



Entry, Descent and Landing (EDL) “State of the Union” and Big Picture

Briefing to Summer Students and the NESC Academy
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Outline

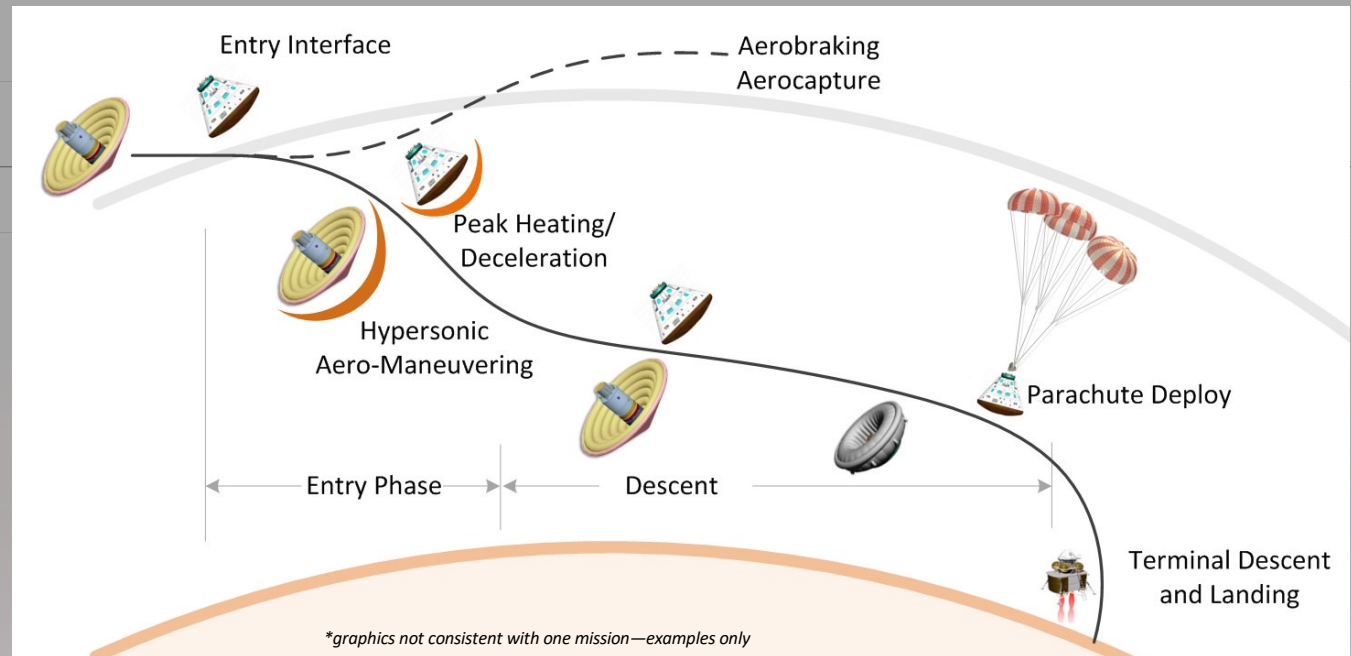


- **EDL Definition and Context**
- **NASA's Moon to Mars Objectives**
- **Architectural Drivers**
- **STMD Strategic Framework**
- **Envisioned Future Priorities and Gaps**
 - Landing Heavy Payloads
 - Precision Landing and Hazard Avoidance
 - EDL at Science Destinations
- **Current Investments and Upcoming Missions**
- **Next Steps**

Entry, Descent and Landing (EDL)



Slowing down, approaching, connecting or touching down on any body with significant gravity; with or without atmosphere.



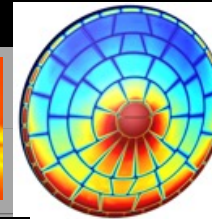
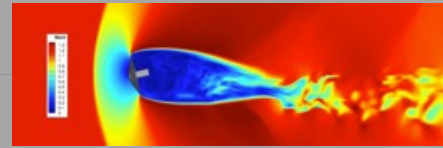
- Three phases of flight
 - Entry – Hypersonic flight: Burn off energy; guide to the target
 - Descent – Supersonic flight: Deploy decelerators or turn on engines
 - Landing – Subsonic flight: Extend landing gear and/or throttle engines for touchdown



EDL Sub-Capabilities

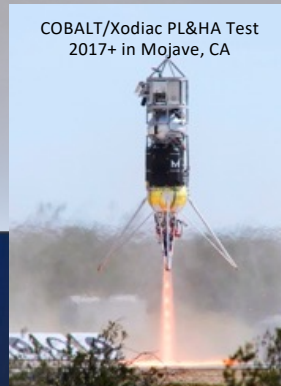
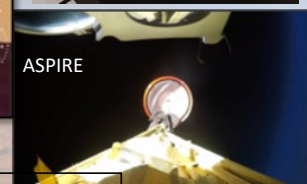
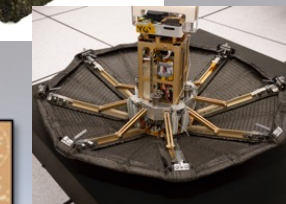
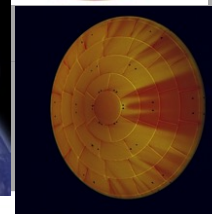
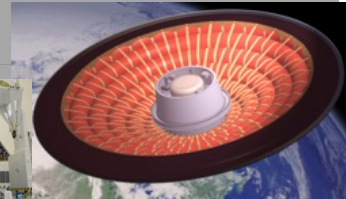
Analytical/
Discipline

- Aerodynamics
- Aerothermodynamics
- Flight Dynamics/Design
- Thermal
- Modeling and Simulation
- *Plume Surface Interaction*



Hardware

- Avionics
- GN&C
- Instrumentation
- Materials – High Temperature/TPS
- Mechanical Design
- *Propulsion**
- Structures
- Textiles



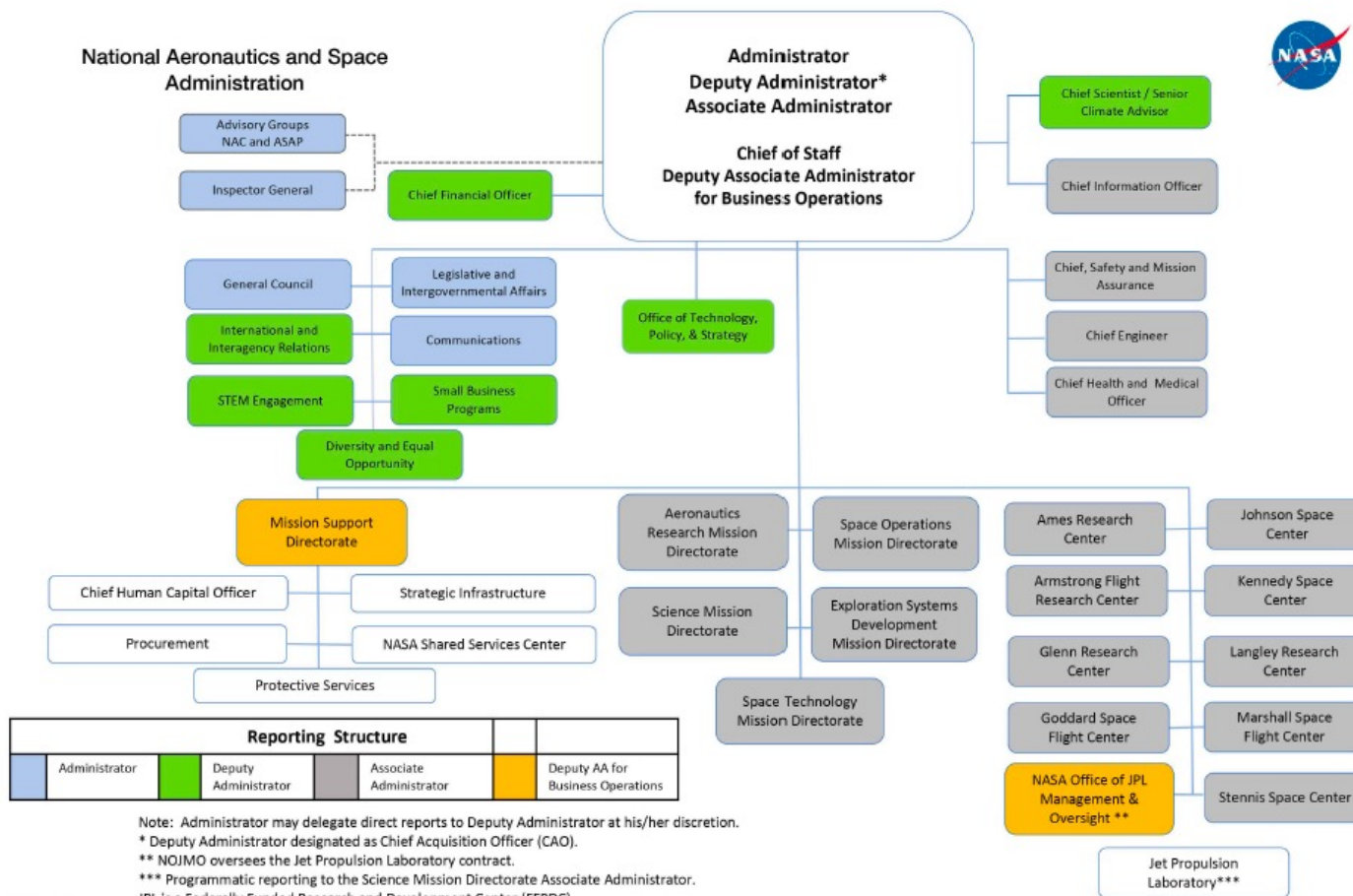
System
Level

- Software
- Mission Design & Analysis
- Systems Analysis
- Systems Integration

NASA Taxonomy: TX09

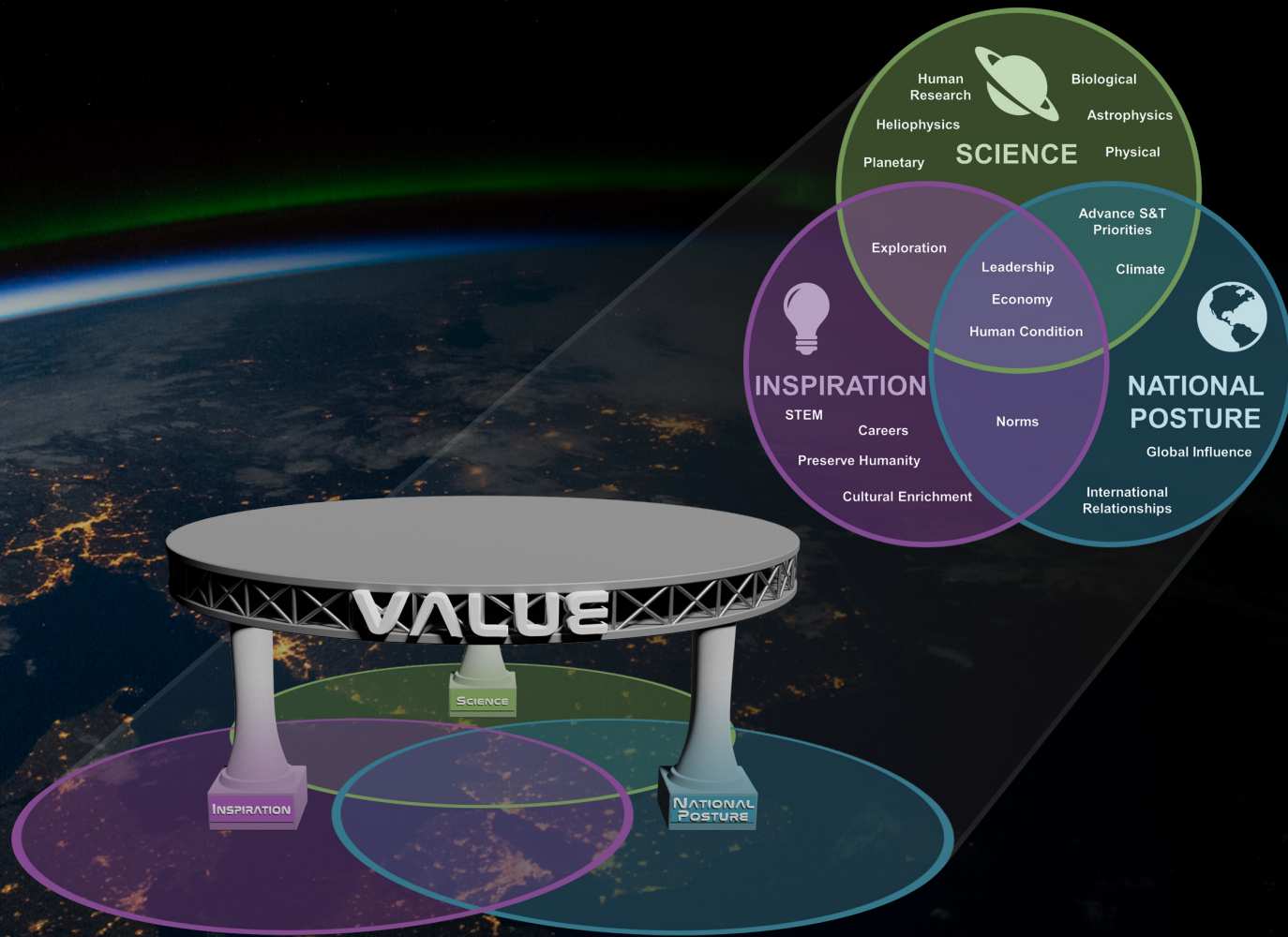
**Propulsion discipline related less directly than others*

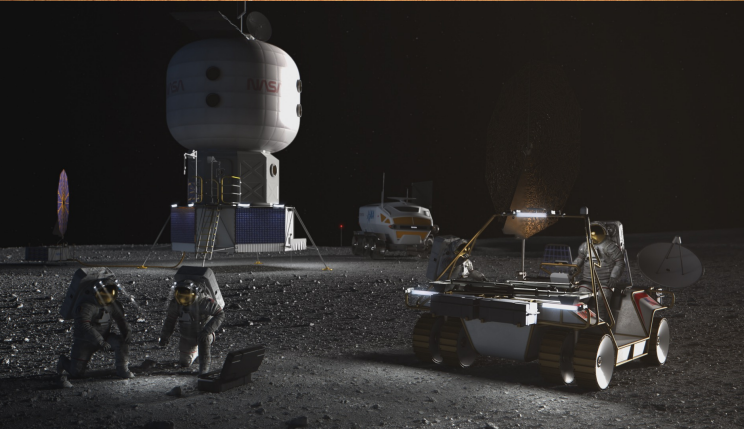
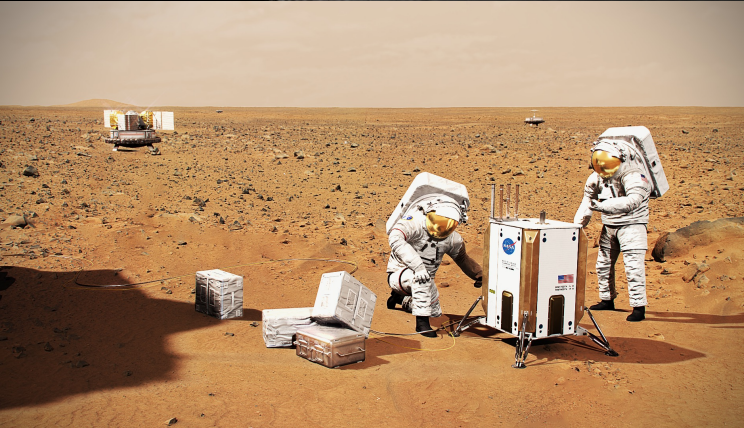
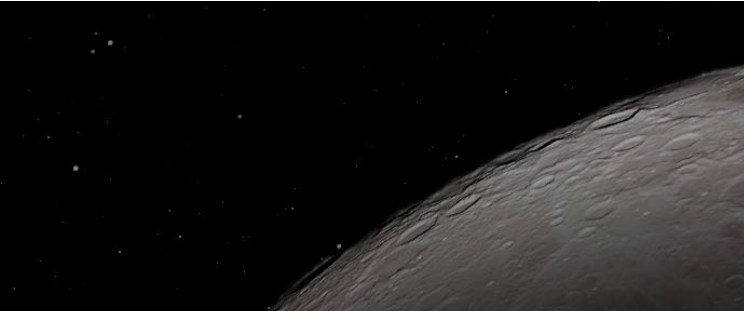
NASA Organizational Structure - Context



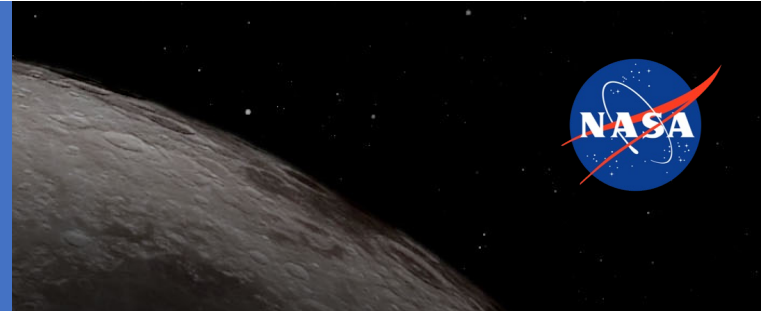
Why Go?

Benefit to Citizens





Create a blueprint
for sustained
human presence
and exploration
throughout the
solar system



Moon To Mars Objectives

• 63 Top-Level Objectives across 10 Top-Level Goals

- 26 Science
- 13 Infrastructure
- 12 Transportation & Habitation
- 12 Operations

• 9 Recurring Tenets (RT)

- Common themes across objectives

• Goal Rationales



- RT-1: International Collaboration
- RT-2: Industry Collaboration
- RT-3: Crew Return
- RT-4: Crew Time
- RT-5: Maintainability and Reuse
- RT-6: Responsible Use
- RT-7: Interoperability
- RT-8: Leverage Low Earth Orbit
- RT-9: Commerce and Space Development

Science Objectives (1 of 4)

Human Presence Science (HPS) Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

Humanity Science (HS) Goal: Address high priority planetary science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

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Recurring Tenets

Common themes across objectives

RT-1: International Collaboration: Partner with international community to address common goals and objectives

RT-2: Industry Collaboration: Partner with U.S. industry to address common goals and objectives

RT-3: Crew Return: Invest resources to build crew return capability to Earth

RT-4: Crew Time: Maximize crew time available to science and engineering activities while ensuring mission duration

RT-5: Maintainability and Reuse: Maximize reuse of hardware and systems to reduce mass and improve sustainability of operations and activities

RT-6: Responsible Use: Conduct all activities for the exploration and use of outer space to peaceful purposes consistent with international obligations and principles of responsible conduct of space

RT-7: Interoperability: Enable interoperability and compatibility between systems and process standards among systems, elements, and users throughout the mission

RT-8: Leverage Low Earth Orbit: Maximize utilization of Low Earth Orbit to support HPS goals

RT-9: Commerce and Space Development: Support the exploration of the universe, where support Earth and to support U.S. industry and innovation





Artemis: Landing Humans On the Moon



Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



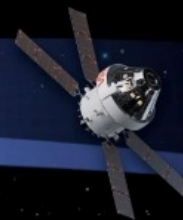
Artemis I: First human spacecraft to the Moon in the 21st century



Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st Century



Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost



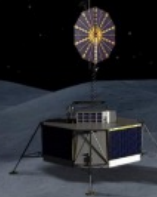
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers



Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey



Uncrewed HLS Demonstration



Humans on the Moon - 21st Century
First crew expedition to the lunar surface



LUNAR SOUTH POLE TARGET SITE

Architecture Segments and Sub-Architectures



Segment: A portion of the architecture, identified by one or more notional missions or integrated use cases, illustrating the interaction, relationships, and connections of the sub-architectures through progressively increasing operational complexity and objective satisfaction.



Human Lunar Return

Initial capabilities, systems, and operations necessary to re-establish human presence on the Moon.



Foundational Exploration

Expansion of operations, capabilities, and systems supporting complex orbital and surface missions to conduct utilization and Mars forward analogs.



Sustained Lunar Evolution

Enabling operations, capabilities, and systems to support regional and global utilization, economic opportunity, and a steady cadence of human missions on and around the Moon.



Humans to Mars

Initial capabilities, systems, and operations necessary to establish human presence on Mars and continued exploration.

Sub-architecture: A group of tightly-coupled systems, functions, and capabilities that perform together to accomplish architecture objectives.

Communication, Positioning, Navigation, and Timing •
Habitation • Human Systems • Logistics • Mobility Systems
• Power • Transportation • Utilization Systems

EDL Involvement by Mission Directorate



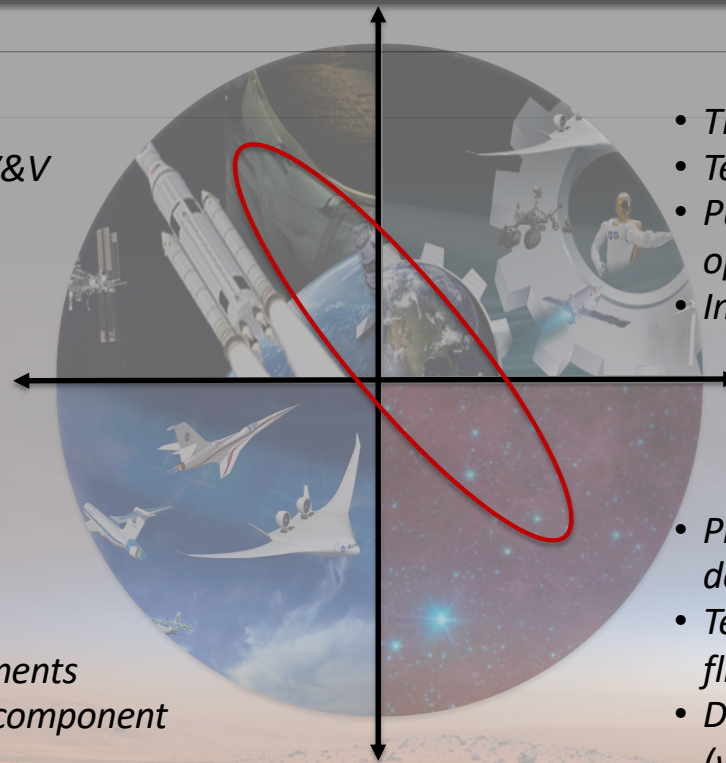
Relative Resources/Assets

ESDMD/SOMD

- Orion EDL system development
- Commercial Crew/Cargo Resupply V&V
- Human Landing System
- Gateway/Lunar architecture studies
- Human Mars architecture studies

STMD

- TRL 3-6+ investments to support other MDs
- Technology Demonstrations
- Public-Private Partnership, SBIR, academic opportunities
- Investment strategy definition



- Hypersonics facility management
- Limited Hypersonics tool developments
- Supports expertise in several EDL component disciplines

- Planetary entry systems design, development, and ops
- Technology incentives and co-funding for flight infusion
- Development of Strategic Knowledge Gaps (with ESDMD)

ARMD

SMD






We Can Think About EDL in 3 Bins



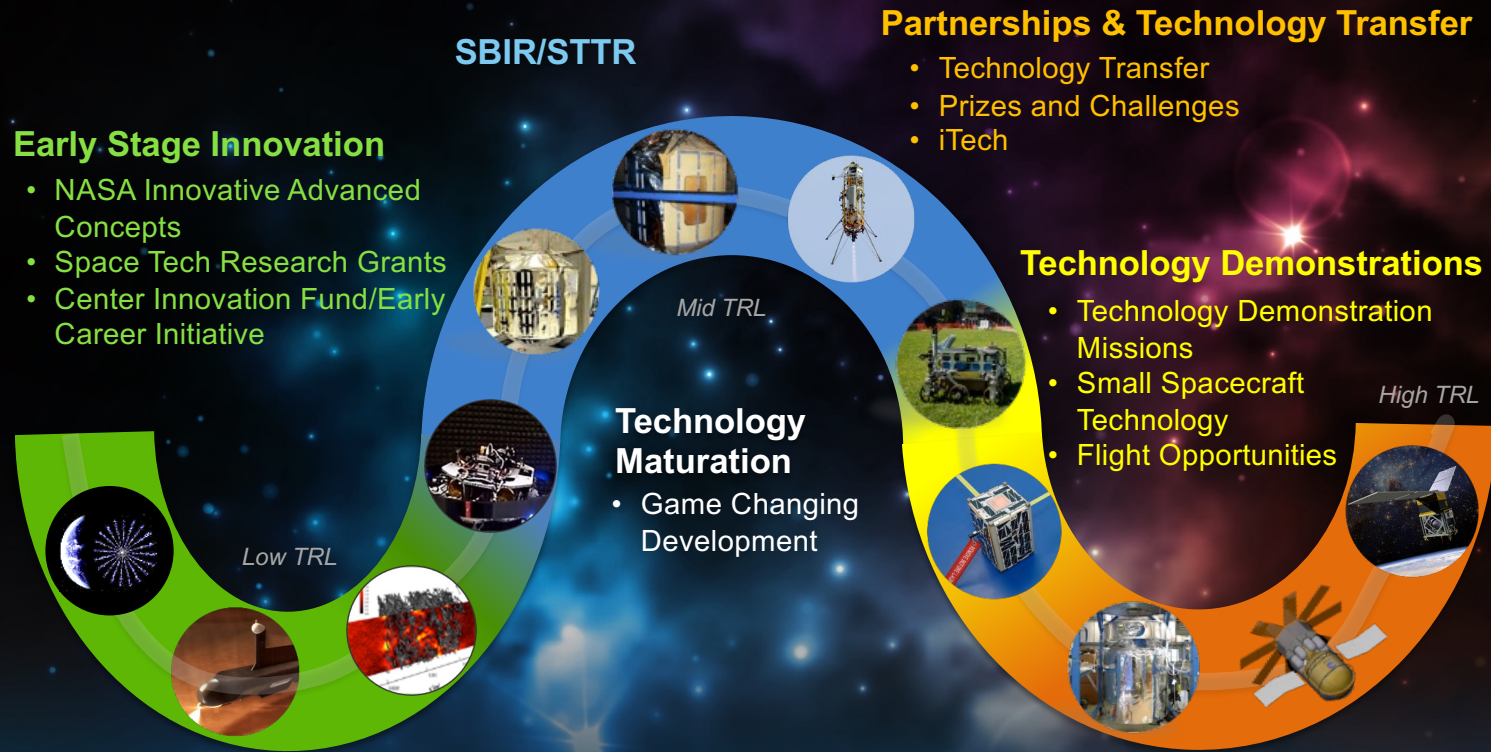
- **Human (Directed and Commercially-Provided):**
 - ✓ Returning humans from Low Earth Orbit
 - Returning humans from beyond LEO (Gateway, the Moon)
 - Landing humans (precisely) on the Moon
 - Landing humans (precisely) on Mars
- **Robotic (Competed and Directed):**
 - ✓ Mars: 9 successful landings, increasing in scale and performance
 - Rest of the Solar System: Venus, Saturn, Titan, Neptune, Uranus, Europa, (Jupiter)
 - ✓ Earth Return of samples (potentially biological, or not)
- **Emerging (*cost is key*):**
 - Small spacecraft: perform EDL or aerocapture at Earth or elsewhere
 - Commercial interest in “asset return” – rocket stages, materials, etc.

STMD Strategic Technology Framework



Lead	Thrusts	Outcomes	Primary Capabilities
 <p>Ensuring American global leadership in Space Technology</p> <ul style="list-style-type: none"> • Advance US space technology innovation and competitiveness in a global context • Encourage technology driven economic growth with an emphasis on the expanding space economy • Inspire and develop a diverse and powerful US aerospace technology community <p>https://techport.nasa.gov/framework</p>	Transforming Space Missions		
	 <p>Go Rapid, Safe, and Efficient Space Transportation</p>	<ul style="list-style-type: none"> • Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions. 	<ul style="list-style-type: none"> • Nuclear Systems • Cryogenic Fluid Management • Advanced Propulsion
	 <p>Land Expanded Access to Diverse Surface Destinations</p>	<ul style="list-style-type: none"> • Enable Lunar/Mars global access with ~20t payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards. 	<ul style="list-style-type: none"> • Entry, Descent, Landing, & Precision Landing
	 <p>Live Sustainable Living and Working Farther from Earth</p>	<ul style="list-style-type: none"> • Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations. • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface. • Technologies that enable surviving the extreme lunar and Mars environments. • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources. • Enable long duration human exploration missions with Advanced Habitation System technologies. [Low TRL STMD; Mid-High TRL SOMD/ESDMD] 	<ul style="list-style-type: none"> • Advanced Power • In-Situ Resource Utilization • Advanced Thermal • Advanced Materials, Structures, & Construction • Advanced Habitation Systems
 <p>Explore Transformative Missions and Discoveries</p>	<ul style="list-style-type: none"> • Develop next generation high performance computing, communications, and navigation. • Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. • Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop technologies for science instrumentation supporting new discoveries. [Low TRL STMD/Mid-High TRL SMD. SMD funds mission specific instrumentation (TRL 1-9)] • Develop transformative technologies that enable future NASA or commercial missions and discoveries 	<ul style="list-style-type: none"> • Advanced Avionics Systems • Advanced Communications & Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing & Assembly • Advanced Manufacturing • Small Spacecraft • Rendezvous, Proximity Operations & Capture • Sensor & Instrumentation 	

STMD Programs – Means to the End Goal



TECHNOLOGY PIPELINE

LAND: Enable Lunar/Mars global access with ~20t payloads to support human missions



Developing landing capabilities that support unique requirements for both the Moon and Mars, to allow for landing greater payload capacity with greater accuracy

LUNAR CAPABILITIES (FEEDING FORWARD TO MARS)

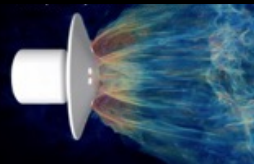
Precision Landing and Hazard Avoidance

Safely and precisely land near science sites or pre-deployed assets (see details in separate package)



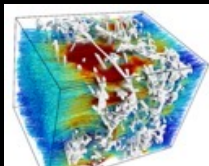
Retropropulsion

Understand flow physics and vehicle control through wind tunnel testing of Mars-relevant configurations; advance CFD modeling



Plume Surface Interaction

Reduce risks to landers and nearby assets by understanding how engine plumes and surfaces behave



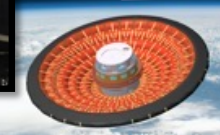
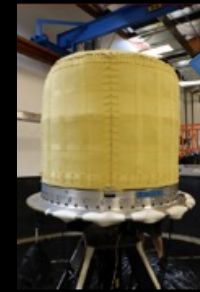
Foundational Modeling, Testing, Instrumentation, and Computing

Measure EDL flight system performance and update/develop unique, critical simulations for EDL/DDL systems

MARS CAPABILITIES

Large Scale Demonstrations

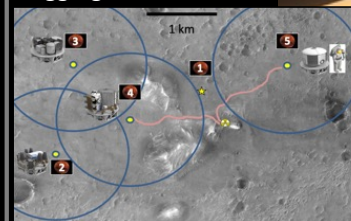
Large structures, including deployables, that can slow down a 20t payload in the thin Mars atmosphere



Assess Alternatives

Earth Flight Tests, such as LOFTID

Aggregate Assets



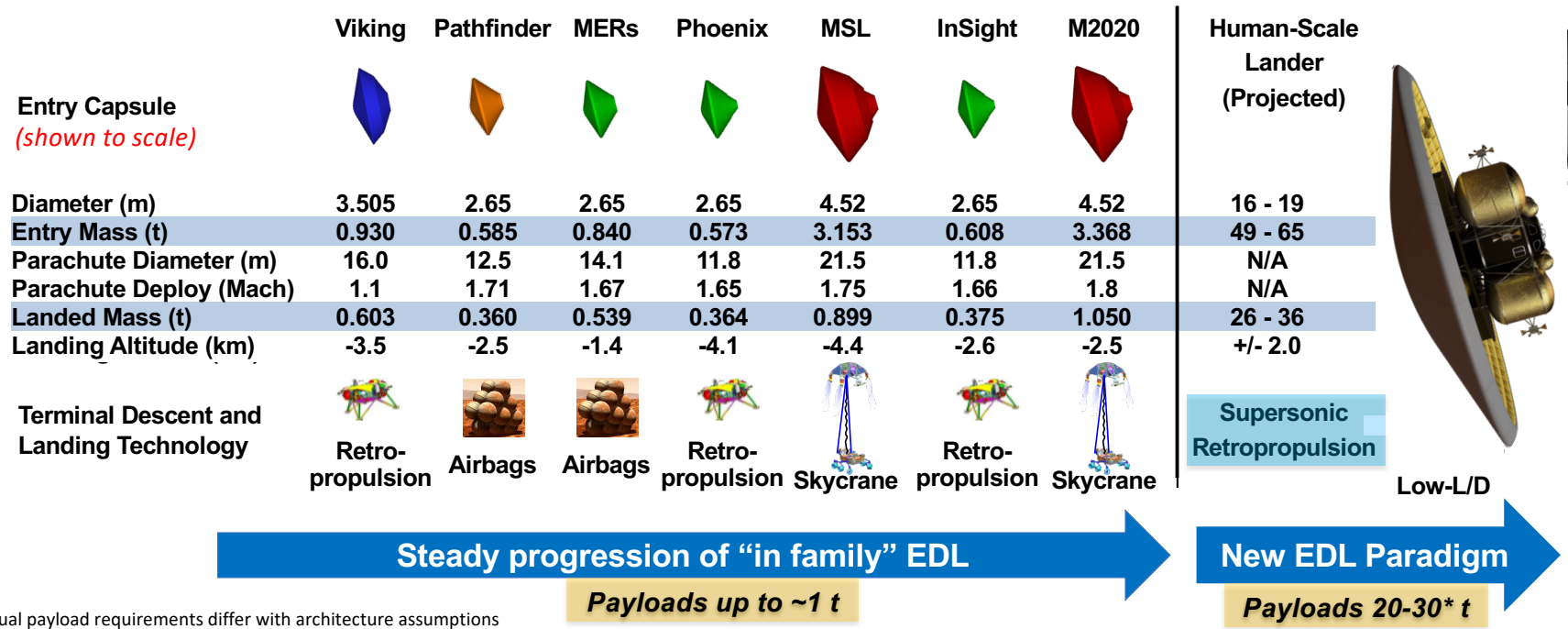
Human Mars EDL



Human Mars EDL Capability Requires a Leap in Scale



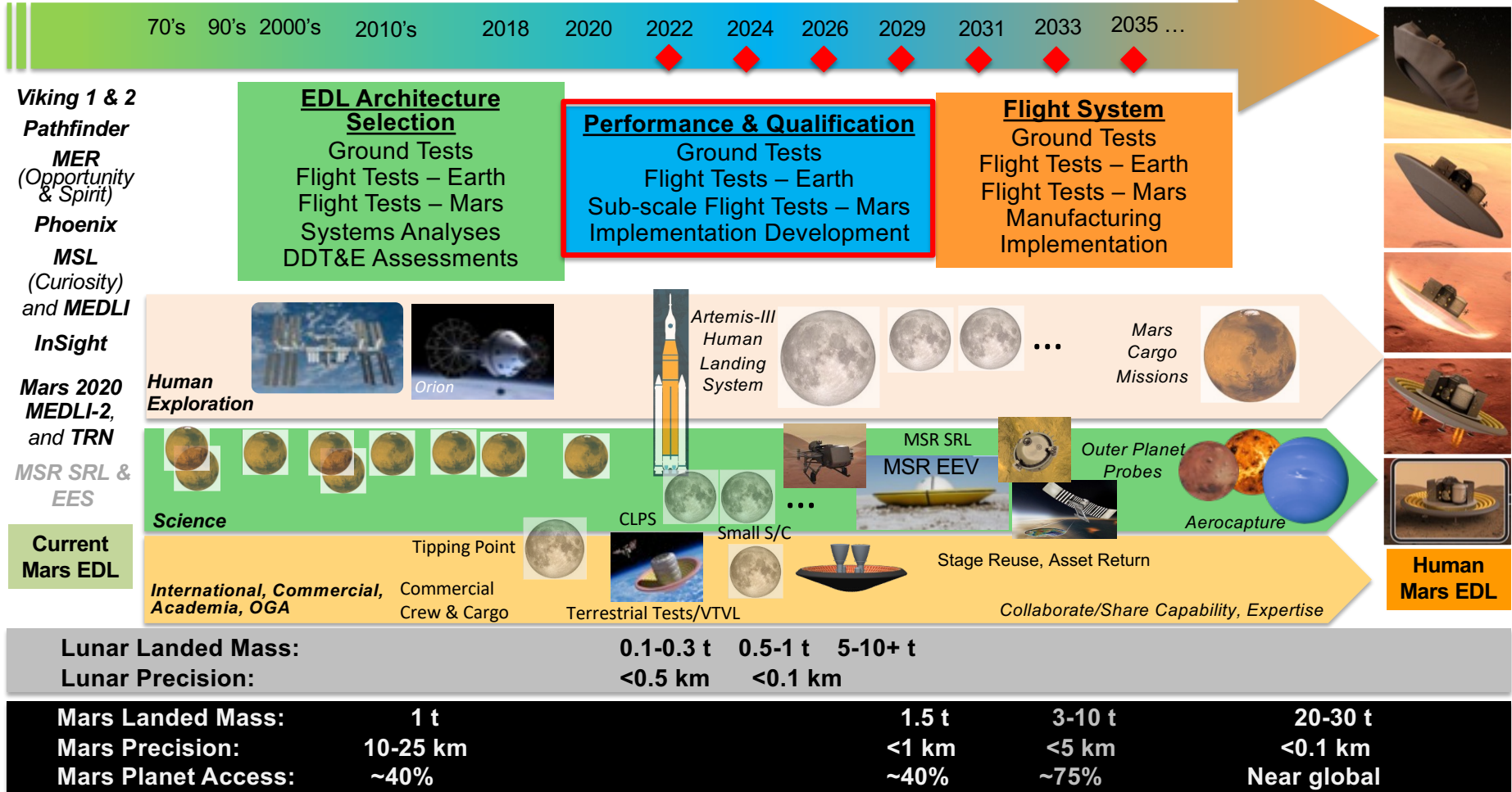
- Viking-derived rigid sphere-cone aeroshells with cross sections that fit in a launch vehicle shroud are not large enough to decelerate heavy payloads in the thin Mars atmosphere – a larger entry system is needed (“E”)
- Supersonic parachutes cannot be used; high-speed propulsive descent is enabling (“D”)
- Precise Lunar landings require and will demonstrate integrated GN&C for the landing and prediction/knowledge of large-engine plume surface interaction (PSI) effects. Both feed forward to large Mars missions (“L”)
- Robust guidance and control throughout entry and descent is required for safe, precise landing (“EDL”)



*actual payload requirements differ with architecture assumptions

Mars EDL is a Long-Term Challenge

Leveraging Lunar Tech Demos and Missions



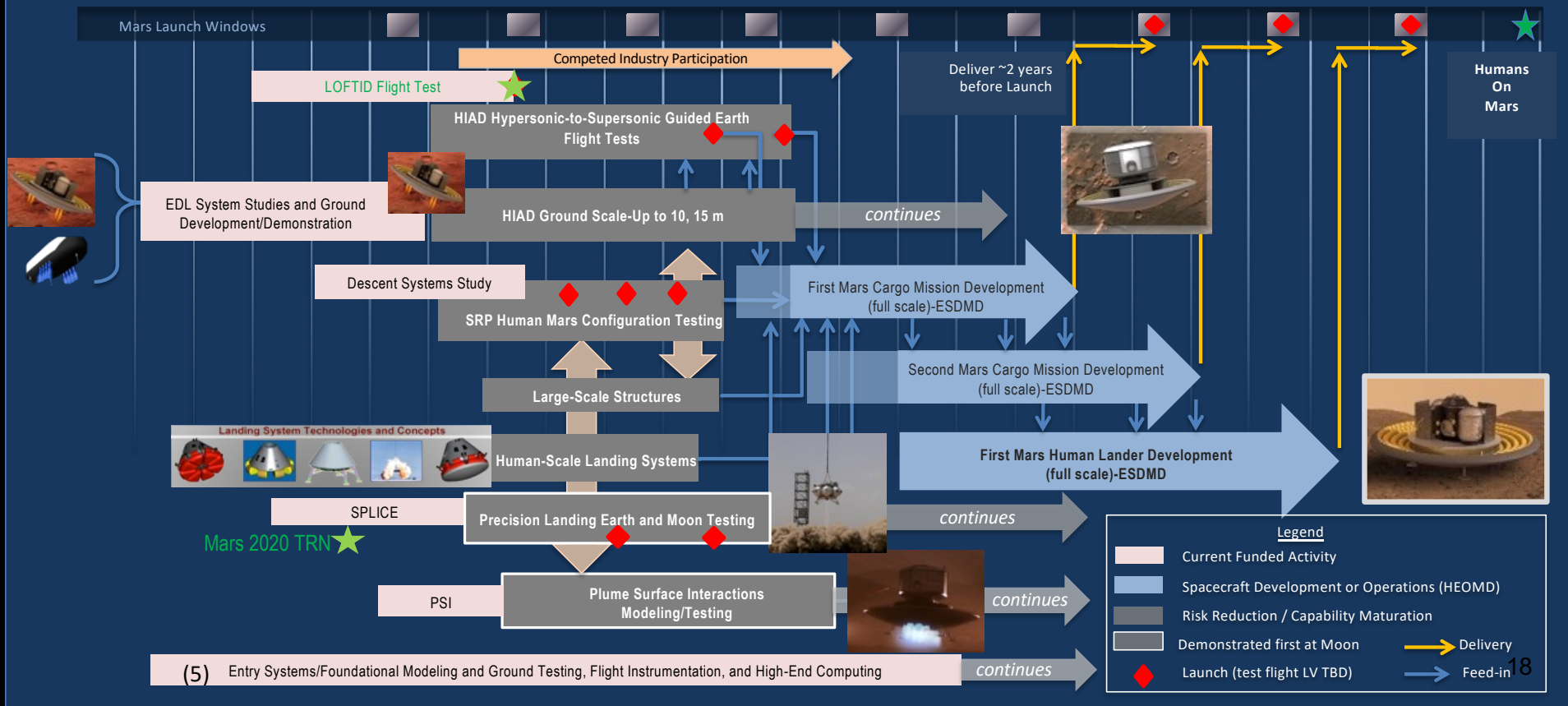
Mars Crew / Cargo Landers for 20t Payloads

Notional Development Plan (Current STMD Investments Noted in Pink Bars)



- The large-scale Mars EDL system is comprised of multiple long-lead elements that all need to be matured in parallel.
- Flight tests of "E," "D," and "L" components occur at Earth. Precision Landing is demonstrated on the Moon. End-to-end Mars validation is performed computationally (as with current vehicles), and the Mars cargo missions serve as the system certification for humans.

NOTE: Numbered items correspond to highest-priority gaps (see page 9). Activity duration and timing are success-oriented and require significant investment increases.



Current/Recent Investments to Achieve 20t Landings



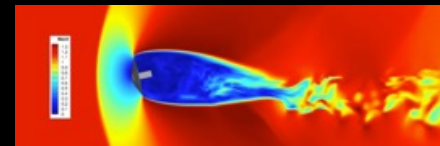
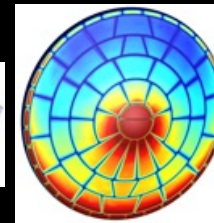
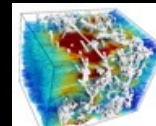
LOFTID

6m inflatable aeroshell test with United Launch Alliance (ULA) – 2022
Post-Flight Analysis in progress



*SPLICE

Precision Landing/Hazard Detection sensor, computing, and algorithm development, flight testing, and commercialization (see "50 m" outcome)



Entry Systems Modeling (ESM)

Advancing core capabilities and reducing mission risk through validation (Aerodynamics, Aerothermal, TPS, GN&C)



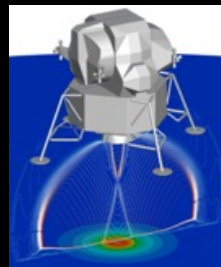
MEDLI-2 (complete)

Heating and pressure sensors on Mars 2020 aeroshell; provided aero/aerothermal model validation data, deep-dive data analysis



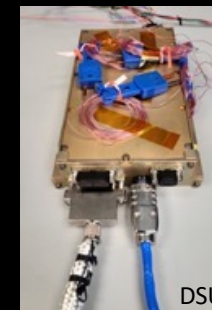
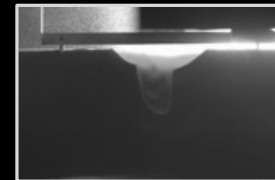
Descent Systems Study

Mid L/D configuration, HIAD and all SRP testing FY22/23



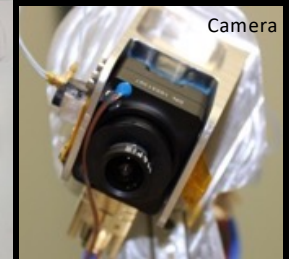
*Plume Surface Interaction (PSI) Mini-Suite

Flight instrument maturation to measure PSI phenomena



*SCALPSS 1.0 and 1.1

Stereo Cameras to measure Plume Surface Interaction under CLPS landers; provides PSI model validation data



Early-Stage investments such as SBIR and academic efforts contribute to most projects shown

*Orange = Demonstration for Lunar missions in Near Term; Lunar-focused investments feed forward directly to Mars

Highest-Priority Technology Gaps – Landing ~20t



- **Aeroshell (Hypersonic Deceleration) System (1)**
 - Flight Test Validation of Integrated High-Mass Mars Entry and Descent Architectures
 - Control Technologies for Exploration Class Inflatable Decelerator
 - Aeroshell/TPS Reliability Prediction
- **Ground Development and Scale-Up of Inflatable Decelerators and Large Structures (2)**
- **Retropropulsion (Supersonic Deceleration) System (3)**
 - Supersonic Retropropulsion (SRP) Modeling & Simulation
 - Supersonic Retropropulsion (SRP) Guidance, Navigation and Control
- **Validated Prediction of Plume-Surface Interaction (PSI) for Vehicles Landing on Mars (4)**
- **Entry Systems/Foundational Modeling and Testing, Instrumentation, and Computing (5)**
 - High-End Computing Capability for EDL Modeling
 - Multi-disciplinary / coupled EDL Performance Models
 - Validated Aerothermodynamic Prediction for Human Mars EDL
 - Thermal Protection System Performance Modeling & Optimization for Human Mars Exploration
 - EDL Flight Vehicle (Aeroshell) Flight Performance Data for Human Mars Entry and Earth Return
 - Low-Cost EDL Flight Instrumentation Data Acquisition System
 - Planetary Aerothermodynamics Test Facility

**Note that all Precision Landing gaps are mapped to the “Land within 50 m” outcome and are therefore not included here. These are CRITICAL to implementing the Artemis architectures.*

Hypersonic Inflatable Aerodynamic Decelerator (HIAD)

Scale-Up and Flight-Testing Approach



IRVE-3 (3 m) – 2012 successful flight test from Wallops Flight Facility - SOA

Established the aerodynamic performance and stability of inflatable heatshield approach

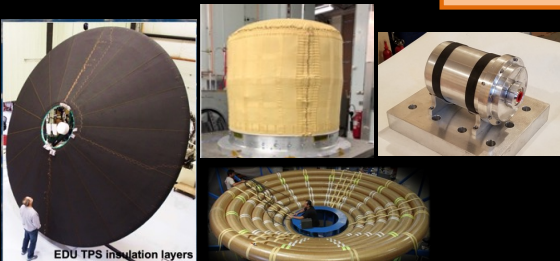


LOFTID Flight Test (6 m) – 2022 flight test in partnership with United Launch Alliance (ULA)

Vandenberg launch with JPSS-2. *HIAD experienced human Mars mission-relevant heating and g-load.*

Ground Scale-up Demonstration

- Mass-efficient materials for structure and TPS
- Improved handling and packing density
- Gas generators: volume-enabling



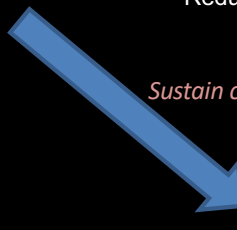
Commercial Rocket Engine Recovery (12 m) – 2024-25+

Frequent industry use will solidify HIAD technology

- Establish large-scale (12 m+) production
- Maintain specialized vendor base
- Return multiple sets of flight data for validation
- Reduce risk for human Mars mission implementation



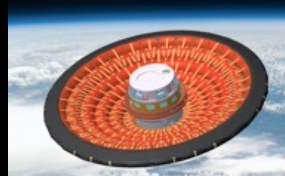
Perform integrated demonstration



Sustain commercial base

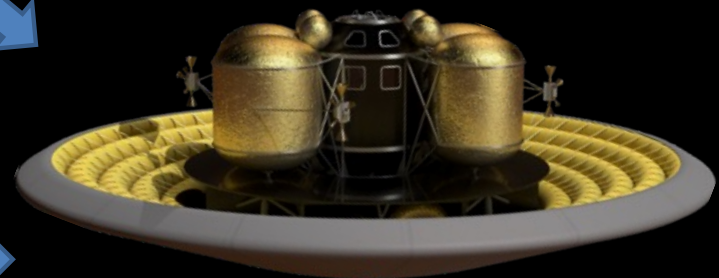
Guided HIAD, SRP Earth Flight Testing (10-15 m)

- Demonstrates closed-loop G&C and transition to propulsive deceleration
- Includes large-scale, mass-efficient structures



Ready for Mars infusion

Human Mars Lander (~18 m)



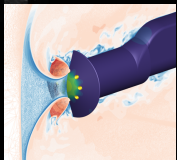
Green = currently funded; Yellow = not yet funded

Retropropulsion Advancement Approach



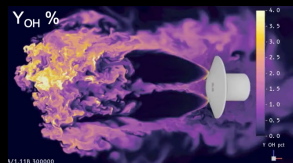
Wind Tunnel Testing with Cold Gas Thrusters (Langley Unitary Plan Wind Tunnel – 2010, 2021-23) - SOA

- Various nozzle configurations, uncertainty quantification, inert gas subscale validation data
- Establishes aerodynamic databases for simulations to assess performance of Mars EDL alternatives



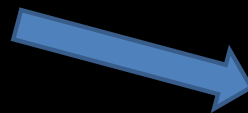
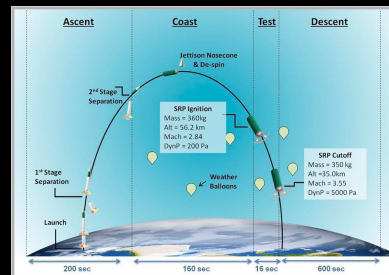
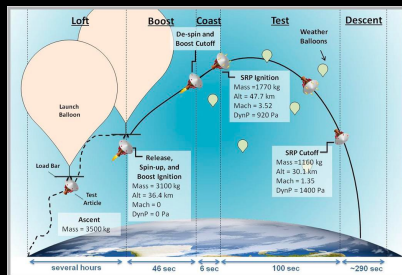
Wind Tunnel Testing with Combustion Engines (Glenn Supersonic and Transonic Tunnels)

- First hot-fire test with chemistry effects, hot-fire subscale validation data
- Establishes aerothermal environments, refines aerodynamics for iterative vehicle design; input to end-to-end flight dynamics simulations of 20 t Mars EDL



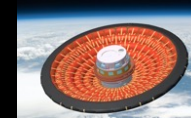
High-Altitude Suborbital Testing (~1m diameter scale)

- Series of tests at larger scale in Mars-relevant environment (density, Mach)
- Continuity in transitions across flight regimes, verifies stability
- Flight-relevant configurations, combustion, system integration



Integration with Hypersonic Decelerator, Transition Test

- Test transition from aerodynamic to propulsive deceleration at Mars-relevant conditions and configurations



(see previous page)

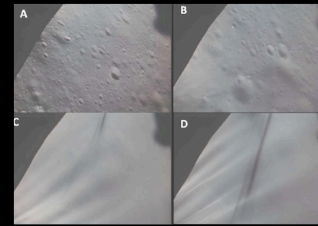
Gradual increase in test fidelity retains flexibility and supports configuration decisions.

Rapid analysis of large datasets is key challenge – requires new tools, computing architectures

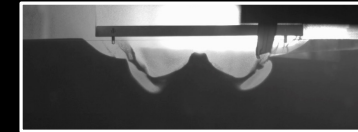
Plume Surface Interaction (PSI) Advancement Approach



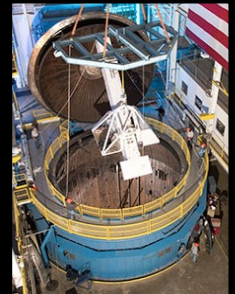
The Challenge: Engine plumes of landing (and ascending) vehicles will disturb the surface below, potentially causing (1) cratering, (2) heating of the vehicle base and legs, and (3) high-speed ejecta impacts on nearby surface assets. Little test or flight data exist to develop and validate predictive models.



Apollo 15 camera obscurations (Metzger, 2011)



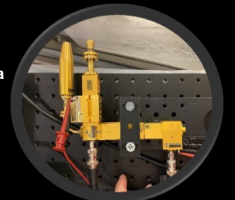
Physics-Focused Ground Test, annular crater in sand (2021)



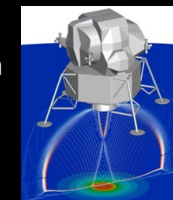
Large-Scale Ground Test, Armstrong Test Facility (OH)



Crater Observation Camera



mm-Wave Doppler Radar



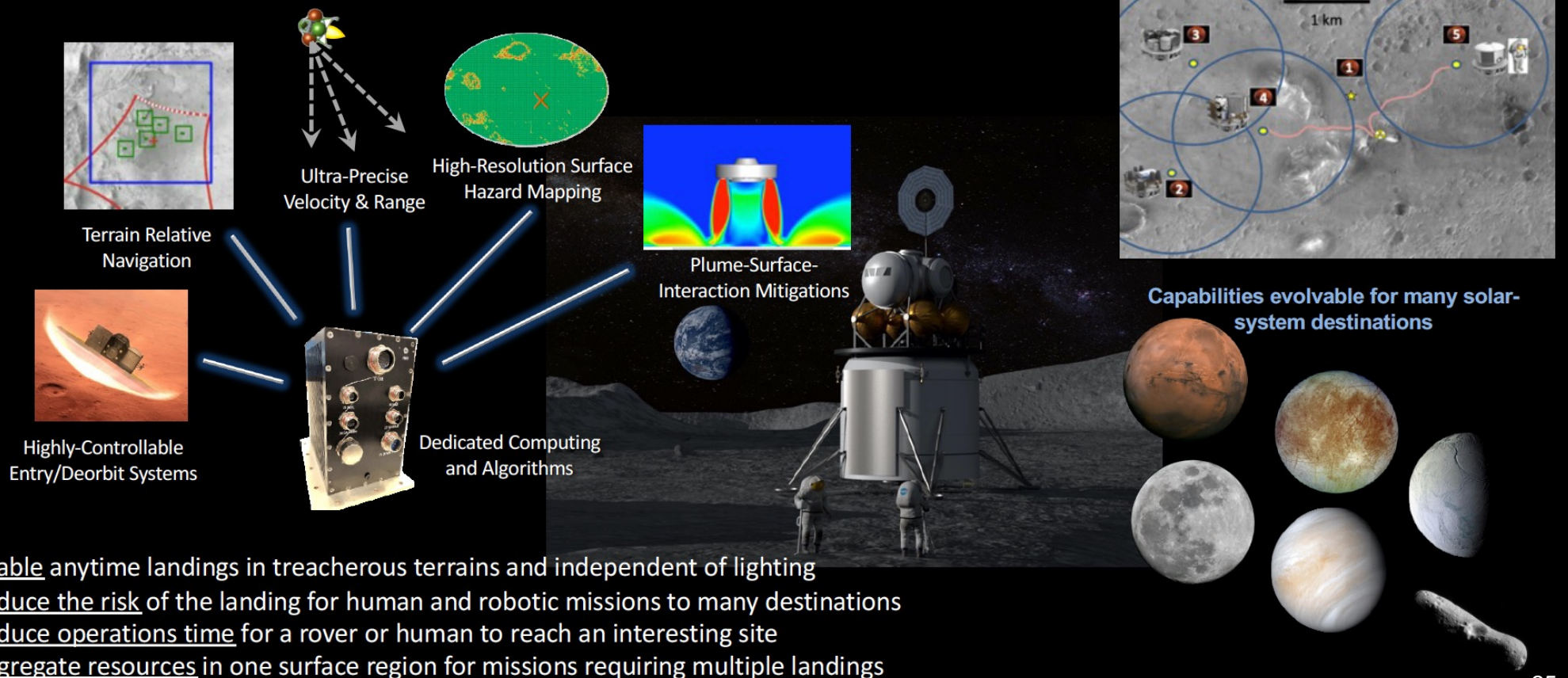
PSI Prediction Model

- **Mature predictive modeling capability, currently unvalidated**
 - Complex, multi-physics problem requiring high-end computing resources to achieve required throughput
 - Key environment that will drive lander and surface asset design **and create dust that requires mitigation**
 - *Obscuration during PSI event may affect precision landing sensor performance/data, in high-thrust cases*
- **Conduct vacuum ground tests with regolith/bedrock simulants to generate initial model validation data**
 - **Small-scale, warm-gas tests varying simulants, vacuum levels (Moon and Mars), nozzle heights and mass flows**
 - **Large-scale (1000 lb_r+) vacuum tests with simulants, combustion – more relevant to human-scale systems**
 - *Limited vacuum facilities exist, to handle both regolith and combustion, at any scale*
- **Develop instrumentation to measure (1), (2), and (3) above**
 - Implement in ground tests to demonstrate instruments and measure relevant quantities for model validation
 - **Instrument CLPS landers (100's of lb_r) for single and multiple PSI phenomena**
 - **Instrument larger lunar and robotic Mars landers with low-SWaPc multi-sensor suites to obtain flight data**

Green = currently funded; Green-Yellow = partially funded; Yellow = not yet funded

LAND: Technologies to Precisely Land Payloads and Avoid Landing Hazards

Developing entry, descent and landing technology to enhance and enable small spacecraft to Flagship-class missions across the solar system



Landing Precision: Development Strategy

Develop Technologies to Precisely Land Payloads and Avoid Landing Hazards



▪ Overarching Goal

- Develop, infuse, and commercialize technologies applicable to robotic and human landers that become part of the future suite of off-the-shelf GN&C (Guidance/Navigation/Control) capabilities for precise safe landing

▪ Overview of Approach

- Sustain an EDL/DDL knowledge base and simulation to capture near-term and future human and robotic mission needs and the evolving commercial and government PL&HA capabilities
- Prioritize development and infusion of cross-cutting EDL/DDL systems, sensors, avionics, and algorithms applicable to human and robotic missions
- Leverage multiple test paradigms (lab, flight, suborbital, space) to accelerate TRL advancement and infusion
- Pursue technology transfer, public-private partnerships, commercial spin-offs and spin-ins to promote closure of EDL/DDL capability gaps and the transition-into/leveraging-of commercial off-the-shelf solutions



Landing Precision: Summary and Logical Next Steps

Develop Technologies to Precisely Land Payloads and Avoid Landing Hazards



■ Current Investment ■ Maintain ■ Future Need

Summary of current approach

- **SPLICE**: developing sensors, computing and software for a baseline integrated capability for precise and safe landing
- **LuNaMaps**: developing and disseminating lunar mapping tools/processes for use by government and industry with lunar landing
- **Europa Lander Concept Study**: developing EDL technologies for the unique environment of Europa with potential for broader infusion
- **Modeling and Architecture Studies**: high-fidelity EDL simulations are continuing mission concept studies to evaluate highly-controllable EDL systems, model PSI, and assess PL&HA technologies that enable the closure of EDL gaps and the strategy evolution
- **Commercialization**: solicitations for public-private partnerships, SBIRs, Tipping Points, etc. are accelerating technology commercialization (spin off and spin in) plus infusion into CLPS missions and non-space applications (consider incentivizing certain EDL/PL&HA technologies for various mission classes)

What are the next steps?

- **Maintain** concept studies, low-TRL investments, EDL-focused SBIR solicitations, academic awards, public-private partnerships, and commercialization to identify new technologies and evolve the development strategy
- **Conduct** planned demonstration tests to validate models, raise TRL, and mitigate infusion risks for EDL technologies
 - **Conduct testing and then disseminate PSI-mitigation approaches for landing systems**
 - **Conduct a lunar demonstration of the SPLICE technologies being actively used (in closed loop) within a landing system**
- **Continue** development toward future generations of EDL and Avionics Technologies
 - **HPSC**: continue development & commercialize → radiation-hard, multicore processing is critical to future envisioned missions
 - **Europa Lidar**: monitor advancement of systems for commercialization and broader-infusion prospects
 - **Active TRN**: develop lidar-based TRN for anytime, anywhere global access (e.g., EDL/DDL for dark/shadowed lunar regions)
 - **Pursue** multi-mode EDL/PL&HA sensors that further advance and miniaturize integrated capabilities

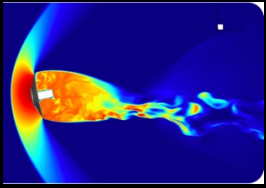
LAND: Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies



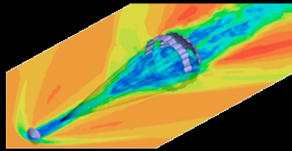
Developing atmospheric entry technology to enhance and enable small spacecraft to Flagship-class missions across the solar system

Entry Systems Modeling & Testing

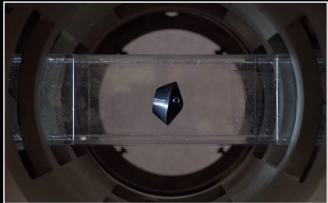
Reducing entry system mass and risk by developing advanced, validated models



"DESKTOP WIND TUNNEL"



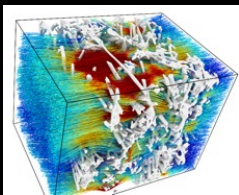
PARACHUTE MODELING



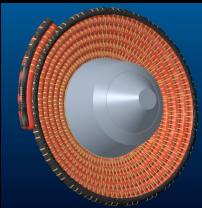
MAGNETIC SUSPENSION WIND TUNNEL



CONFORMAL MATERIALS



IN-DEPTH MATERIAL RESPONSE



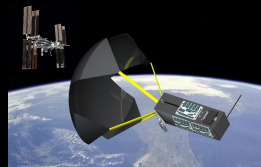
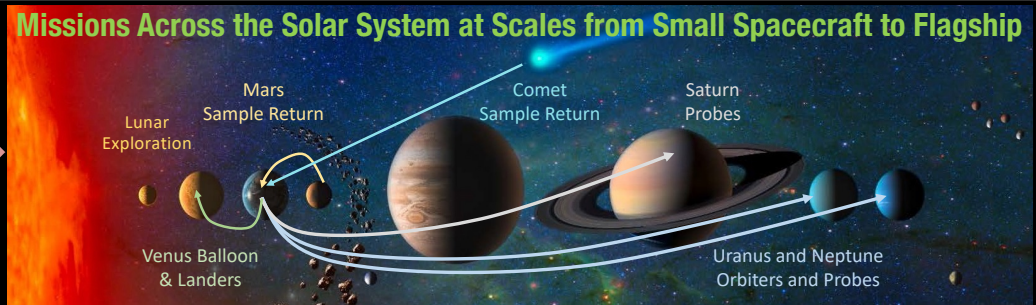
DEPLOYABLE DECELERATORS



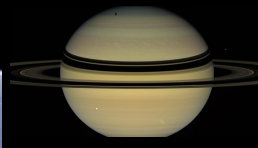
3D WOVEN HEATSHIELDS

Hardware Development
 Maturing new materials and systems to fill performance gaps and enable new missions

to enable



PRECISION DEORBIT



SATURN PROBE



TITAN PINPOINT LANDING



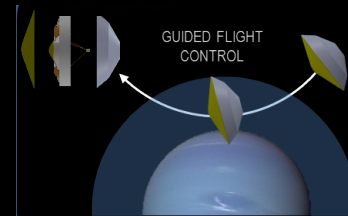
MARS SAMPLE RETURN



Increasing Science Return, Decreasing Risk, Cost, and Schedule



ICY MOON PRECISE LANDING



ICE GIANT AEROCAPTURE



HIGH-SPEED SAMPLE RETURN

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

Mission Priorities from the 2022 Planetary Decadal Survey

List of Missions Includes Entry, Descent and/or Landing (EDL)



	2022 Decadal Survey Priority	Enabling/Enhancing EDL Capability Advancement
Flagship	Uranus Orbiter and Probe*	Aerocapture for orbiter; atmospheric modeling, aero/aerothermal modeling, mass-efficient entry system
	Enceladus Orbilander*	<i>Unclear. Precision landing/hazard avoidance?</i>
	Europa Lander*	<i>Hazard detection and avoidance</i>
	Mercury Lander*	<i>Unclear. Precision landing/hazard avoidance?</i>
	Neptune-Triton Odyssey	Aerocapture for orbiter (?); atmospheric modeling, aero/aerothermal modeling, mass-efficient entry system
	Venus Flagship*	Atmospheric modeling, aero/aerothermal modeling, mass-efficient entry system, precision landing?

New Frontiers 5 (2024 AO)

- Comet Surface Sample Return (CSSR)*
- Lunar South Pole-Aitken Basin Sample Return *
- Ocean Worlds (only Enceladus)
- Saturn Probe*
- Venus In Situ Explorer*
- Io Observer
- Lunar Geophysical Network (LGN)*

New Frontiers 6

- Centaur Orbiter and Lander (CORAL)*
- Ceres sample return*
- Comet surface sample return (CSSR)*
- Enceladus multiple flyby (EMF)
- Lunar Geophysical Network (LGN)*
- Saturn probe*
- Titan orbiter
- Venus In Situ Explorer (VISE)*

New Frontiers 7

- New Frontiers 6 list, plus
- Triton Ocean World Surveyor

* = mission involves EDL

Reference: <https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032>

Planetary EDL Subsystem SOA

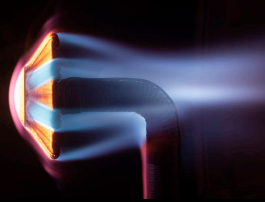


TPS

- Investments over the past ~15 years have produced materials that span the expected planetary mission space for the next 1-2 decades



HEET



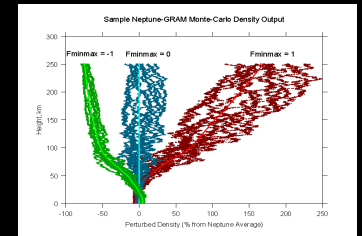
ADEPT/Spiderweave



PICA

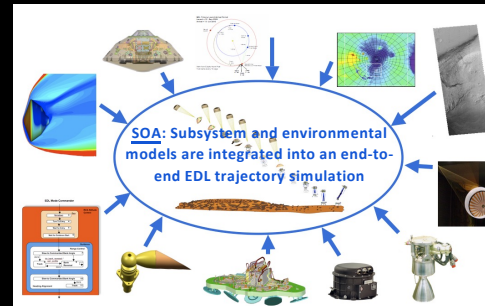
Atmosphere Models

- GRAM update for PSD destinations of interest nearing completion; New data inclusion forthcoming



GN&C Modeling

- Baseline models under development for expected planetary mission space; Quantified uncertainty forthcoming

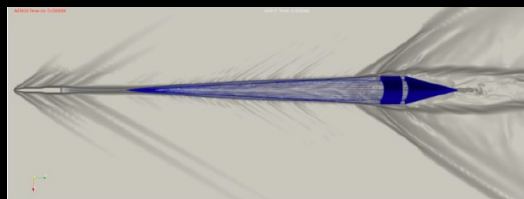


Parachutes

- Mars2020 flew largest supersonic chute to date; MSR plans even larger. Modeling SOA lags hardware/testing, but is under active development



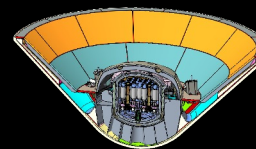
M2020 Parachute



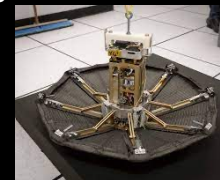
Aero/FS Simulation of ADEPT

Architecture/System

- EES designed for high reliability. ADEPT & HIAD provide scalability beyond rigid capsules, SRP provides extensibility beyond parachutes



EES



ADEPT



HIAD (LOFTID)



SRP Simulation

Enabling Aerocapture for Ice Giant Missions

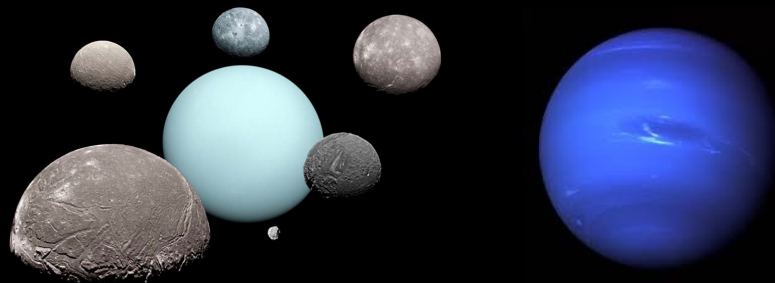


Challenges

- High entry speed leads to high heat rates
- Long atmospheric pass leads to high heat loads
- Aerothermodynamic uncertainties result from H₂/He atmosphere
- Atmospheric uncertainties are significant
- Uranus: Precision approach/maneuvering needed to avoid rings
- Neptune: High exit velocity required, for Triton observation orbit

Forward Plan/Approach

- Pursue focused H₂/He investments in Entry Systems Modeling (ESM) and leverage ACCESS STRI to reduce uncertainties in aerodynamics and aerothermodynamics, integrate material response, quantify risk, reduce entry system mass. **Infuse tools and methods to mission.**
- Establish atmospheric models, including Uranus-GRAM and Neptune-GRAM
- Perform Earth demonstration of aerocapture, including applicable aerodynamic shape and guidance and control methods
- Use advanced TPS materials appropriate for efficient insulation, robust heat tolerance.
- **Infuse characterization and modeling tools to mission.**
- Gather flight data through DrEAM and MEDLI3 to validate predictions and inform future missions.
- Develop low-SWaPc instrumentation for Ice Giant entry systems.



Orange = summary of infusion path

What's Next in EDL (2024-40)?



- **We will land precisely on the Moon, first with commercially-provided landers (small), then evolving to human-scale**

- Lightweight, inexpensive sensors for precise landing (feeds to Mars); integration on commercial landers
- Plume/surface/vehicle interactions near touchdown (feeds to Mars)
- Integrated simulations for assessing landers and sensor suites (feeds to Mars)

EDL

Challenges:

- **Commercial efforts in EDL are growing: low-cost Earth return**
- **We want to return samples from Mars by late 2020's or early 2030's**

EDL

Challenges:

- Landing ~1500 kg precisely, next to samples that Mars 2020 caches
- Landing a rocket on Mars and autonomously launching it
- Returning the samples to Earth in a capsule with 1×10^{-6} probability of failure

- **Scientists want to go to Venus, Ice Giants, Ocean Worlds, and Outer Planets (& back)**

- EDL Challenges: rugged terrain, unknown/thick atmospheres, high entry speeds

- **Scientists want to go to Mars more often**

- EDL Challenges: cost, risk tolerance

- **We have the long-term goal of landing humans on Mars**

- EDL Challenges: high mass, precise landing, risk posture for humans

Summary

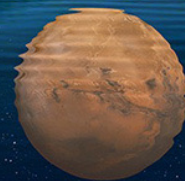


- **EDL is a critical exploration function made of specialized disciplines and subsystem designs**
- **Our community is a critical part of NASA's upcoming lunar, Mars, science, and commercial partnership/economic growth objectives**
- **We have many ongoing missions in development, technology maturation efforts, and engagements with industry**
- **We are engaged in multi-Mission Directorate efforts to align objectives, architectures, and technology investments**
- **The future of EDL is bright, and we need the next generation of engineers, researchers and technologists to meet all of NASA's lofty exploration goals!**



EXPLORE
MOON_{to}MARS

Thank you!



Acronyms



- **ADEPT – Adaptable, Deployable Entry and Placement Technology**
- **DSS – Descent Systems Study**
- **ECLSS – Environmental Control and Life Support Systems**
- **ESM – Entry Systems Modeling**
- **HEEET – Heatshield for Extreme Entry Environment Technology**
- **HEOMD – Human Exploration and Operations Mission Directorate**
- **HIAD – Hypersonic Inflatable Aerodynamic Decelerator**
- **ISRU – In-Situ Resource Utilization**
- **LOFTID – LEO Flight Test of an Inflatable Decelerator**
- **NDL – Navigation Doppler LIDAR**
- **SMD – Science Mission Directorate**
- **SPLICE – Safe, Precise Landing Integrated Capabilities Evolution**
- **STMD – Space Technology Mission Directorate**
- **TRN – Terrain Relative Navigation**
- **TPS – Thermal Protection System**