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The Hypersonic Inflatable Aerodynamic Decelerator (HIAD) Mission Applications Study

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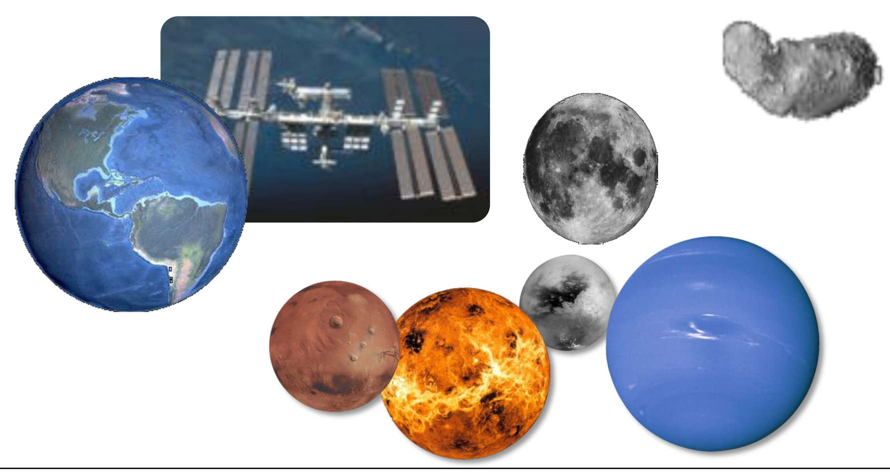
The HIAD Project

- The current state of the art for an entry system aeroshell is a rigid blunt metallic substructure with a TPS overlay
  - This is characteristically heavy and constrained by the size of the launch vehicle.
- The HIAD Project, part of NASA's Game Changing Development Program seeks to enable larger aeroshells by using an inflatable packed within the launch vehicle
  - A key benefit is increased payload to a planet's surface
- The HIAD Project is organized into 3 main elements; Flexible Sys. Dev., Advanced Concepts, and Flight Validation



Potential Applications: ISS Downmass, Launch Vehicle Asset Recovery, Earth Entry, Planetary Exploration

HIAD Mission Apps. Study Objectives

An element of Advanced Concepts is the Mission Applications Study, which has the following high-level objectives:

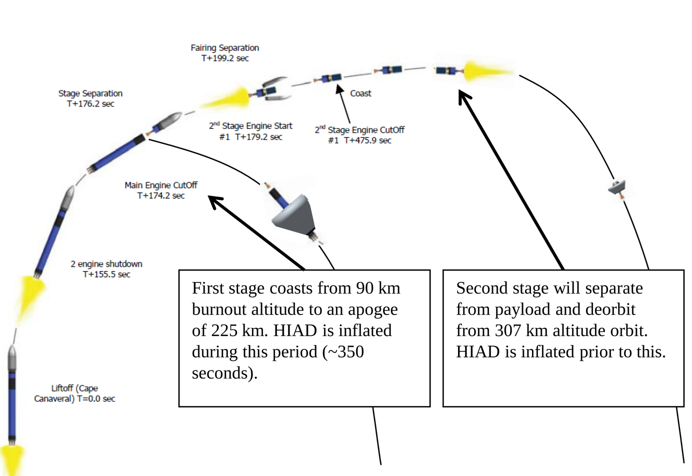
- ✓Identify improvements associated with HIAD integration within the concept of operations (CONOPS) of high priority missions
  - Reduced launch costs?
  - Increased performance margins?
  - Expanded mission potential and science return?
- ✓Provide full systems view of HIAD integration
- ✓Conduct what-if scenarios to guide future investments

Technical Approach

- The general approach is to simulate a trade space customized to each mission architecture. Typical trade parameters include:
  - Entry flight path angle
  - Entry velocity
  - Entry mass
  - HIAD diameter
- Iterate on HIAD mass in consideration of the trajectory head load and dynamic pressure
  - Utilize the Entry Descent and Landing Systems Analysis, Exploration Feed Forward mass model[1].
- Apply system constraints (e.g. heat rate limits) to identify regions of feasibility
- Select design points based on mission objectives (e.g. landing altitude)
- Perform conceptual level design of the entry system to better understand the impact of HIAD technology infusion into the concept of operations
  - Also validates and informs updates to trade-level mass models
- Revisit trade space and recommended HIAD sizing as required
- Deviations from this approach as well as additional assumptions are noted within the analysis plan of each mission investigated
- Example missions under investigation include:
  - Mars Direct Entry: Mars Southern Highlands
  - Launch Vehicle Asset Recovery: SpaceX Falcon 9

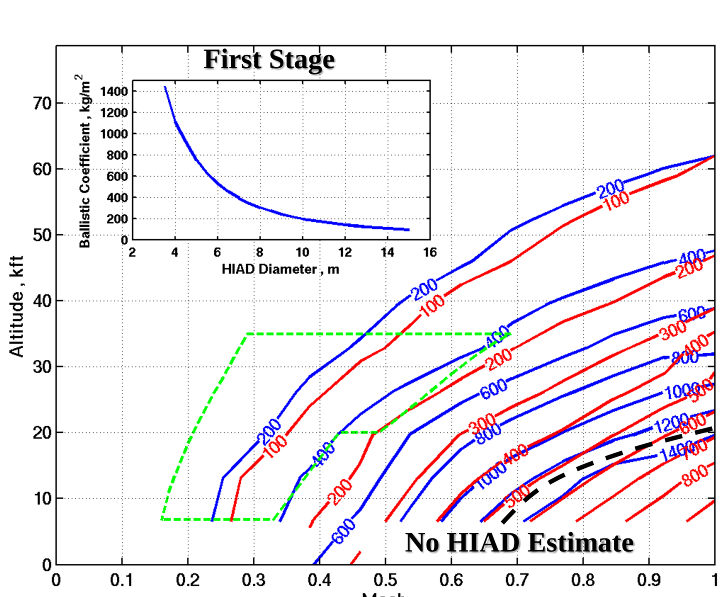
Launch Vehicle Asset Recovery

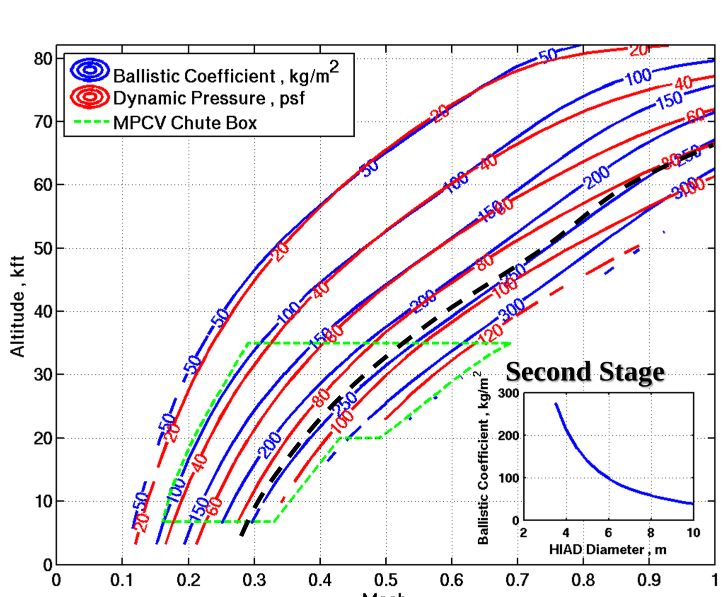
- Recovery of launch vehicle assets has the potential to reduce the overall cost of launch services while avoiding further proliferation of orbital space debris
- The Launch Asset Recovery Study investigates the potential benefits of a HIAD in recovering launch vehicle assets (e.g. first/second stage boosters and avionics)
  - Use HIAD to enable recovery by delivering to MPCV chute deploy conditions
- Booster Recovery Trade Space Parameters
  - First Stage
    - Mass of First Stage is varied from 19 to 22 Metric Tons: First Stage is 19.24 t dry
    - Initial Relative Velocity varied from 2,700 to 3,200 m/s
    - HIAD diameter varied from 3.5 to 15 m
  - Second Stage
    - Mass of Second Stage is varied from 3 to 4 Metric Tons: Second Stage is 3.1 t dry
    - Deorbit delta-v varied from 100 to 500 m/s
    - HIAD diameter varied from 3.5 to 10 m



Booster Recovery Mission Timeline [3]

- Results:





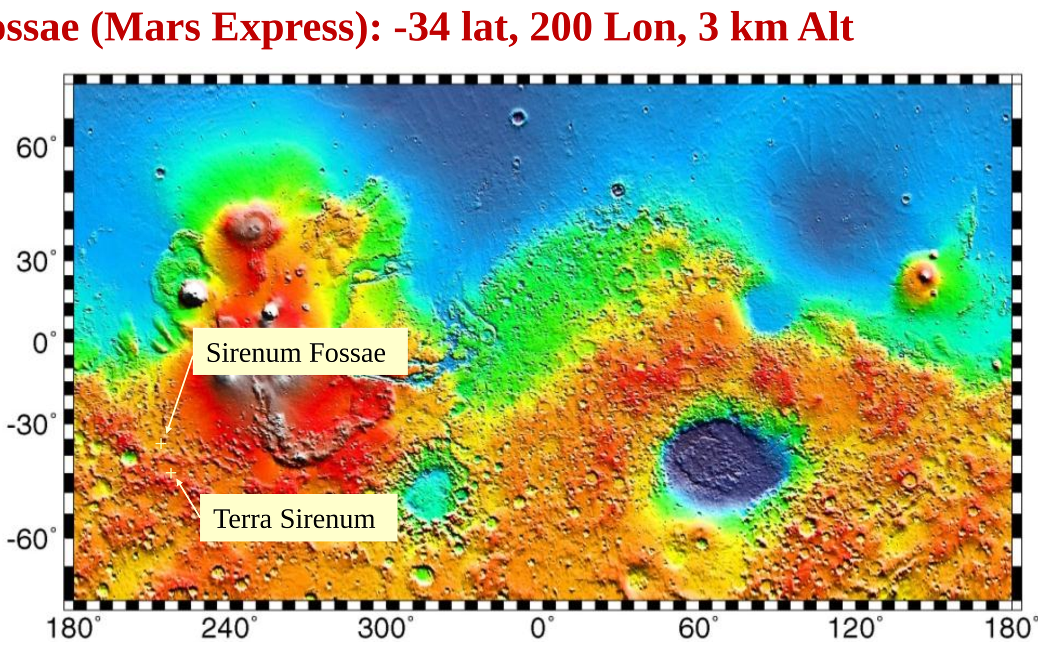
- For the First Stage, the optimal solution is a 10-m HIAD with an estimated weight of 1.5 MT (HIAD enables first stage recovery)
- For the Second Stage, the optimal solution is 6-m HIAD, with an estimated weight of 0.25 MT (HIAD provides margin to second stage recovery)

Mars Southern Highlands

- Discovery of flowing water in craters throughout the southern highlands raises interest in this potential landing region
- Potential candidate landing sites:
  - Terra Sirenum (Malin[2]): -40 lat, 210 lon, 1.5 km Alt
  - Sirenum Fossae (Mars Express): -34 lat, 200 Lon, 3 km Alt

Mars Topography

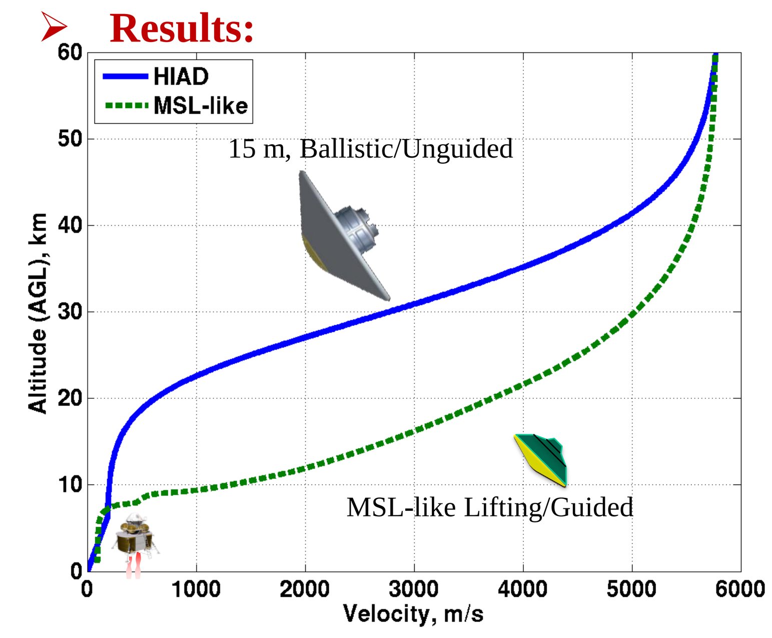
Locations above 1 km (orange, red or grey) not accessible with current CONOPS

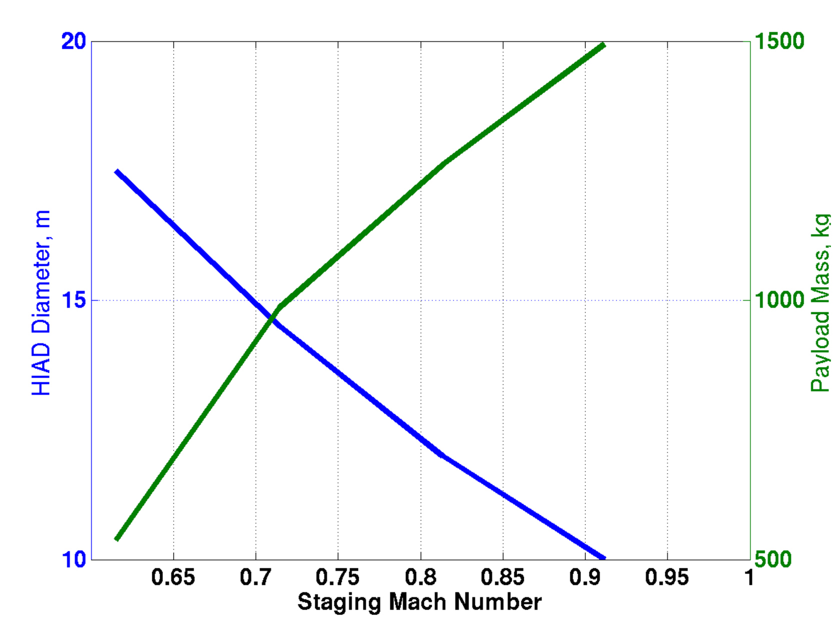


- The Mars Southern Highlands study is investigating several architectures

Architecture	Hypersonic	Supersonic	Subsonic	Status/Comments
01.01.05	HIAD	HIAD	Parachute	Small mass systems
01.01.06	HIAD	HIAD	Retroprop.	
01.02.02	HIAD	Retroprop.	Retroprop.	SRP stage to ground
01.02.05	HIAD	Retroprop.	Retroprop.	SRP separate from landing stage
01.03.00	HIAD	Parachute	-	Small mass systems, large parachute
01.03.06	HIAD	Parachute	Retroprop.	MSL-like
01.04.00	HIAD	Skirt	Retroprop.	Small mass systems, large skirt
01.04.06	HIAD	Skirt	Retroprop.	

- Architecture 01.01.06 setup:
  - HIAD straight to subsonic retropropulsion
  - MSL-class mission (3400 kg entry mass) with MSL-like component masses
  - Aerodynamic database based on High Energy Atmospheric Reentry Test vehicle development (approximately a 55 deg. spherecone)
  - Aeroheating based on Sutton-Graves and Tauber-Sutton convective and radiative heating indicators (with margins applied)
- Results:





- Staging condition drives HIAD sizing
- 15-meter HIAD to subsonic retropropulsion allows MSL-class payload to +4 km MOLA with no supersonic or parachute events
- Staging at higher Mach numbers could allow significantly more payload mass
- Landed payload mass nearly constant over landing sites investigated (0-4 km MOLA) elevation

CONCLUSIONS & OUTLOOK

- Hypersonic Inflatable Aerodynamic Decelerators have the potential to significantly enhance space and planetary exploration missions
- The HIAD Mission Applications Study is in the process of identifying and quantifying specific benefits through a full systems engineering view of HIADs within the context of high priority missions
- In the coming year, modeling and analysis performed within the HIAD Mission Applications Study will improve the fidelity of current investigations and explore additional missions, which target destinations such as Venus, Titan, and Uranus

References:

[1] Samareh, Jamshid, "Estimating Mass of Inflatable Aerodynamic Decelerators Using Dimensionless Parameters", 8th International Planetary Probe Workshop (IPPW-8), Portsmouth, Virginia, June 6-10, 2011.

[2] Malin, Michael C., Edgett, Kenneth S., "Evidence for Recent Groundwater Seepage and Surface Runoff on Mars". Science (2000) Vol. 288. no. 5475, pp. 2330 – 2335.

[3] SpaceX Space Exploration Technologies, "Falcon 9 Launch Vehicle Payload User's Guide, Rev 1", http://www.spacex.com/Falcon9UsersGuide_2009.pdf, Copyright -- SpaceX 2009.