HIgh Masses On Mars (HIMOM) – Spinoffs & Integrated Risk Reduction

NASA Space and Technology Mission Directorate Early Career Initiative Proposal

Breanna Johnson (JSC) and Sarah D’Souza (ARC)

August 4, 2022

Motivation

NASA Strategic Plan – 2022

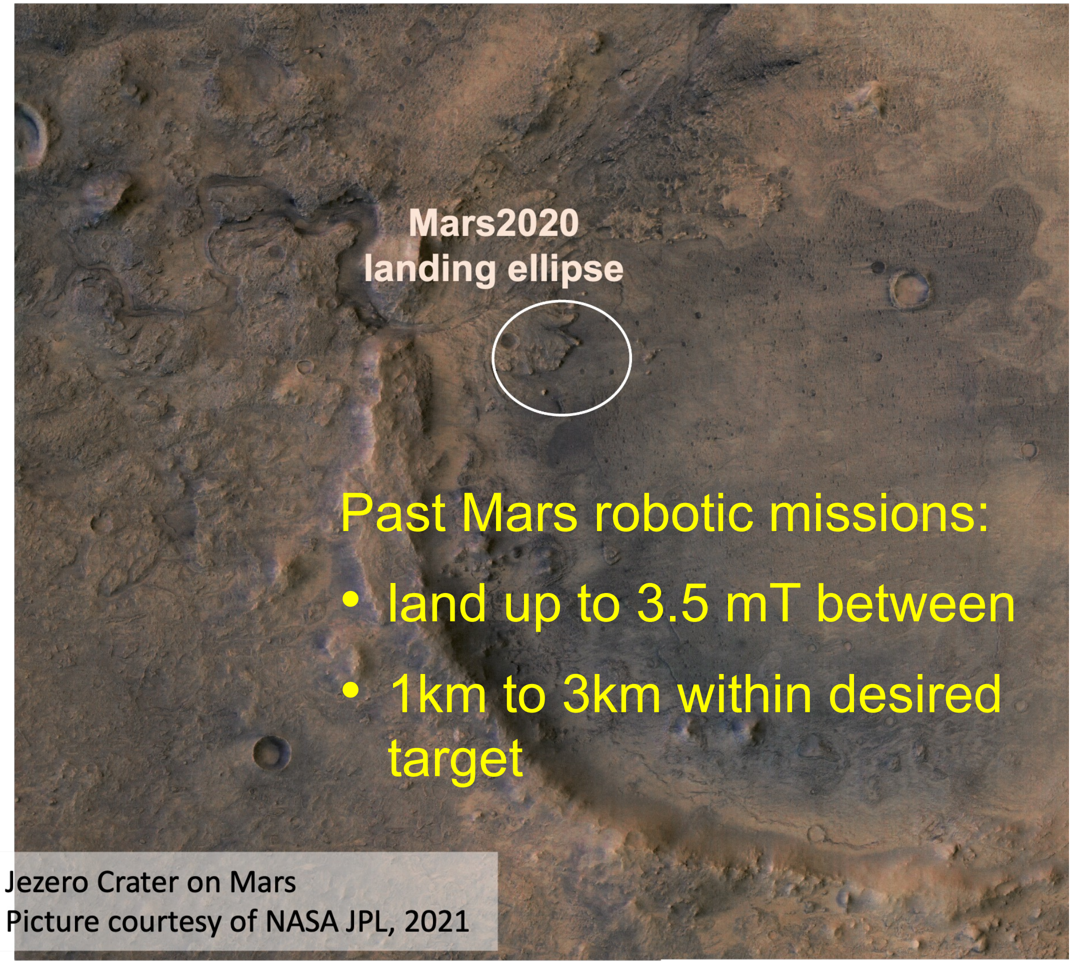
“Extend human presence to the Moon and on towards Mars for sustainable long-term exploration, development, and utilization ..... **Develop a human spaceflight economy enabled by a commercial market**”

EXPLORE MOON to MARS

Demonstrate the capabilities required for human missions to Mars and other destinations.

Need to precisely land high masses on Mars very close to desired locations and assets.

Motivation

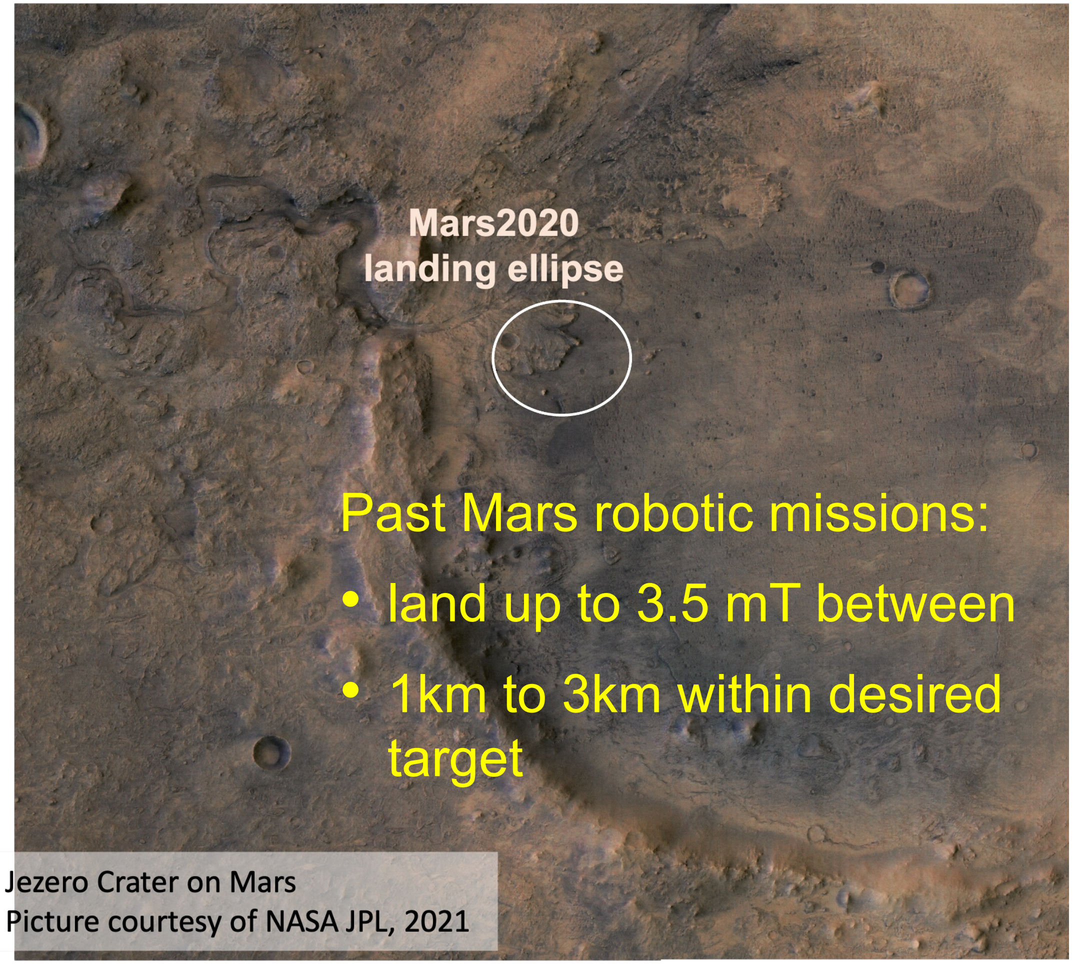


Past Mars robotic missions:

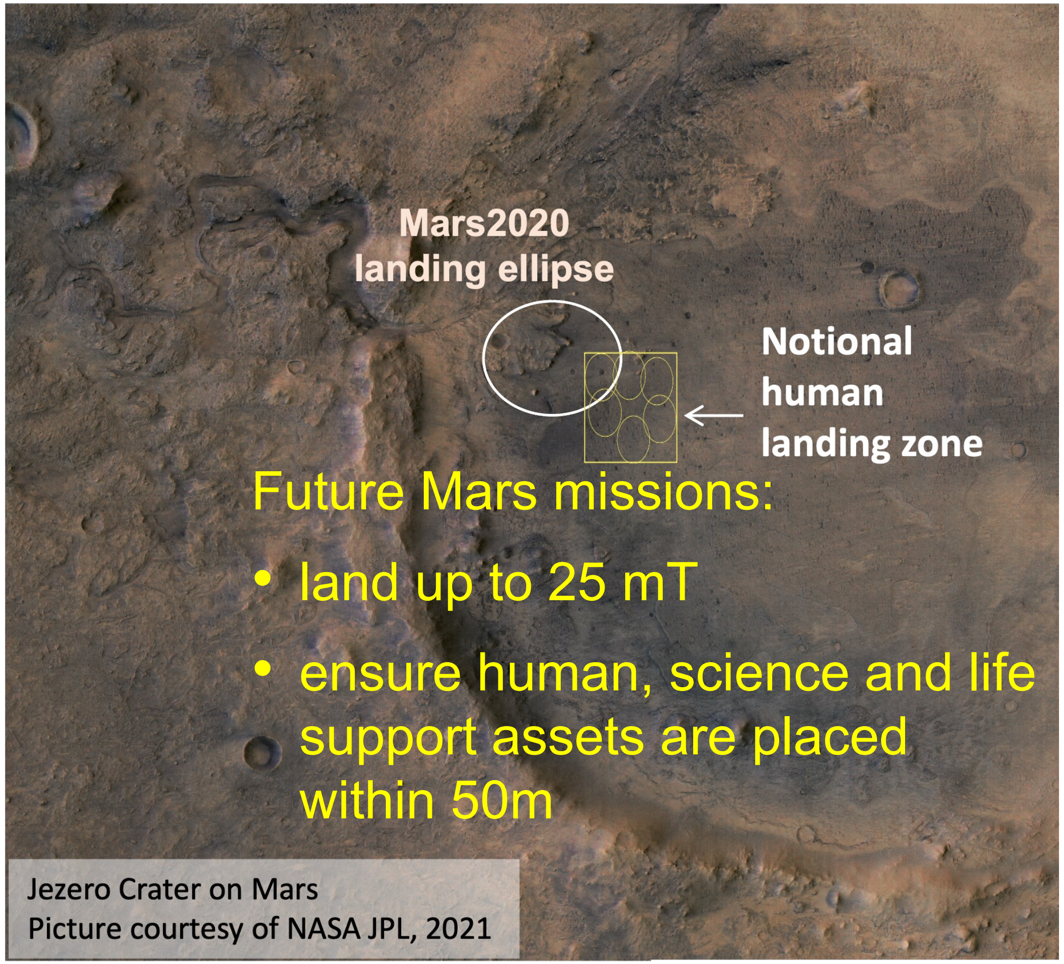
- land up to 3.5 mT between
- 1km to 3km within desired target

Jezero Crater on Mars
Picture courtesy of NASA JPL, 2021

Motivation

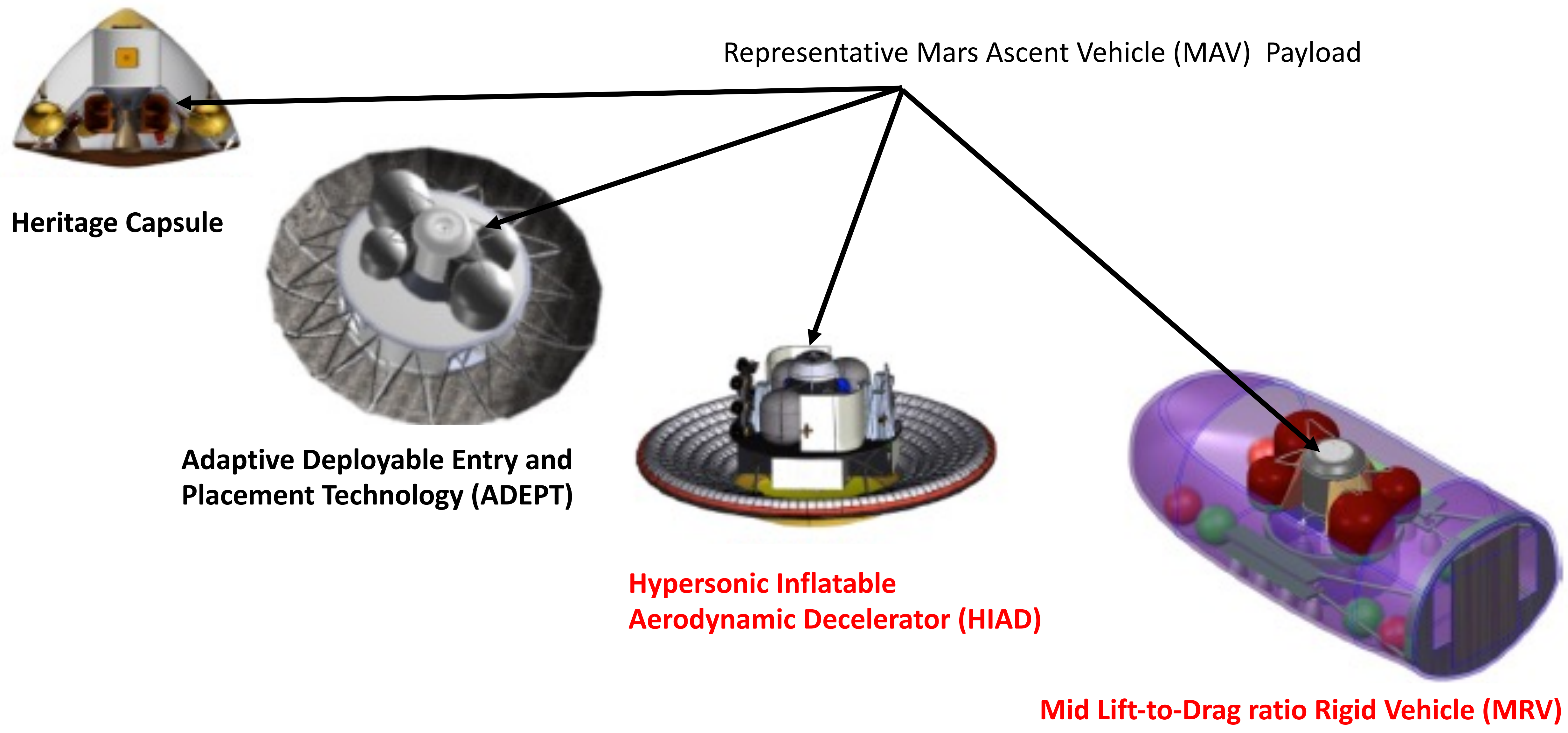


Jezero Crater on Mars
Picture courtesy of NASA JPL, 2021

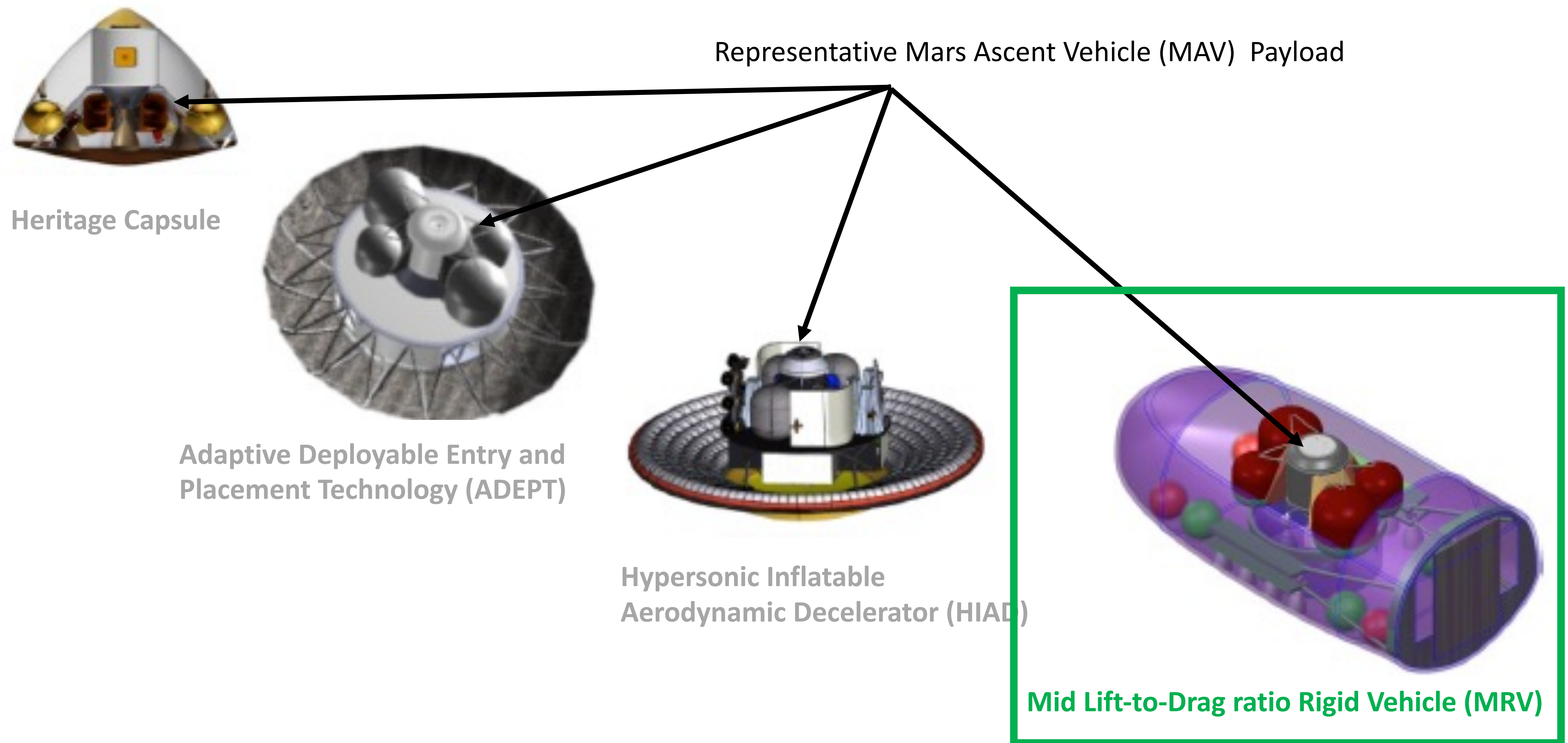


Jezero Crater on Mars
Picture courtesy of NASA JPL, 2021

NASA Human Mars EDL Architectures Explored



NASA Human Mars EDL Architectures Explored



Design Features/Benefits of Mid-L/D Rigid Vehicle

Leverage NASA Pioneered Technology

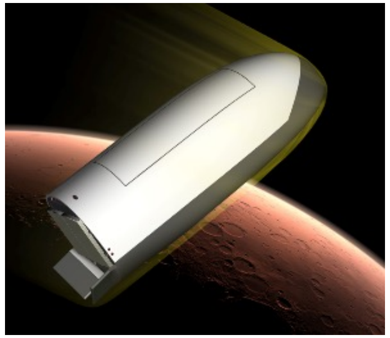
- **Minimizes need for new technology development** – similar shapes flown at Earth: X-37, ESA IXV, ICBM's, Falcon upper stage
- Blend of aerosurfaces and RCS for aerodynamic trim and bank angle flight control is a **well-established and proven technique** for rigid entry vehicles (e.g., Space Shuttle)

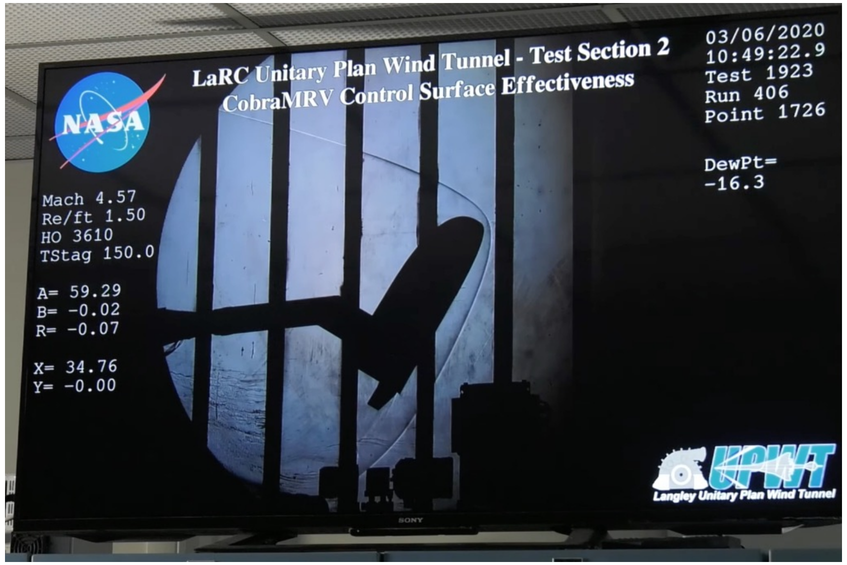
Performance Benefits

- **Provides greater trajectory control authority** to compensate for entry dispersions and optimize trajectory flexibility and environments
- Cargo bay **provides full protection of internal payload** from the aerocapture and EDL aerodynamic, thermal, and dust environments

Configuration Efficiencies

- Shape makes efficient use of the SLS payload fairing to **maximize the available cargo volume** for a rigid body vehicle
- Configuration is **scalable** for ease of ground and flight testing
- **Reduced complexity** in EDL and surface ConOps





Mid-L/D Vehicle State-of-the-Art

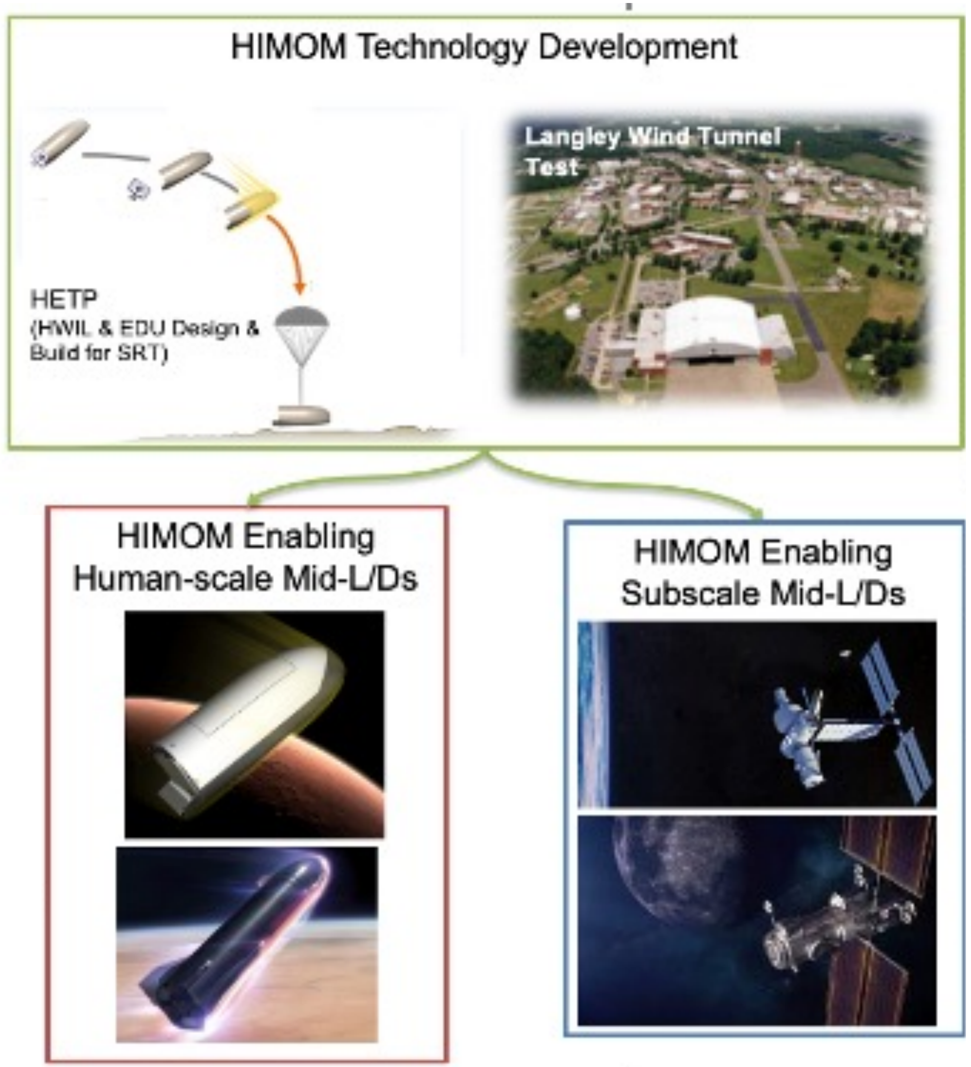
		Paper	Sub/Transonic x <= M1	Supersonic M1 < x < M5	Hypersonic flight* M5 < x < M15	Re-entry Hypersonic flight* M20 < x
lifting body		IXV, SpaceRider				✓ IXV (1/1) - shuttle guidance
	 	X33, XLV->X38	✓ X38 [B52 drop test 13km]			
		IM	✓ IM (drop test)			
		SN Dreamchaser	✓ SN (helicopter drop test, full scale) [3km alt]			
		DARPA-AF HTV2				✗ DARPA-AF HTV2 (0/2)
		[SX F9]		✓ [SX F9] (M5-6)		
		SX Starship	✓ SX Starship (1/5) (10km alt drop test)			
“stubby” winged lifting body		X37				✓ X37
		Shuttle				✓ Shuttle (133/135)

Wings vs. wing-removal bring new issues and warrant more study

HIMOM Vision

Development of a **hypersonic entry testing platform** (**HETP**) to provide direct **benefit to NASA, university, and industry** partners by providing a path to increased frequency of **meaningful test opportunities for critical EDL technologies at reduced cost, time, and complexity**, doing for for EDL, what CubeSats have done for space technologies.

Primary Deliverable



Develop **hypersonic entry testing platform** (HETP) that leverages NASA and Commercial Space ground tests, flight tests, wind tunnel testing, and appropriate fidelity models, for full range of mid-L/D vehicle scales, to drive accelerated advancement of:

- Human scale mid-L/D Entry Vehicles
- Subscale mid-L/D Entry Vehicles for on-demand small payload return

This proposal focuses on using the HETP to make **key advancements** in:

- aerodynamic modeling
- new GNC implementations
- thermal protection system (TPS) materials

HIMOM Research Objectives

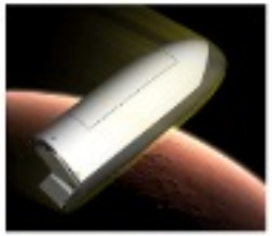
Objective	Description	Impact	SOA Link
1	**Conduct scalable integration and packaging trade studies**	(a) Identifies **minimum viability** for integrated small-scale mid-L/D vehicles for SRT. Identified **payload manifest** feeds forward into Obj. 3.	S1, S2, S3, S4
		(b) Leverages trade study results to develop a **scaled orbital trade study,** providing infusion into commercial partners' **LEO/lunar payload return** endeavors. This also enables mid-L/D vehicle use for lunar and planetary **sample return**.	

HIMOM Enabling Subscale Mid-L/Ds

HIMOM Research Objectives

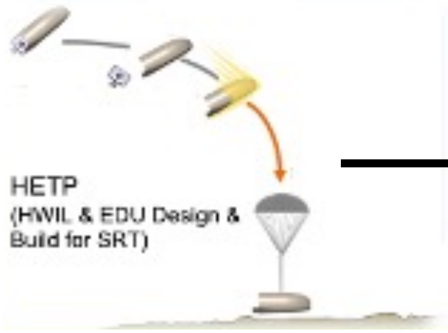
Objective	Description	Impact	SOA Link
1	**Conduct scalable integration and packaging trade studies**	(a) Identifies **minimum viability** for integrated small-scale mid-L/D vehicles for SRT. Identified **payload manifest** feeds forward into Obj. 3.	S1, S2, S3, S4
		(b) Leverages trade study results to develop a **scaled orbital trade study,** providing infusion into commercial partners' **LEO/lunar payload return** endeavors. This also enables mid-L/D vehicle use for lunar and planetary **sample return**.	
2	**Validate modeling of high-risk critical technologies**	(a) Establishes improved **CFD prediction capability** for mid-L/D aeroshell & flap **aerothermal** and **real gas effects**, based on WTT, CFD, flight sensor, and thermal imaging data.	S1, S2, S4, S5
		(b) Allows for entry flight data analysis and model anchoring, improving **flight mechanics** simulation confidence for assessed **GNC** strategies.	

HIMOM Enabling Human-scale Mid-L/Ds



HIMOM Research Objectives

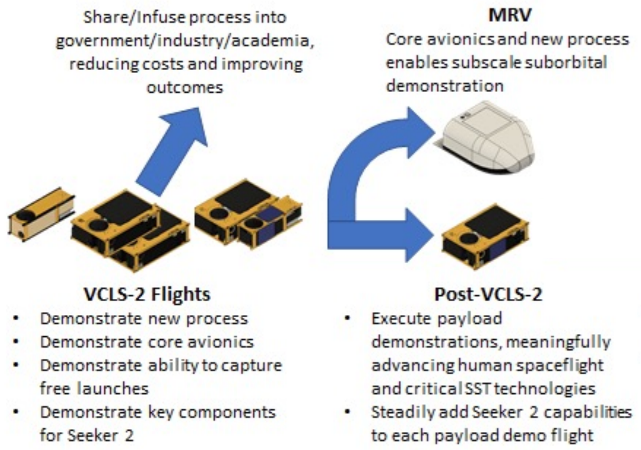
Objective	Description	Impact	SOA Link
1	**Conduct scalable integration and packaging trade studies**	(a) Identifies **minimum viability** for integrated small-scale mid-L/D vehicles for SRT. Identified **payload manifest** feeds forward into Obj. 3.	S1, S2, S3, S4
		(b) Leverages trade study results to develop a **scaled orbital trade study,** providing infusion into commercial partners' **LEO/lunar payload return** endeavors. This also enables mid-L/D vehicle use for lunar and planetary **sample return**.	
2	**Validate modeling of high-risk critical technologies**	(a) Establishes improved **CFD prediction capability** for mid-L/D aeroshell & flap **aerothermal** and **real gas effects**, based on WTT, CFD, flight sensor, and thermal imaging data.	S1, S2, S4, S5
		(b) Allows for entry flight data analysis and model anchoring, improving **flight mechanics** simulation confidence for assessed **GNC** strategies.	
3	**Deliver key components of a hypersonic entry test platform (HETP)**	(a) Creates a rapid **GNC algorithm-to-flight** pipeline, leveraging advances from CubeSat rapid development processes (SEEKER/R5) and NASA investments into a user-friendly, end-to-end validated simulation tool, **Genesis**.	S1, S2, S3, S4
		(b) Enables packaging and integration lessons learned that are not explored in Obj. 1. Note: A full build of an Engineering Development Unit (EDU) of the vehicle for an SRT is a stretch goal.	



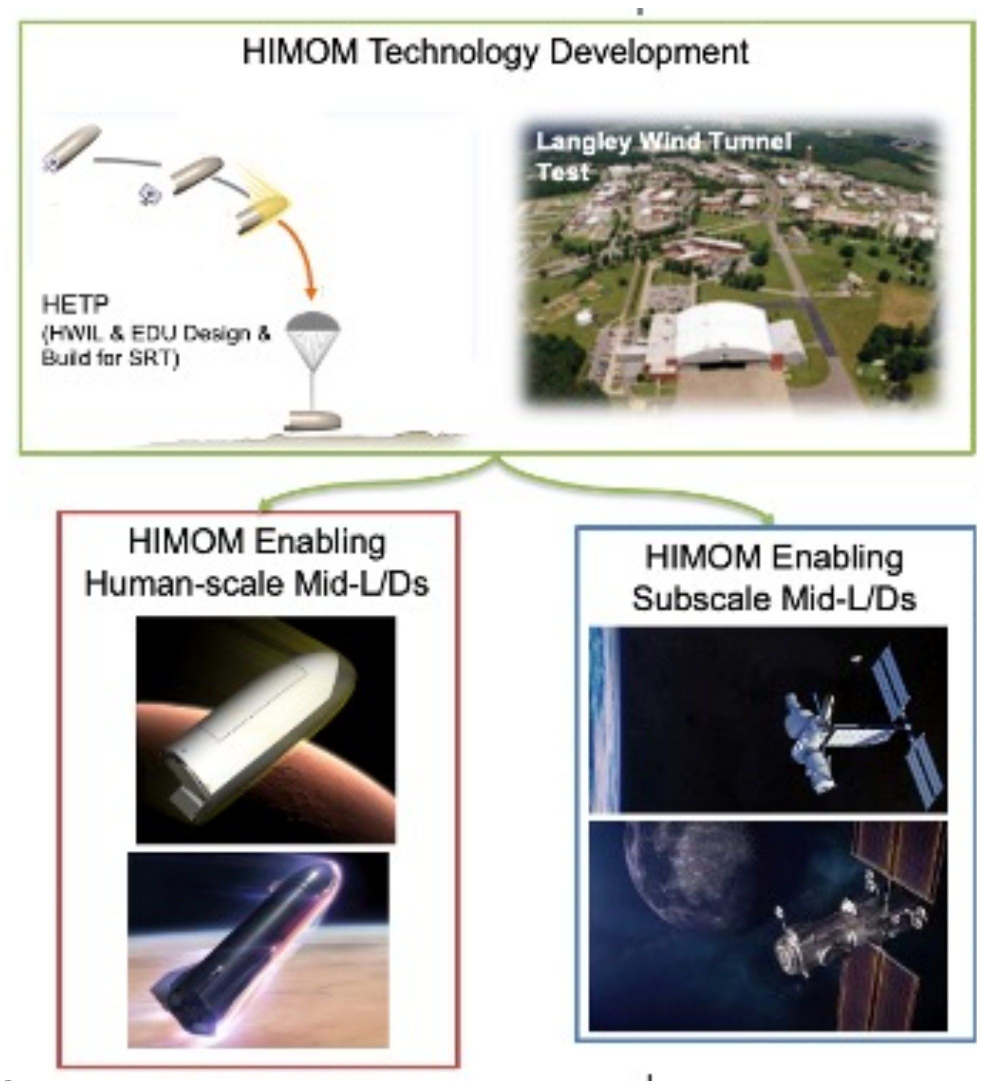
Genesis - Flight Simulation Framework

Genesis is a generic, variable-DOF, multi-body flight mechanics simulation for atmospheric and powered flight around a single planetary body.

Benefits of Genesis:
- Mostly implemented in Julia
  - Easier to learn
  - Great package manager
  - Great facilities for leveraging HPC environments
  - FAST
  - Can easily pull in models from other languages
- Interoperability with Copernicus for end-to-end mission design
- Genesis is a library, trajectory runs are function calls, easily composes to more complicated analyses



Primary Deliverable



Develop **hypersonic entry testing platform** (HETP) that leverages NASA and Commercial Space ground tests, flight tests, wind tunnel testing, and appropriate fidelity models, for full range of mid-L/D vehicle scales, to drive accelerated advancement of:

- Human scale mid-L/D Entry Vehicles
- Subscale mid-L/D Entry Vehicles for on-demand small payload return

This proposal focuses on using the HETP to make **key advancements** in:
- aerodynamic modeling
- new GNC implementations
- thermal protection system (TPS) materials

The HIMOM Team - NASA

Lead Center Johnson Space Center

Principal Investigator Breanna Johnson

JSC Support

	Role
Sam Pedrotty	Systems Engineering Lead
Ami Yang	Communications & Avionics Lead
Joshua Geiser	Guidance Simulation Analyst
Esteban Guzman	GNC & HWIL Analyst
Keith Coulson	Propulsion System Lead
Peter Clarke	Aerothermal Analyst

Mentors	Discipline
Ronald Sostaric	EDL GNC and Project Management
Daniel Matz	Genesis and Flight Mechanics
Benedicte Stewart	Aerodynamics and Aerothermal

ARC Support

	Role
Sarah D'Souza (TSS)	Systems Integration Lead
Benjamin Margolis (AA)	Aerosurface Controls Prototyping
Dirk Ekelschot (TSS)	Aerothermal Analyst
Jayme Berstell (TSS)	Mechanical Design Analyst

Mentors	Discipline
Joseph Garcia (AA)	CobraMRV Aeroshell Mentor
Chun Tang (TSA)	Aerothermodynamics

The HIMOM Team – External Partners

External Partners

SpaceX	- Support validation of NASA models with **Starship flight data** - Collaborate with NASA in developing the **Starship models for the wind tunnel tests**
SpaceWorks	- Perform a comparative assessment evaluating the technical & commercialization impacts of a mid-L/D lifting body relative to its current (RED) capsule - **Internal packaging** will be examined at **various vehicle scales** to establish a reference size payload capability and sensitivities to small and large payloads
Carnegie Mellon University (CMU)	- **Provide entry and aerocapture guidance development and algorithms** - Suggest challenge cases/improvements for future NASA guidance comparison efforts
San Diego State University (SDSU)	- **Provide an end-to-end entry, descent, and landing (EDL) guidance algorithm** - Suggest challenge cases/improvements for future NASA guidance comparison efforts

National Aeronautics and Space Administration

Ames Research Center
Entry Systems and Technology Division

Mars Entry Spacecraft Technology Gaps

The Space Technology Mission Directorate (STMD) and Exploration Systems Development Mission Directorate (ESDMD) have documented priority EDL gaps.

Primary Areas	**9 Entry, Descent, and Landing**
	9.1.2 Hypersonic Decelerators, **9.4.3** System Integration and Analysis, **9.4.7** GN&C Sensors and Systems
	13 Ground, Test, and Surface Systems
	13.2.4 Verification and Validation of Ground, Test, and Surface Systems, **13.2.5** Flight and Ground Testing Methodologies
	15 Flight Vehicle Systems
	15.1.2 Aerothermal, **15.1.8** Ground & Flight Test Technologies, **15.2** Flight Mechanics
	17 Guidance, Navigation, and Control
	17.1.1 Guidance Algorithms, **17.5.5** Vehicle Flight Dynamics and Mission Design Tools/Techniques
Related Areas	**9.4.1** Architecture Analyses, **9.2** Descent, **9.4.5** Modeling and Simulation, **9.4.6** Instrumentation and Health Monitoring