11th International Planetary Probe Workshop: Pasadena, California, USA, June 15th – 20th 2014

# A Structural Concept Study for Planetary Probes and Sample Return Vehicles

**Scott Perino* and Javid Bayandor**
*Crashworthiness for Aerospace Structures and Hybrids (CRASH) Lab*
Department of Mechanical Engineering
Virginia Tech

**Jamshid Samareh and Sasan Armand**
*NASA Langley Research Center*
Hampton, VA

*PhD Candidate

## Objective

Develop a parametric finite element structural dynamics analysis methodology to enable rapid assessment of future atmospheric entry probe configurations for multiple missions and to facilitate sizing for launch and entry loads. Integrate the method into the system analysis M-SAPE tool[1]

## Background of Entry Probe Concept

1998: Entry probe concept was first envisioned for MSR[2] and called an Earth Entry Vehicle (EEV).

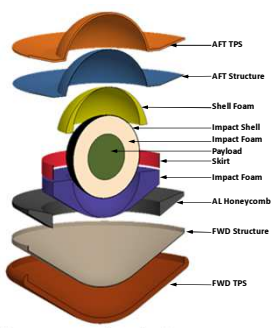
2002: First experimental impact test of the probe's impact absorber conducted at LaRC[3]

2004: EEV presented at IPPW [5]

2013: Parametric and automated structural dynamics FEM analysis and sizing tools developed and validated[6]

## The Atmospheric Entry Probe Concept

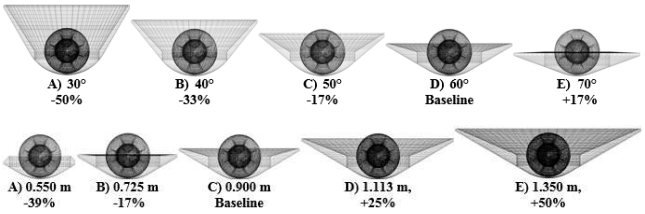
- Probe is launched into space and reenters with a payload into Earth or other planetary body
- Aerodynamically stable ballistic reentry design with no parachutes or retrorockets
- Design is flexible, passive, and reliable: Suitable for reduced risk planetary probe and sample return missions
- Potential use for entry at Earth, Mars, Venus, Uranus, etc.




**A possible entry probe design for the MSR mission[1]**

## Parametric Structural Dynamics Analysis Method

- NASTRAN FEMs are 'built' in seconds within Patran using a script written in the PCL code language
- Geometry, material properties, load and boundary conditions, mesh grids, and analysis controls all parametric
- Automated launch and reentry dynamics analysis: Inertial, frequency response, acoustic, and reentry loads
- Rapid parametric studies now possible: Cone angle, vehicle diameter, payload mass, TPS density, elastic modulus, and structural thickness investigated
- Successfully automated the FEM process that previously could take days to generate each data point using traditional GUI model generation methods




**Results of automated build process for various cone angle and vehicle diameter FEMs**

## Results

•Parameters varied from -50% to +50% of baseline values where possible

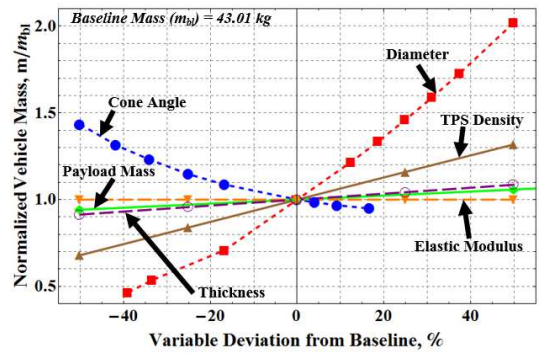
•136 analyses conducted on 34 unique vehicle configurations

•Automated method: Computationally limited → 3 h - 3 days
Manual method: Humanly limited → 1 - 2 months

**Baseline Parameter Values**

| Geometry | | Mass | | Materials | |
|---|---|---|---|---|---|
| Cone Angle | Vehicle Diameter | Payload | Bottom TPS | Elastic Modulus | Thicknesses |
| 60° | 0.9 m | 5 kg | 34.78 kg/m$^2$ | 70 GPa | 2 - 3 mm* |

*Each sub-component of the primary structure has a different thickness. For the parametric analysis, all thicknesses were scaled equally.

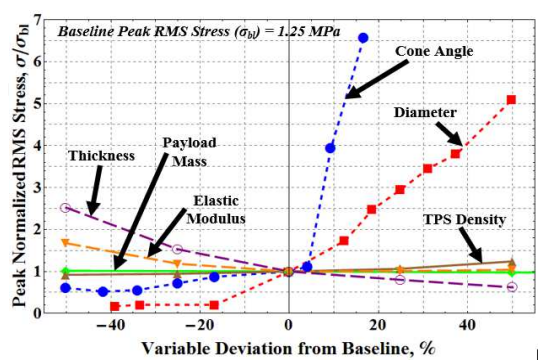



**Normalized vehicle mass plot from parametric study**

•Cone angle and vehicle diameter found to be most influential on vehicle mass and structural response

•Highest stress observed for inertial launch analysis on -50% cone angle model which had 2.7x baseline stress and only 1.4x baseline stress

•For full details see Ref. 7




**Normalized RMS stress plot from random acoustic parametric analysis**

## Ongoing Work

Full EEV impact simulations are being conducted. New energy absorber designs, analysis improvements, and full integration with the M-SAPE multidisciplinary analysis tool is underway.

## Acknowledgments

This work was funded by the NASA In-Space Propulsion Technology Program (ISPT).

## References

[1]Samareh, J. A., Lou Glaab, Richard Winski, Robert Maddock, Anjie Emmett, and Michelle Munk, Parul Agrawal, Steve Sepka, Jose Aliaga, Kerry Zarchi, and Nancy Mangini, Scott Perino and Javid Bayandor, Charles Liles "Multi-Mission System Analysis for Planetary Entry (M-SAPE)," NASA TM-2014-XXXXXX In Review.

[2]Mitcheltree R., Braun R., Hughes S. and Simonsen L. "Earth-Entry Capsule for Mars Sample Return," IAF-00-Q.3.04, 51st International Astronautics Federation Congress, Rio de Janeiro, Brazil, Oct, 2-6, 2000.

[3]S. Kellas, "Design , Fabrication and Testing of a Crushable Energy Absorber for a Passive Earth Entry Vehicle," Hampton, VA, 2002.

[4]M. D. Billings, "Analytical Impact Entry Simulations of Energy-Absorbing Sample Return Earth Spheres Vehicle for a Mars," NASA, Hampton, VA, 2002.

[5]Dillman, R., Laub, B., Kellas, S., and Schoenenberger, M., "Development and Test Plans for the MSR EEV," 2nd International Planetary Probe Workshop, August 2004.

[6]S. Perino, J. Bayandor, and A. Siddens, "A Comprehensive Structural Dynamic Analysis Approach for Multi Mission Earth Entry Vehicle ( MMEEV ) Development," NASA CR-2013-218003. June, 2013.

[7]Perino, S. V, Bayandor, J., Armand, S. C., and Samareh, J. A., "A Structural Concept Study for Planetary Probes and Sample Return Vehicles," AIAA Journal of Spacecraft and Rockets, In Review, 2014.