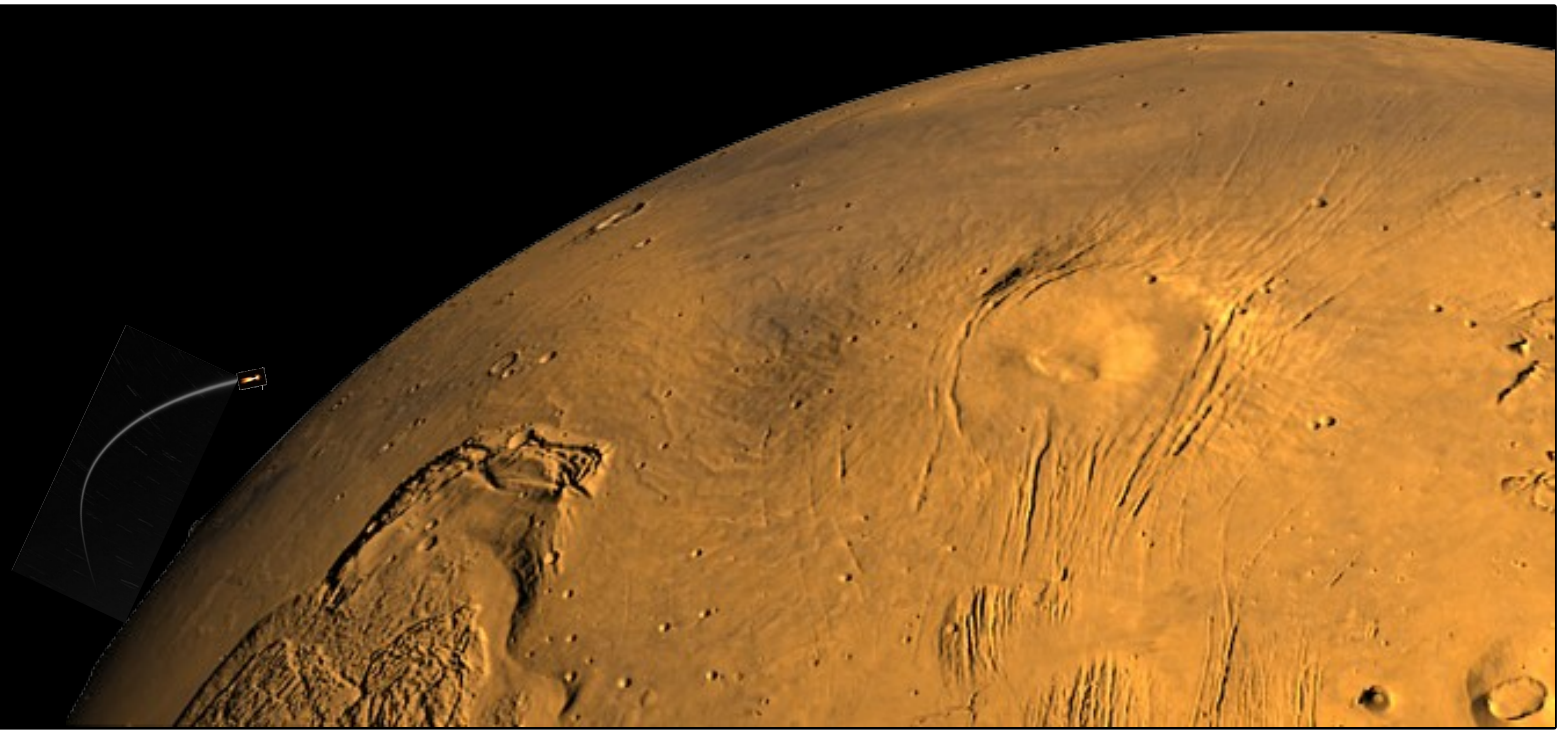
Mars Ascent Vehicle



Jet Propulsion Laboratory
California Institute of Technology

MARSHALL
SPACE FLIGHT CENTER

Integrated Design for the MSR DAC-0.0 Mars Ascent Vehicle

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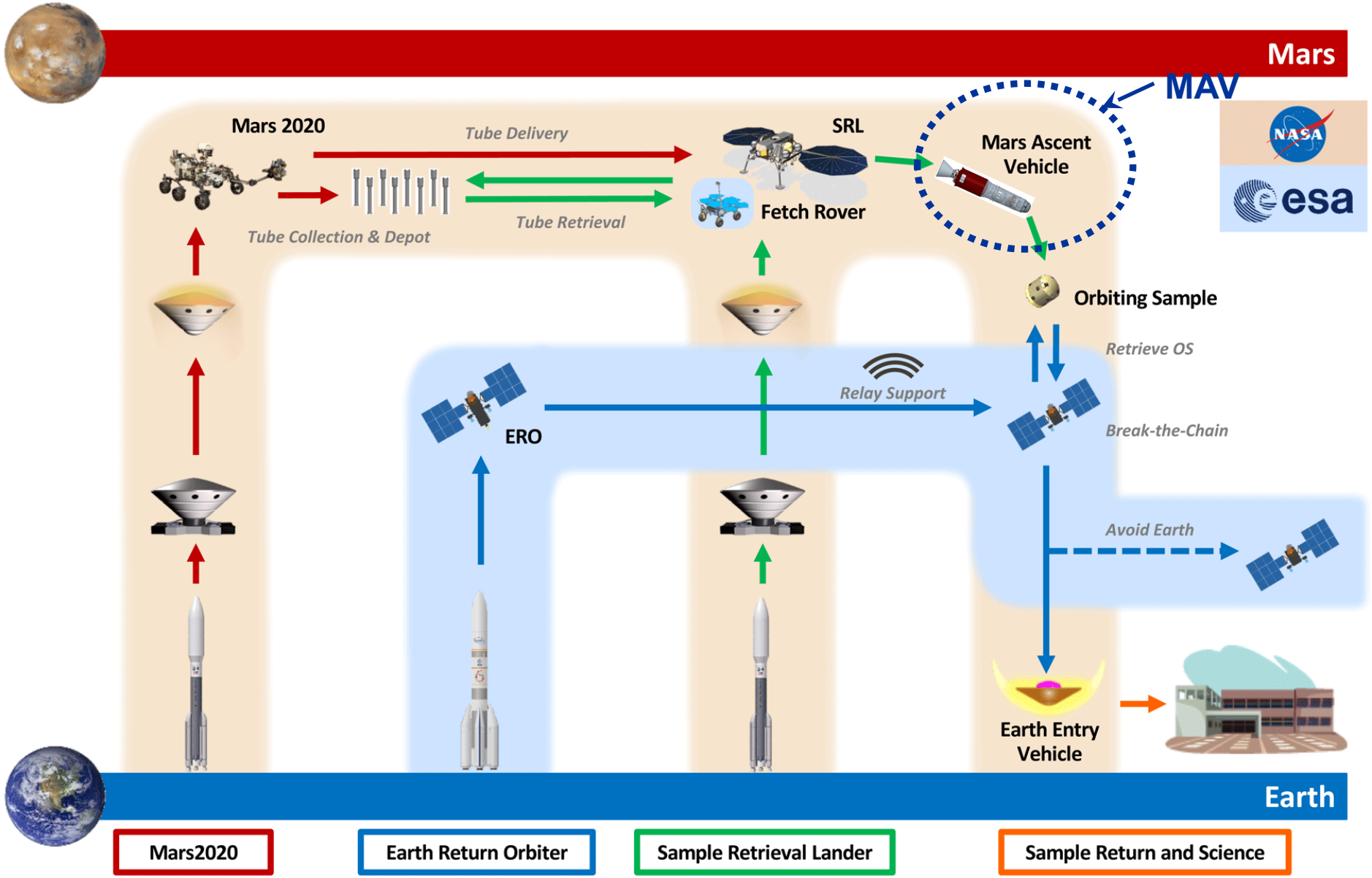
NASA Marshall Space Flight Center

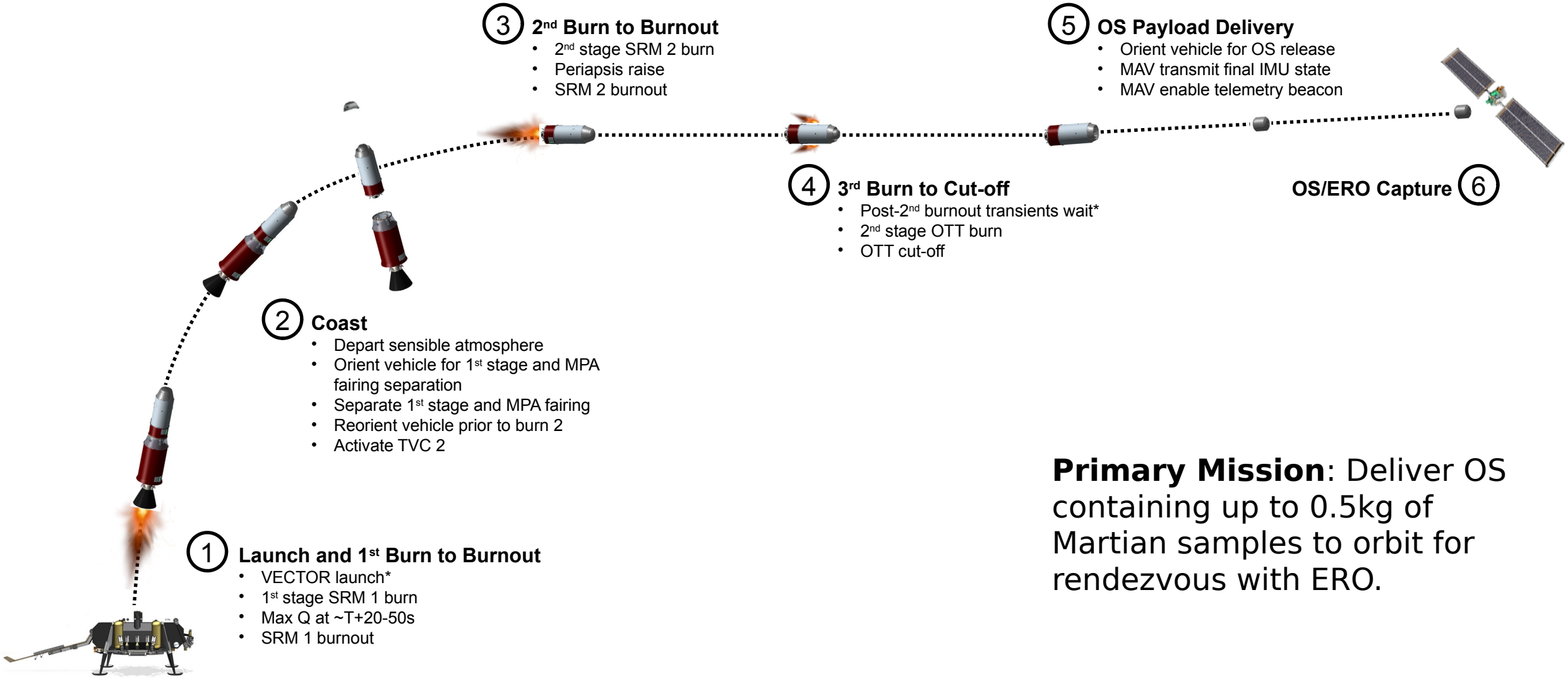
March 2021
IEEE Aerospace Conference

Mars Sample Return and MAV



Pre-decisional. For planning and discussion purposes only.

MAV Ascent Profile



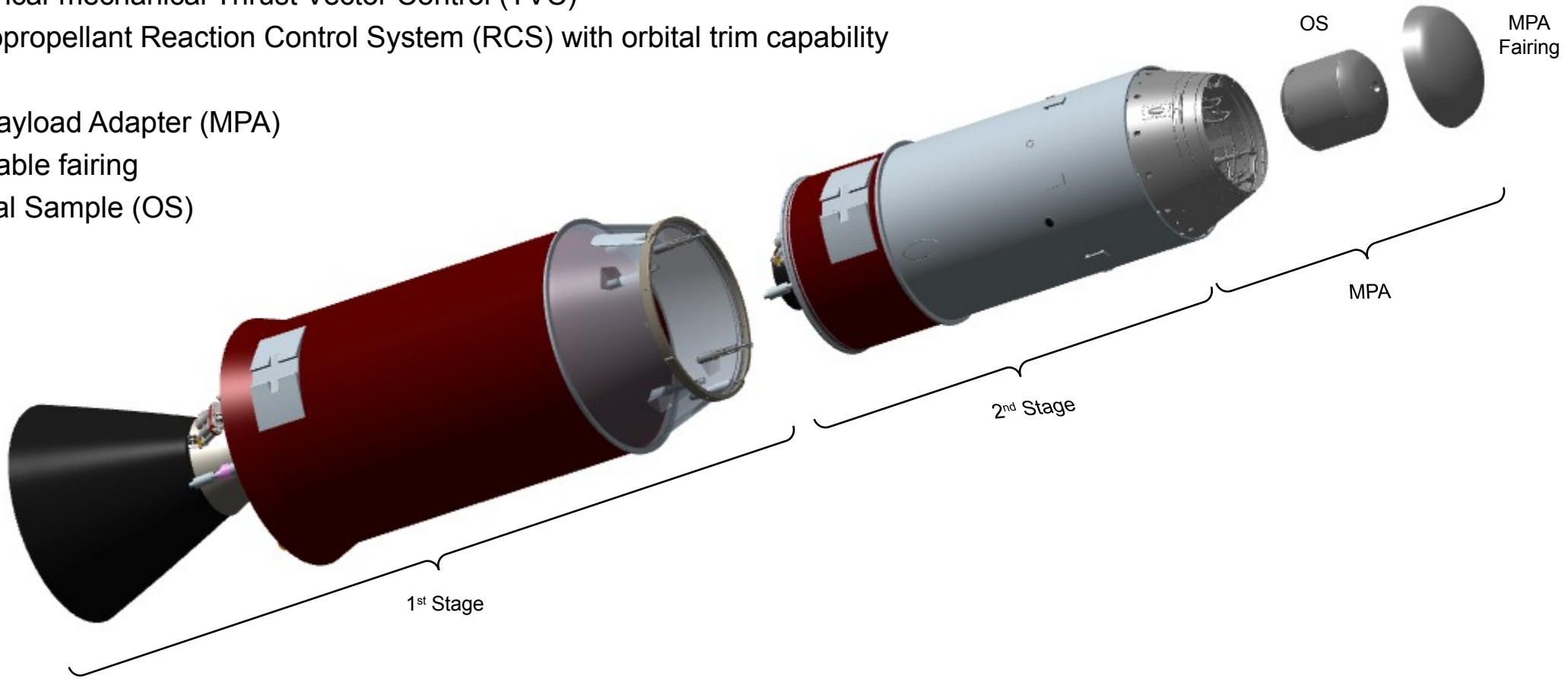
Primary Mission: Deliver OS containing up to 0.5kg of Martian samples to orbit for rendezvous with ERO.

1st Burn	Coast	2nd Burn	3rd Burn (*incl. trans. wait)	Prep for OS Separation	Loiter
~60 – 80s	~390 – 530s	~20 – 30s	~0 – 130s	~Minutes	~Days

MAV Concept: MAS Overview

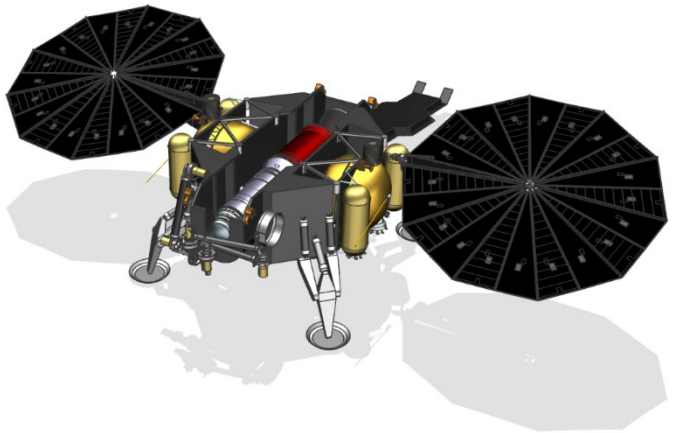
Mars Ascent System (MAS) consists of:

- Mars Ascent Vehicle (MAV)
  - Two-stage (guided, guided) solid motor vehicle
  - Pyrotechnic stage separation
  - Electrical-mechanical Thrust Vector Control (TVC)
  - Monopropellant Reaction Control System (RCS) with orbital trim capability
- MAV Payload Adapter (MPA)
  - Ejectable fairing
  - Orbital Sample (OS)

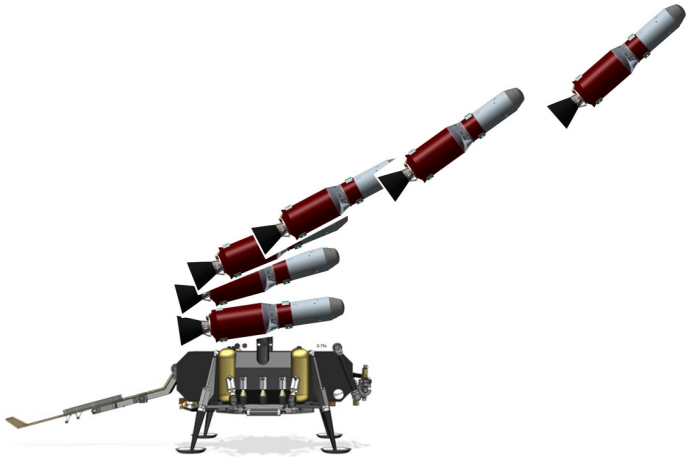


Design Analysis Cycle 0.0

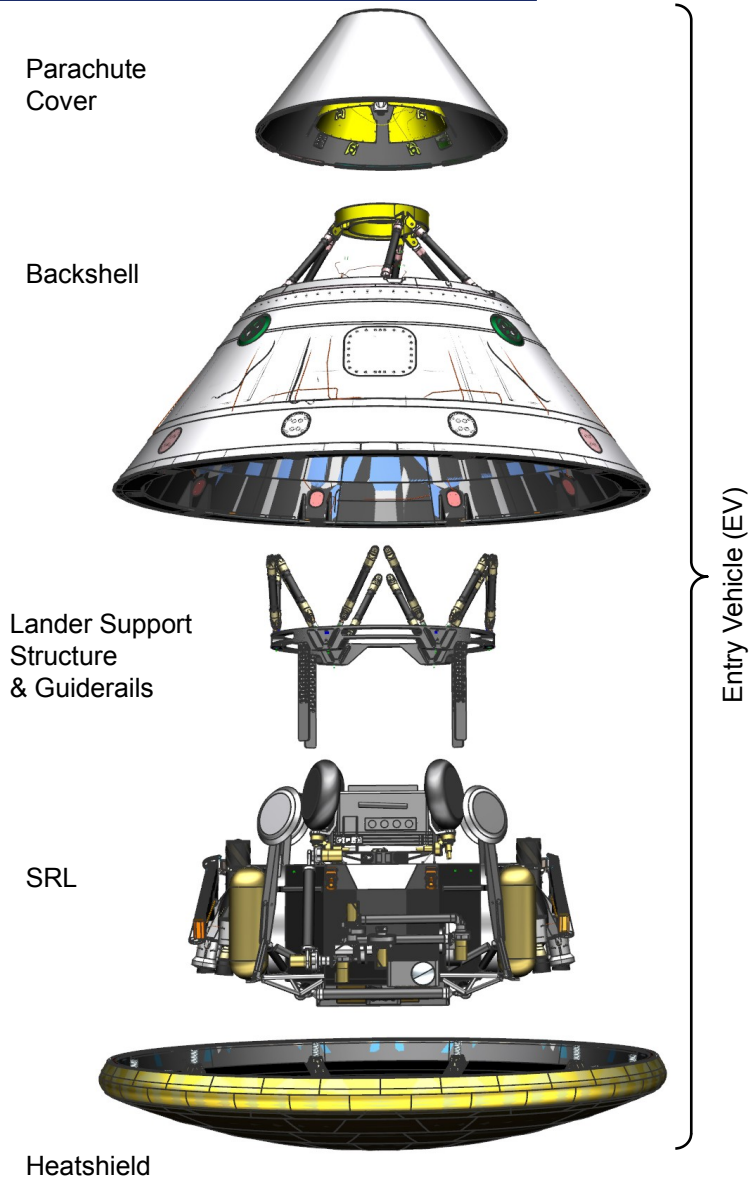
- DAC-0.0 performed January - June 2020 to advance fidelity of MAV design for NASA Key Decision Point A (KDP-A).
- KDP-A transitions MAV Project from pre-Phase A design – marked by feasibility concept studies – to Phase A design defined by concept and technology development.
- KDP-A completed in December 2020 following additional architecture updates.



MAV Stowed Within Lander Prior to Ejection



VECTOR: Vertically Ejected, Controlled Tip-Off Rate

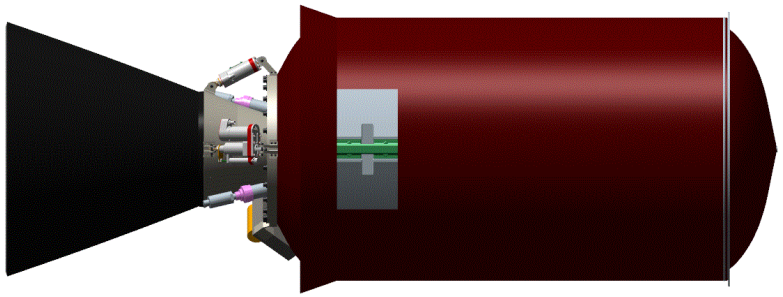


MAV Integration with Cruise Stage

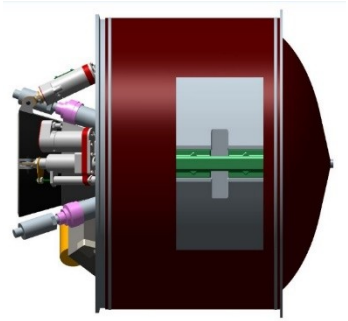
*Conceptual elements shown.

Main Propulsion Design

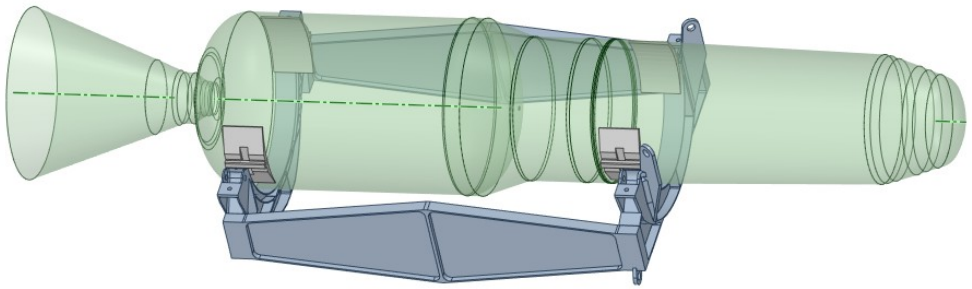
- Main propulsion system consists of two solid rocket motors, using high Technology Readiness Level (TRL) propellant with heritage in Mars missions.*
- Computational Fluid Dynamics (CFD) used in nozzle designs for increased performance.
- Structural case analysis defined by launch pressures/temperature and Mars Entry, Descent, Landing (EDL)/launch loads. Composite cases for both motors.
- Thermal analysis performed to determine affects of asymmetric motor heating during ignition.
- Challenge with solid propulsion vehicle in that it is difficult to design to a precise orbit. This presented greater predicted orbital dispersions.



Solid Rocket Motor (SRM) 1



SRM2

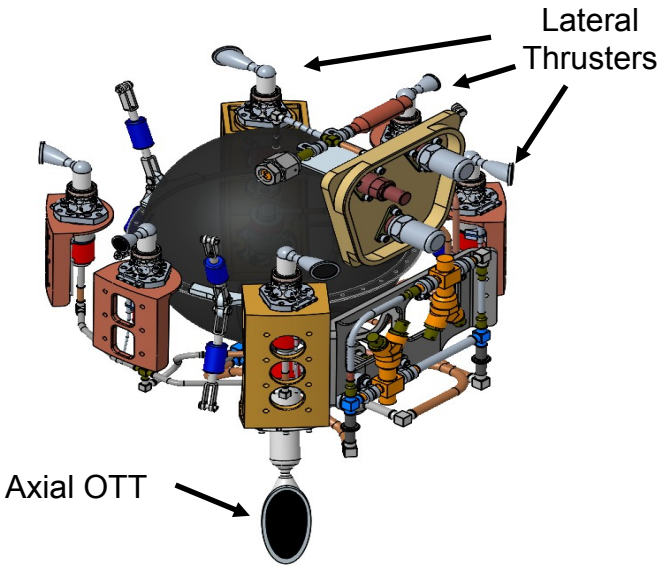


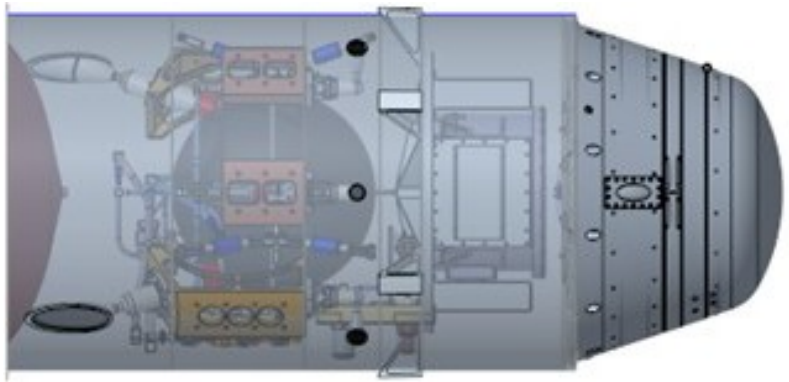
VECTOR attach points on SRMs

*TP-H-3062 solid propellant, used in Mars exploration rovers Spirit and Opportunity and Mars Pathfinder Entry/Descent/Landing

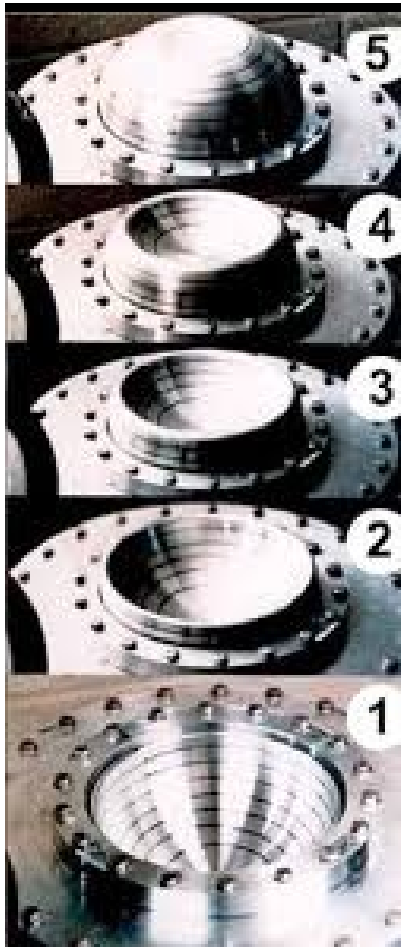
Reaction Control System Design

- RCS provides roll control during motor burns and full attitude control during coast. TVC provides pitch and yaw control during burns.
- RCS consists of monopropellant hydrazine blowdown system with high TRL commercial hardware.
- Comprises six lateral thrusters and two larger Orbit Trim Thrusters (OTTs). OTTs used to improve orbital insertion accuracy.
- Propellant stored in a titanium tank with an elastomeric diaphragm to reduce ullage and slosh.
- Relatively high freezing point of hydrazine (+2°C) requires additional heaters.





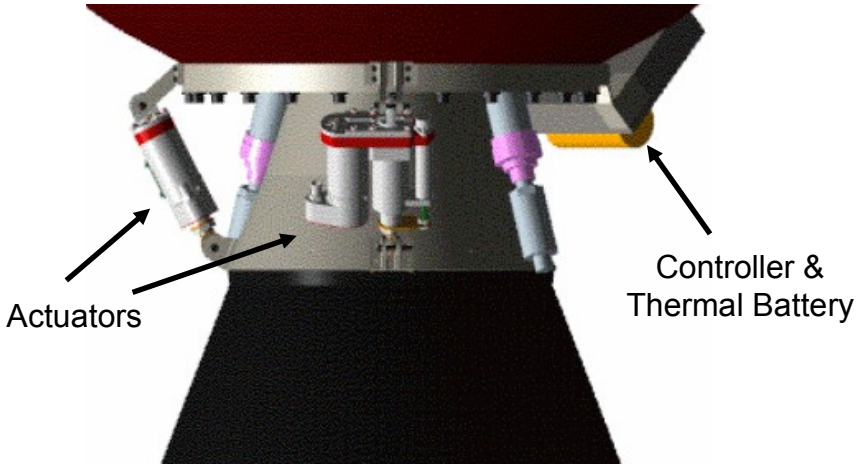
RCS Location Within Forward Structure



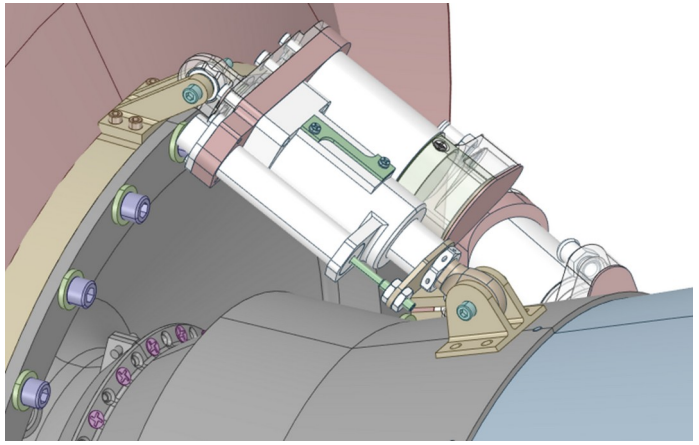
Example Diaphram

Thrust Vector Control Design

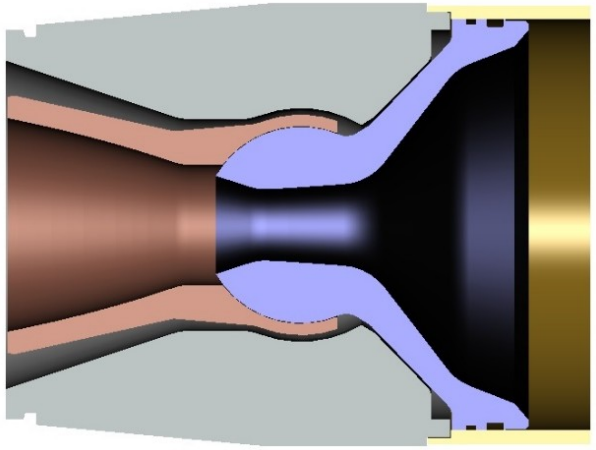
- TVC provides pitch and yaw control during motor burns.
- Nozzle gimbal performed with traditional ElectroMechanical Actuators (EMAs), mounted on aft end of each SRM.
- Each stage has an independent TVC system, featuring two actuators, a controller, and a thermal battery.
- Gimbal nozzle features a Supersonic Splitline (SSSL) 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. SSSL does not feature any elastomerics.



SRM1 TVC System



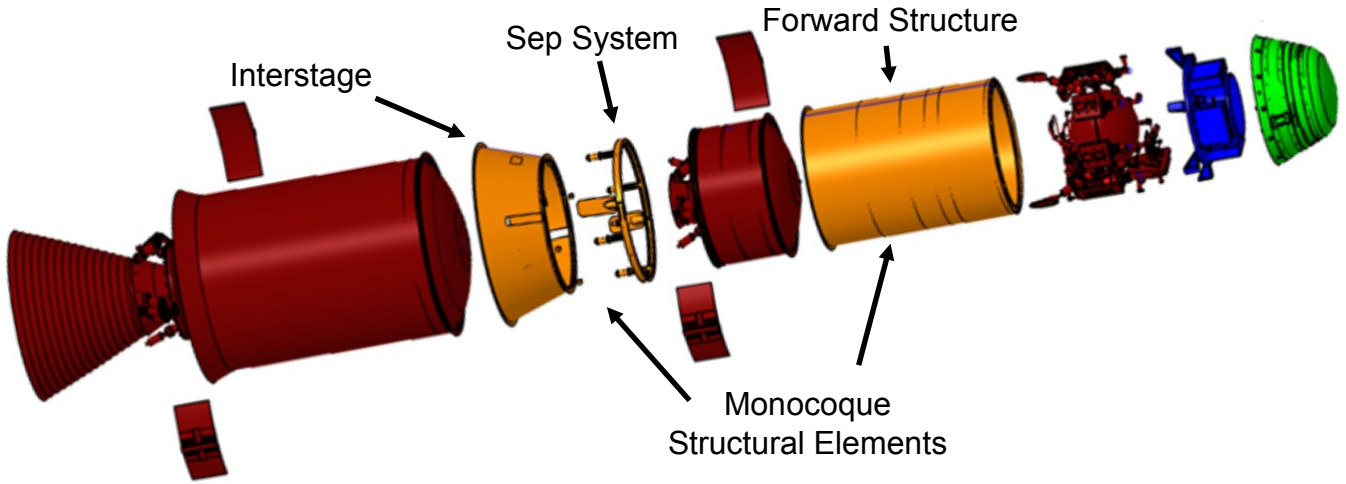
SRM1 Pitch EMA

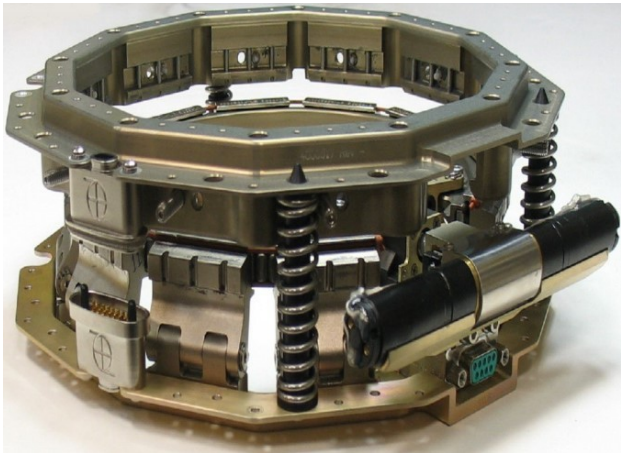


Example SSSL Trapped Ball Design

Structural and Mechanical Design

- Unique structural design challenge as vehicle must survive approximately 15g lateral loads during Mars EDL.
- Non-propulsive structural elements designed of high TRL machined monocoque construction from simple ring forgings.
- Finite Element Model (FEM) loads analysis served as input for stress analysis and structural failure mode determination.
- Two primary mechanisms examined:
  - Stage separation mechanism featured mid-high TRL spring loaded clamp-band.
  - Pyrotechnic mechanisms for SRM ignition, TVC thermal battery activation, RCS isolation valves, and separation system release.



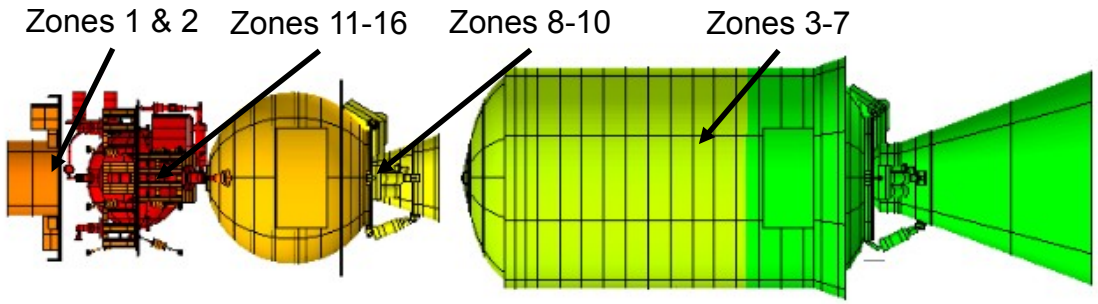


Sample Clamp-Band Separation System

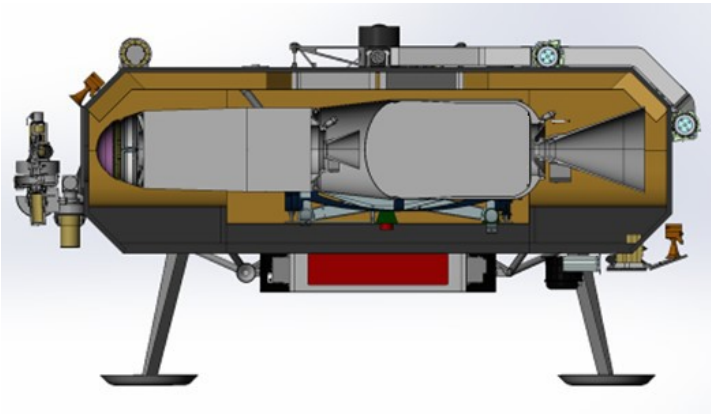
MAV FEM Mesh

Thermal Design

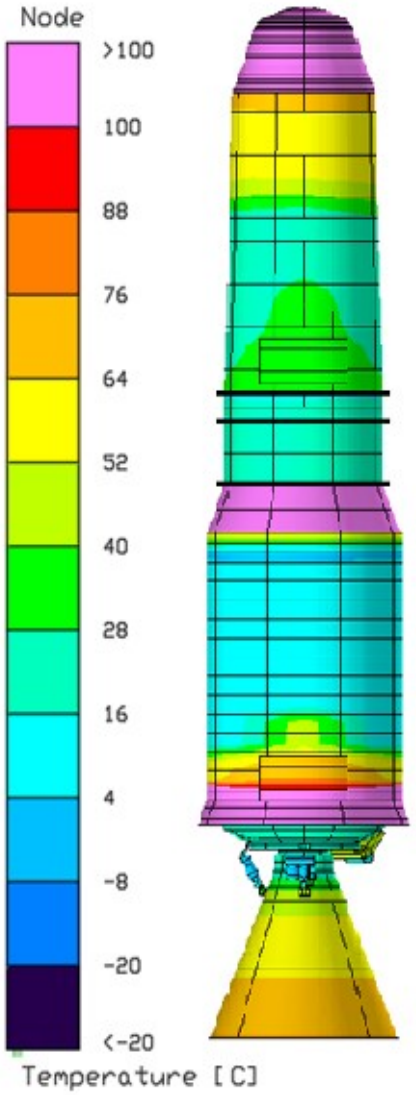
- MAV stored within thermal “igloo” during cruise to Mars and on surface, maintaining constant temperature prior to deployment.
- Thermal system makes use of 16 heater zones controlled via heaters and Platinum Resistant Thermometers (PRTs). Each zone has different components with different thermal constraints.
- Passive insulation further reduces temperature gradients and provide protection from induced thermal environments.
- Mars ascent mission is short, with active thermal control during ascent not needed. High temperatures due to aeroheating does not impact most internal components*.



Thermal Control Zones



MAV Stored within Lander Igloo

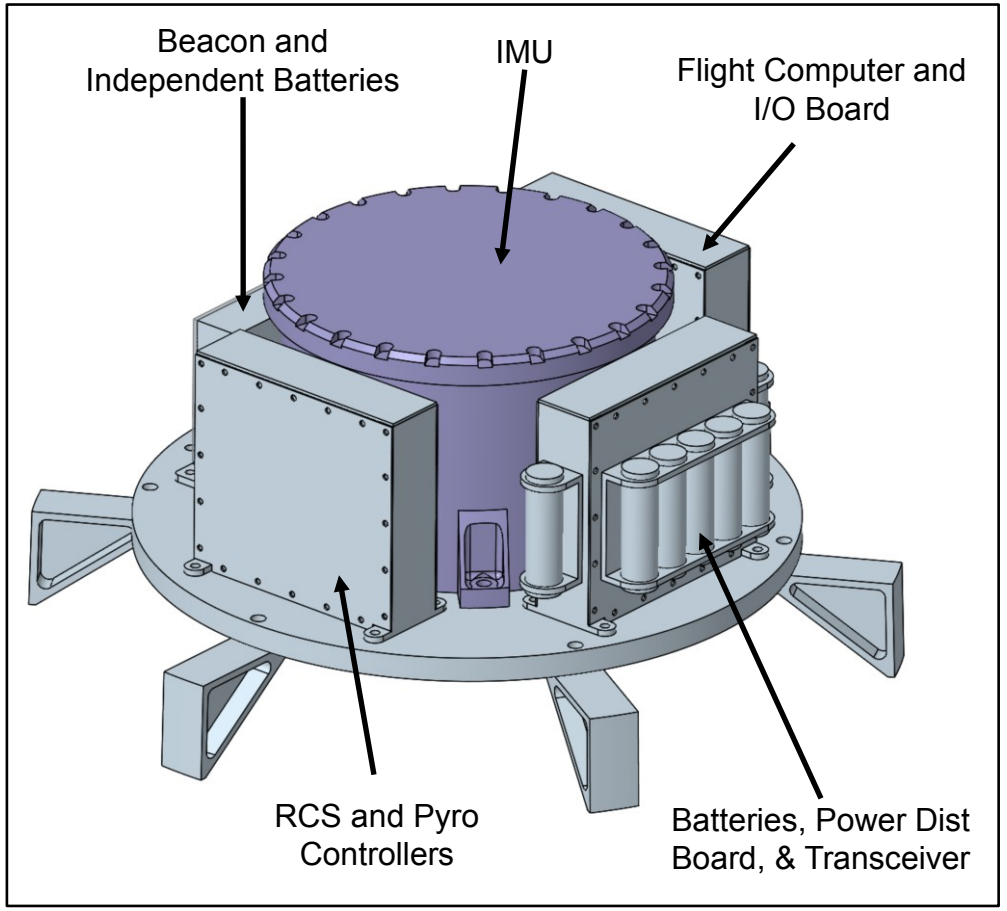


Peak Temperature Profile During Ascent

*Stage 2 TVC controller exceeded expected upper limit thermal assumptions. To be addressed in future analyses.

Avionics Design

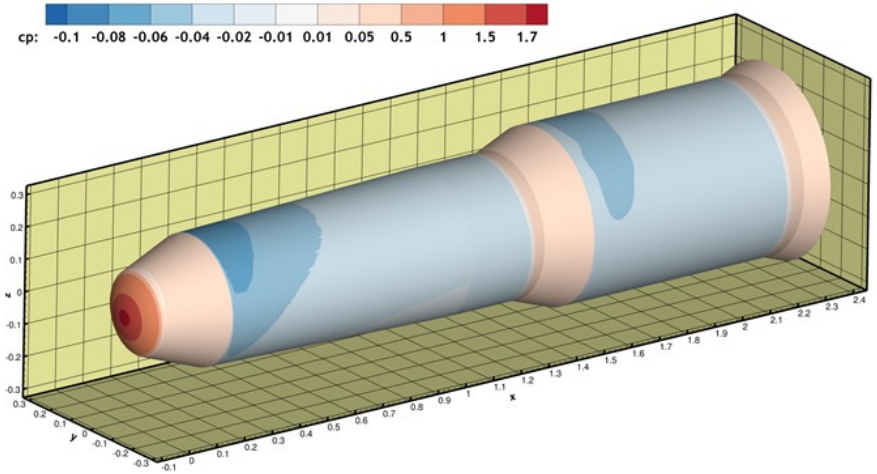
- Avionics consists of three primary functions: Command and Data Handling (CDH), communication, and power.
- CDH carried out by flight computer, controllers, IMU.
- Flight software algorithms control vehicle response to external stimuli and mitigate off-nominal situations. All flight operations are autonomous.
- Unique mission constraints required a highly specialized Inertial Measurement Unit (IMU), allowing for gyrocompassing.
- Communications managed by transmitter, antenna, and navigational beacon.
- Power managed by batteries, power distribution board, and cabling.
- Umbilicals with lander provides power and direct control of several systems while stowed.
- All avionics have to function in environments outside of typical design operation.



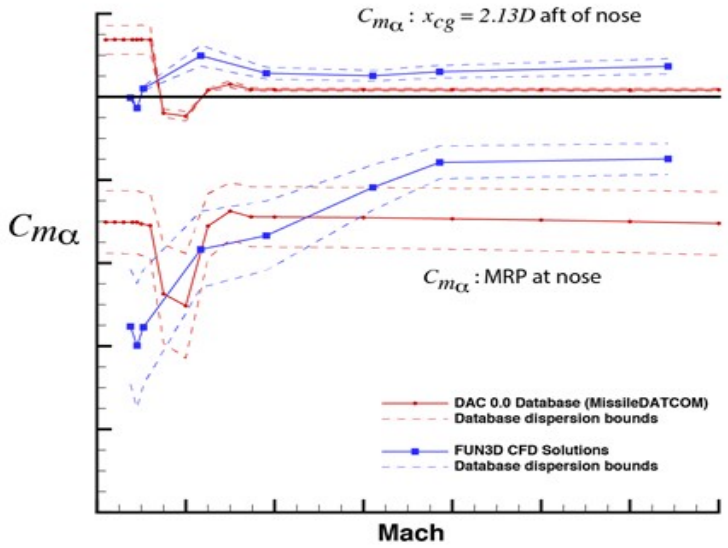
Avionics Hardware Layout

Aeroscience Environments

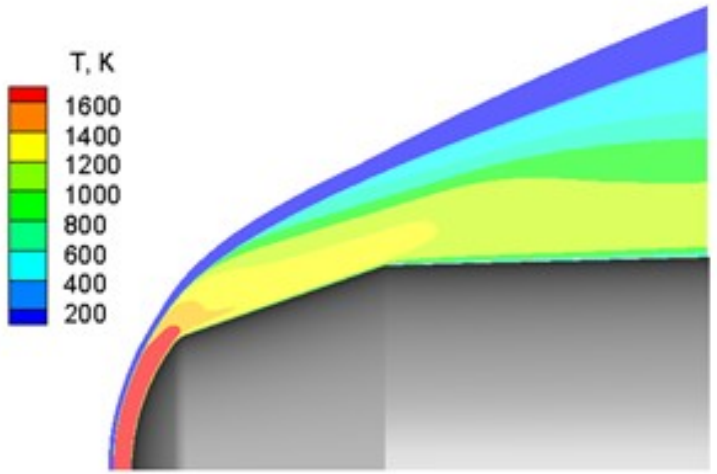
- Vehicle behavior affected by interaction with Martian environment despite low atmosphere. Aerodynamics, aerothermodynamics, and external acoustics analyzed.
- CFD performed to assess aerodynamic stability and develop aero coefficients for use in trajectory optimization. Vehicle is aerodynamically unstable for most of ascent.
- Aerothermodynamics analysis used for sizing of thermal hardware. Peak heating identified at high pressure region of nose.
- Liftoff acoustics, plume-induced acoustics, and ascent aeroacoustics environments used as inputs to integrated vehicle loads model. Acoustics found to not be a significant source of load.



Example Pressure Distribution



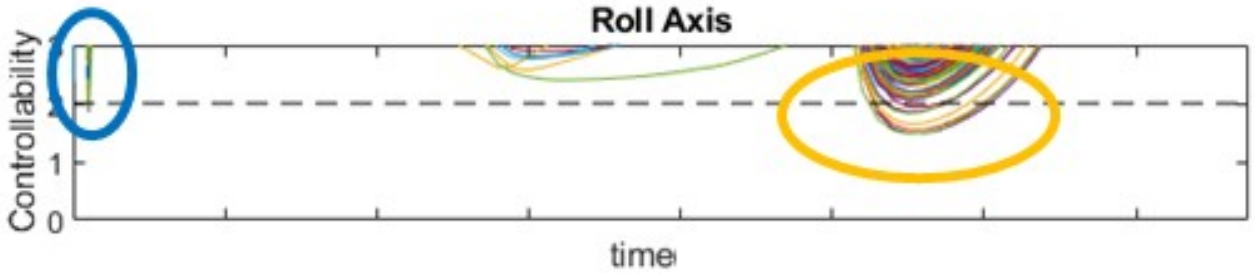
Aerodynamic Stability



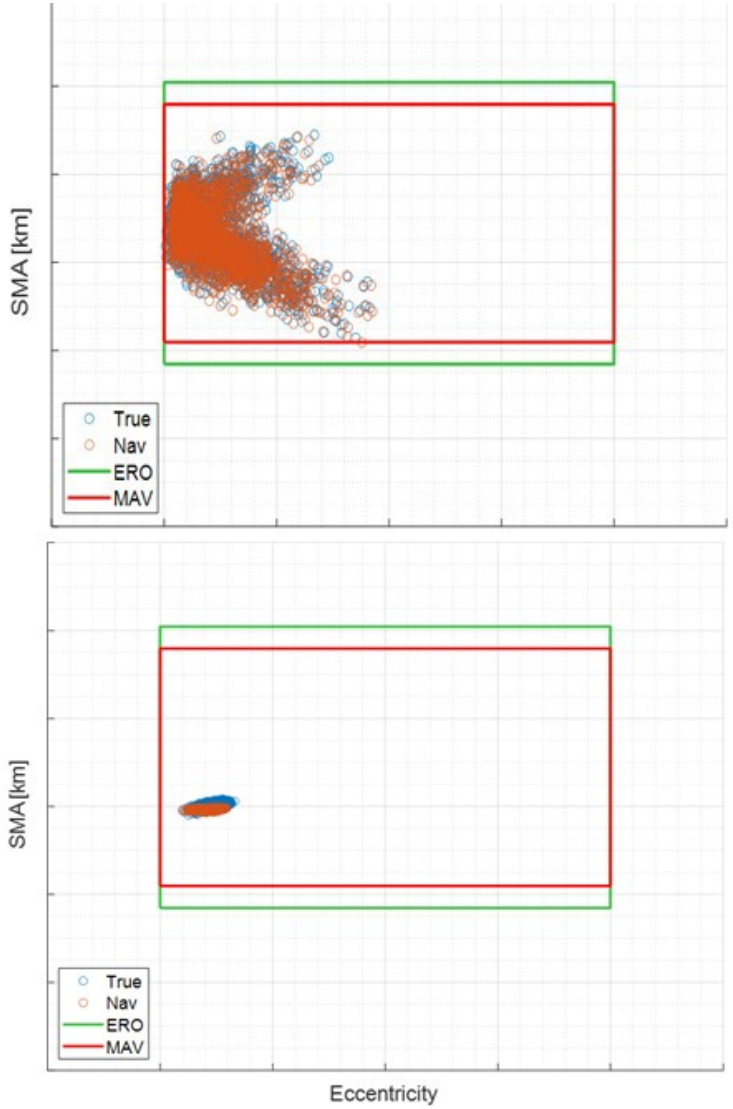
Nose Flowfield Aeroheating

Guidance, Navigation, and Control Design

- Vehicle designed to deliver 16kg payload to 343km @ 27◦ inclination.
- Nominal 6DOF trajectory iteratively developed with propulsion sizing and vehicle geometry.
- Overall flight plan includes both open- and closed-loop guidance. Energy management maneuver and OTTs used to reduce dispersions in final injected orbit.
- Uncertainty parameters addressed via dispersed simulations. Dispersions focused on motor performance, launch conditions, atmosphere, mass/payload variations, and RCS/TVC performance.
- RCS/TVC performance are major contributors to vehicle controllability. Stability margins compared to standard 6dB for GM and 30° for PM. Nominal cases well within margins.



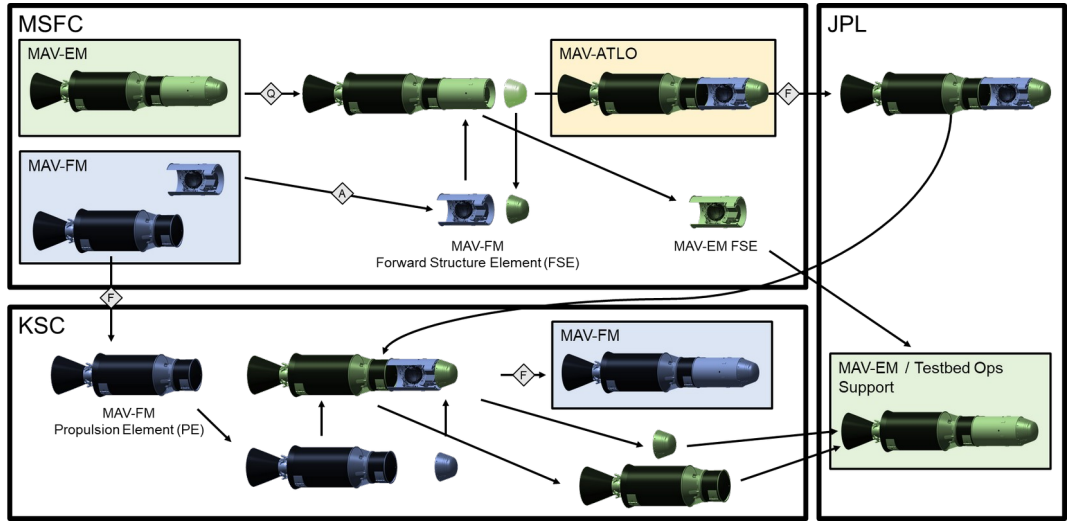
Minor Controllability Violations in Roll Axis From Dispersed Cases



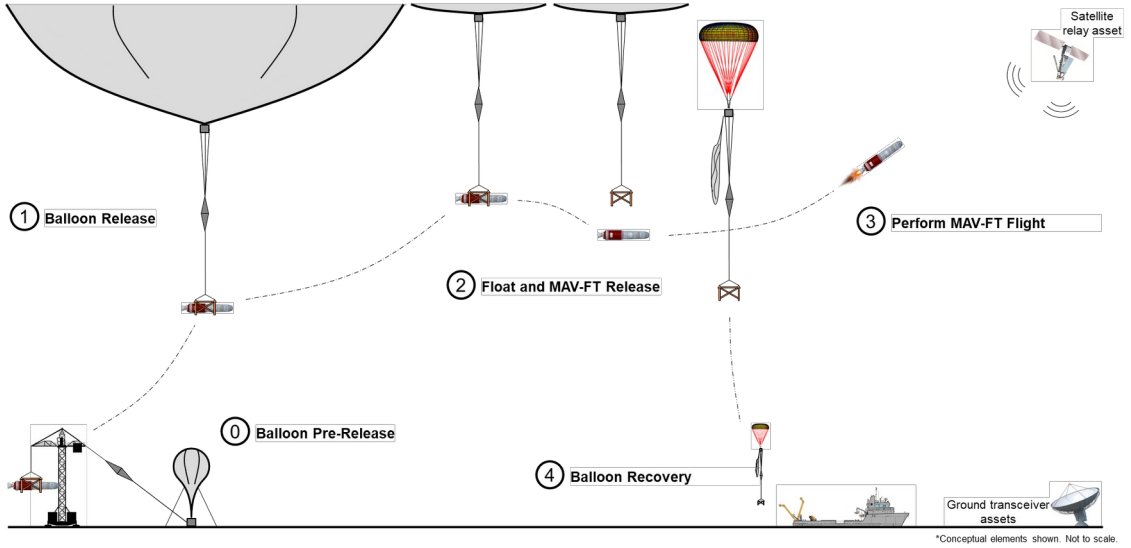
Effect of Closed-Loop Guidance, Energy Management, and OTTs on Orbital Dispersions

Assembly, Integration, & Testing

- AI&T planning included vehicle assembly from subsystem components, verification & validation (V&V) testing, and feasibility assessment of an Earth-based flight test program.
- Three MAV units planned: Engineering Model (EM), Flight Test (FT) unit, and Flight Mission (FM) unit.
- Rigorous qualification testing planned for individual subsystem assemblies, including hardware-in-the-loop and flight software integration, where applicable.
- Integrated vehicle Earth-based flight test planned, launching in high altitude to replicate Martian surface environments.



Assembly & Integration Process for EM and FM units

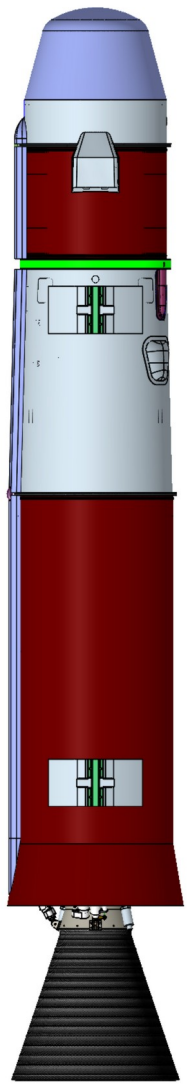


Notional Earth-based Test Flight

DAC-0.0 Design and Beyond

- DAC-0.0 vehicle analysis concluded concept can successfully deliver 16kg payload including 30 sample tubes to target Martian orbit, meeting all Lander stowage size and mass constraints.
- Addition of OTTs and tweaking of guidance algorithms significantly reduced orbit dispersions. Monte Carlo simulations helped further identify sensitivities and improve overall design.
- After DAC-0.0, MSR campaign determined it had insufficient mass & volume margins within entire lander system based on heritage experience from developing Curiosity rover. Mass allocations were significantly reduced for all elements, including MAV.
- Modifications to MAV architecture traded ~145kg at the expense of orbital insertion accuracy.

DAC-0.0 Design
June 2020



Current Design
December 2020

Questions?

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