Jet Propulsion Laboratory
California Institute of Technology

Robotic Mars Sample Return and Earth Entry Vehicle Concept Development

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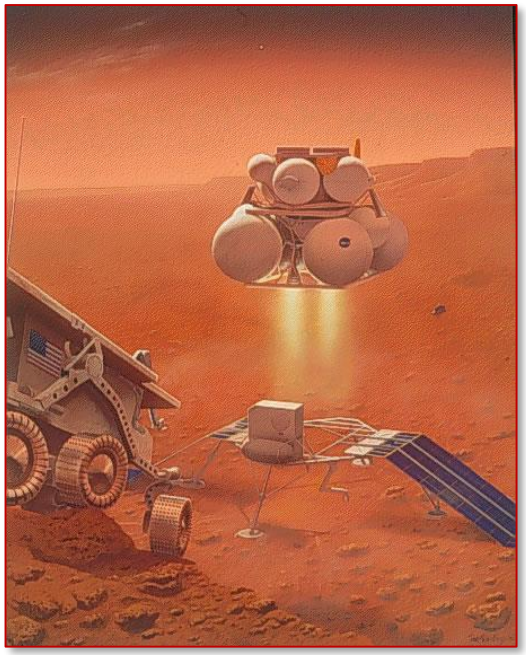
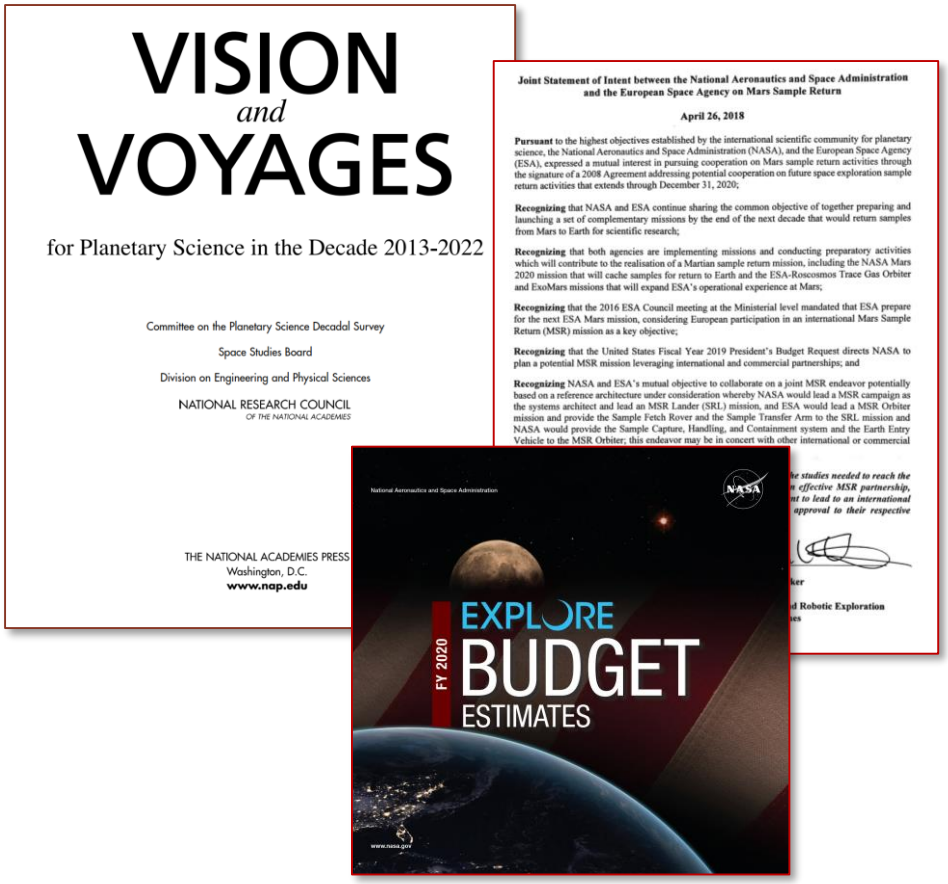
Mars Sample Return (MSR)

- NASA and other countries have studied Mars Sample Return for several decades
- Recent events provide growing evidence that MSR may become the next large NASA Mars Program endeavor after the Mars 2020 rover





VISION *and* VOYAGES

for Planetary Science in the Decade 2013-2022

Committee on the Planetary Science Decadal Survey

Space Studies Board

Division on Engineering and Physical Sciences

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Joint Statement of Intent between the National Aeronautics and Space Administration and the European Space Agency on Mars Sample Return

April 26, 2018

Pursuant to the highest objectives established by the international scientific community for planetary science, the National Aeronautics and Space Administration (NASA), and the European Space Agency (ESA), expressed a mutual interest in pursuing cooperation on Mars sample return activities through the signature of a 2008 Agreement addressing potential cooperation on future space exploration sample return activities that extends through December 31, 2020;

Recognizing that NASA and ESA continue sharing the common objective of together preparing and launching a set of complementary missions by the end of the next decade that would return samples from Mars to Earth for scientific research;

Recognizing that both agencies are implementing missions and conducting preparatory activities which will contribute to the realisation of a Martian sample return mission, including the NASA Mars 2020 mission that will cache samples for return to Earth and the ESA-Roscosmos Trace Gas Orbiter and ExoMars missions that will expand ESA's operational experience at Mars;

Recognizing that the 2016 ESA Council meeting at the Ministerial level mandated that ESA prepare for the next ESA Mars mission, considering European participation in an international Mars Sample Return (MSR) mission as a key objective;

Recognizing that the United States Fiscal Year 2019 President's Budget Request directs NASA to plan a potential MSR mission leveraging international and commercial partnerships; and

Recognizing NASA and ESA's mutual objective to collaborate on a joint MSR endeavor potentially based on a reference architecture under consideration whereby NASA would lead a MSR campaign as the systems architect and lead an MSR Lander (SRL) mission, and ESA would lead a MSR Orbiter mission and provide the Sample Fetch Rover and the Sample Transfer Arm to the SRL mission and NASA would provide the Sample Capture, Handling, and Containment system and the Earth Entry Vehicle to the MSR Orbiter; this endeavor may be in concert with other international or commercial

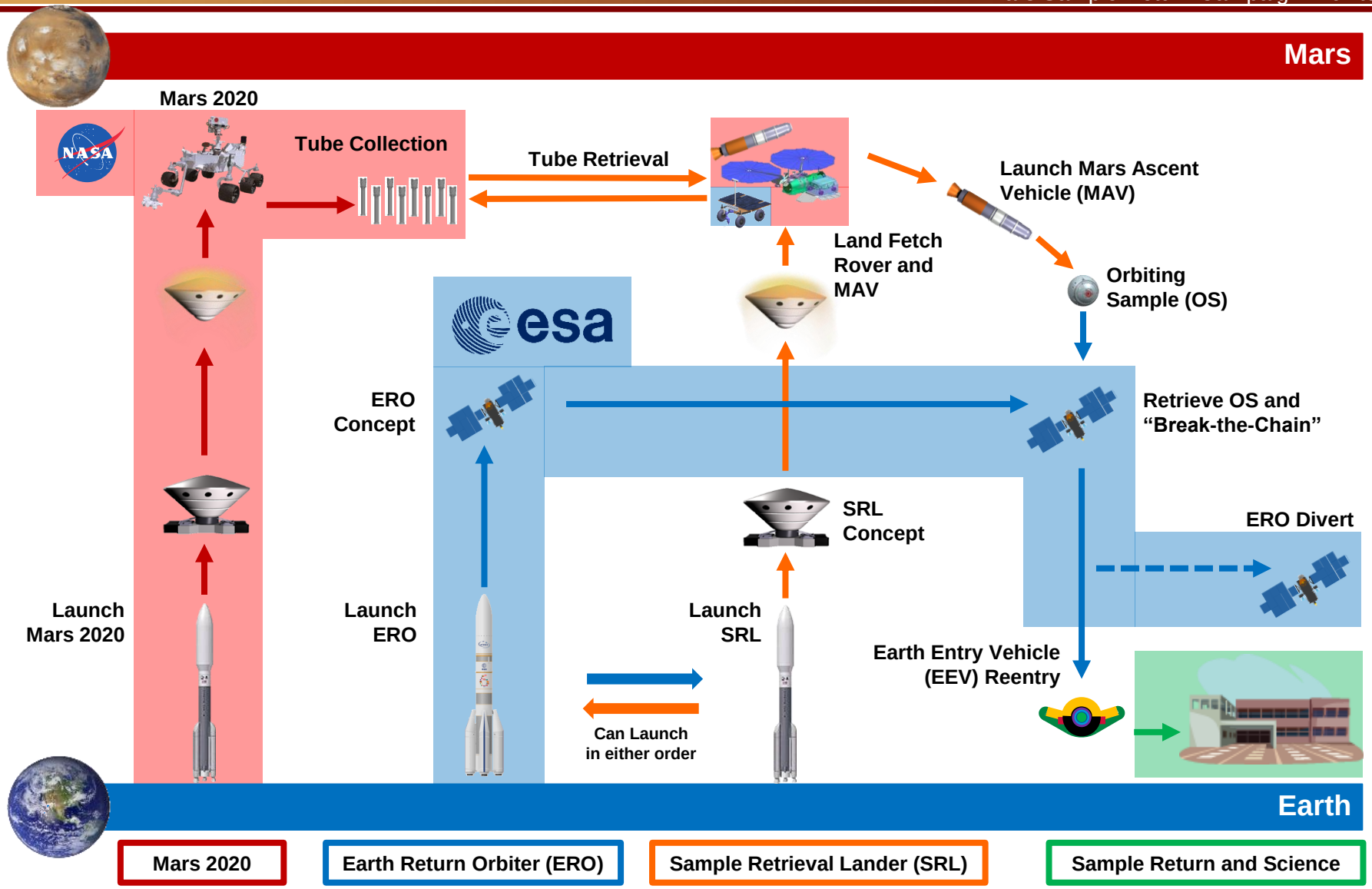
National Aeronautics and Space Administration

FY 2020

EXPLORE BUDGET ESTIMATES

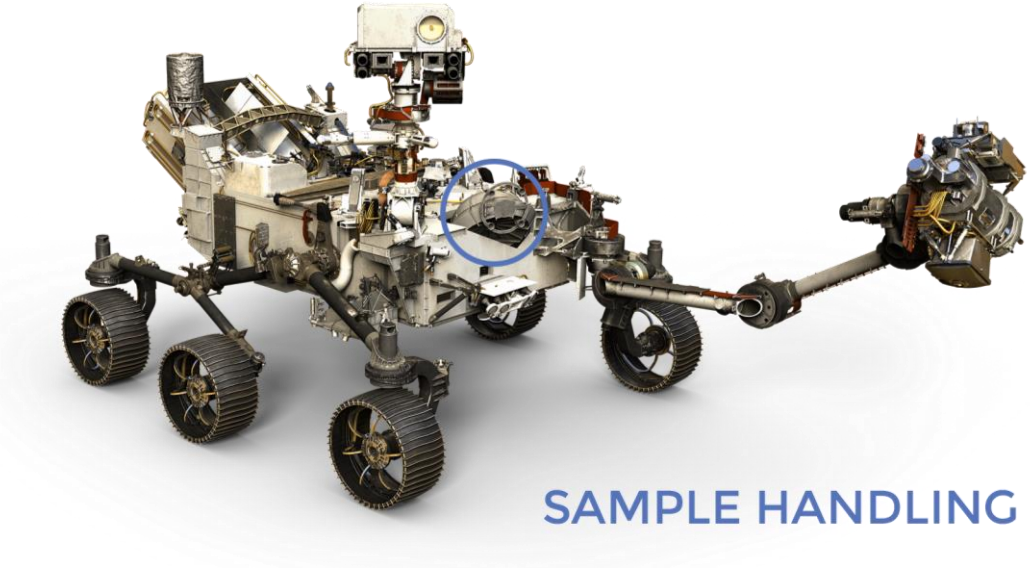
www.nasa.gov

MSR Concept Architecture*



*Per NASA/ESA Joint Statement of Intent, 26 April 2018

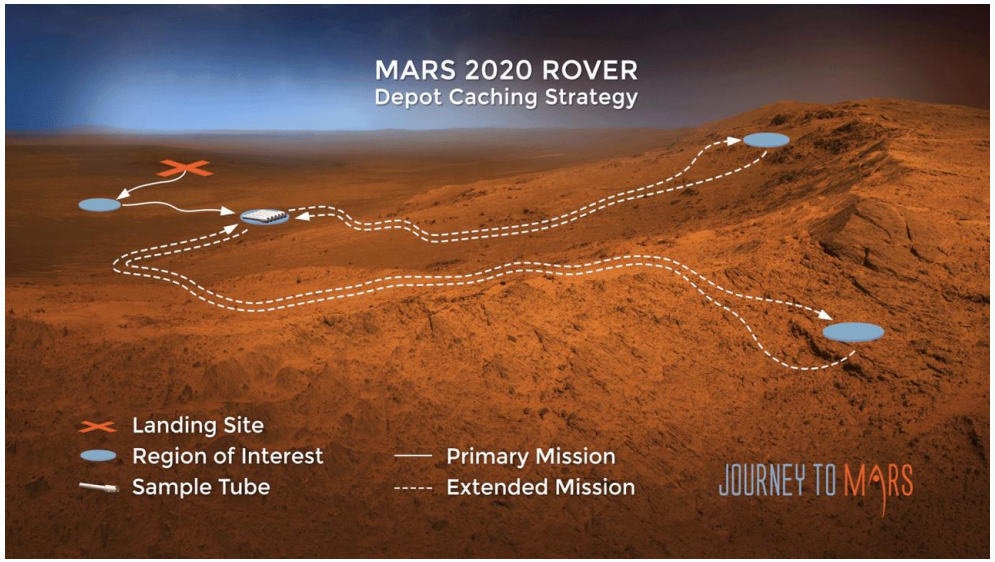
Mars 2020



Mars 2020

- Objective (MSR-related): Collect and deposit at least 20 soil and rock samples
- Includes: 42 sample tubes, 5 witness tubes, sample-acquisition and caching hardware
- Currently in final assembly and integration for launch in 2020

Mars 2020 rover may gather 20 or more samples from different regions of interest and deposit in common "depot" location



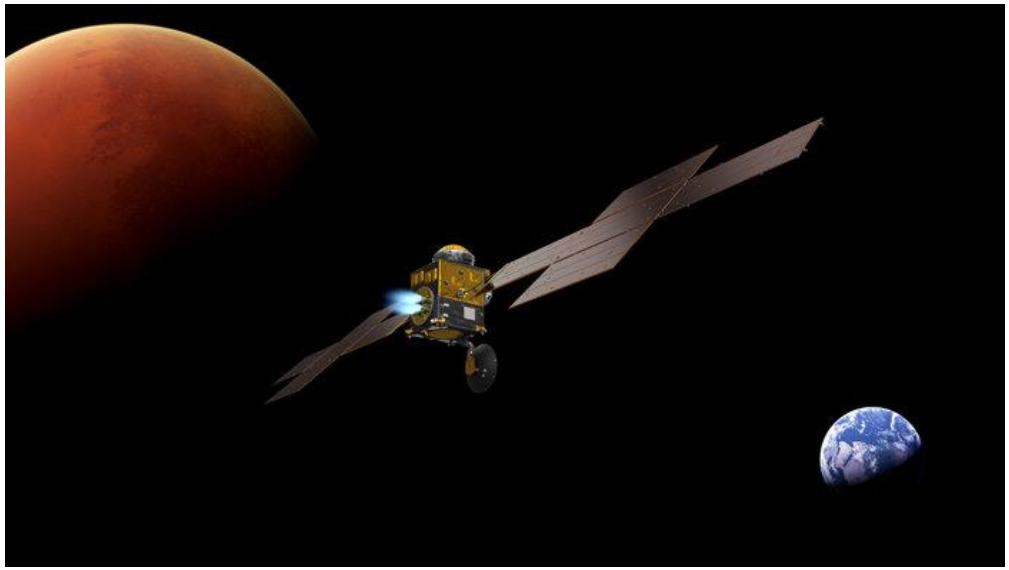
Sample Retrieval Lander / Earth Return Orbiter

Sample Retrieval Lander (SRL) Concept

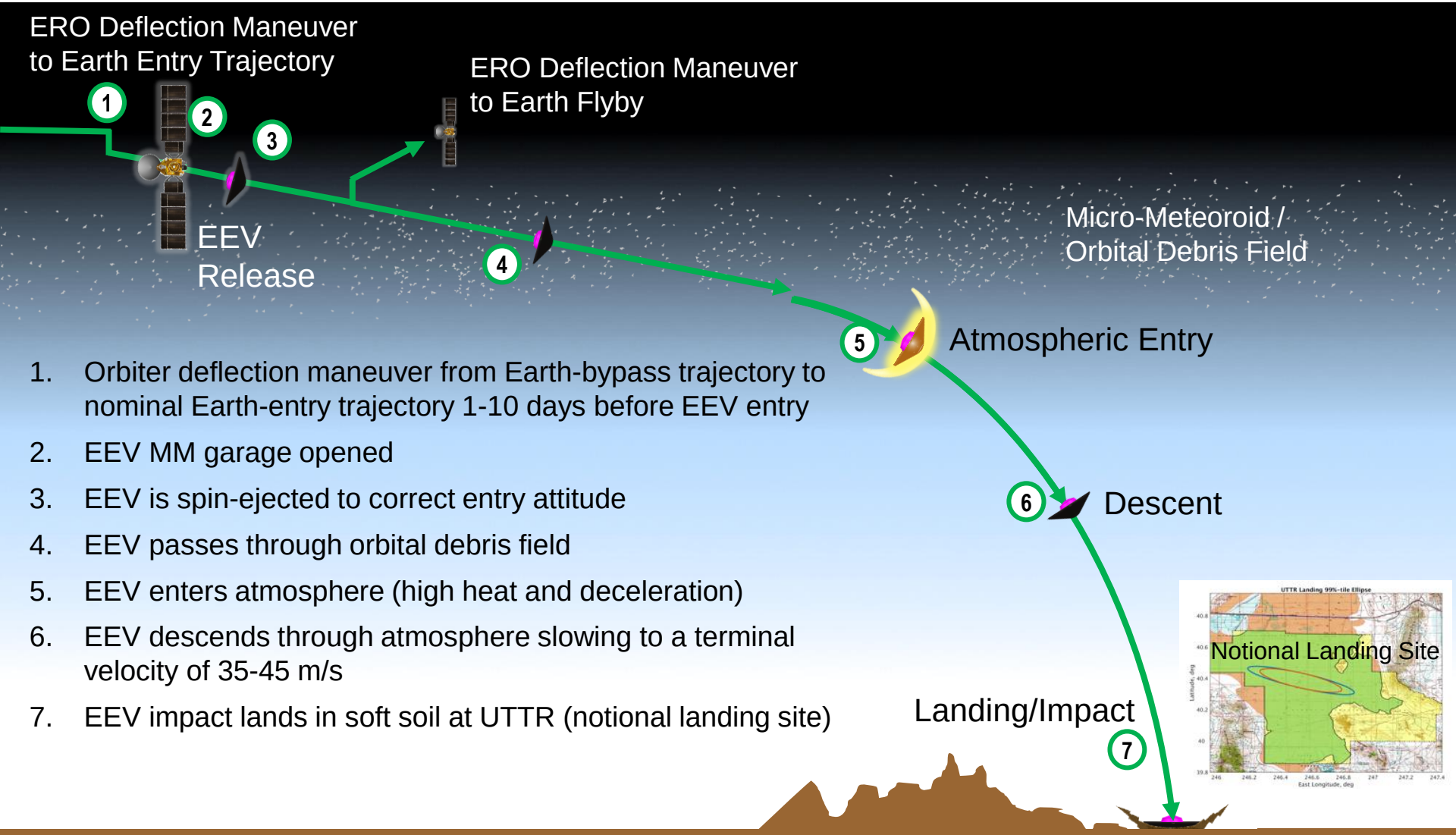
- Objective: Fetch samples on Mars and launch into Mars Orbit
- Includes: Fetch Rover, Mars Ascent Vehicle (MAV), Orbiting Sample (OS)
- NASA studies ongoing for both powered propulsive landing, as well as MSL-derived Skycrane options

Earth Return Orbiter (ERO) Concept

- Objective: Acquire OS in Mars orbit, enclose in EEV, and return EEV to Earth
- Includes: Capture/Containment Recovery System (CCRS), and Earth Entry Vehicle (EEV)
- ESA conducting studies on ERO architecture with contractors



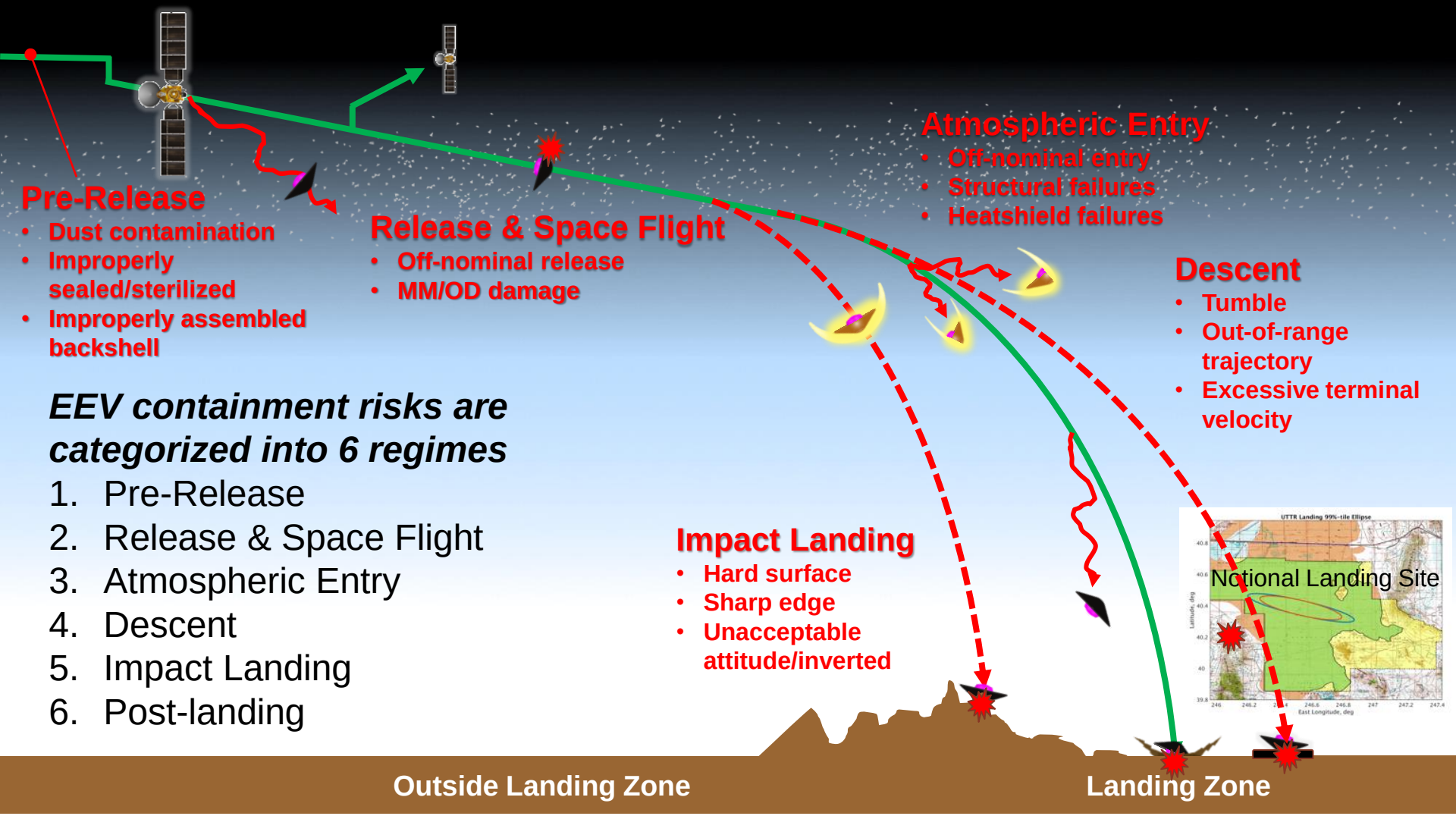
Bringing Samples Back to Earth



1. Orbiter deflection maneuver from Earth-bypass trajectory to nominal Earth-entry trajectory 1-10 days before EEV entry
2. EEV MM garage opened
3. EEV is spin-ejected to correct entry attitude
4. EEV passes through orbital debris field
5. EEV enters atmosphere (high heat and deceleration)
6. EEV descends through atmosphere slowing to a terminal velocity of 35-45 m/s
7. EEV impact lands in soft soil at UTTR (notional landing site)

Bringing Samples Back to Earth – Risks

**** Examples of potential off-nominal situations shown in in red***



EEV containment risks are categorized into 6 regimes

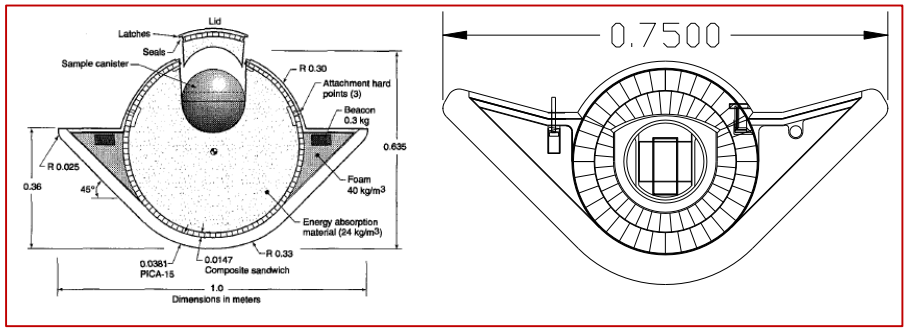
1. Pre-Release
2. Release & Space Flight
3. Atmospheric Entry
4. Descent
5. Impact Landing
6. Post-landing

MSR EEV History

Earlier Concepts

Early proposal concepts, small, light, notional. Limited analysis, never built

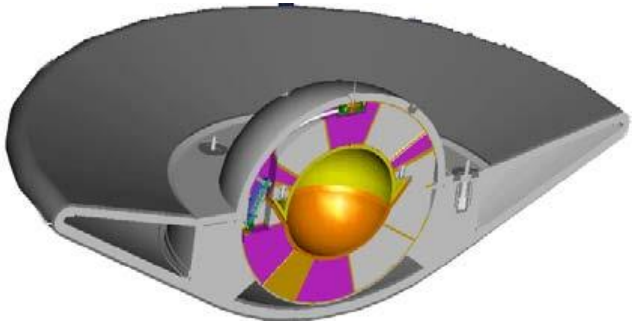
- TPS: PICA
- Shape: 45 deg sphere-cone, 33 cm nose radius



03/05 MSR Campaign Design

Significant structural, aero, impact analysis, and vehicle testing leading to a Preliminary Design Review.

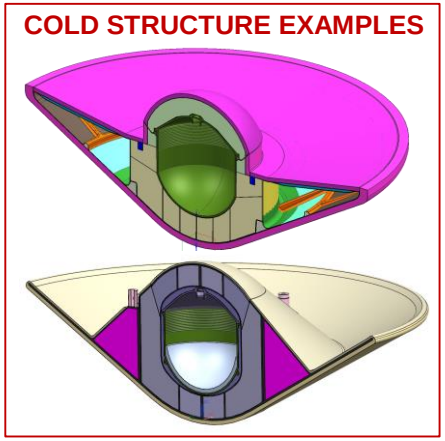
- TPS: Carbon-Phenolic (CP) TPS
- Shape: 60 deg sphere-cone, 30 cm nose radius
- Mass: 44 kg total
- OS: 5 kg (16 cm diameter)
- V_{entry}: 11.6 km/s

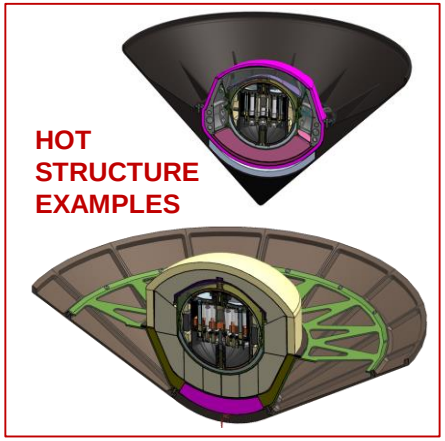


Recent EEV Concepts

Based on new ideas as well as derived from past studies. Some structural, aero, impact analysis & testing.

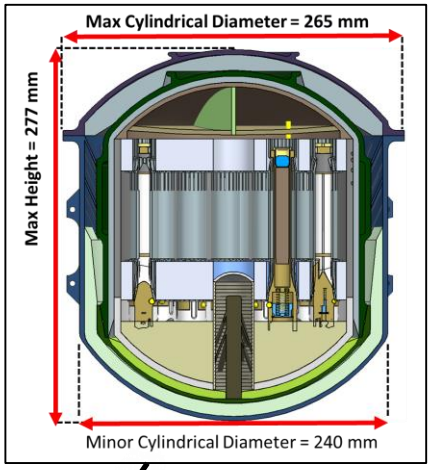
- TPS: PICA, HEEET, Carbon-Carbon
- Shape: 45-60 deg sphere-cone, 2-30 cm nose radius
- Mass: from 60 to 100 kg total mass
- OS: 12 kg (28 cm diameter)
- V_{entry}: from 11.5 to 13 km/s





Current EEV Design Approach

Example 20-tube Contained Orbiting Sample (OS) Concept



Focus on Passive Design Solutions

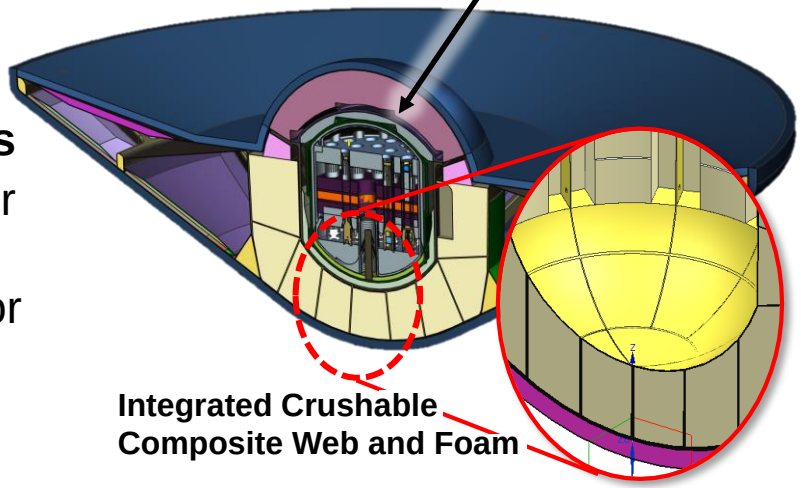
- No active mechanisms or electronics
- No parachutes, retrorockets
- Aerodynamically stable from hypersonic through terminal velocity

Implement Robust and Proven TPS Technology

- Must consider aerothermal performance and mass, as well as Micrometeoroid and Orbital Debris robustness

Meet Landing and Containment Requirements

- Multiple layers of impact energy absorbers for landing and thermal isolation
- Redundant containers around OS/samples for containment assurance
- Landing ellipse safety within UTTR (notional landing site)



EEV = a simple ballistic entry vehicle concept with a design emphasis on robustness and certifiability

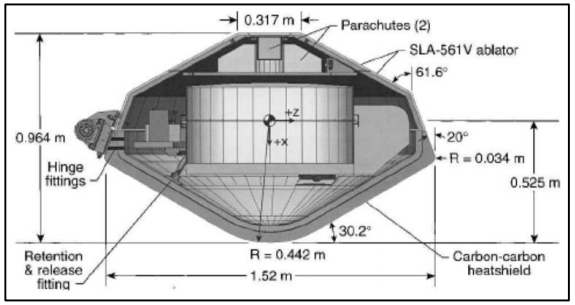
UTTR Utah Test and Training Range

Thermal Protection System Options

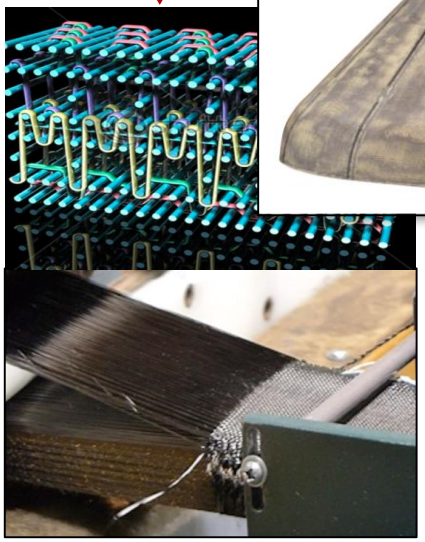
- Carbon-Phenolic
- Carbon-Carbon
- PICA
- HEEET
  - Tiled / Dual Layer
  - Single / Insulation Layer only

Focus of recent EEV concepts

Carbon-Phenolic
High density ablator material for extreme entry environments
Heritage: Galileo Probe, Pioneer-Venus



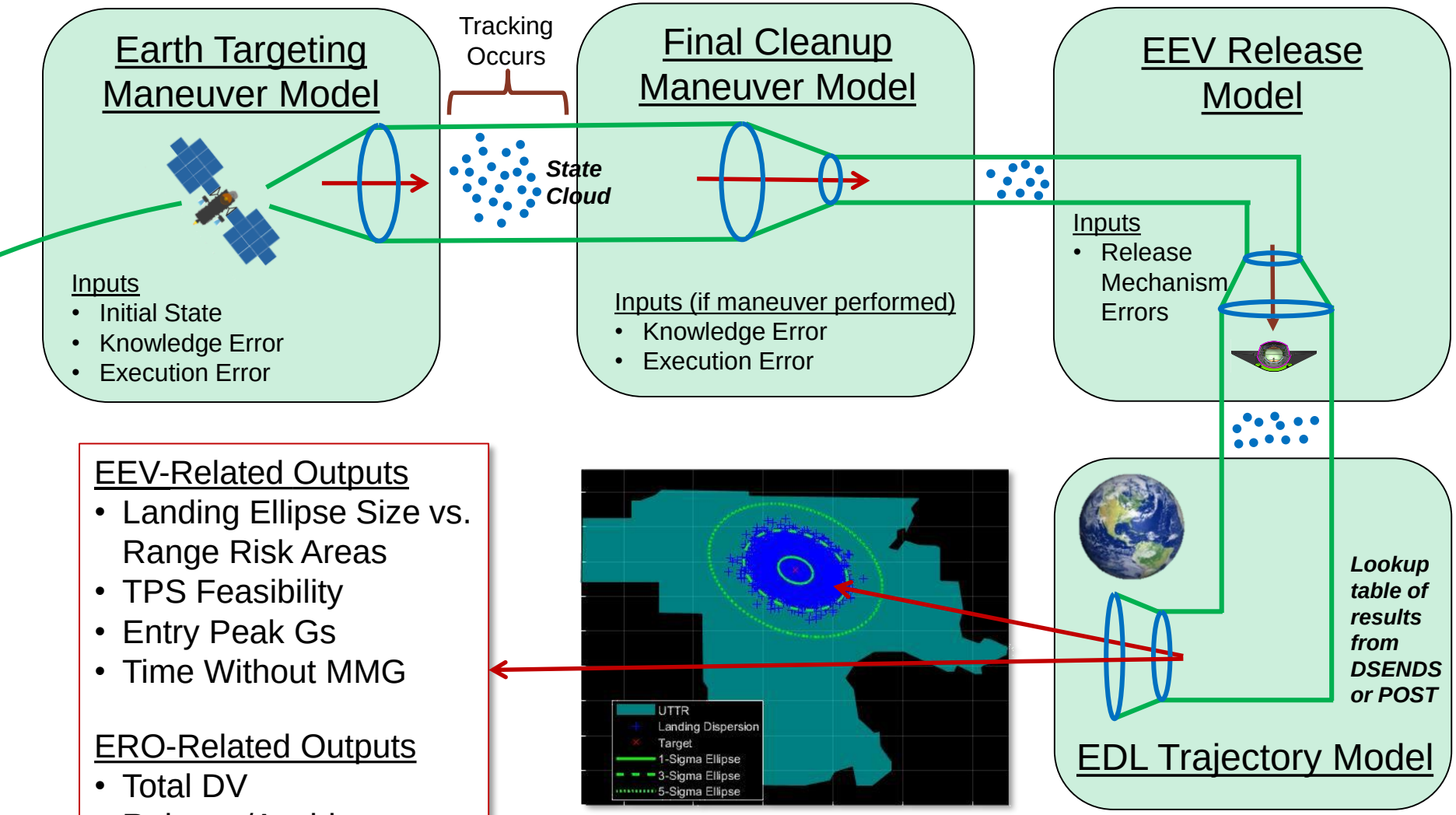
Carbon-Carbon
2D or 3D woven carbon non-ablator capable of high-temperatures >2000K
Heritage: Genesis, Shuttle, military



HEEET
3D Woven TPS in development at NASA for extreme environments

PICA
Low density ablator
Heritage: Stardust, MSL, Mars 2020, more

ELEET: EEV Landing Ellipse Error Tool



EEV-Related Outputs

- Landing Ellipse Size vs. Range Risk Areas
- TPS Feasibility
- Entry Peak Gs
- Time Without MMG

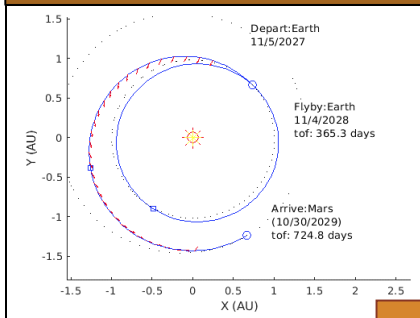
ERO-Related Outputs

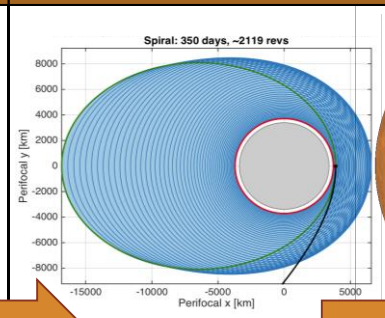
- Total DV
- Release/Avoidance Backup Time

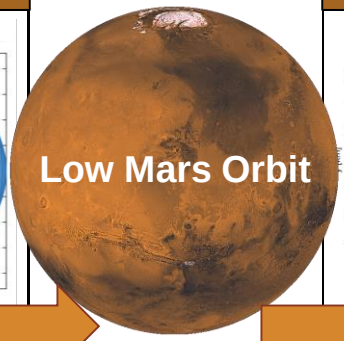
ELEET fuses multiple domain models to provide insight into performance vs. capability trades

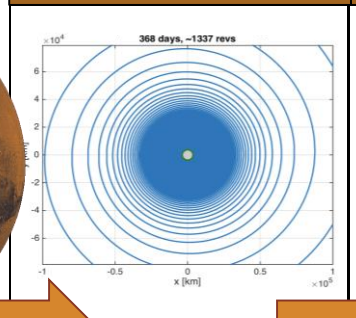
Micrometeoroid/Orbital Debris (MM/OD) Risk

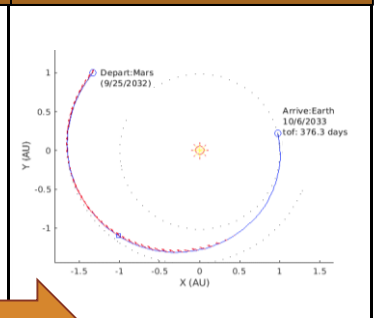
Earth-to-Mars	Mars Spiral-In		Mars Spiral-Out	Mars-to-Earth







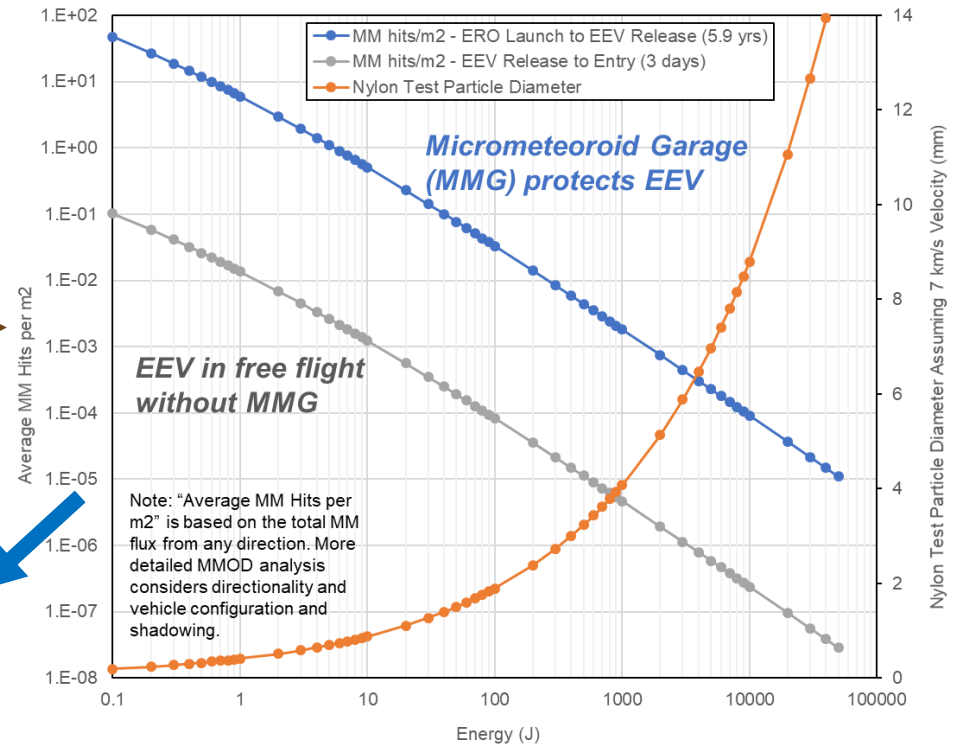




Input Interplanetary Trajectory

Run NASA's MEM and ORDEM models to generate MM/OD Flux Environments

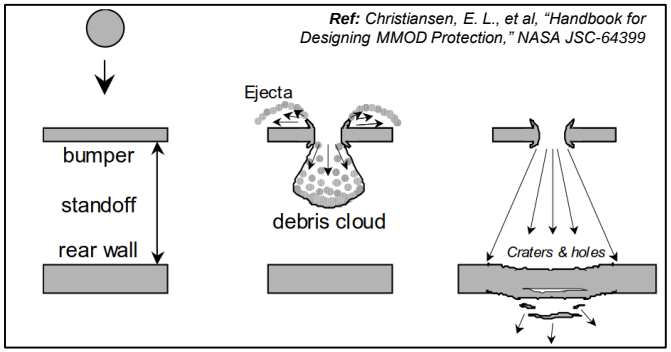
Assess MM/OD Protection and TPS using Ballistic Limit Equations, Hyper-Velocity Impact Testing, Hydrocode simulations

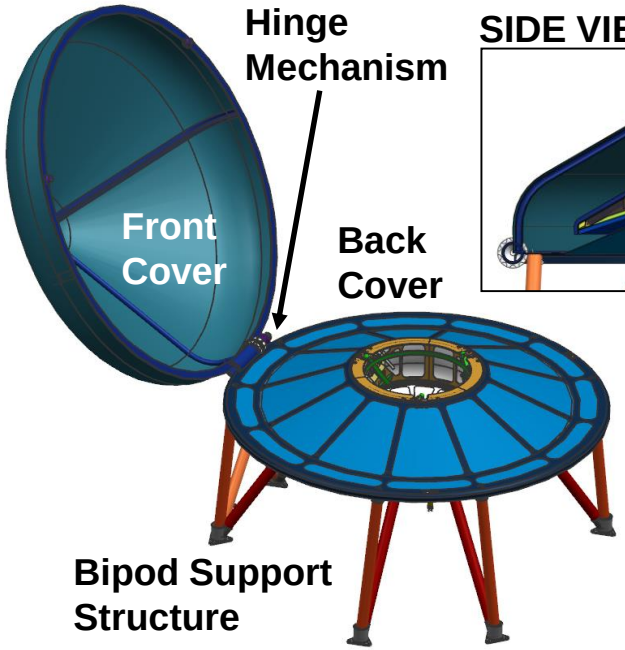


MEM: Meteoroid Engineering Model
ORDEM: ORbital Debris Engineering Model

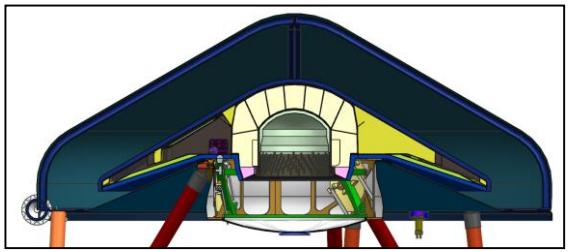
EEV Micrometeoroid Garage (MMG)

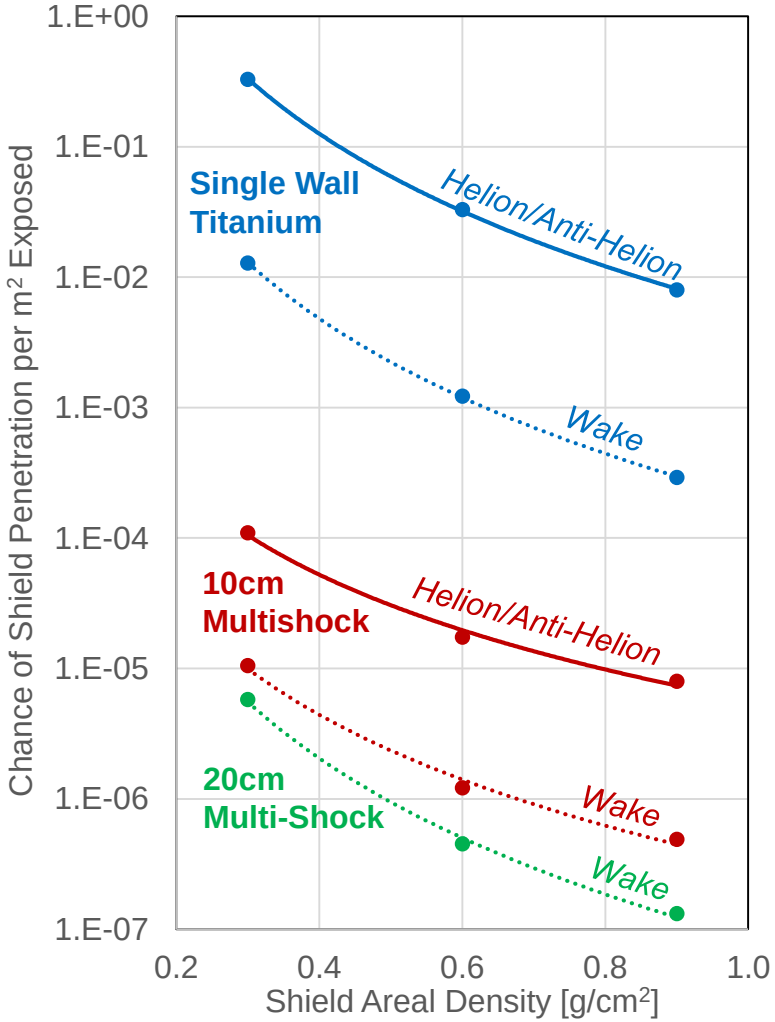
- At worst, EEV will be in space environment for up to 6 years
- MMG would protect EEV for 99.9% of this time





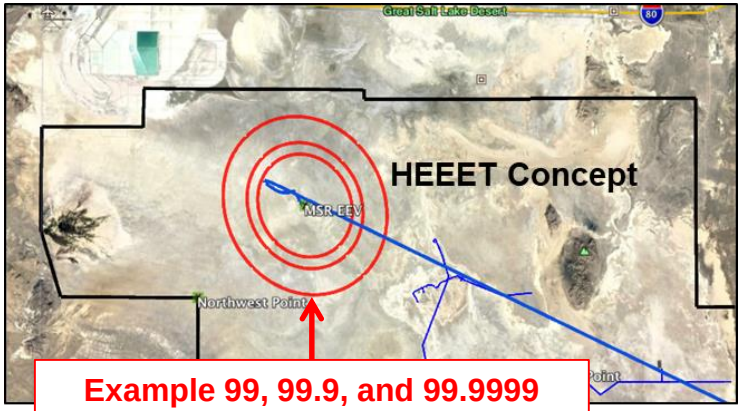
SIDE VIEW:



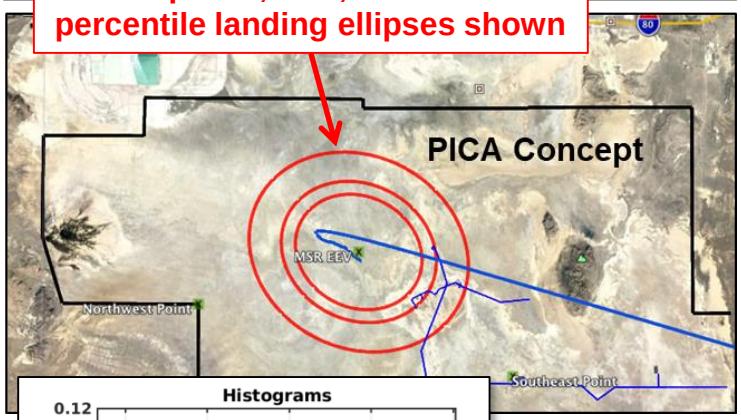


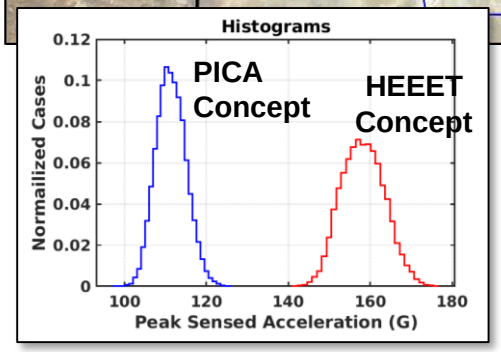
Trajectory, Aeroheating, Aerodynamics

- High-fidelity analysis and testing on-going to mature concepts

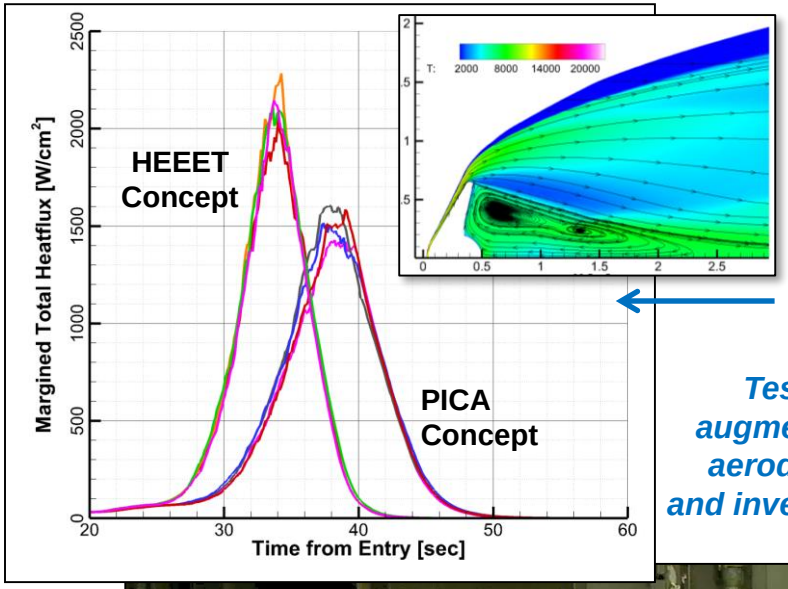


Example 99, 99.9, and 99.9999 percentile landing ellipses shown



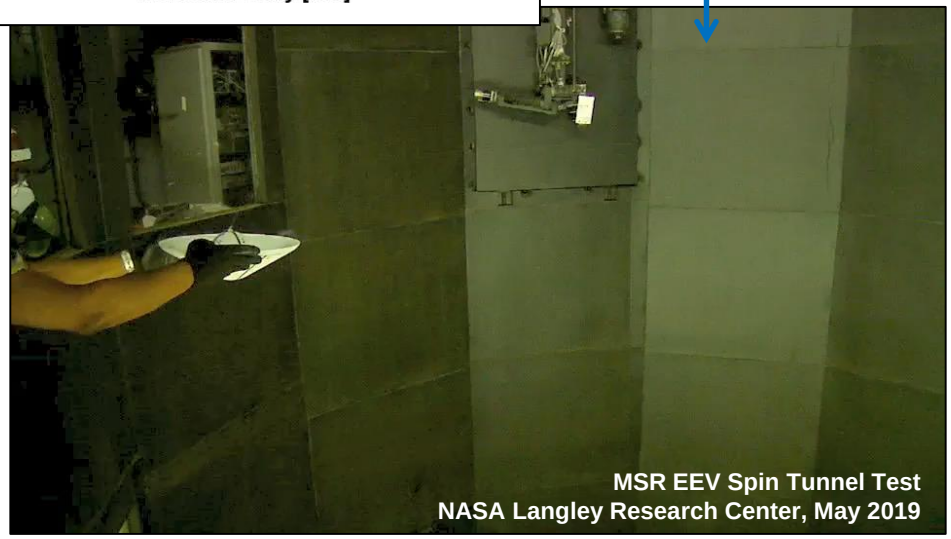


6DOF trajectory simulations (POST) help inform design choices and illuminate vehicle performance



CFD simulations (DPLR, NEQAIR) provide high-fidelity anchoring of margined convective and radiative heating environments

Testing underway to augment existing 6DOF aerodynamic database and investigate geometry modifications

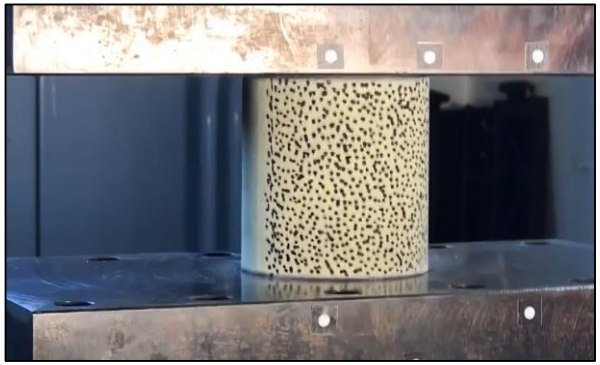


MSR EEV Spin Tunnel Test
NASA Langley Research Center, May 2019

Structural Testing / Model Development

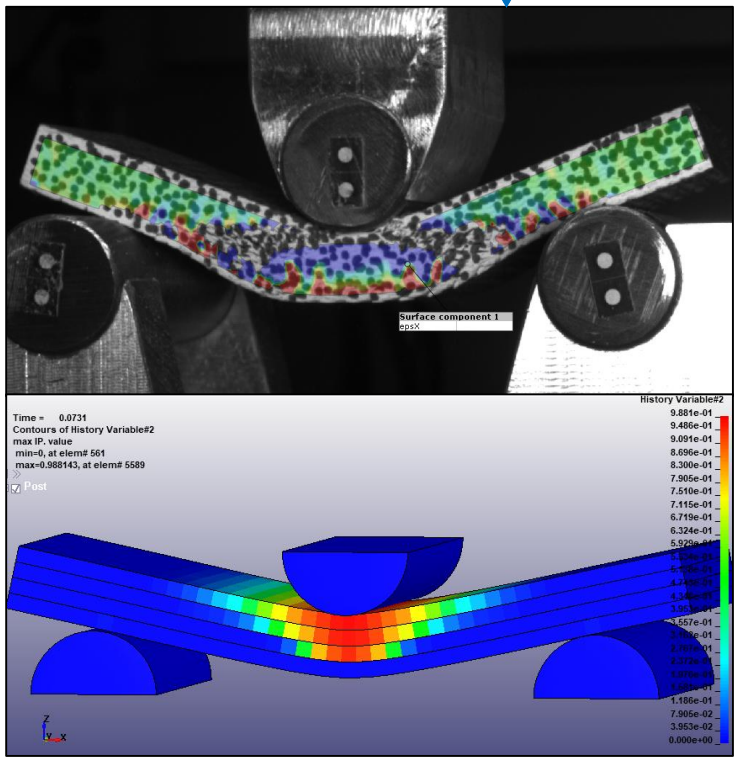
- EEV structure experiences three primary load scenarios
  - Launch – typically <10 Gs static
  - Entry – between 100-200 Gs depending on design
  - Landing – can be 1000's of Gs, very short pulse

Requires advanced structure models for high strain rate analyses such as LS-DYNA



PICA has relatively low strength-to-failure, and can typically be ignored in dynamic structural analyses

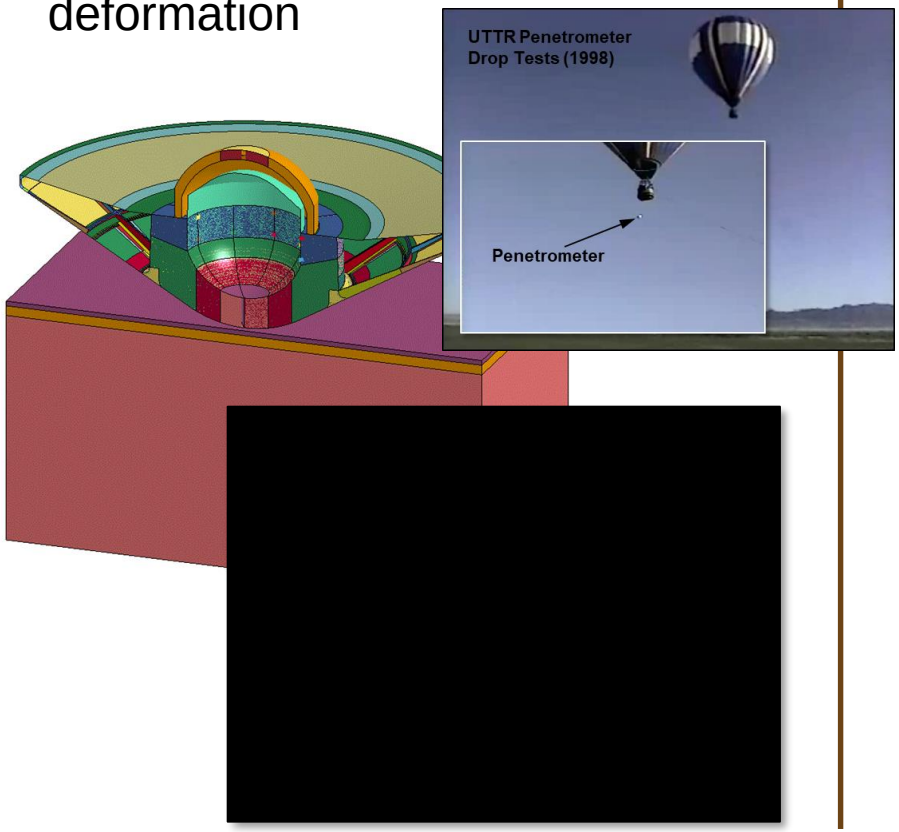
HEEET exhibits much larger strain-to-failure characteristics



Energy Attenuation for Landing Impact

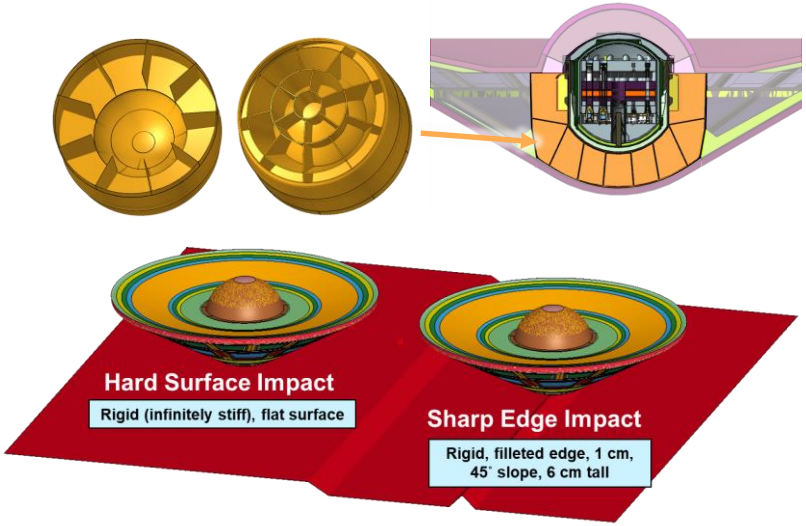
Nominal Landing Scenario

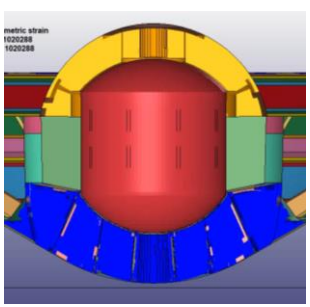
- Primary Objective: Meet science goals (<1300 Gs at OS)
- UTTR soil absorbs landing energy
- CAM designed for minimal deformation

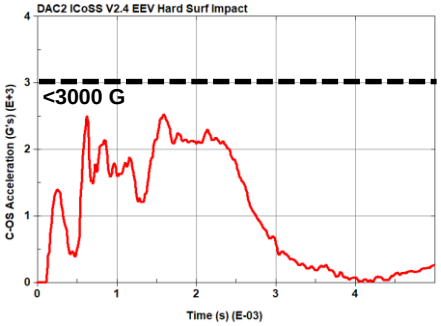


Off-Nominal Landing Scenario

- Primary Objective: Maintain sample containment (<3000 Gs at OS)
- CAM deforms to absorb energy and avoid sharp edge penetration

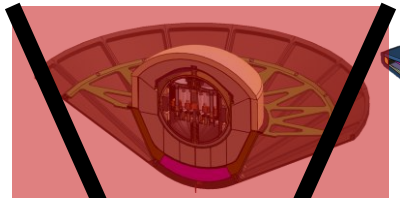


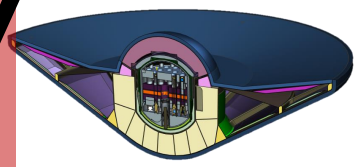


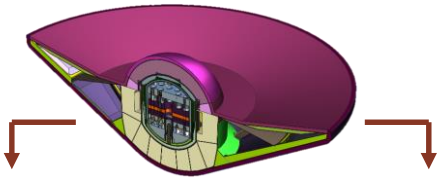


Example EEV Design Concepts

Hot Structure Concept removed from tradespace due to testability, material manufacturing lead-time, and certifiability concerns





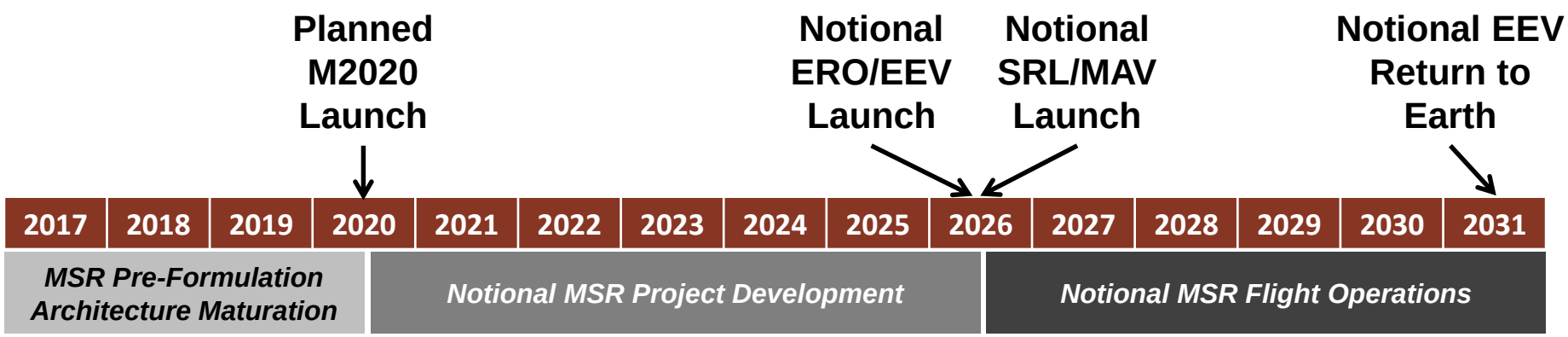


	Hot Structure*	PICA	T/DL HEEET	S/IL HEEET
Forebody TPS	3D Carbon-Carbon	PICA	Tiled HEEET Dual Layer	Single-Piece HEEET Insulation Layer
Aftbody TPS	Shuttle Tile	PICA	PICA	PICA
Approx. Entry Mass[1]	90 kg	63 kg	85 kg	80 kg
Max Diameter	1.3 m	1.3 m	1.3 m	1.3 m
Nose Radius	30 cm	30 cm	30 cm	30 cm
Entry Flight Path Angle	-20 deg	-18 deg	-25 deg	-25 deg
Peak Heat Flux[2]	1433 W/cm^2	1130 W/cm^2	1620 W/cm^2	1620 W/cm^2
Peak Entry Load[3]	130 G	122 G	173 G	173 G

**** Hot Structure design based on earlier design iteration – includes larger spherical OS design and preliminary entry state assumptions***
[1] Approximate entry mass includes mass growth allowance
[2] Unmargined 99.87%-ile value from trajectory analyses; value depends strongly on entry state (velocity and flight path angle)
[3] Unmargined 99.87%-ile value from trajectory analyses

Design and analysis on-going to refine and mature concepts – these results represent a "snapshot" in time of the designs

Summary

- MSR Earth Entry Vehicle design concept is maturing
  - High-fidelity analysis and testing advancing EEV design details
  - ELEET informing “big picture” ERO/EEV architecture trades

- Forward Work
  - Continue EEV concept design cycles to mature designs
  - Potentially down-select to single primary TPS concept by end of 2019
  - Additional testing to inform design process
    - Wind tunnel, arc jet, structures, and more