Session 6B: Drag, aerobraking and aerocapture techniques

Multi-Mission Earth Entry Vehicle Design Trade Space and Concept Development Status

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Introduction

- *The Multi-Mission Earth Entry Vehicle (MMEEV) concept was first introduced at IPPW6 in 2008 (Georgia Tech – Atlanta, GA).*
- *Development of the MMEEV concept is directed by NASA's In-Space Propulsion Technology Development Program.*
- *The MMEEV concept is based on the Mars Sample Return (MSR) EEV design, which due to planetary protection requirements, is designed to be the most reliable space vehicle ever flown.*
- *Such a concept provides a logical foundation by which any sample return mission can build upon in optimizing an EEV design which meets their specific needs.*
- *By preserving key design elements, the MMEEV concept provides a platform by which key technologies can be identified, designed, developed and flight proven prior to implementation on MSR.*
- *By utilizing a common design concept, any sample return mission, particularly MSR, will benefit from significant risk and development cost reductions.*
- *This presentation will summarize the current status of the MMEEV concept development as well as provide an overview of future work.*

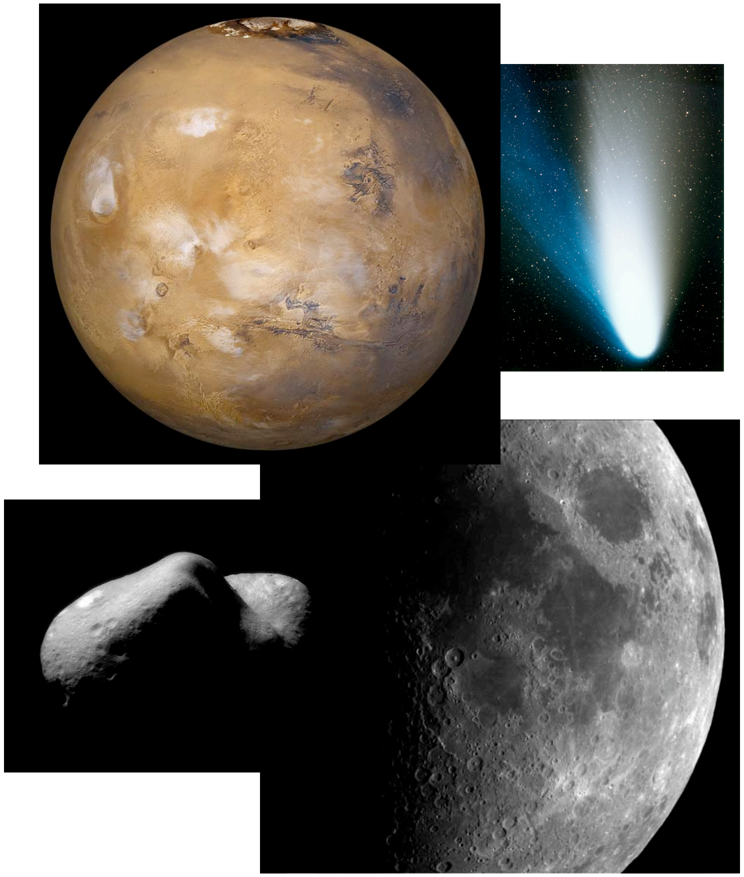
High Reliability MMEEV Design Elements

The high reliability of the MSR EEV design is rooted to two design elements which are preserved in the MMEEV concept.

- "Chute-less" design:
  - Combined reliability of parachutes and automated deployment systems ~ 10^{-3}.
  - Parachute system adds mass and increases capsule ballistic coefficient.
    - Increases aero-heating and risk to heat shield.
    - Exacerbates ground impact event in the event of parachute failure.
    - Reduces aerodynamics stability.
  - Packaging of parachute system interferes with sample transfer and placement.
  - Landing footprint is slightly increased due to greater sensitivity to winds.
  - Requires power, sensors, flight computer, sensors, pyros, etc.

- Aerodynamic stability :
  - Provides robust performance against a wide range of entry condition dispersions, as well as atmospheric uncertainties.
  - Extensive aerodynamic database development and testing has been compiled for the 60º sphere-cone forebody shape.
  - Aftbody shape provides for hypersonic re-orientation capability, even when spin-stabilized 180º backwards or tumbling.

Design Trade Space (v1)



- Several MMEEV design requirements will vary greatly across sample return missions.
  - Payload accommodations :
    - consider payload masses between 5 and 30 kg
    - assume spherical volume with fixed density
    - vary vehicle diameter from 0.5 to 2.5 m
  - Entry conditions (inertial) :
    - entry velocities between 10 and 16 km/s
    - entry flight path angles between -5° and -25°
- MMEEV performance is evaluated across the trade space in several areas of likely interest to sample return missions.
  - Total vehicle mass (at entry)
  - Configuration
  - Aeroheating
  - Impact dynamics

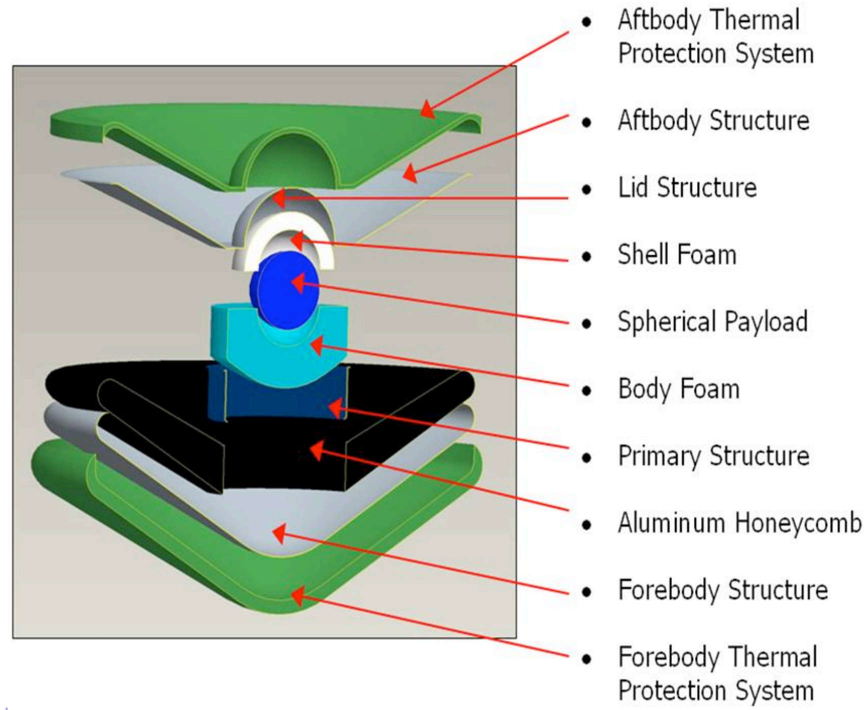
Since each individual sample return mission may have a unique set of performance metrics of highest interest, the goal is to provide a qualitative performance comparison across the specified trade space. From this, each sample return mission can select the most desirable design point from which to begin a more optimized design.

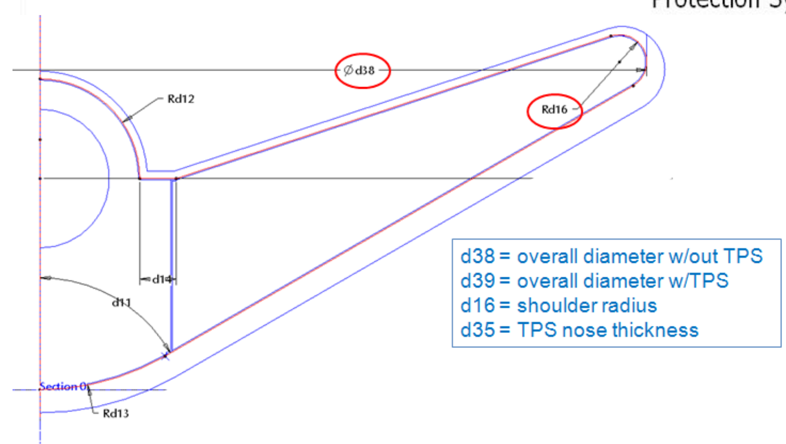
Parametric Vehicle Model

- The MMEEV concept utilizes a simplified parametric vehicle (CAD) model which can be easily scaled across the full range of vehicle trade space parameters.
- The parametric vehicle model (v1) inputs are the payload mass and overall vehicle diameter.
- The scaling behavior is defined by specified relationships determined through past experience, analysis, and/or mission specific requirements, for example:

  d16=0.03125*(d38+d35*1.5)-d35/2

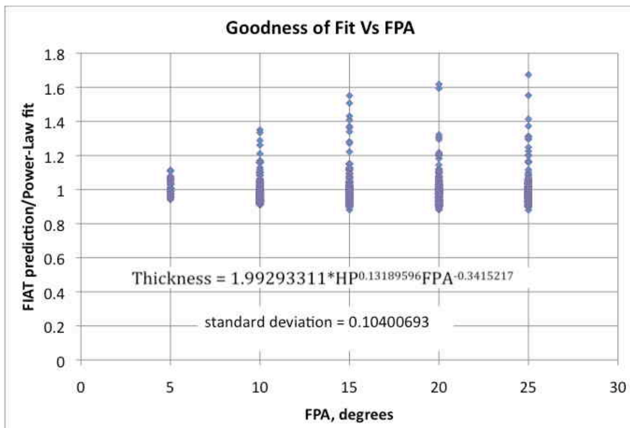
- The MMEEV parametric model was used to determine the mass properties of the vehicle (without forebody TPS), across the entire vehicle trade space, for use in the MMEEV performance simulation.

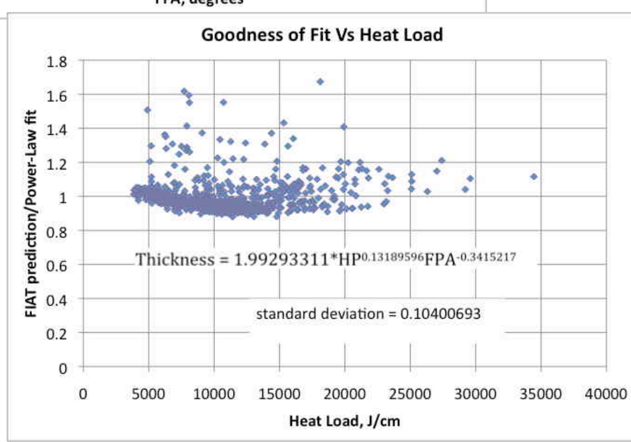




Forebody TPS MER

A Mass Estimating Relationship (MER) model for a candidate forebody TPS material was created to size the TPS as a function of the vehicle (e.g. Ballistic Coefficient) and trajectory (e.g. entry conditions).





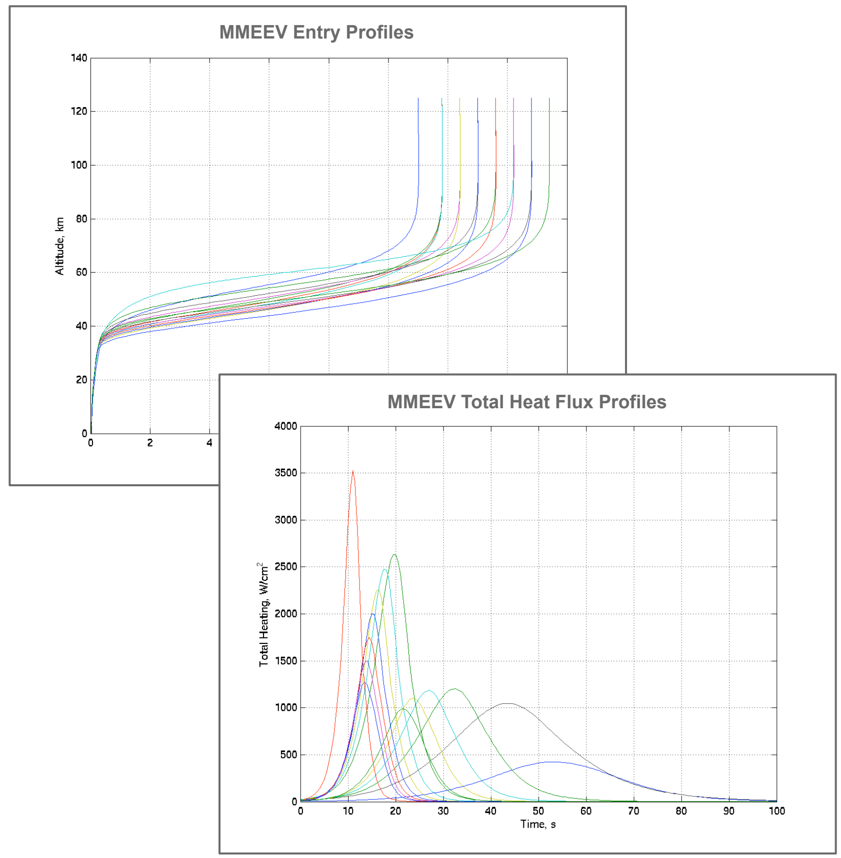
- First MER developed for Phenolic Impregnated Carbon Ablator (PICA).
- The MMEEV aeroheating environment was estimated across the entire mission and vehicle trade space.
  - 840 trajectories total – of these approximately 120 trajectories had no recession and were not used as part of the correlation
- Correlation developed for TPS thickness based on FIAT modeling of TPS response at the forebody stagnation point.
- Constraints of an adiabatic back wall and maximum back wall temperature of 250°C.
- PICA TPS MER model validated against FIAT modeling results from Stardust and Galahad (New Frontiers 3 Step 1 Proposal)*.

** Maddock, R., et. al., "An Application of the Multi-Mission Earth Entry Vehicle: Galahad", IPPW7 (Poster Session), Barcelona, Spain, 14-18 June 2010.*

MMEEV Performance Simulation

With the modularity of POST II and the large number of inputs available, the simulation software has been updated to evaluate the MMEEV performance across the entire trade space.

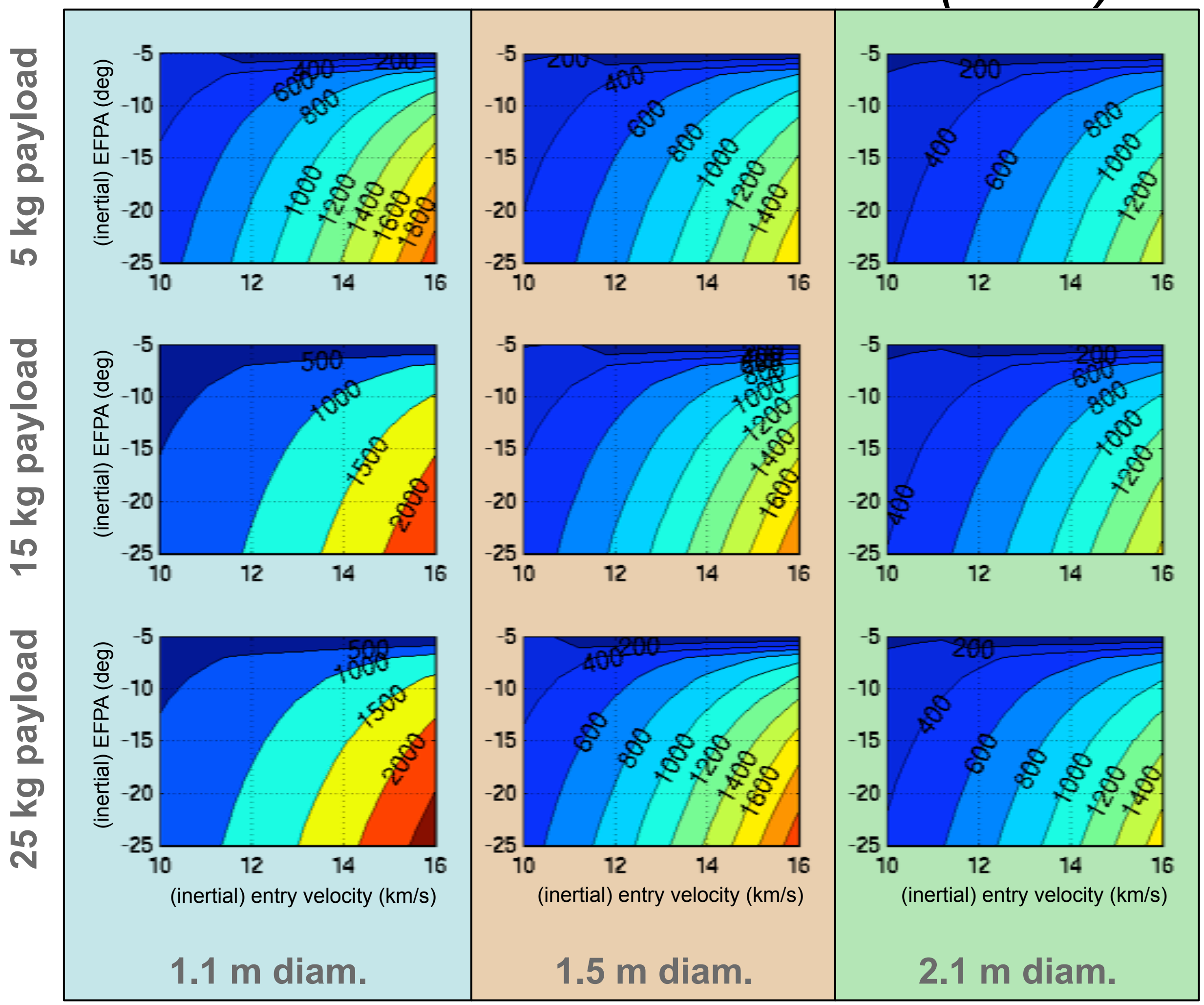
- Atmosphere Model and Winds
  - EarthGRAM09
- Aerodynamics and Aeroheating*
  - covers free-molecular, hypersonic, supersonic, transonic, and subsonic regimes
  - includes all relevant ground testing data
  - convective (cold-wall) heat flux
  - radiative heat flux
- Vehicle
  - size and reference areas
  - mass properties (parametric vehicle mass model and TPS MER)
- Other project unique models
  - simplified 1D impact dynamics using energy balance



** Trumble, K., Dyakonov, A., and Fuller, J., "Multi-mission Earth Entry Vehicle Aerodynamic and Aerothermal Analysis", IPPW7 (Poster Session), Barcelona, Spain, 14-18 June 2010.*

Sample of v1 Performance Summary

MMEEV Maximum Total Heat Flux* (W/cm^2)



* Aeroheating calculations for entry velocities > 14 km/s may be unreliable due to flow ionization which is not accounted for here. Additional analysis in this area is planned.

Trade Space and Model Development

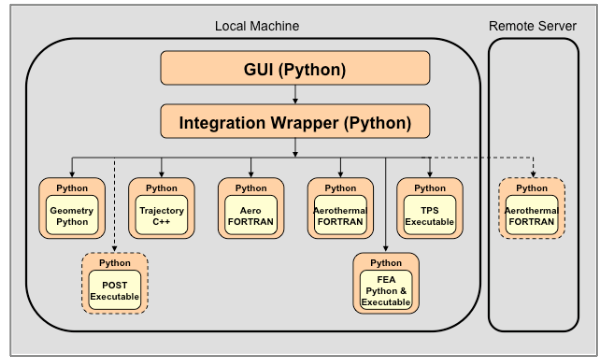
This is simply the first step in the development of the MMEEV performance models and tools. Many updates and enhancements are already planned for future versions.

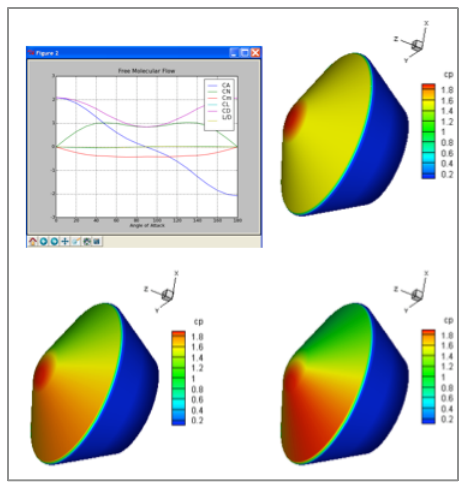
- The mission and vehicle trade space will be continuously modified (contracted / expanded) based on inputs from mission studies as well as ongoing analysis and determination of what configurations are feasible versus unattainable do to physical or performance limitations.
- Updated vehicle model.
  - modify/add configuration scaling rules and relationships as required
  - expand payload trade space to include mass density variations as well as volume envelope
  - include higher fidelity impact dynamics model currently under development at the Georgia Institute of Technology* for use in scaling impact foam thickness
  - develop additional TPS MERs
    - cover full range of forebody and aftbody heating environments
    - include enthalpy estimates to determine hot-wall heat flux
    - include ionization effects on flow properties at higher speeds
    - estimate transition to turbulent flow
  - include primary structure sizing model
- Develop thermal (soak) model.
- Integrate MMEEV models into the EDL "Quicklook" Tool.

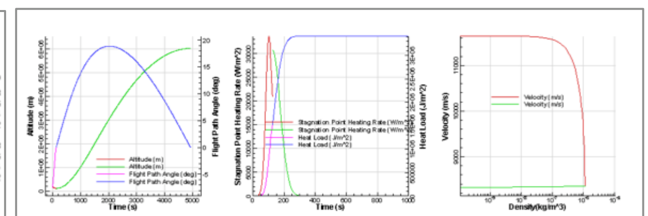
** Bauer, N., Tanner, C., "Earth Entry Vehicle Impact Analysis", IPPW7 (Poster Session), Barcelona, Spain, 14-18 June 2010.*

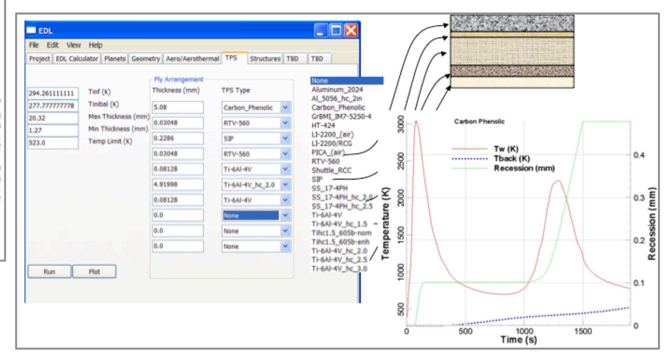
EDL "Quicklook" Tool

- A prototype EDL system analysis tool has been developed for missions to celestial bodies with atmosphere (Venus, Earth, Mars, Jupiter, Saturn, Titan, Neptune, and Uranus).
- Python, a platform independent language, is used for tool integration as well as GUI.
- Includes modules for:
  - Vehicle Geometry/Mass
    - Python-based script
    - CAD/ProE interface definition underway
    - mass model interface (ProE output, Excel, etc.) underway
  - Trajectory
    - simple 3DOF implemented
    - POST II implementation underway
  - Aeroynamics
    - DACFREE implemented
  - Aerothermal
    - Simheat implemented
    - Latch/Unlatch will be included
  - TPS sizing
    - FIAT implemented
    - MER utilization implemented
  - Structural Finite Element Model
    - NASTRAN implemented









Ongoing MMEEV Activities

ISPT is also actively working and/or has plans to work in several other areas critical to the successful completion of the MMEEV objectives.

- Aerodynamics testing throughout the flight regime (hypersonic, transonic and subsonic) using both wind tunnel and ballistic range facilities.
  - Used with CFD to validate aerodatabase model.
- Materials properties testing of impact foams in support of the development of the impact dynamics model.
- TPS materials testing.
  - Carbon Phenolic has been identified as the most likely material for use in MSR.
  - Effects of Micrometeoroid and Orbital Debris (MMOD) damage.
- Vehicle-level systems engineering; how best to integrate these new technologies into a working system.
- Identification and support of a first flight application opportunity.
  - If not available through NASA Science Mission Directorate (SMD) or Exploration Mission Directorate (EMD), development of a dedicated flight test will be pursued.
- Other MSR focused development.
  - Dust Mitigation and Vehicle Sterilization

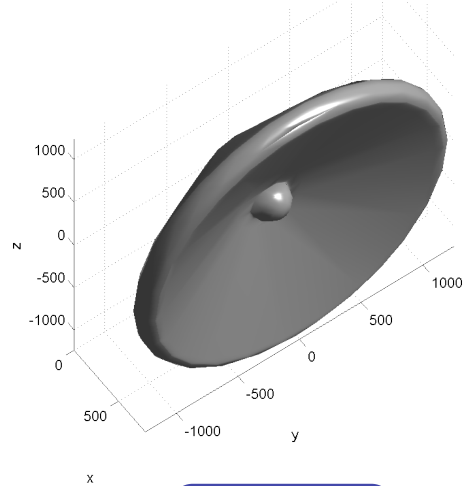
Summary

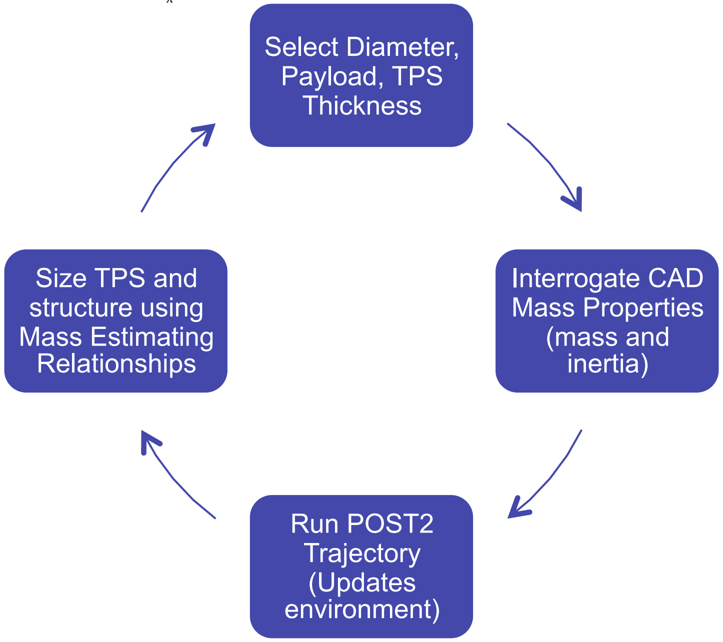
- The vast experience with the Mars Sample Return Earth Entry Vehicle design has laid a very strong foundation for the development of a very reliable EEV which can be used for various sample return missions.
- The fundamental principles of a chute-less design and aerodynamic performance were identified by MSR as keys to providing a highly reliable EEV system.
- The MMEEV provides a flexible platform by which technology development and flight test experience can be applied (either as cross-feeding or feed-forward), reducing both risk and cost for all sample return missions, particularly MSR.
- With the support and direction of NASA's ISPT Program, the MMEEV development has a strong plan forward to help identify and develop key technologies needed to return samples from across the solar system safely to Earth.
- In the process, a very capable and flexible design tool will be developed to add any sample return mission in understanding the design and performance of an EEV across their particular set of mission and payload trade considerations.

Backup Slides

Parametric Mass Model

- There are three mass components in the MMEEV simulation:
  - Vehicle structure mass including payload (kg)
  - Forward TPS mass (kg)
  - Aft TPS mass (kg)
- The parametric CAD model is used to create tabular mass property data by varying payload mass, diameter, forward TPS thickness, aft TPS thickness and TPS material type
- By iterating on required TPS thickness subject to the heat load indicator from the trajectory, TPS mass can be sized to suit the needs of the mission environment





Program to Optimize Simulated Trajectories II

- POST II is a generalized point mass, rigid body, discrete parameter targeting and optimization trajectory simulation tool originally developed in the 1970's for Space Shuttle Program. It has become an industry standard and has been transferred and/or utilized by hundreds of organizations in government, industry, and academia.
- NASA Langley Research Center and the Atmospheric Flight and Entry Systems Branch (AFESB) has used POST II extensively to perform Entry, Descent, and Landing (EDL) simulations for planetary exploration.

POST II has been flight validated on several missions.

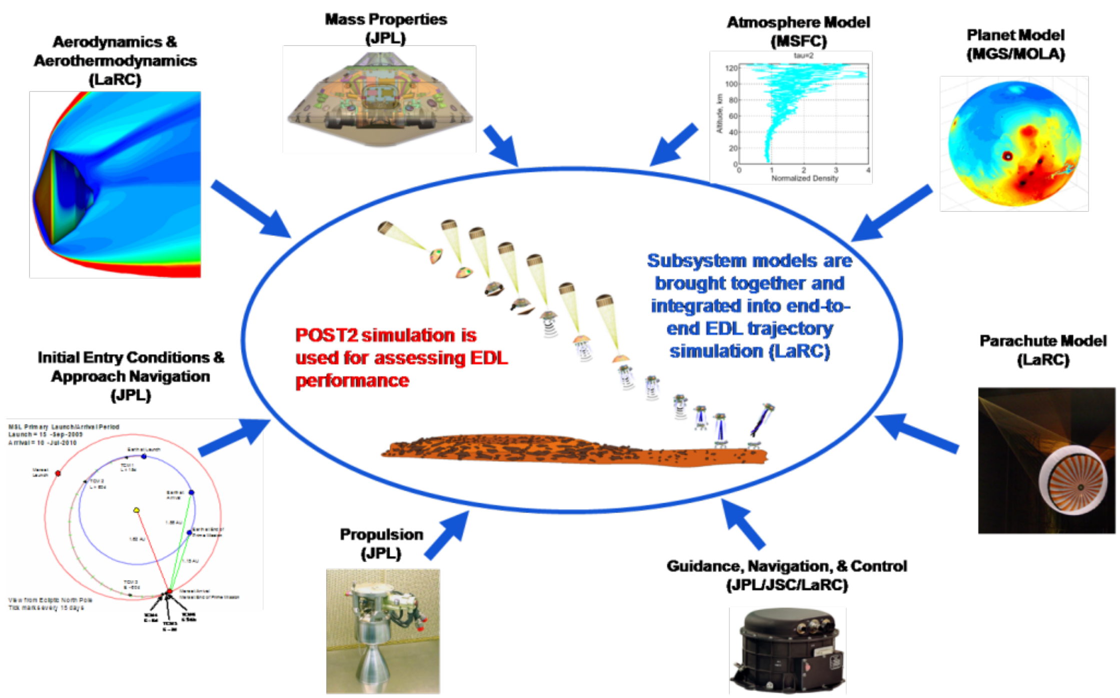
- *Mars Exploration Rover, Genesis, Stardust, X-43 (Hyper X), Huygens Probe, Mars Phoenix Lander, and many others*

POST II is currently being used on several flight projects.

- *Mars Science Laboratory, Orion, Ares, Launch Abort System, and many others*

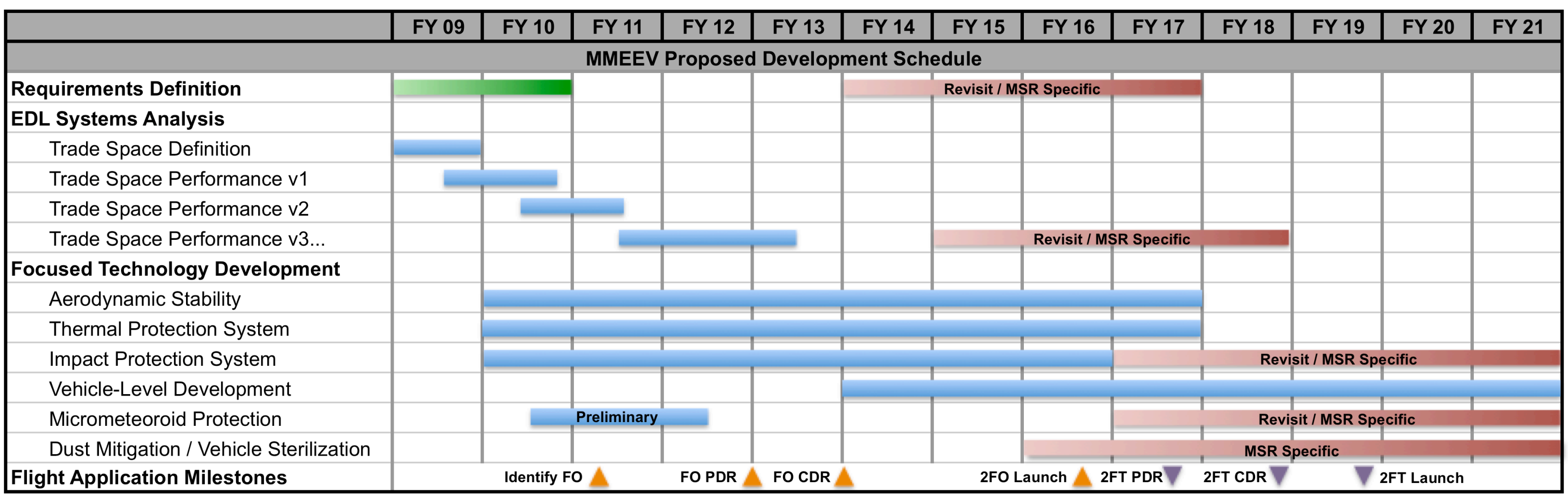
POST II has been used for numerous system studies of ascent, entry, and other space vehicles.

- *including launch vehicles, air-breathing propulsion systems, aerocapture, aero-gravity assist, and aerobraking*



MMEEV Development Plan

- The recommended MMEEV development plan was constructed to support key technology readiness for a first flight application as early as 2012-2013 (TRL6).
  - includes aerodynamic stability and TPS technologies
  - impact protection technology development would be possible to level needed for flight opportunity
- If an SMD or EMD mission opportunity is not available, a dedicated flight test can be used to ensure MMEEV readiness for a MSR flight opportunity as early as 2022.
  - Would also incorporate vehicle-level development technology, driven significantly by the sample containment system likely required for MSR.
- Focus on other MSR specific technologies can be given after a successful application of the MMEEV design concept.



FO = Flight Opportunity (or Flight Test), 2FT = secondary / backup Flight Test