Entry and Thermal Protection Systems Developments at NASA for Missions to Moon, Mars and Beyond

Presented by Dr. Ellerby on behalf of

Ethiraj Venkatapathy
NASA's Senior Technologist for Entry System Technology

Colleagues that contributed to the developments highlighted in this talk:
M. Barnhardt, A. Cassell, M. Cheatwood, D. Ellerby, J. Feldman, P. Gage, M. Stackpoole J. Vander Kam, P. Wercinsk and M. Wright

October, 3, 2019
International Conference on Flight Vehicle, Aerothermodynamics and Re-entry Missions and Engineering

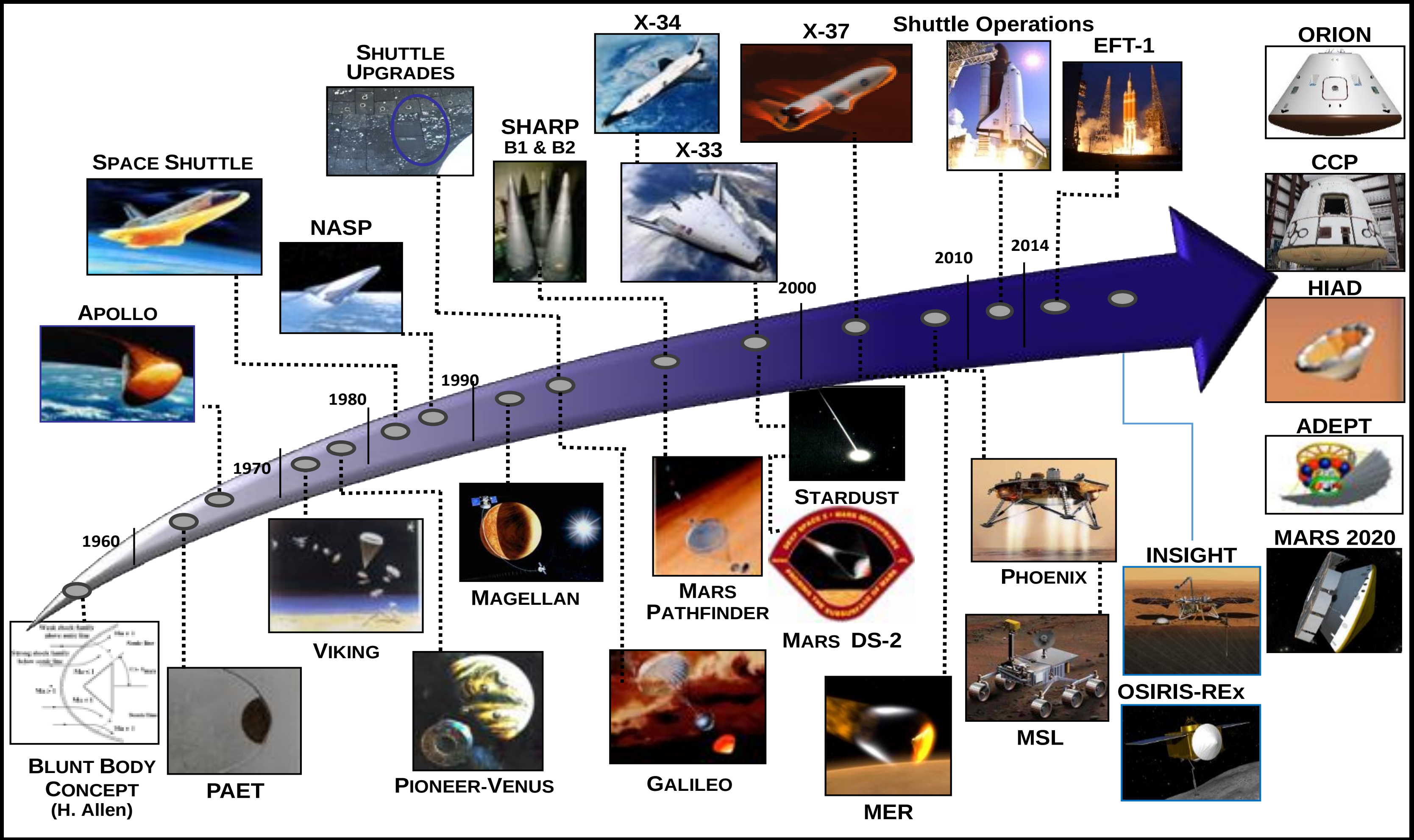
Ethiraj.Venkatapathy-1@nasa.gov

What is this talk about?

- NASA has a long history of innovations and contributions towards enabling both robotic in situ science and human missions

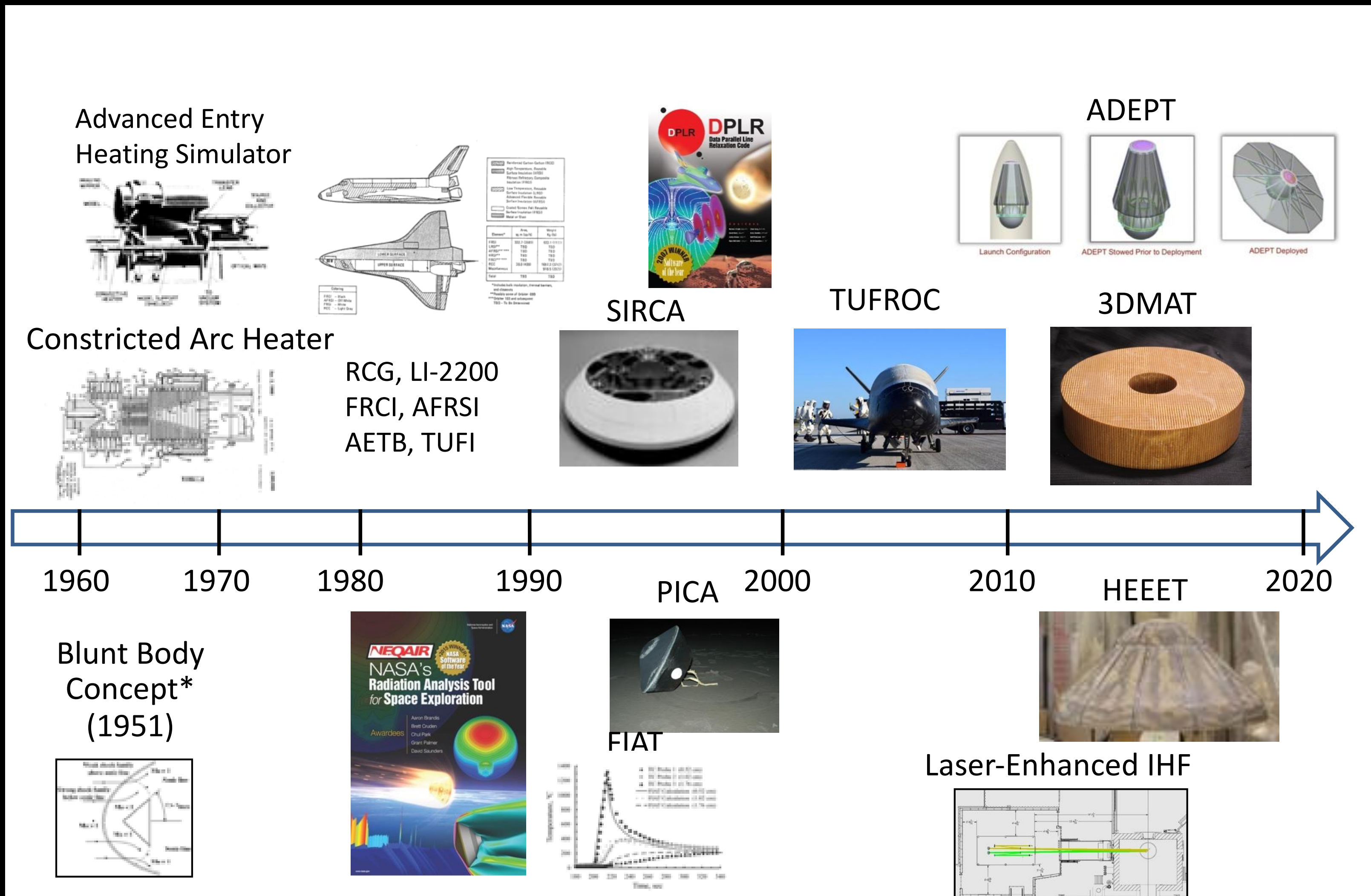
- This talk highlights some of the recent innovations in thermal protection materials and systems, and in entry technologies that are enabling current missions and laying the ground work for future scientific and human exploration missions.

Ames' Heritage and Continuing Contributions to NASA Missions

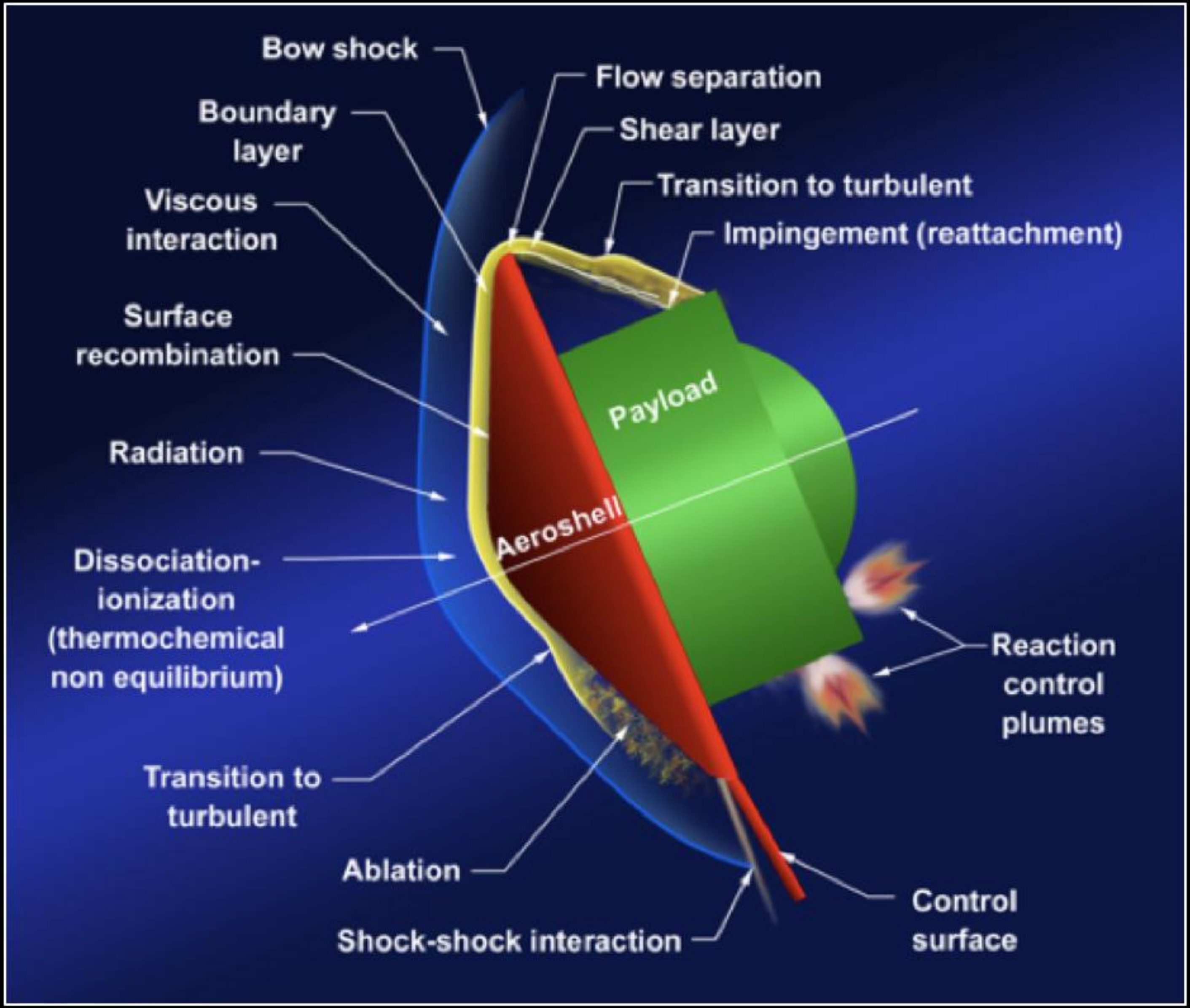


* H. Julian Allen and Al Eggers, "A Study of the Motion and Aerodynamic Heating of Ballistic Missiles Entering the Earth's Atmosphere at High Supersonic Speeds," NACA-RM-A53D28, 1953 / NACA-TR-1381, 1958.

NASA Ames Entry Systems Related Inventions



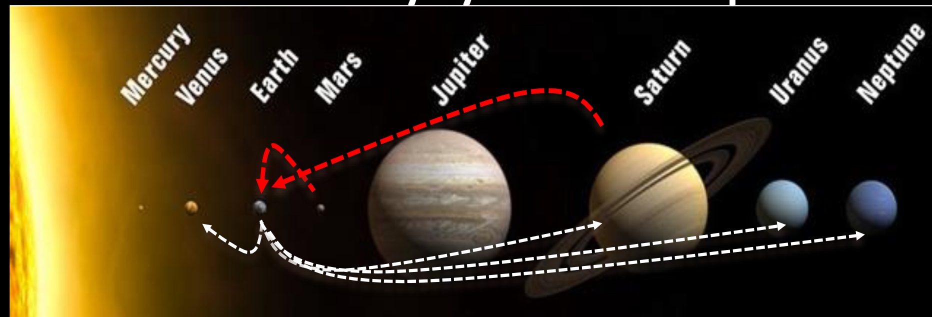
Ethiraj.Venkatapathy-1@nasa.gov



Ethiraj.Venkatapathy-1@nasa.gov

Remainder of the Talk – Highlighting Recent Innovations

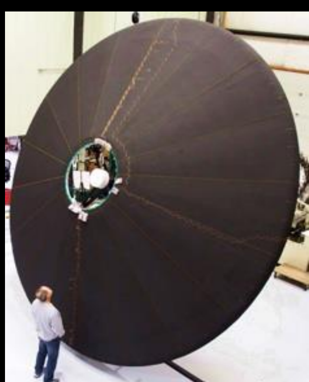
Materials and Entry System Development



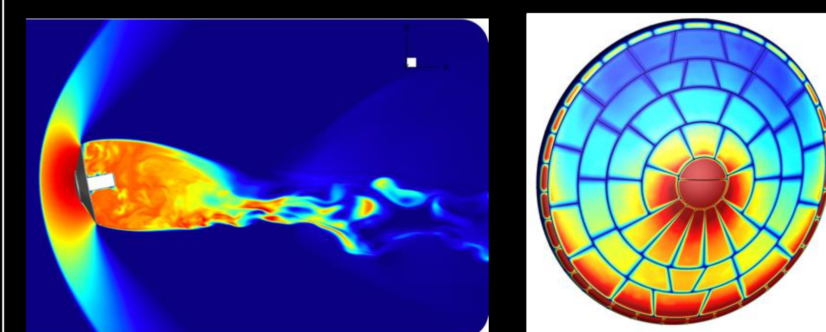
Adaptive Deployable Entry Placement Technology (ADEPT)

Heatshield for Extreme Entry Environment Technology (HEEET)

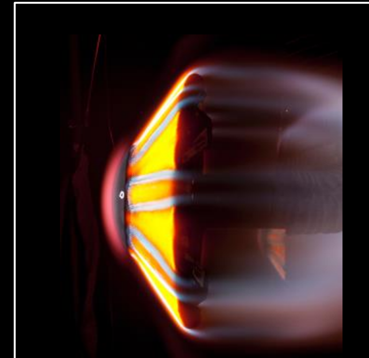
3-D Multi-functional Ablative TPS (3-D MAT) enabling Orion Lunar return



Hypersonic Inflatable Aerodynamic Decelerator (HIAD)



Modeling and Simulation of Entry Systems

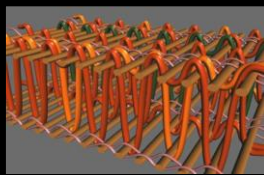


Arc Jet Testing

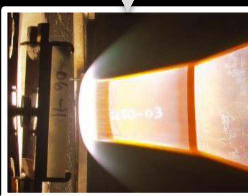
3-D Weaving

New Materials and Systems Innovation – 3-D Weaving

Enabling Human and Robotic Science Missions



Woven TPS CIF
Partnered with BRM



Woven TPS
GCDP 1st BAA

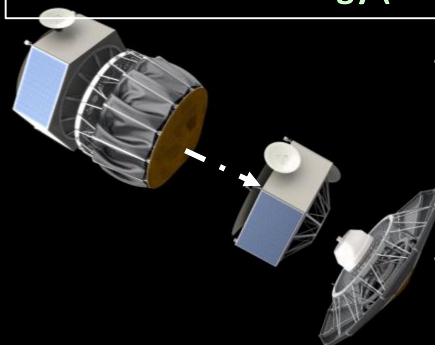
Woven TPS CIF

Multifunctional Ablative TPS (3D-MAT)
3 years and ~$3M

Enabling Orion with Lunar Capable Compression Pad

EM1 (2020) and Beyond

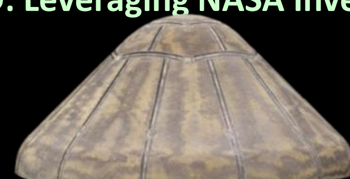
Adaptable Deployable Entry and Placement Technology (ADEPT)



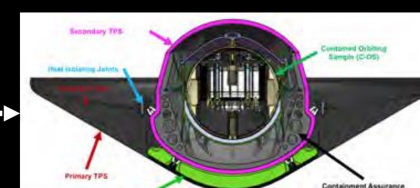
- Human Mars and Heavy Payload
- Small Spacecraft
- Drag Modulated Aerocapture

Heatshield for Extreme Entry Environment Technology (HEEET)

- Enable missions to Venus, Saturn and Ice-Giants (~ 3500 W/cm^2, 5 atm.)
- DoD: Leveraging NASA Investment



Simplex
Discovery
New Frontiers

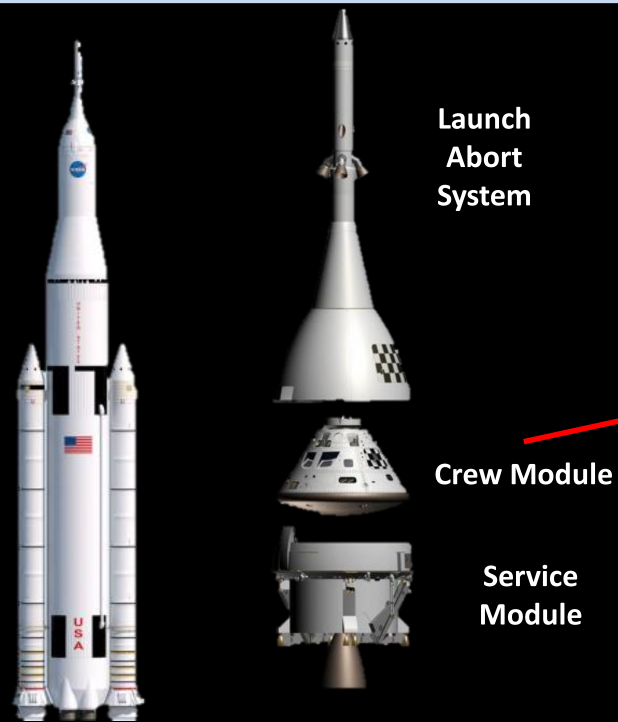


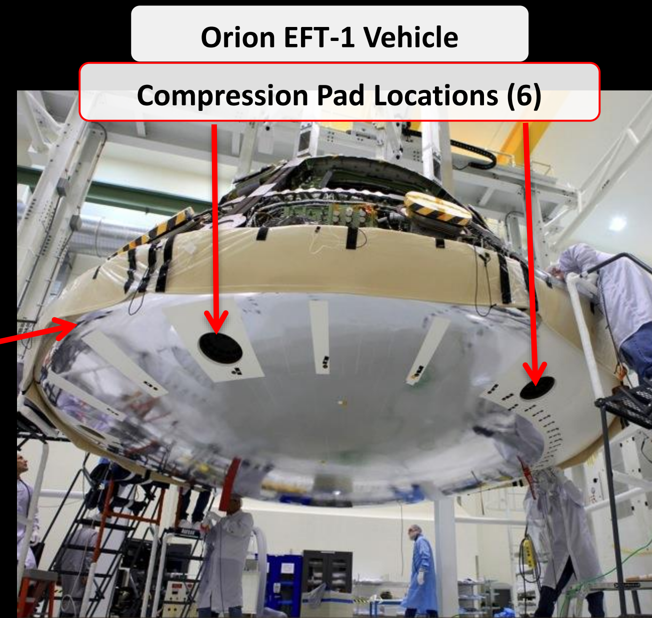
MSR EEV (2026)
(Option for Heatshield)

April 2011 | Jan. 2012 | June, 2012 | Oct, 2013 | HEEET at TRL 6 (05/19)

Ethiraj.Venkatapathy-1@nasa.gov

3-D Multi-functional Ablative TPS (3-D MAT) for Orion Compression Pad



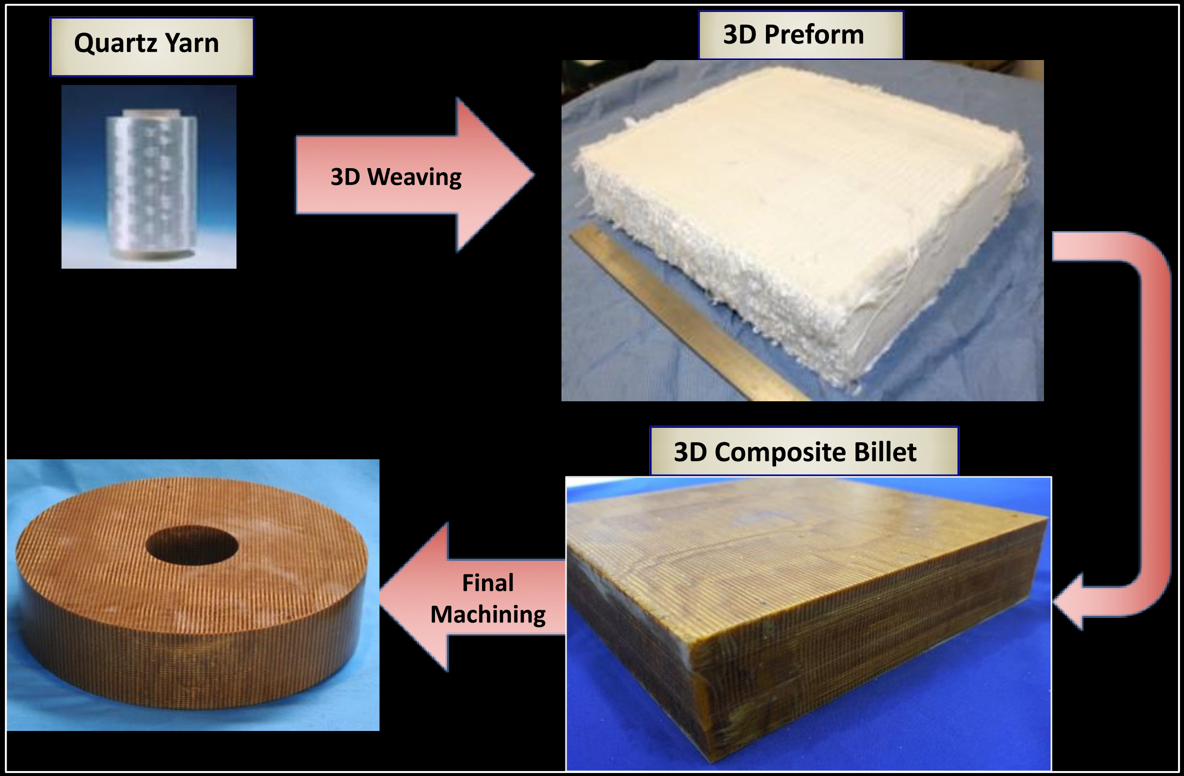


Orion compression pads are the interface between Crew Module (CM) & Service Module (SM) Required to withstand:

- Launch, ascent and in-space
  - structural loads
- Pyro-shock (CM/SM separation event)
- Earth re-entry (high heating, ablation)

EFT-1 carbon phenolic pads contained inter-laminar cracks (post-flight observation)

Technical Challenges – Weaving and Resin Infusion

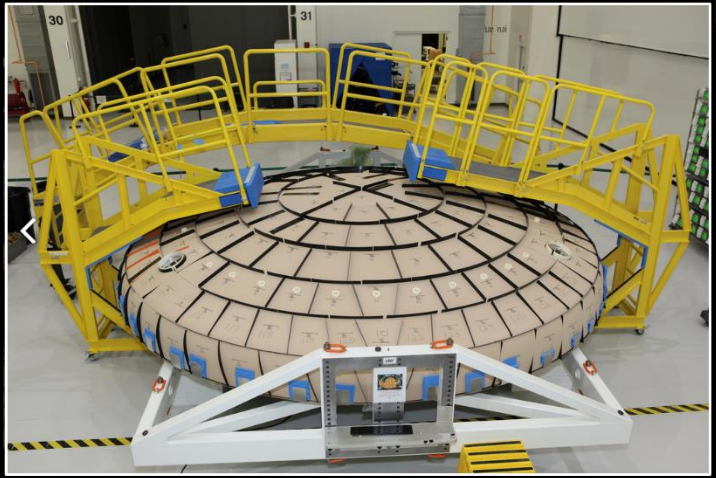


- **Challenge: Establishing partnership with industry (weaving and resin infusion), experimenting, testing, design assessment and demonstrating the capability for mission adoption in less than 36 months and $3M.**
- **3-D MAT has been adopted for 18 different locations/use on the Orion Spacecraft, in addition to the compression pad application.**

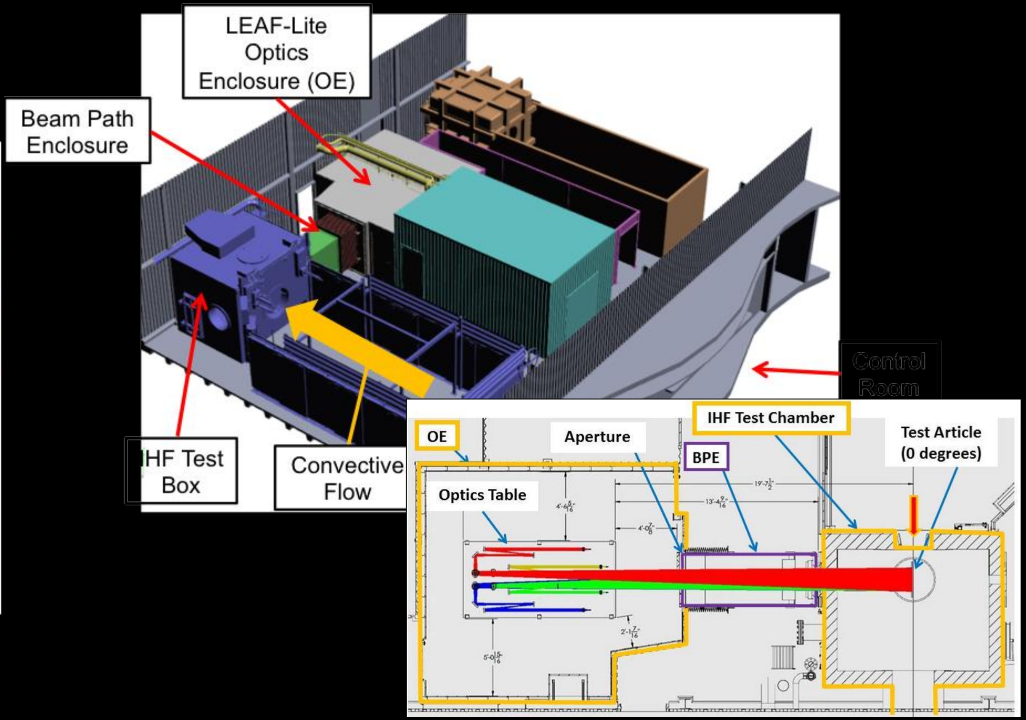
Arc Jet testing of 3-D Multifunctional Ablative TPS (3-D MAT)

Laser-Enhanced Arc Jet (IHF) Facility

- **Primarily designed for Orion Lunar Return heatshield certification**
- **200,000 W Laser power addition required major facility upgrades including modifications to the plenum, new nozzle (9"), large wedges and overall operational safety.**



Orion Block Avcoat Heatshield

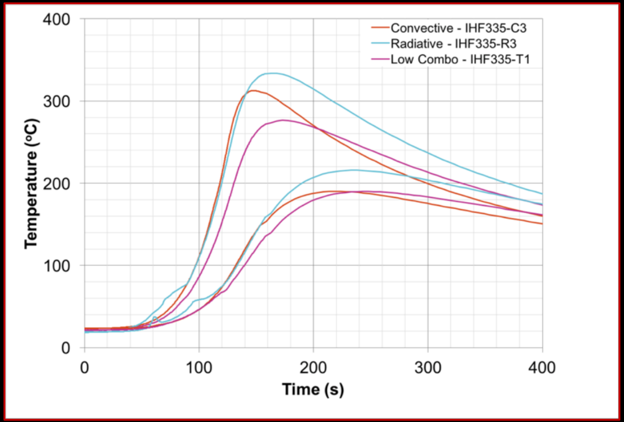


Shock layer radiation is a significant percentage of entry heating

- **Understanding the ablative TPS material/system response**

Avcoat Exploratory Results

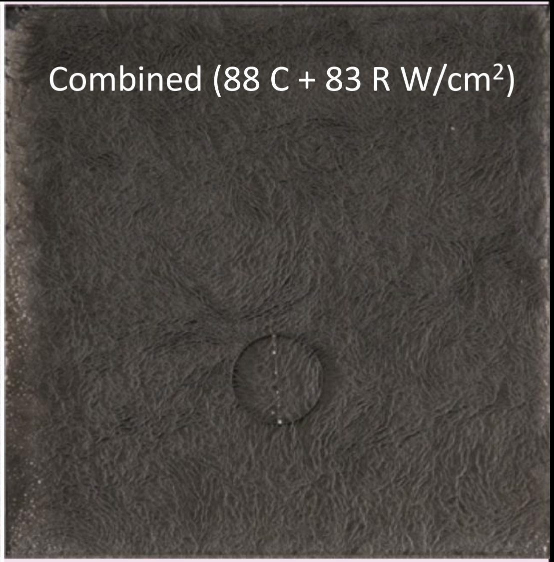
(Acknowledgement: Geoff Cushman and Antonella Alunni)



- Exploratory Avcoat test results imply differences between radiative, convective and combined heating

- Entire surface covered in glass

- Glass limited to periphery



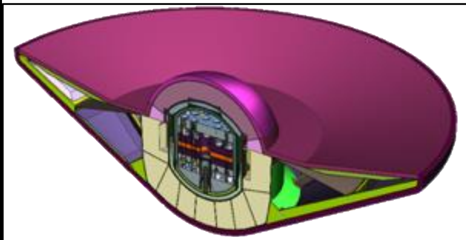
- Glass limited to periphery

Acknowledgement: Geoff Cushman and Antonella Alunni[1]

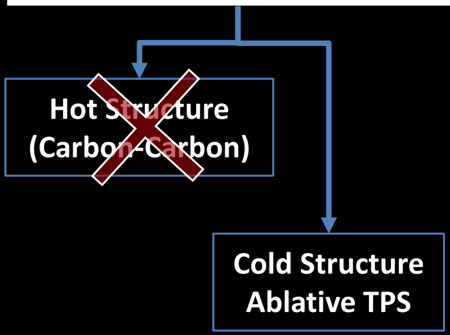
Ethiraj.Venkatapathy-1@nasa.gov

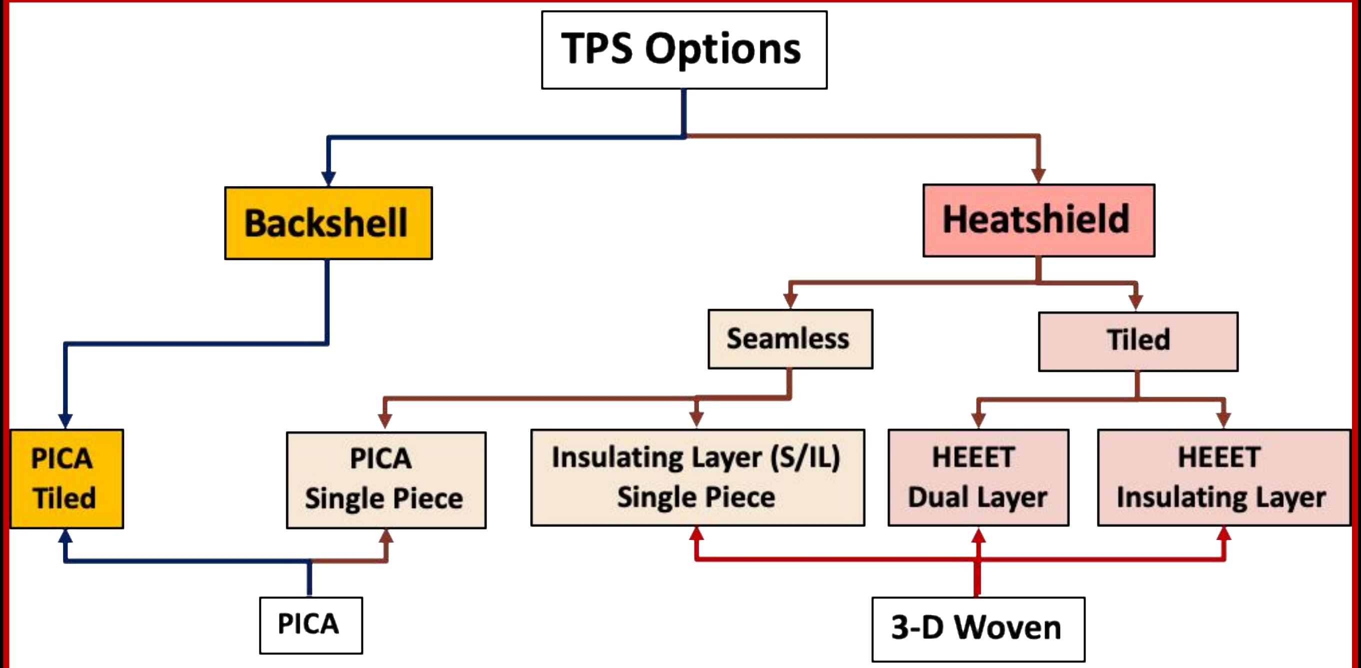
NASA Invented TPS Technologies: Mission Infusion into MSR EEV

Earth Entry Vehicle



- Passive, ballistic entry
- 1.3 m diameter, 60° sphere-cone
- 63 – 85 kg depending on TPS choice

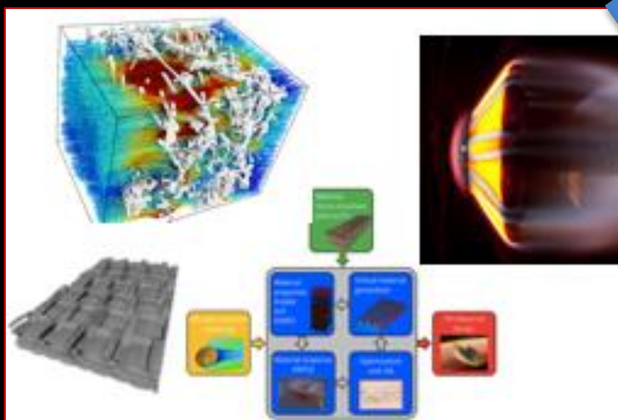


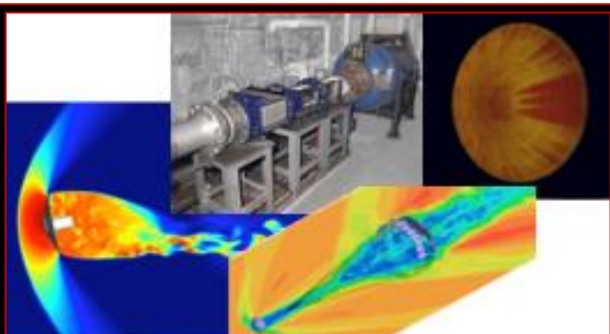


Modeling and Simulation: Core Investment Areas

Predictive Materials Modeling

Advanced models for PICA, Avcoat and woven TPS; Micro- to engineering-scale analysis tools; Detailed material characterization and model validation



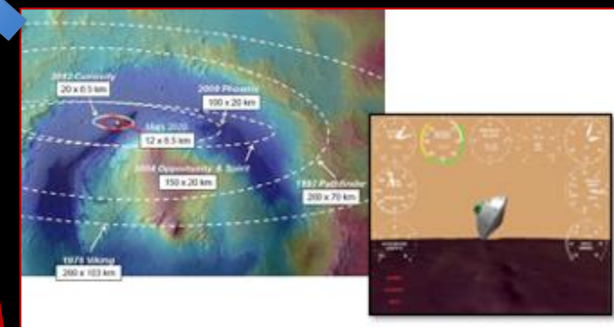


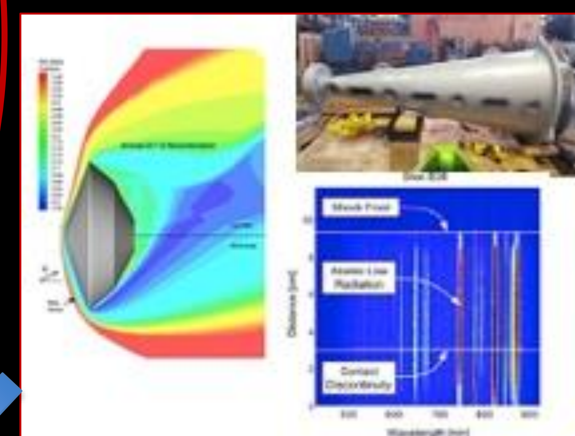
Aerosciences

Parachute dynamics; Free-flight CFD; Magnetic suspension wind tunnels; Experimental validation; Roughness, Advanced computational methods

Guidance, Navigation, and Control

Entry guidance methods to enable precision landing of large robotic and human Mars missions

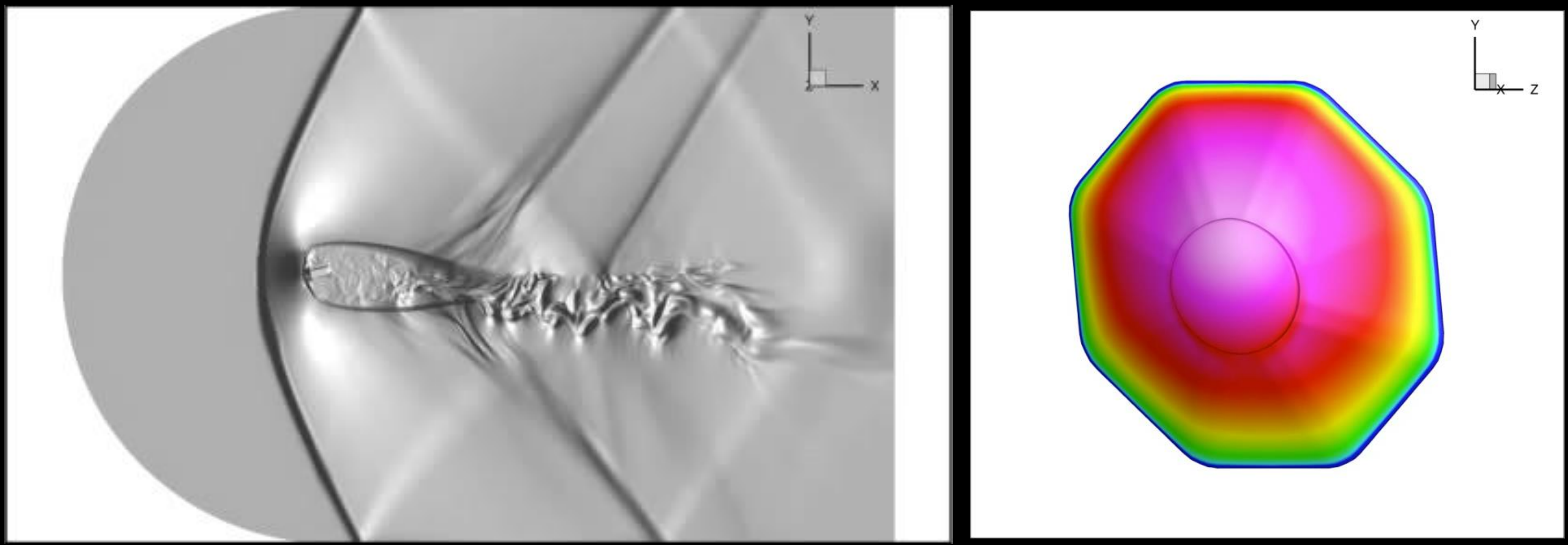




Shock Layer Kinetics and Radiation

Radiation databases and models for Earth entry and other destinations of interest; High-fidelity coupled analysis tools

Modeling and Simulation:
High Fidelity 6-DOF CFD Simulation



SR-1 Flight Trajectory Simulations - Free Flight CFD

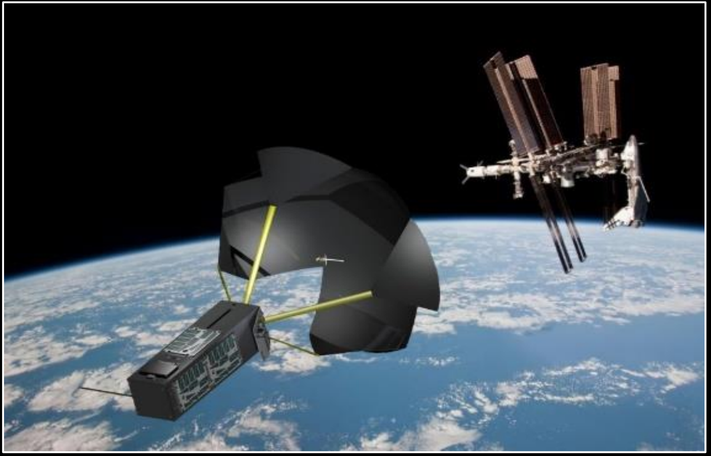
- **We first validate our simulations with ground test facility and then do our "simulations as we fly" – Advances in Computational tools allow us to do this**

Exo-Brake

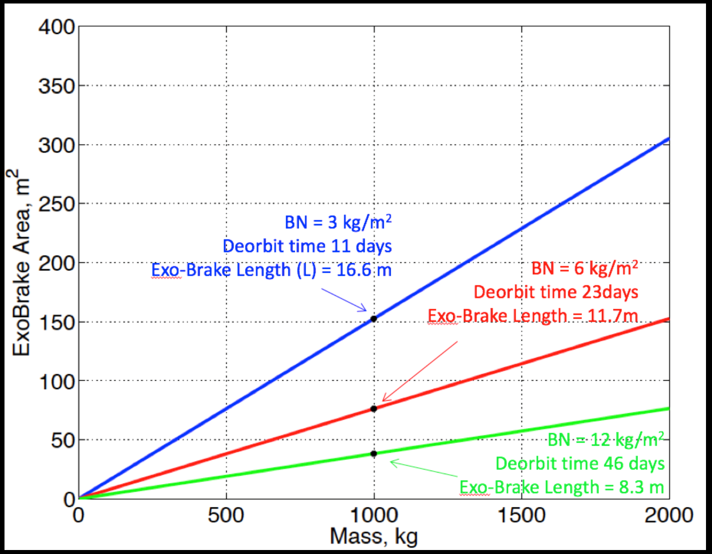
The Exo-Brake is essentially a tension device which retains its shape during the higher dynamic pressures close to entry interface.

- Enables targeted propellent-less deorbit from LEO
- Targeting accuracy (at entry interface) of 50km via predictor-corrector control, drag modulation, and timed release (200km demonstrated to date)

Exo-Brake Deployed After NanoRacks Launch



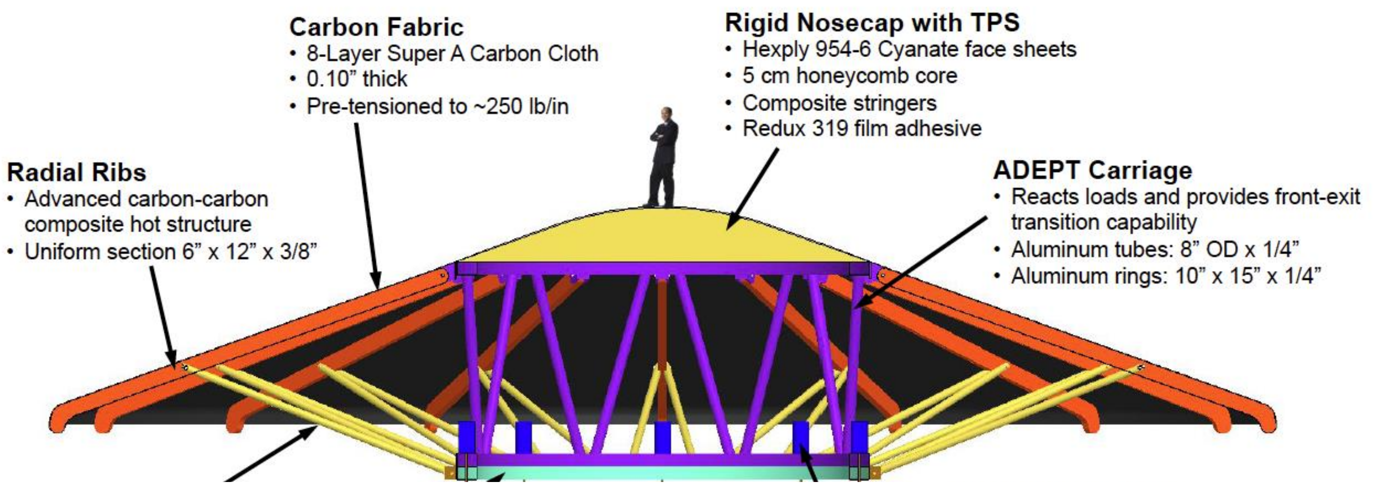
- **Flight History:**
  - Four successful deorbits from ISS (one modulated)
  - Next spacecraft (TES-7) on orbit now (scaling)
- **Potential Applications:**
  - On demand sample return, **debris deorbit**, stage separation, planetary net-landers



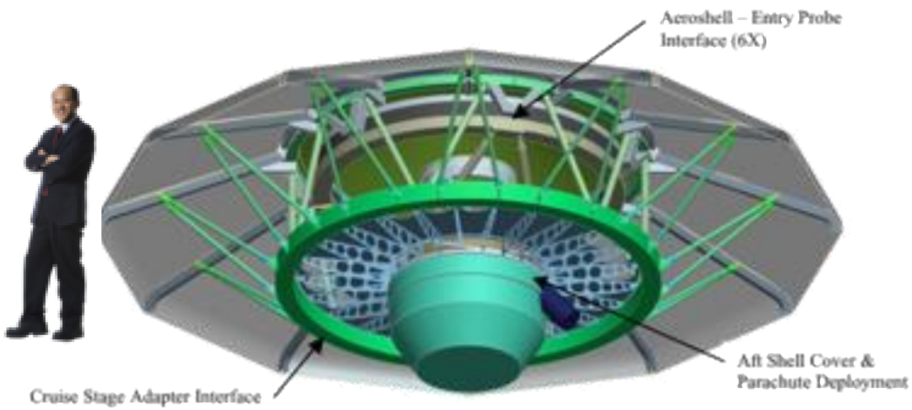
Scalability for Deorbit from 250km

ADEPT: Scalable Entry System

23m: Mars Exploration



6m: Venus Lander

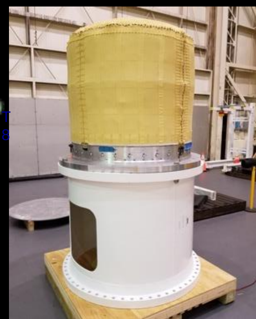


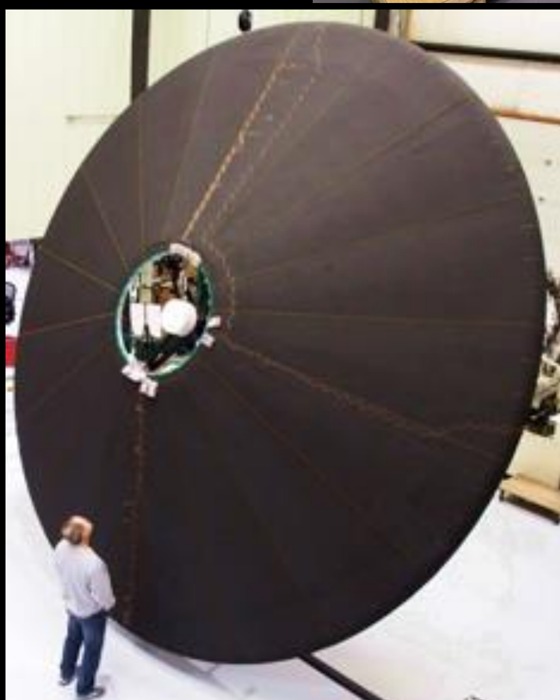
1m: "Nano" ADEPT

Inflatable: HIAD and LOFTID

(NASA Langley Leading and NASA Ames supporting)

A Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a deployable aeroshell consisting of an Inflatable Structure (IS) that maintains shape during atmospheric flight, and a Flexible Thermal Protection System (FTPS) employed to protect the entry vehicle through hypersonic atmospheric entry.





6m Inflated Entry System Flight Test Mar 2022

Concluding Remarks

- NASA's focus on science missions including Mars sample return and in-situ investigation of Ice Giants, and human missions to the Moon and Mars in the coming decades are the drivers for focused development in
  - Thermal protection materials and systems
  - Novel entry system technologies
  - Innovations in modeling and simulation
  - Improved ground and flight testing
- Some of these technologies have already been, or are close to, mission infusion, while others are making great progress.

Ethiraj.Venkatapathy-1@nasa.gov