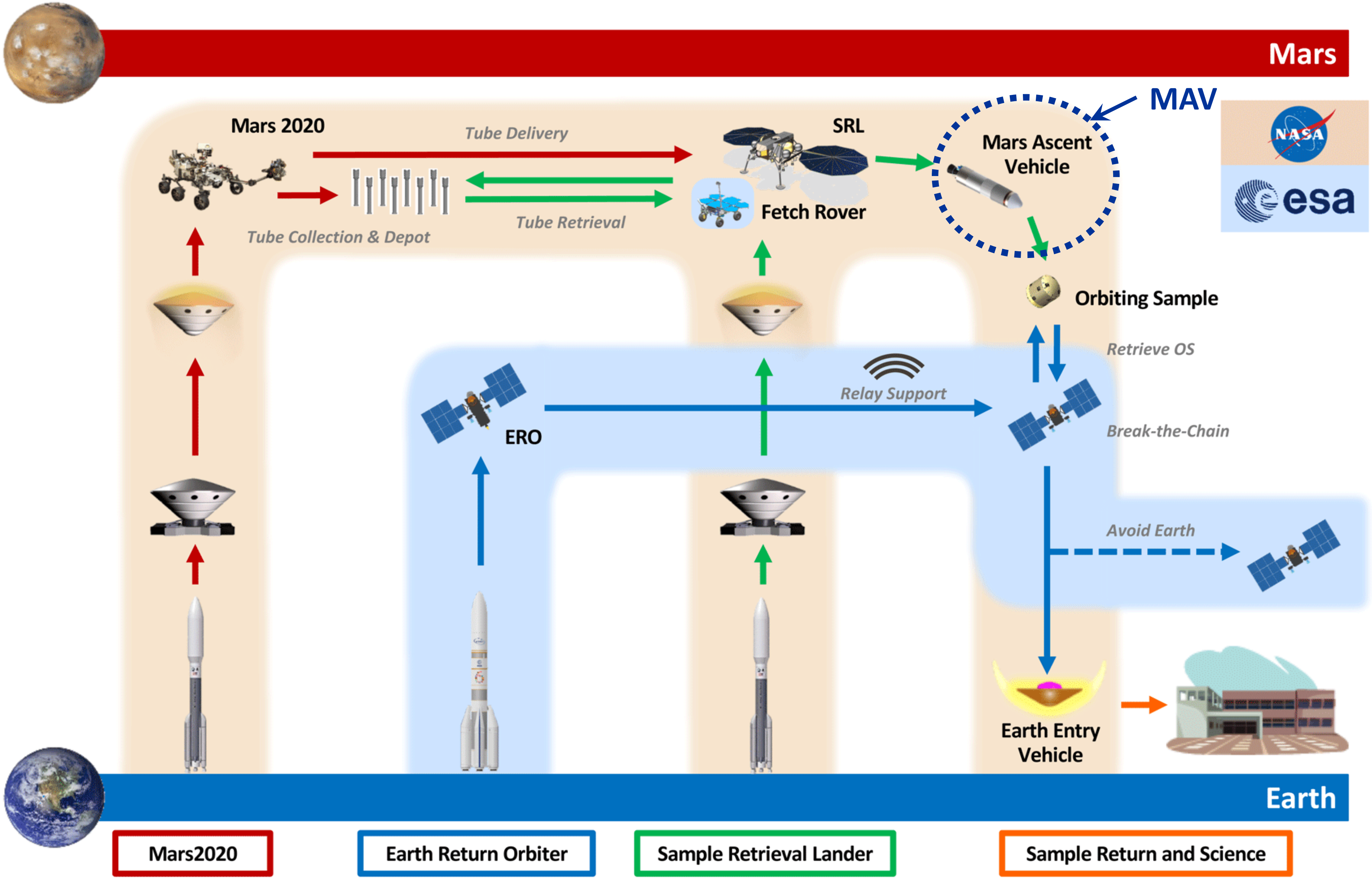
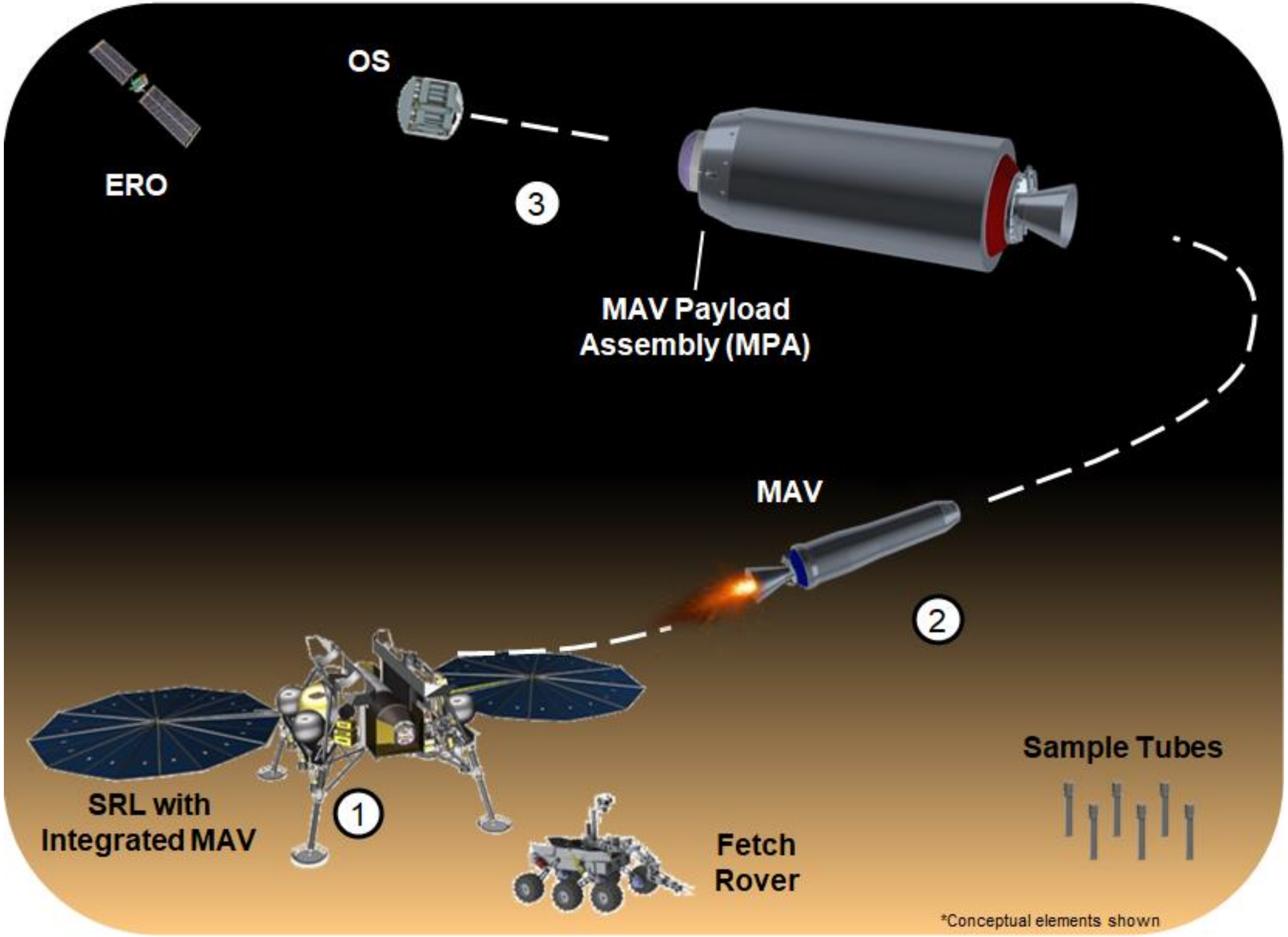
IEEE Aerospace Conference

Mars Sample Return and MAV



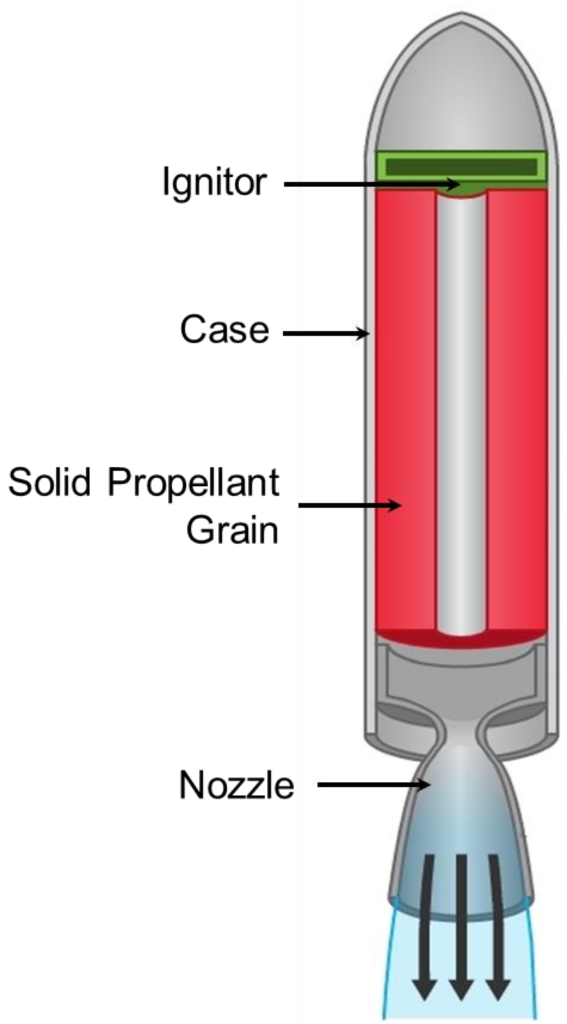
MAV Mission Objectives

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

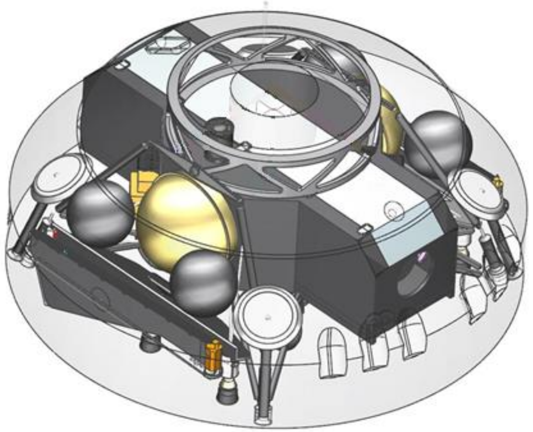
- From January-July 2019, PAA was performed to mature the designs for two MAV concepts: MAV-Hybrid and MAV-Solid. This presentation will focus on the **MAV-Solid** design. Decision made in December 2019.
- Analysis focused on **discriminators** between two designs
- Solid Propulsion Overview
  - Fuel and oxidizer already mixed into solid propellant
  - Simple design does not require moving parts
  - High TRL and reliability
  - Performance determined by grain and nozzle designs
  - Cannot be actively throttled or shut down
  - Lower ISP than liquid/hybrid counterparts
  - Potential issues with extremely cold environments
  - Manufacturing and handling safety

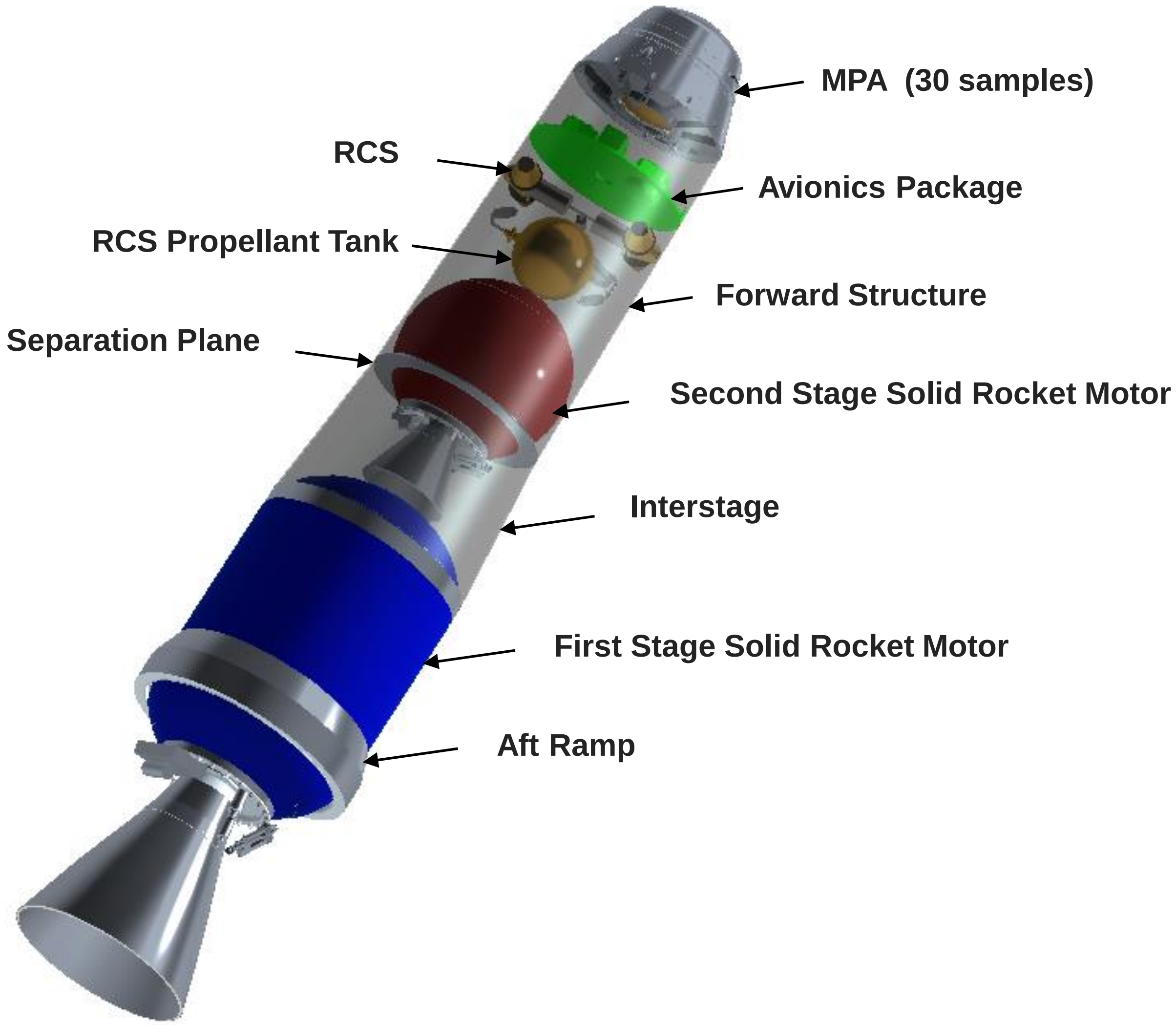


PAA Solid Configuration

Two-Stage Solid Motor Vehicle

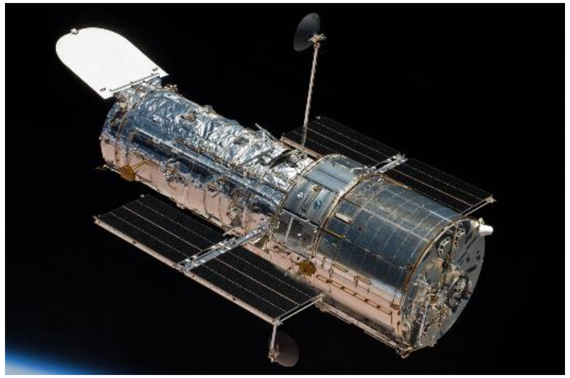
- Designed to deliver 16kg payload to circular orbit of 343km @ 25^{o} inclination
- Solid motors for both stages
- Non-pyrotechnic stage separation
- Electrical-mechanical Thrust Vector Control (TVC)
- Monopropellant Reaction Control System (RCS)
- Solid igniters
- **Note: Some systems have changed dramatically since the conclusion of the PAA.**

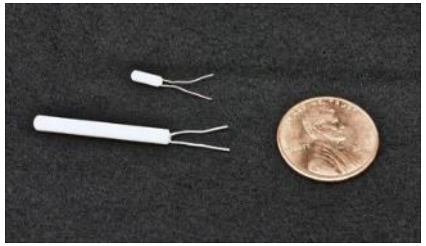




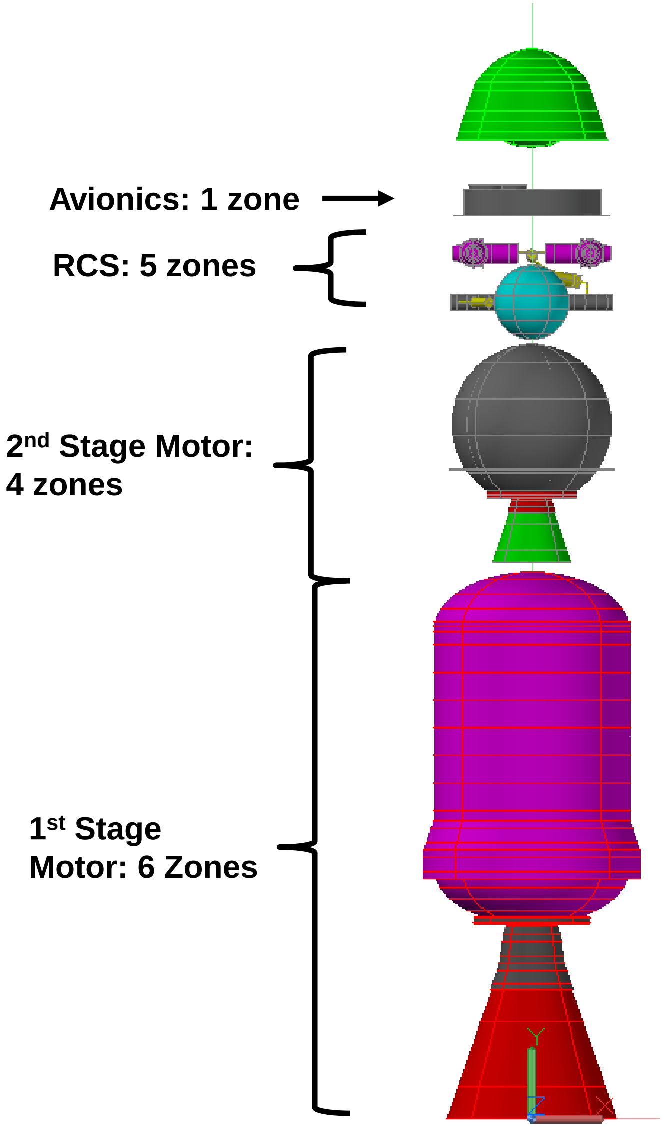
Thermal Design

- 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 16 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.
- Liquid RCS would need to be kept at significantly higher temperatures than other components
- Thermal gradients across SRMs need to be taken into consideration.


Aluminized Polyimide is used on Hubble Space Telescope

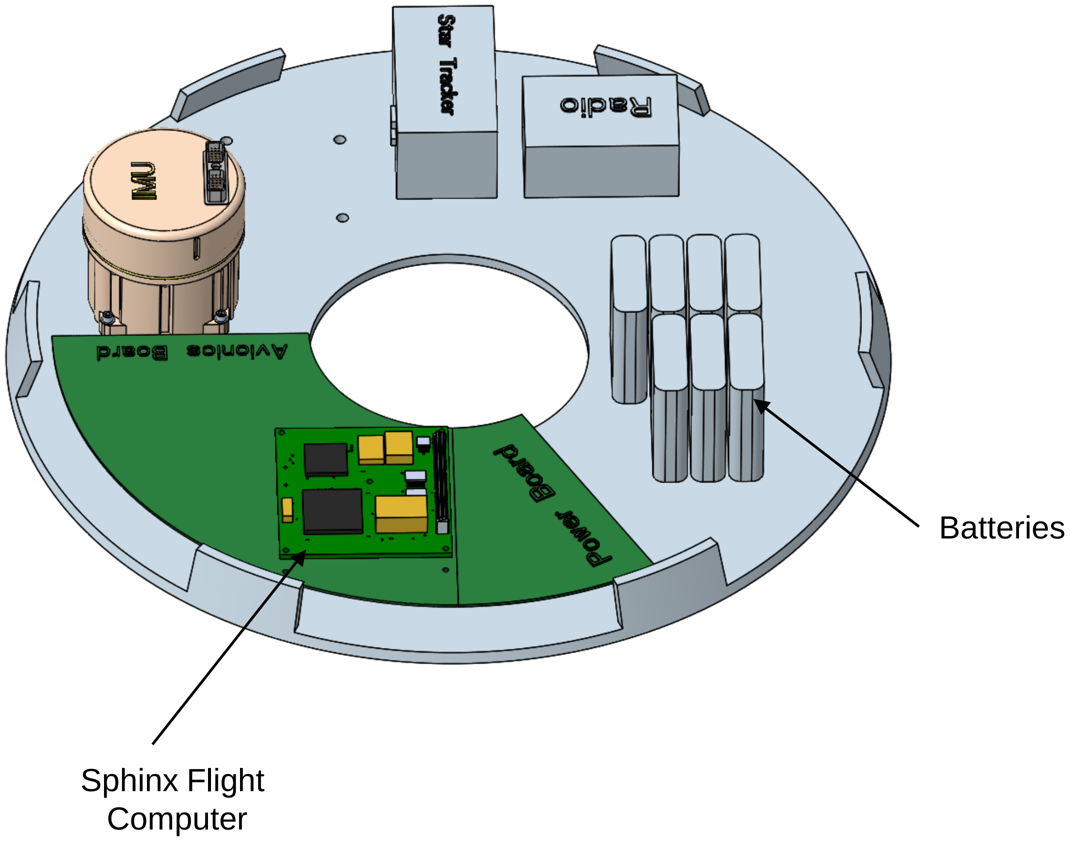

PRT Sensors


Single Element Polyimide Patch/Strip Heaters



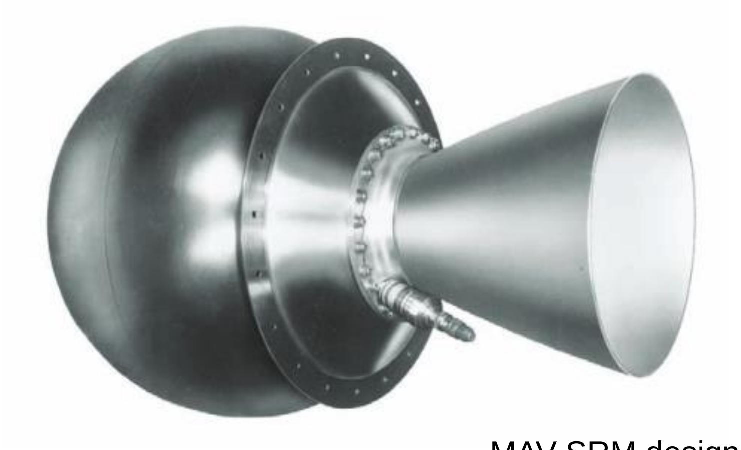
Avionics Design

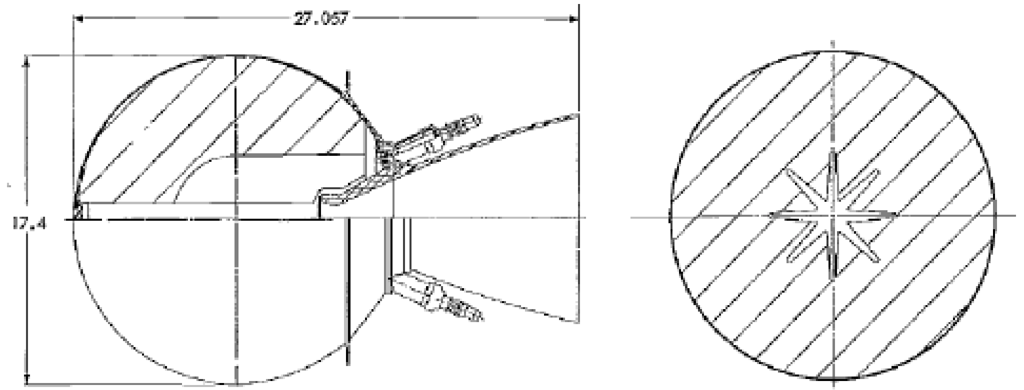
- Avionics responsible for three primary functions: Command and Data Handling (CDH), communication, and power.
- CDH carried out by flight computer, star tracker and IMU.
- Communications managed by transceiver, antenna, and navigational beacon.
- Power managed by batteries, power distribution board,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



Propulsion Design

- Two motors. Burn times and thrust profiles defined beforehand in the design phase.
- Burn rate and thrust profile tied to pressure. Martian environment presents a unique condition.
- Solid propellant defined based upon performance in extremely cold temperatures and heritage in Martian environment*
- Structural case analysis defined by surface/launch pressures and temperature. Composite case for 1st stage motor and titanium case for 2nd stage.
- Inherent issue with solid propulsion vehicle in that it is difficult to design to an accurate orbit quality. This presents complications with orbital dispersions.



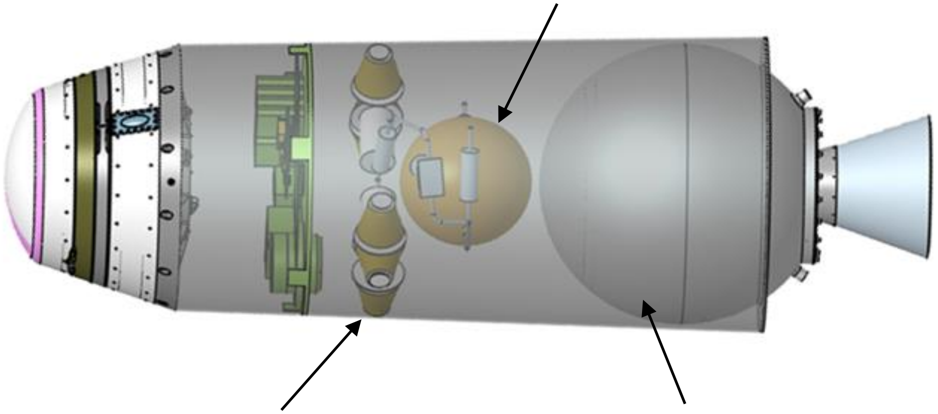


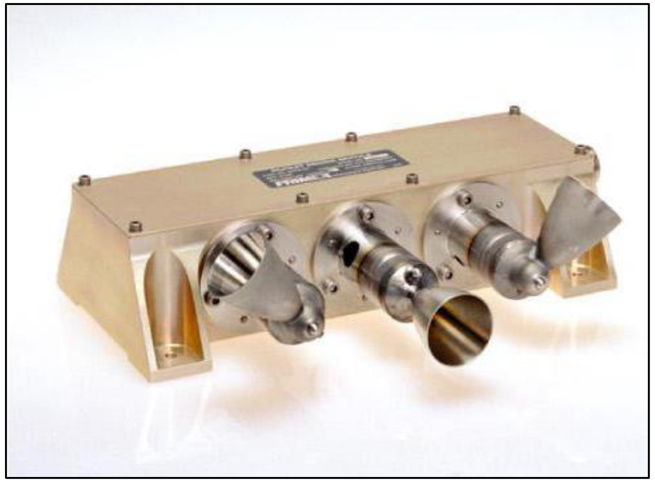
MAV SRM designs similar to NG Star 17 SRM**

*Mars exploration rovers Spirit and Opportunity and Mars Pathfinder Entry/Descent/Landing
** Northrop Grumman Star 17 Solid Rocket Motor: https://www.northropgrumman.com/Capabilities/PropulsionSystems/Documents/NGIS_MotorCatalog.pdf

Reaction Control System Design

- RCS provides roll control during motor burns and full control during coast. Thrust Vector Control (TVC) provides pitch and yaw control during burns.
- RCS consists of a hydrazine blowdown system containing high TRL components.
  - Nitrogen cold gas originally considered.
  - Original design featured six independent RCS thrusters, arranged in two groups of three.
  - Propellant tank designed with a metal diaphragm to reduce ullage and slosh.
  - Hydrazine freezing point is relatively high (+2°C) compared to MAV non-operating temperatures.

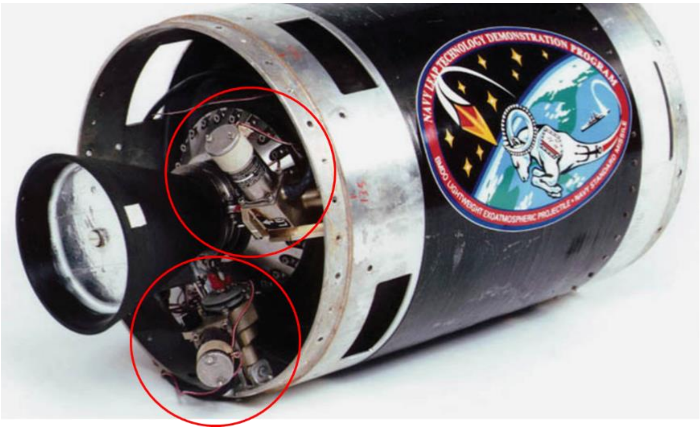




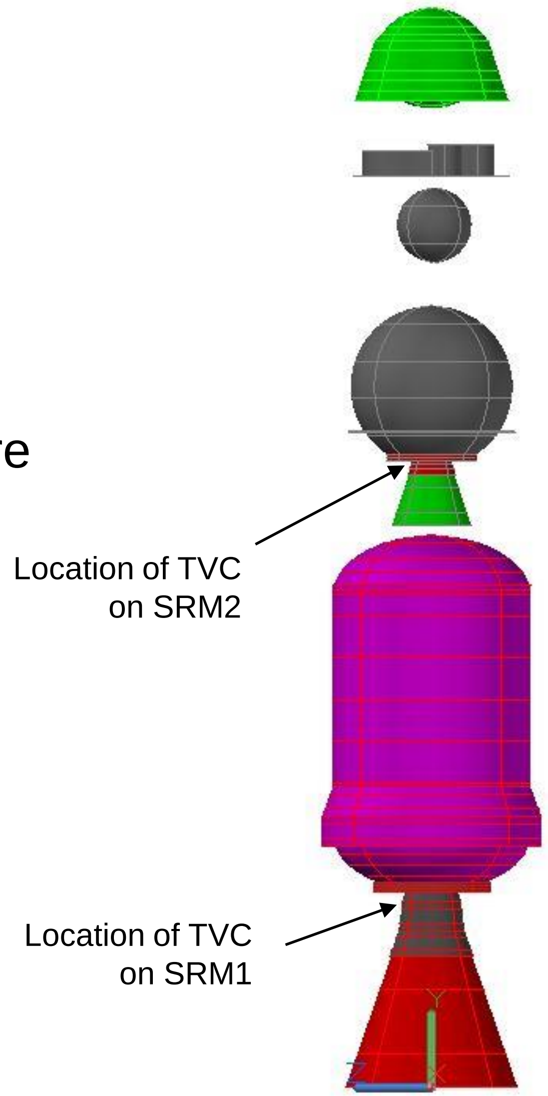
Sample RCS Thruster Module

Thrust Vector Control Design

- TVC provides pitch and yaw control during motor burns.
- Nozzle gimbal performed with traditional electromechanical actuators.
- Each stage has an independent TVC system, featuring two actuators.
- TVC power provided by thermal batteries.
- Gimbal nozzle features a supersonic splitline with a trapped ball design.
  - Joint is located downstream of nozzle throat, reducing erosion.
  - Typical TVC systems do not operate at such low temperatures due to material incompatibilities. Further developments with supersonic splitline are planned.



MAV TVC Actuators similar to those on NG Star 12GV* SRM

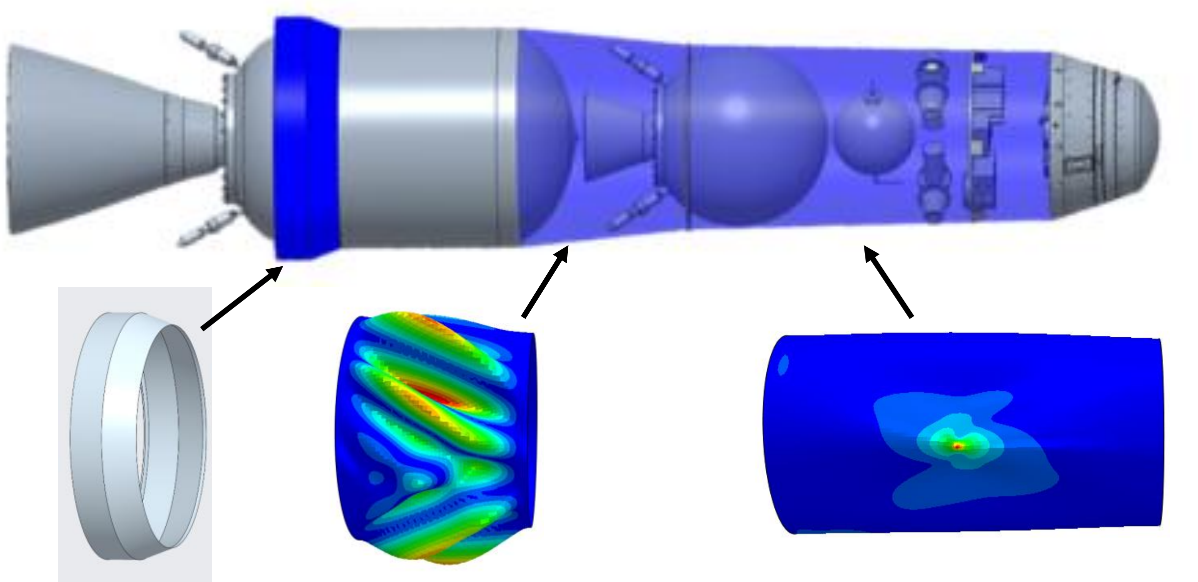


*Northrop Grumman Star 12GV Solid Rocket Motor: https://www.northropgrumman.com/Capabilities/PropulsionSystems/Documents/NGIS_MotorCatalog.pdf

Structures Design

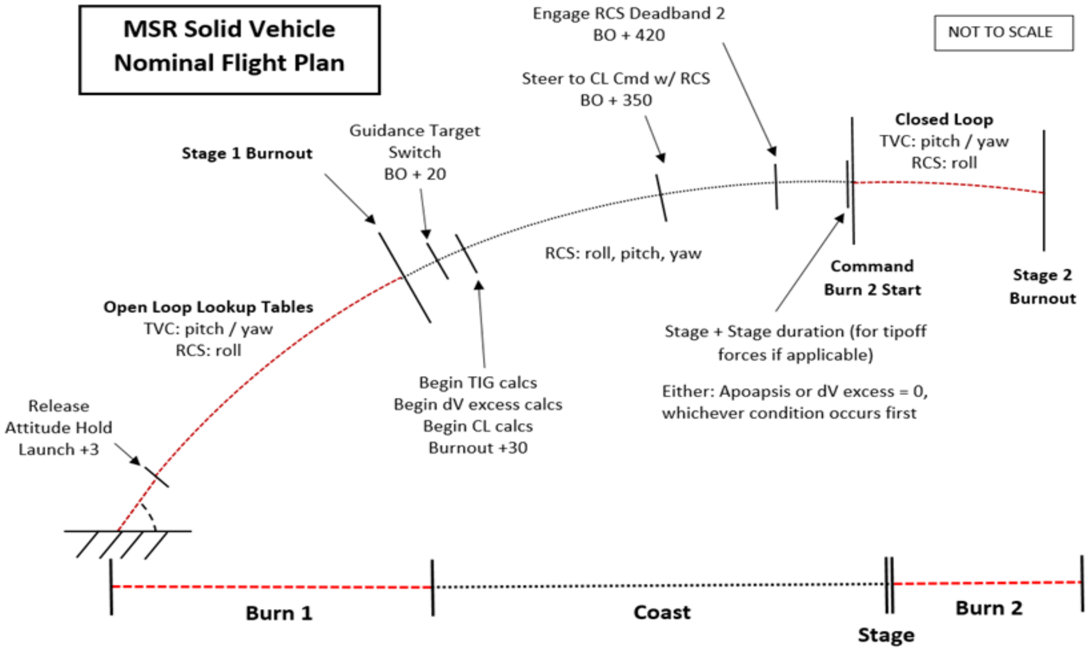
- Unique structural design challenge as vehicle must survive approximately 15g lateral loads during Mars Entry/Descent/Landing (EDL).
- Center of Gravity (CG) drives SRL performance in addition to MAV performance.
- Monocoque construction make SRL attach a significant design point. Attach points most effectively located at SRM flanges.
- Aft ramp assumed to take no significant loads.
- Non-pyro stage separation mechanism must be able to sustain EDL loads.
- Additional induced loads such as aeroacoustics found that the thin Martian atmosphere has no significant impact on the vehicle.

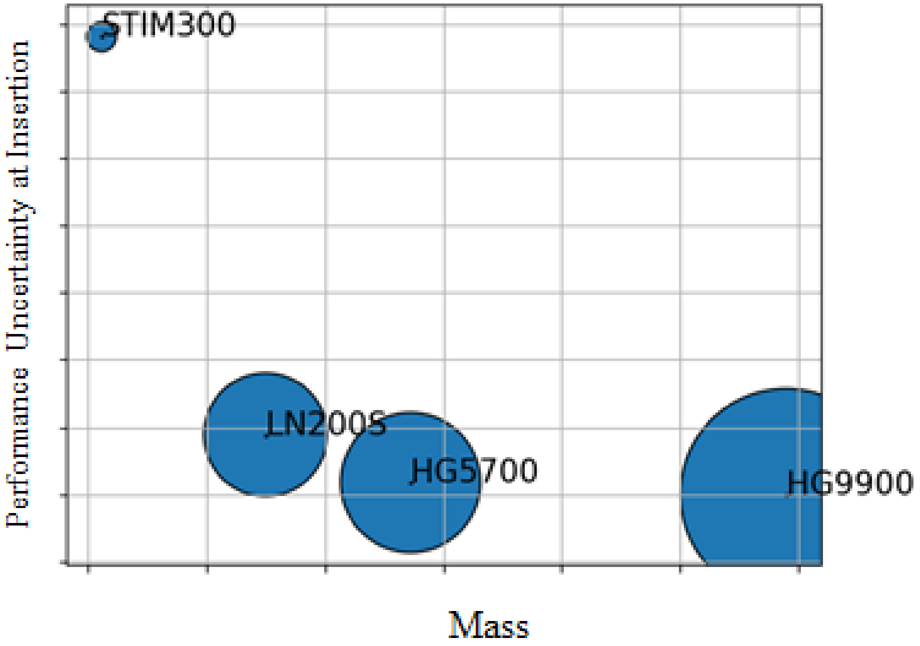
MAV Stage Separation Mechanism Similar to Planetary Systems Corp Lightband



Guidance, Navigation, and Control Design

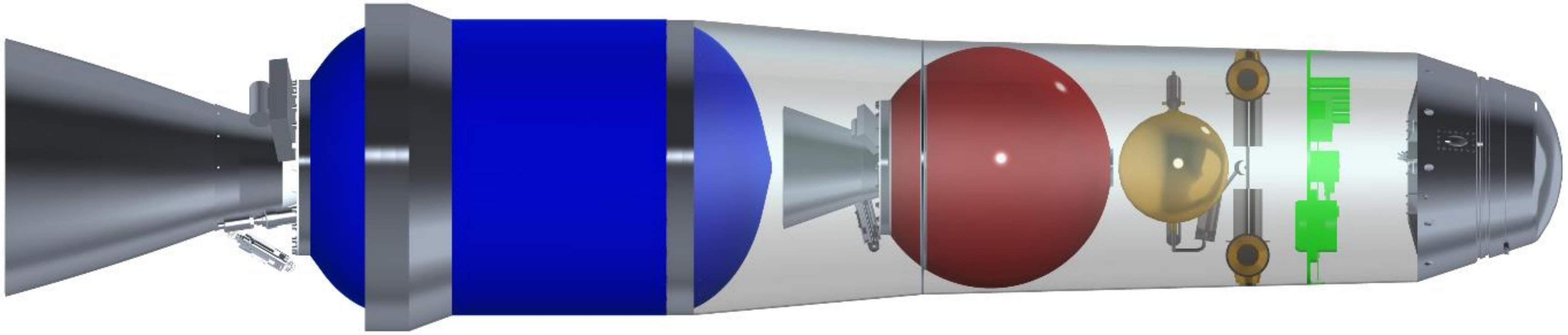
- Vehicle designed to deliver 16kg payload to 343km @ 25^o inclination.
- Initial 3 Degree of Freedom (3DOF) trajectory analysis determined necessary thrust/flow rates for motor sizing.
- 6DOF analysis followed 3DOF to determine capability of TVC and RCS. Excess motor energy identified by 6DOF. Energy management maneuver effectively mitigates this.
- Marginal aerodynamic instability identified, however, vehicle still remains controllable throughout ascent.
- Unknown parameters addressed via dispersed simulations. Dispersions focused on motor performance, launch conditions, atmosphere, mass variations, and RCS/TVC performance. Large orbital dispersions discovered, requiring a mitigation method.
- Unique mission environment resulted in need for highly specialized Inertial Measurement Unit (IMU) that can accurately perform on Mars.

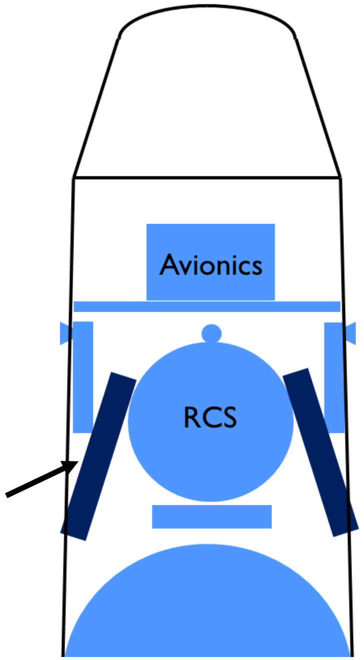




Decision Package for MAV

- Solid configuration was found to successfully deliver 16kg payload of an expected 30 sample tubes to Martian orbit, meeting all size and mass constraints
- Undesirable orbital dispersions found the need for orbit quality “cleanup”. Following PAA, two axial thrusters were added to RCS design to reduce dispersions.
- Updated RCS design added significant versatility to solid configuration.
- Decision Package Review held at NASA MSFC in November 2019. Ultimately, solid vehicle design was chosen going forward.





Questions?