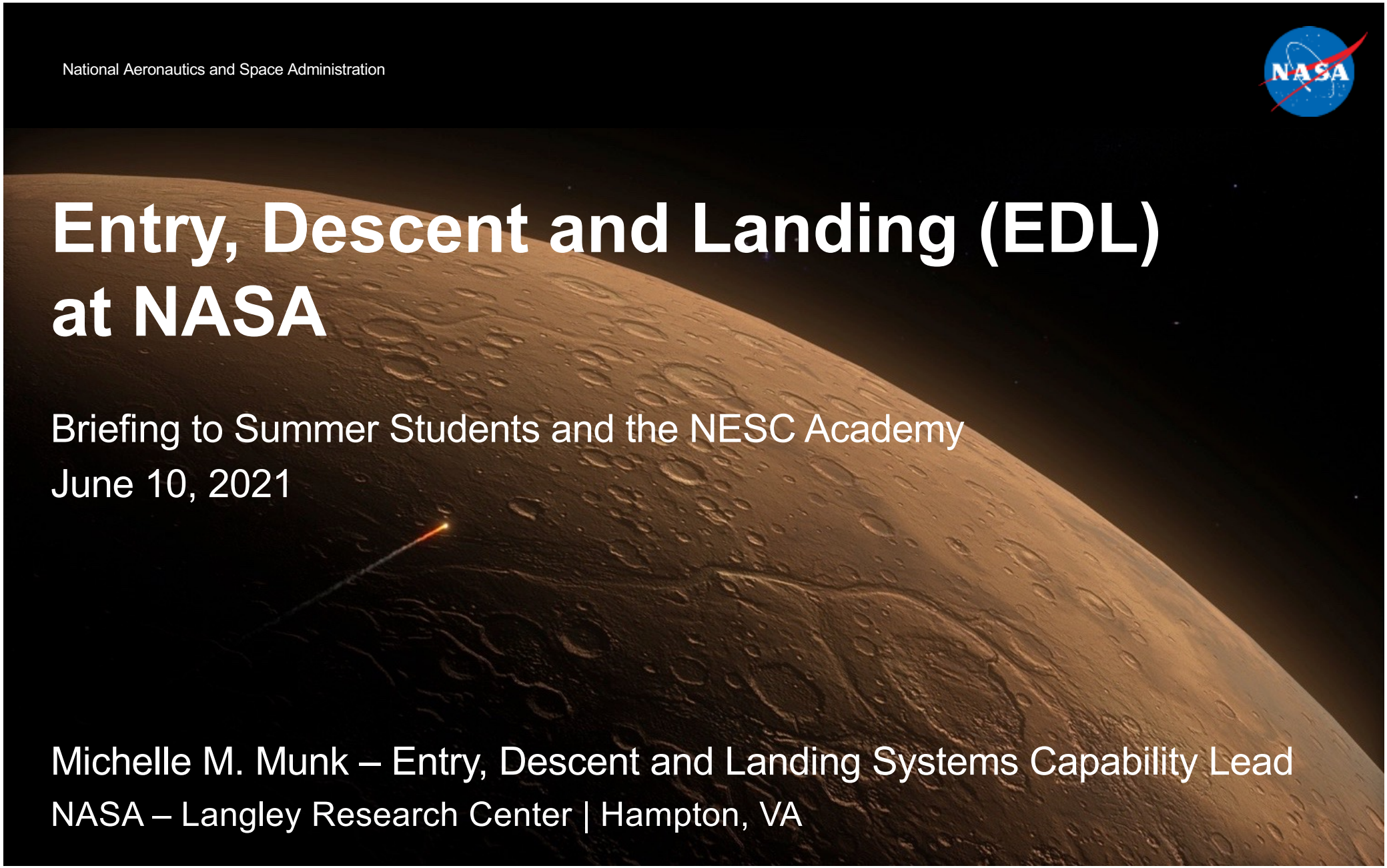
National Aeronautics and Space Administration



Entry, Descent and Landing (EDL) at NASA

Briefing to Summer Students and the NESC Academy

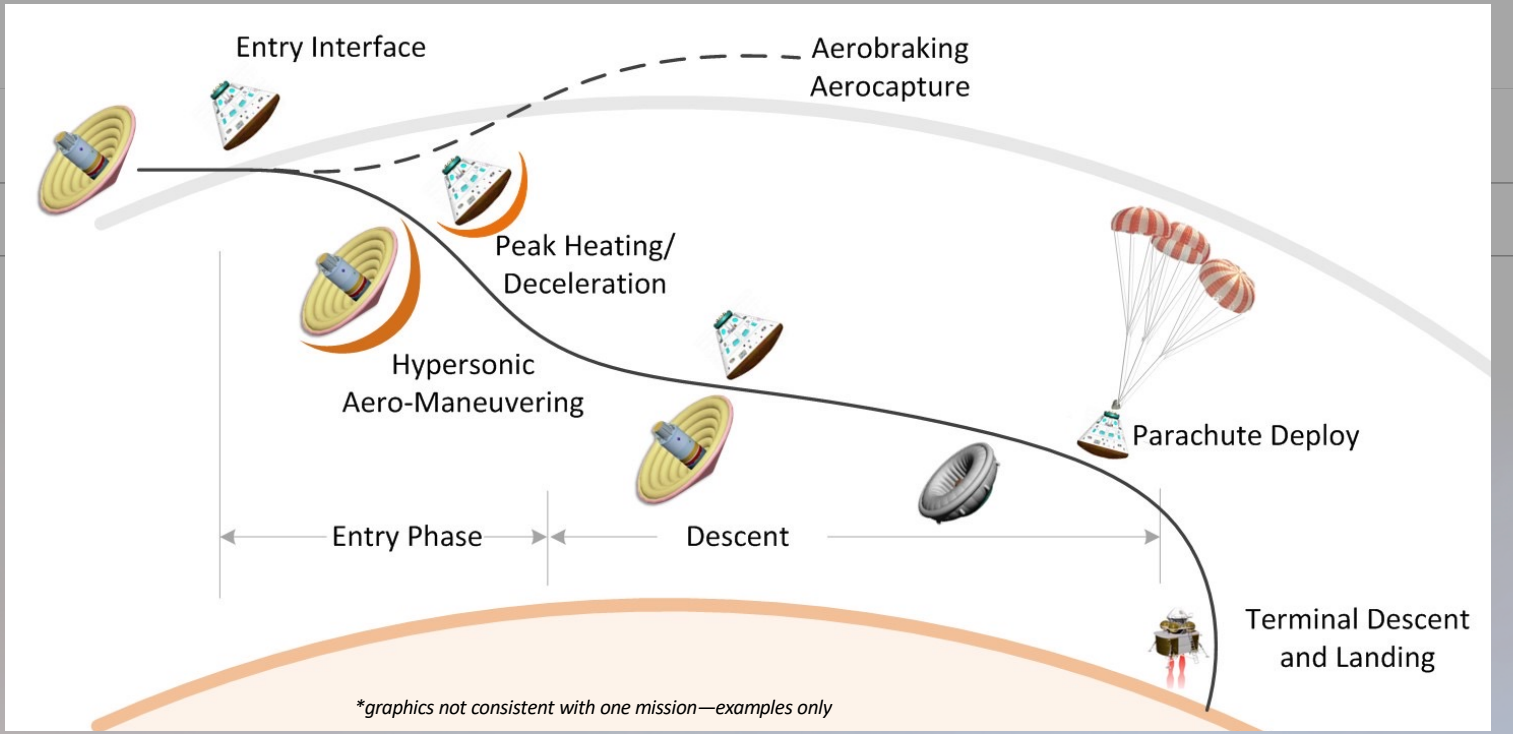
June 10, 2021

Michelle M. Munk – Entry, Descent and Landing Systems Capability Lead

NASA – Langley Research Center | Hampton, VA

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

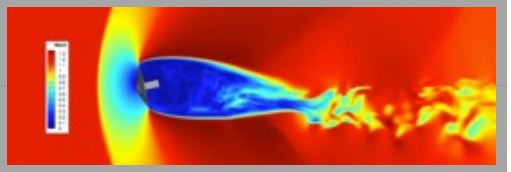
- Aerodynamics
- Aerothermodynamics
- Flight Dynamics/Design
- Thermal
- Modeling and Simulation

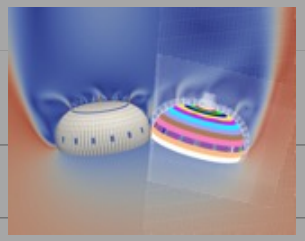
Hardware

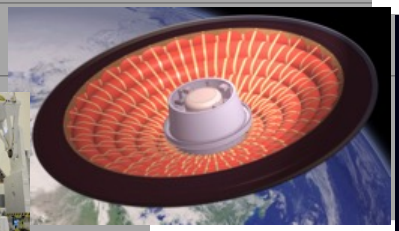
- Avionics
- GN&C
- Instrumentation
- Materials – High Temperature
- Mechanical Design
- *Propulsion**
- Structures
- Textiles

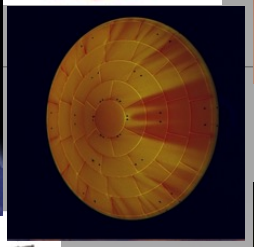
System Level

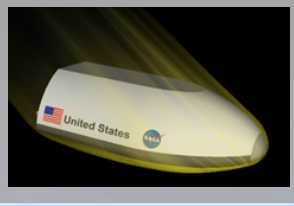
- Software
- Mission Design & Analysis
- Systems Analysis
- Systems Integration

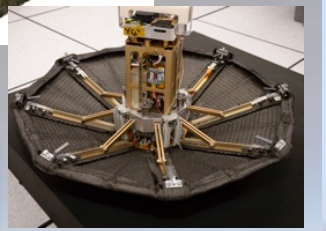


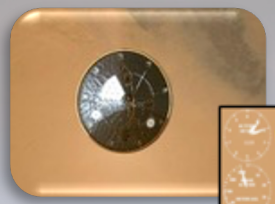


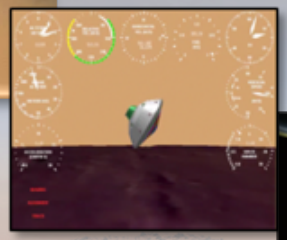


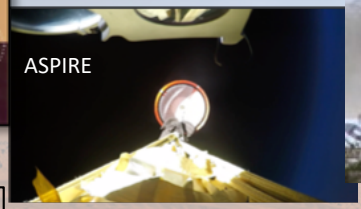


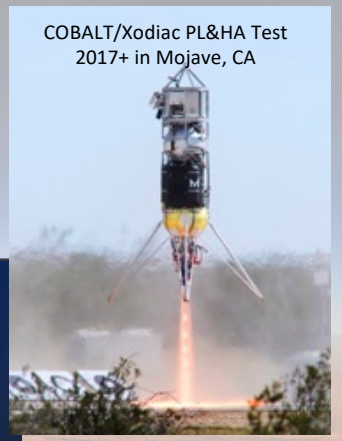








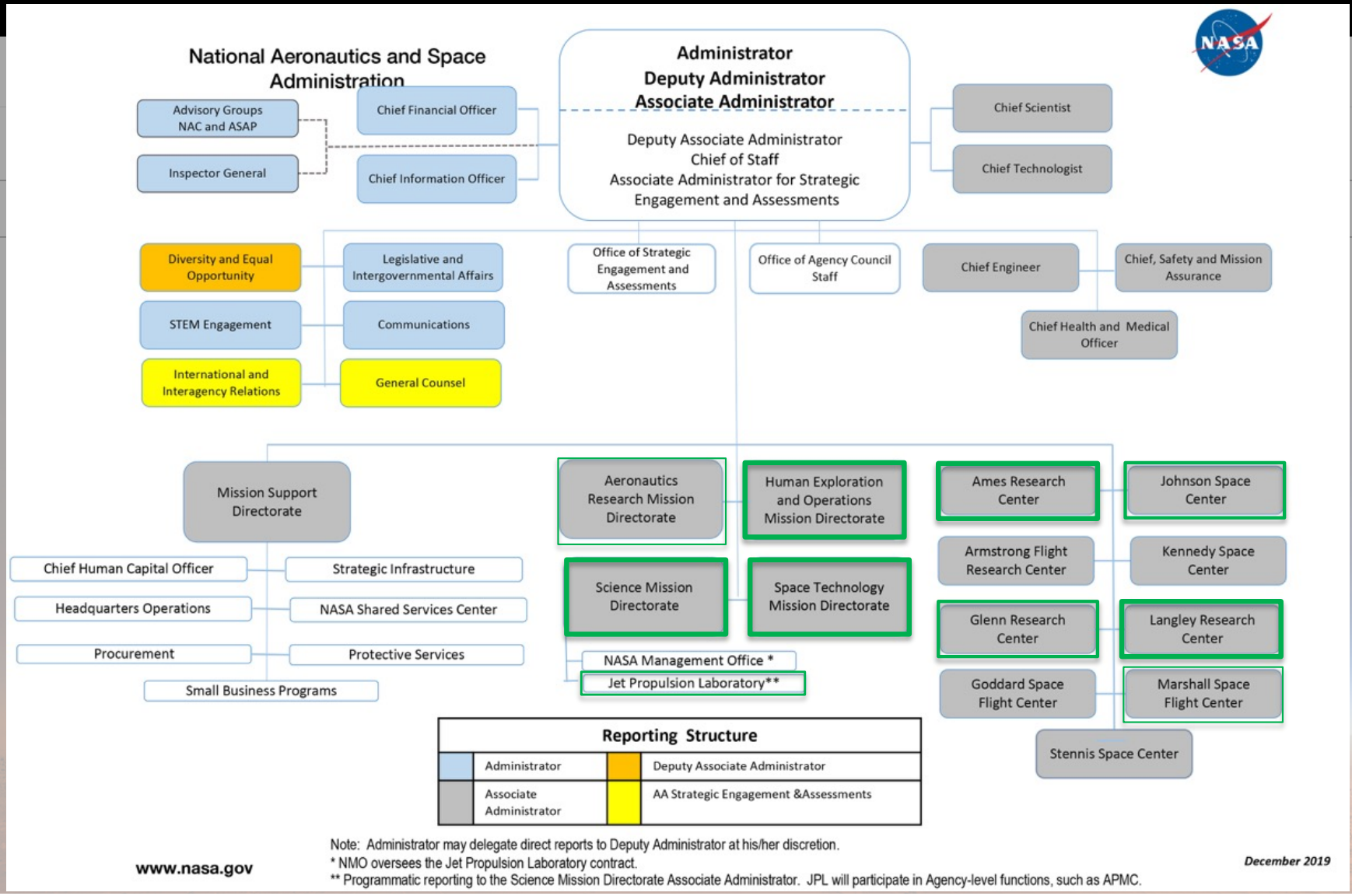




NASA Taxonomy: TX09

*Propulsion discipline related less directly than others

NASA Organizational Structure - Context



EDL Involvement by Mission Directorate

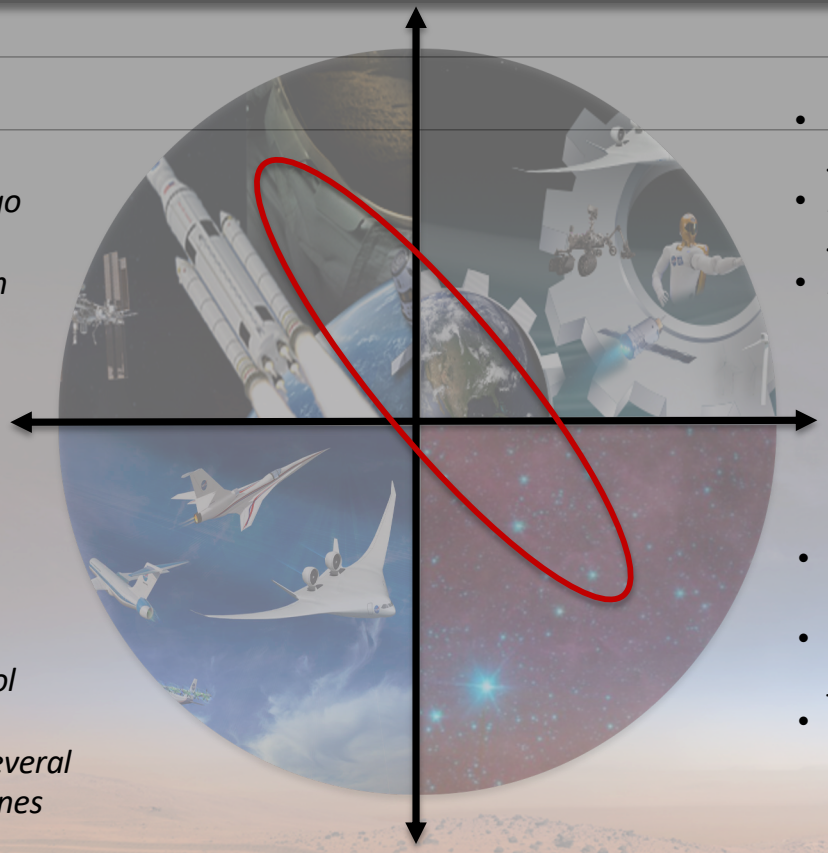
Current Resources/Assets

HEOMD

- *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*
- *Public-Private Partnership, SBIR, academic opportunities*
- *Investment strategy definition*



ARMD

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

SMD

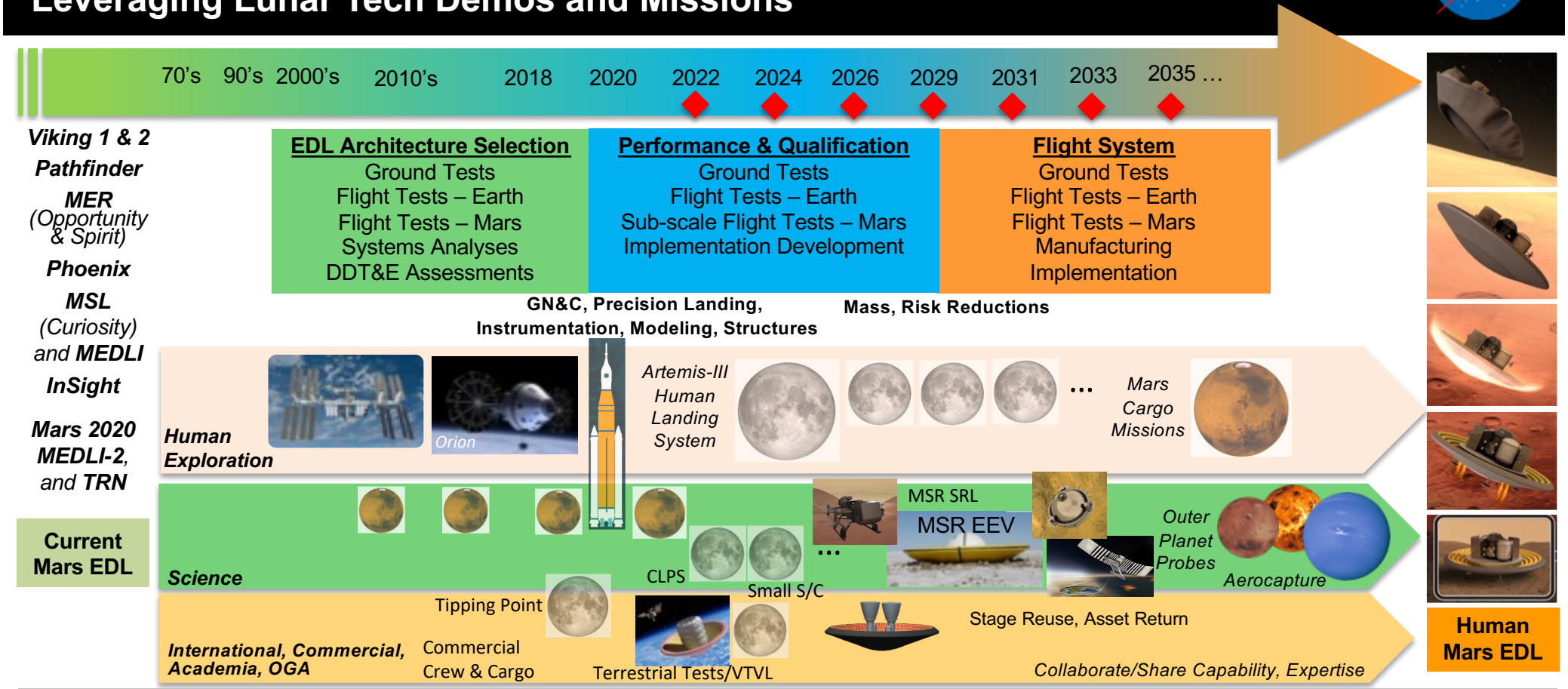
- *Planetary entry systems design, development, and ops*
- *Technology incentives and co-funding for flight infusion*
- *Development of Strategic Knowledge Gaps (with HEOMD)*

We Can Think About EDL in 3 Bins

- **Human:**
  - Returning humans from Low Earth Orbit
  - Returning humans from beyond LEO (Gateway, the Moon)
  - Landing humans on the Moon
  - Landing humans on Mars
- **Robotic:**
  - 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
  - Commercial interest in “asset return” – rocket stages, materials, etc.

Mars EDL is a Long-Term Challenge

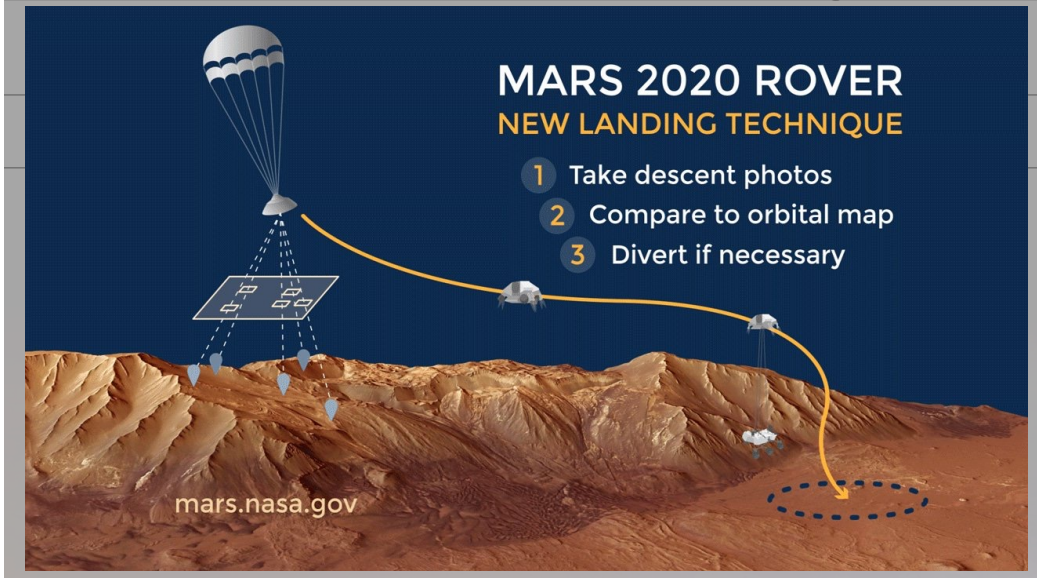
Leveraging Lunar Tech Demos and Missions

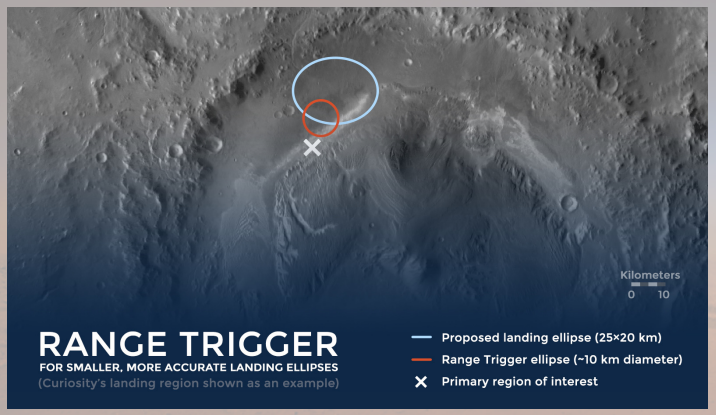


Lunar Landed Mass:		**0.1-0.3 t**	**0.5-1 t**	**5-10+ t**
Lunar Precision:		**<0.5 km**	**<0.1 km**	**<0.1 km**
Mars Landed Mass:	**1 t**		**3-10 t**	**20-30 t**
Mars Precision:	**10-25 km**		**<2 km**	**<0.1 km**
Mars Planet Access:	**~40%**		**~75%**	**Near global**

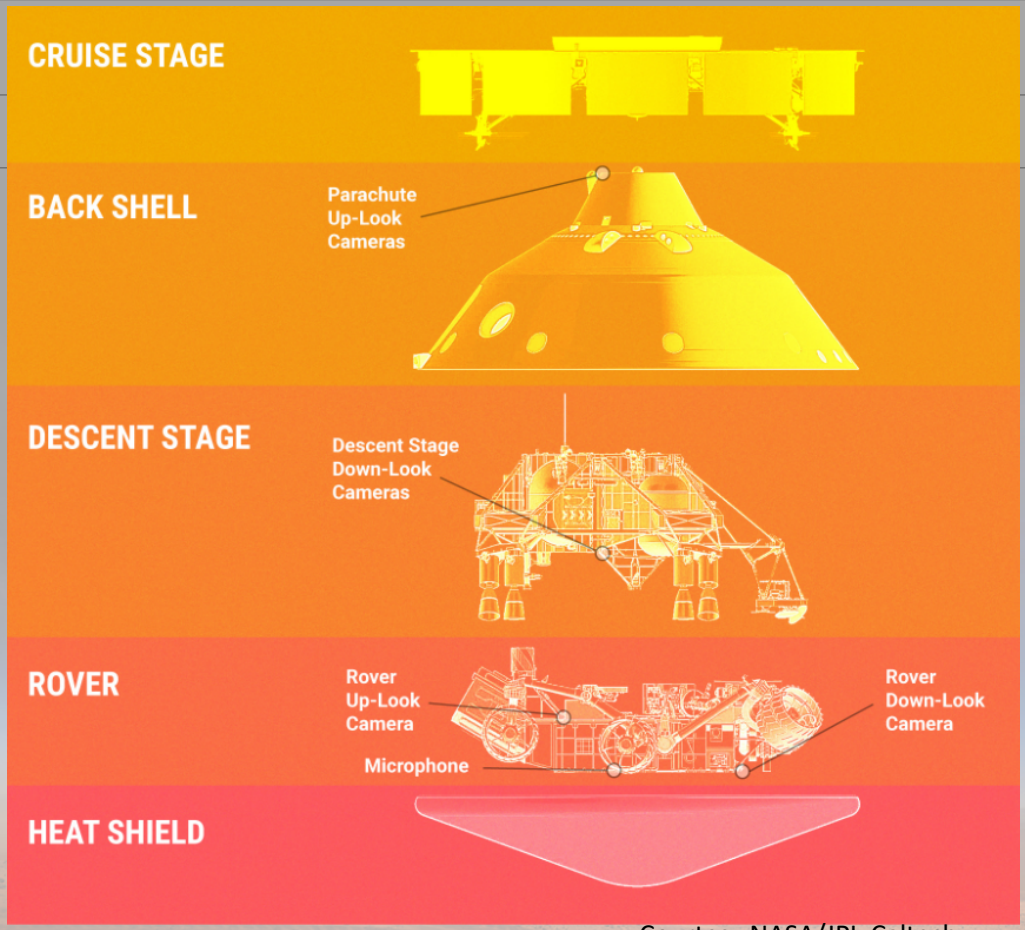
What Was New About Perseverance EDL?

More Precise Landing

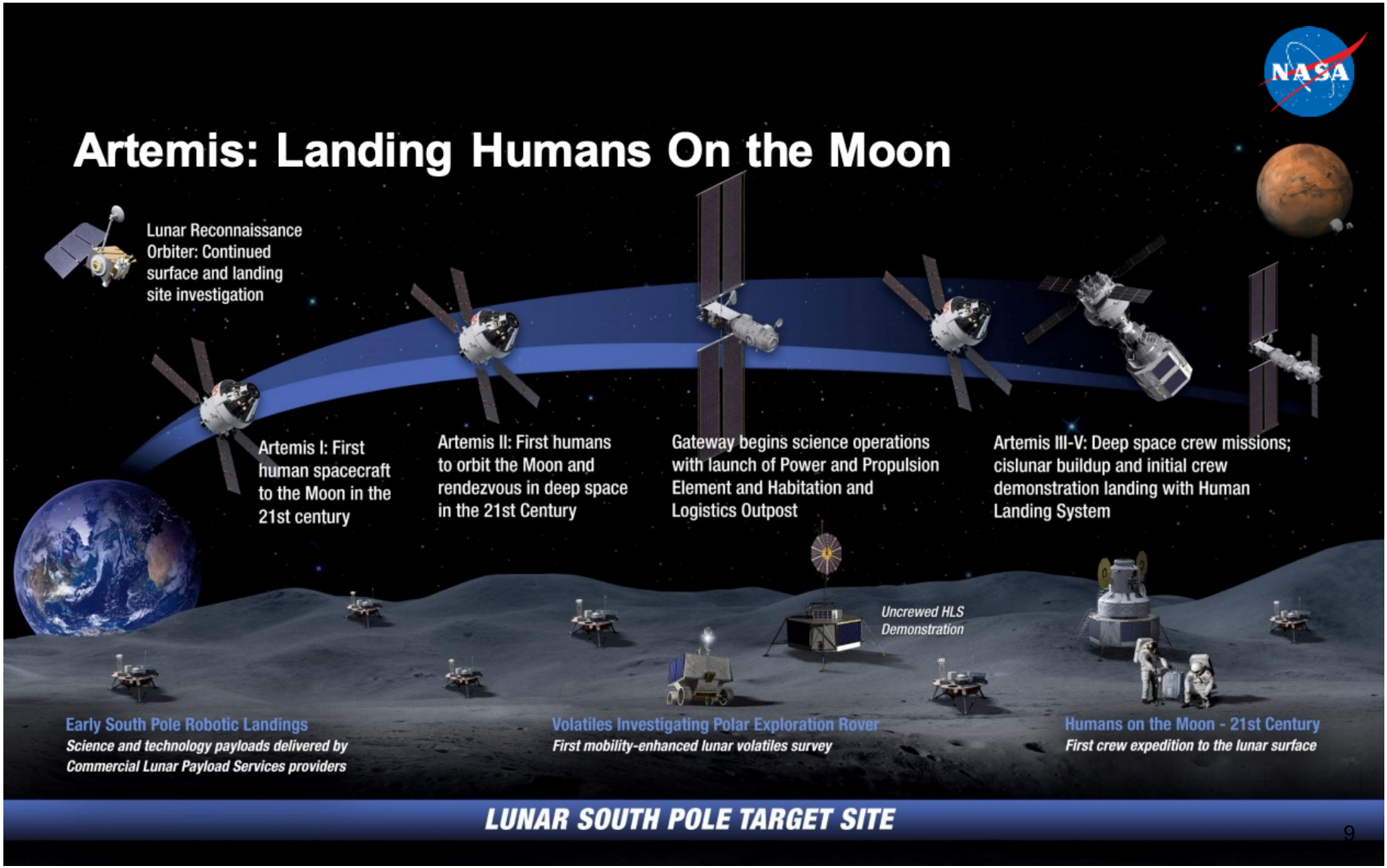


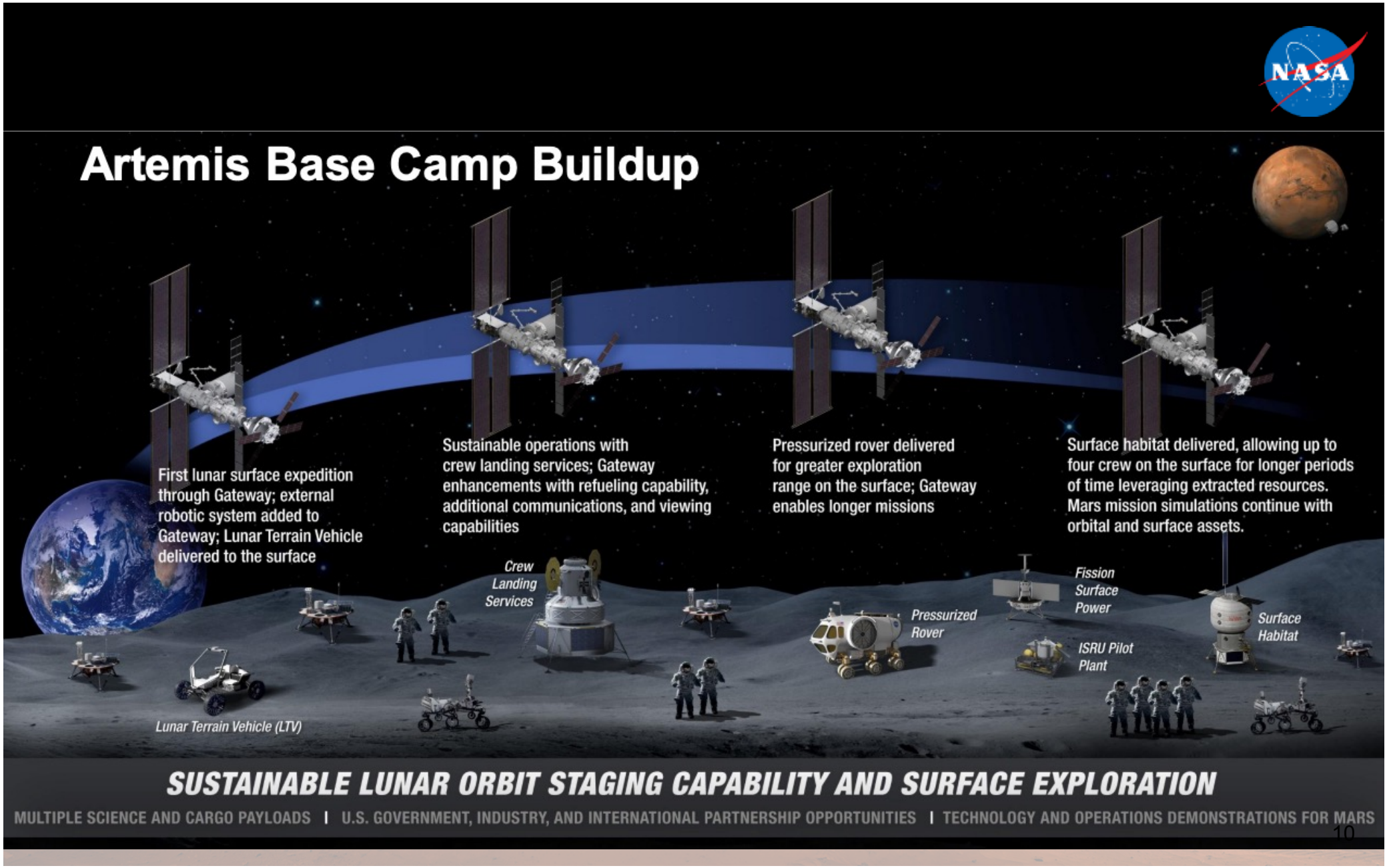


More EDL Views!



Courtesy NASA/JPL-Caltech


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
Uncrewed HLS Demonstration
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
Humans on the Moon - 21st Century
First crew expedition to the lunar surface
LUNAR SOUTH POLE TARGET SITE


Artemis Base Camp Buildup
First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface
Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities
Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions
Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets.
Crew Landing Services
Pressurized Rover
Fission Surface Power
ISRU Pilot Plant
Surface Habitat
Lunar Terrain Vehicle (LTV)
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Driving EDL Assumptions

From Moon-to-Mars Campaign *Draft*

- **Boots on Mars in 2039**
  - Three landers are launched in 2033, 2035, and 2038 to achieve 2039 Nuclear-enabled opposition-class crewed mission with Venus flyby, 30-day surface stay
  - Requires first cargo lander at KSC for integration in late 2031
- **SLS shroud diameter is 8.4 m**
- **Payload mass is 22-26 t (under study)**
- **Precise landing to within 100 m (or less) for asset aggregation**
- **Landers are delivered to Mars orbit via propulsive burns, not Aerocapture**
- **EDL technology maturation achieved through ground development and Earth flight test. Mars test achieved through first (2033) cargo lander.**

Mars Landers: Comparison

	Viking	Pathfinder	MERs	Phoenix	MSL	InSight	M2020
Entry Capsule							
Diameter (m)	3.505	2.65	2.65	2.65	4.52	2.65	4.5
Entry Mass (t)	0.930	0.584	0.832	0.573	3.153	0.608	3.440
Parachute Diameter (m)	16.0	12.5	14.0	11.8	19.7	11.8	21.5
Parachute Deploy (Mach)	1.1	1.57	1.77	1.65	2.2	1.66	1.75
Landed Mass (t)	0.603	0.360	0.539	0.364	0.899	0.375	1.050
Landing Altitude (km)	-3.5	-2.5	-1.4	-4.1	-4.4	-2.6	-2.5
Terminal Descent and Landing Technology	 Retro-propulsion	 Airbags	 Airbags	 Retro-propulsion	 Skycrane	 Retro-propulsion	 Skycrane

Steady progression of "in family" EDL

Payloads up to 1 t

- **Viking-heritage Entry, Descent, and Landing (EDL) technologies cannot land masses required for human Mars exploration**
- **Supersonic parachutes cannot be extended to high-mass EDL**
- **Propulsive descent and landing are enabling for human-scale EDL at Mars**

About Systems Capability

- **The 4 Mission Directorates have the dollars, and the Centers have the pool of people and facilities to implement the missions (a matrixed organization)**
- **It is important that the Agency maintain the talent and facilities it needs, for the future.**
  - There are some "special," critical things that only NASA does, and that we do only once every several years—such as **entry, descent, and landing** on a planet
  - In addition, EDL is used by multiple Mission Directorates and multiple missions, so it's difficult to pinpoint an "owner"
  - Systems Capability Teams (and Leads) were created to make sure these vital systems have advocacy and a long-term plan for sustainment (especially as leadership and/or direction changes)
- **The next generation of engineers is a vital part of that sustainment!**

Space Technology Strategic Framework

Lead	Thrusts	Outcomes	Primary Capabilities
Ensuring American global leadership in Space Technology • Lunar Exploration building to Mars and new discoveries at extreme locations • Robust national space technology engine to meet national needs • U.S. economic growth for space industry • Expanded commercial enterprise in space	**Go** Rapid, Safe, and Efficient Space Transportation	• 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.	• Nuclear Systems • Cryogenic Fluid Management • Advanced Propulsion
	Land Expanded Access to Diverse Surface Destinations	• 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.	• Entry, Descent, Landing, & Precision Landing

	Live
	Sustainable Living and Working Farther from Earth
		• 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 Life Support & Human Performance technologies.
			• Advanced Power
			• In-Situ Resource Utilization
			• Advanced Thermal
			• Advanced Materials, Structures, & Construction
			• Advanced Life Support & Human Performance

	Explore Transformative Missions and Discoveries	• 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 transformative technologies that enable future NASA or commercial missions and discoveries	• Advanced Avionics Systems • Advanced Communications & Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing & Assembly • Advanced Manufacturing • Small Spacecraft • Rendezvous, Proximity Operations & Capture

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.

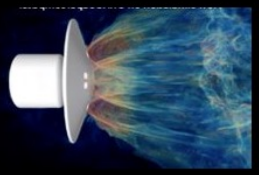
Lunar Capabilities (Feeding Forward to Mars)

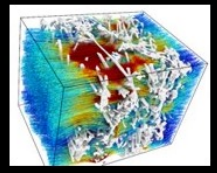
Plume Surface Interaction

Reduce lander risk by understanding how engine plumes and surfaces behave

Retropropulsion

Wind tunnel testing of Mars-relevant configurations; CFD modeling comparisons





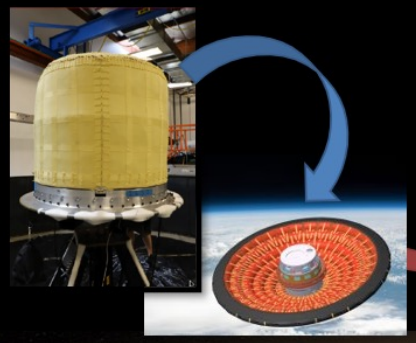
Data Return and Model Improvements

Measure EDL flight system performance and update unique, critical simulations for Moon and Mars

Mars Capabilities

Large Scale Demonstrations

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



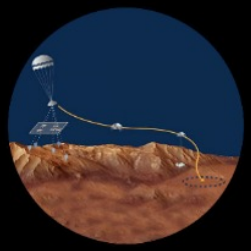
Assess alternatives

Earth Flight Tests, such as LOFTID

Human Mars EDL

Develop Technologies to Land Payloads Within 50 m Accuracy and Avoid Landing Hazards.

Enable safe, pinpoint landings closer to high value science/operational targets while avoiding hazards.

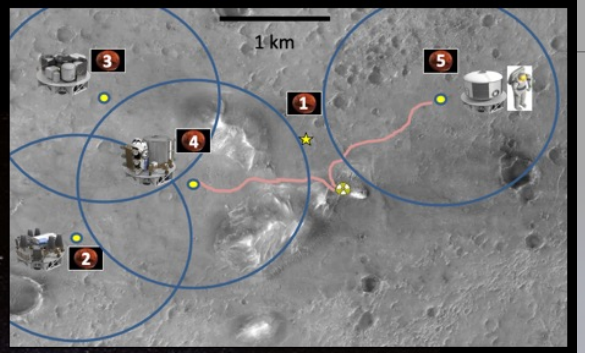


Terrain Relative Navigation

Navigation Doppler LIDAR

Hazard Detection LIDAR

Descent and Landing Computer and Algorithms



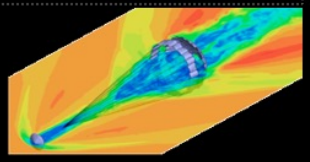
<u>Enable</u> anytime landings in treacherous terrains
<u>Reduce the risk</u> of the landing
<u>Reduce the operations time</u> for a rover or human to reach an interesting site
<u>Aggregate resources</u> in one area

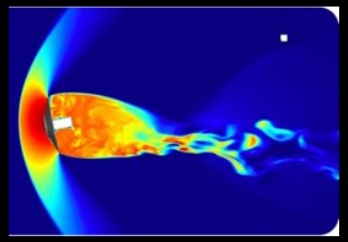
Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies.

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

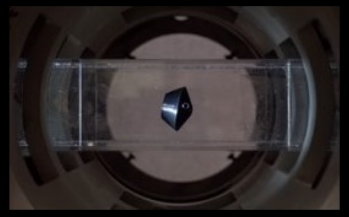
Entry Systems Modeling

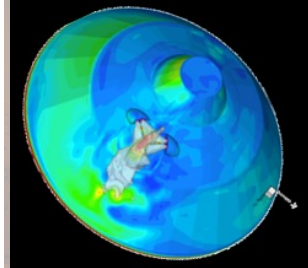
Reducing entry system mass and risk by developing advanced, validated models

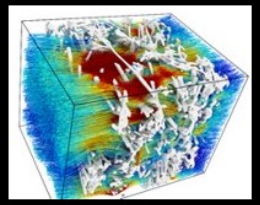




Integral to

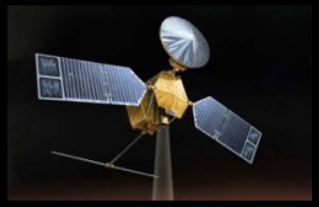


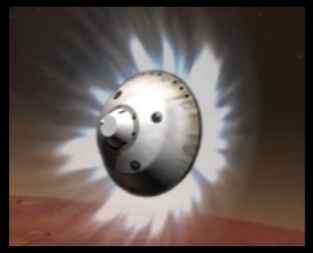




Mission Design and Ops

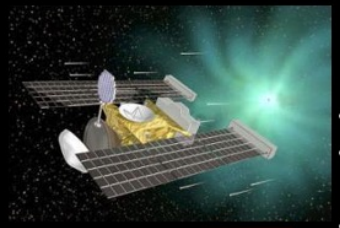
- Systems Studies
- Mission Architectures
- Aerobraking
- Aerocapture
- Entry Trajectory Analysis

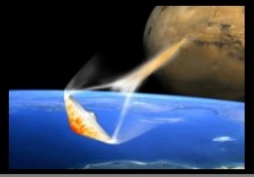




Flight Environments Characterization

- Atmospheric Modeling
- Wind tunnel / arcjet testing
- Computational fluid dynamics
- Flight testing and instrumentation
- Flight reconstruction



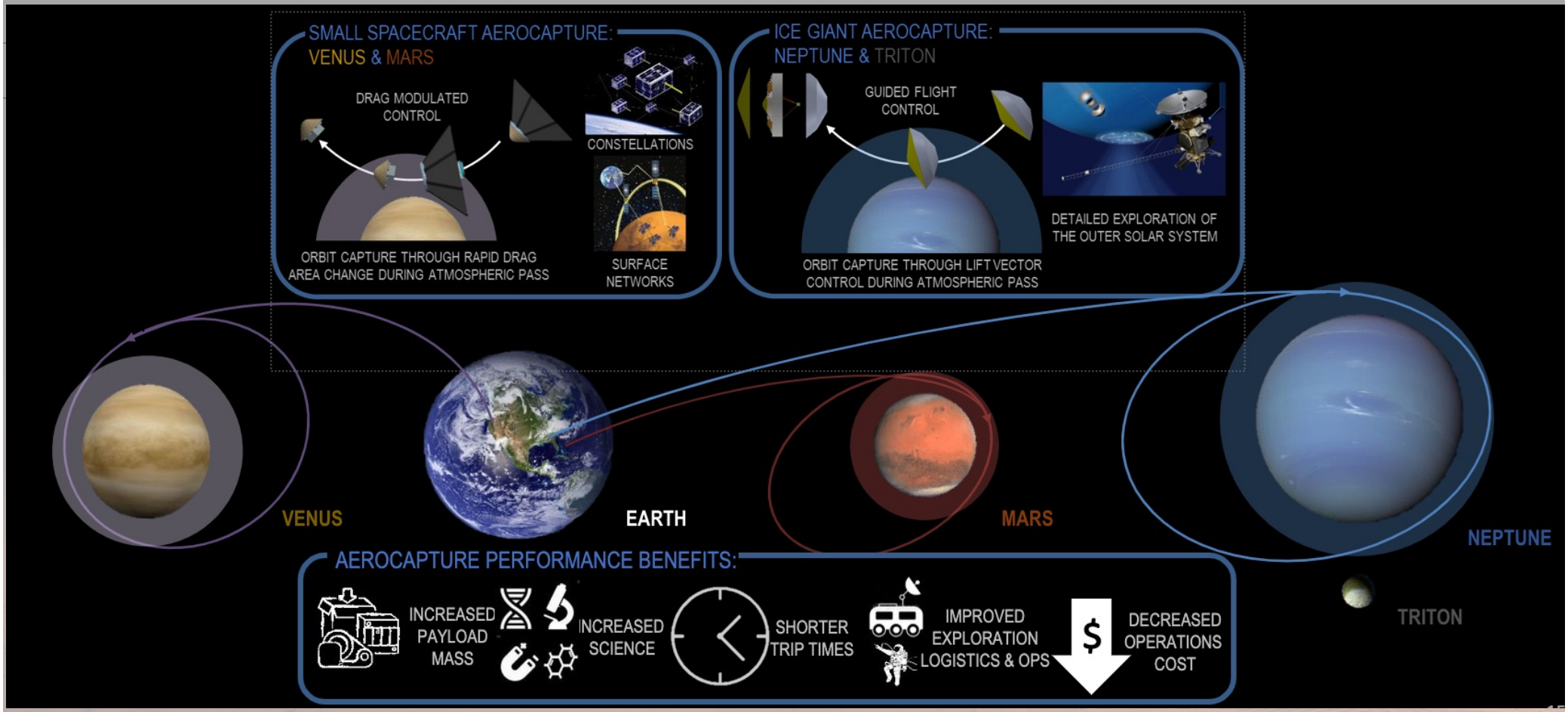


Advanced Systems Development

- Structures
- Thermal Protection Systems (TPS) materials
- Deployable decelerators
- Guidance, Navigation and Control
- Precision landing sensors
- Landing systems

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



EDL & Precision Landing *Draft* Gaps

Lunar-Focused

- Land large payloads on the Moon
- Land within 50 m of desired site (develop sensors, algorithms)
- Establish consistent lunar maps
- Be able to predict Plume Surface Interaction (PSI)
- Obtain PSI flight data

Science Mission-Focused

- Design high-reliability EDL systems
- Develop EDL/Aerocapture capability for small spacecraft
- Perform aerocapture at ice giants
- Enable safe landing on Europa
- Develop technologies for large landers

Mars-Focused

- Land 20+ t on Mars
- Land within 50 m of desired site
- Establish consistent Mars maps
- Be able to predict PSI
- Conduct flight tests of hypersonic entry system
- Conduct flight tests of retropropulsion system
- Scale up large rigid and inflatable structures
- Develop landing attenuation methods

Cross-Cutting

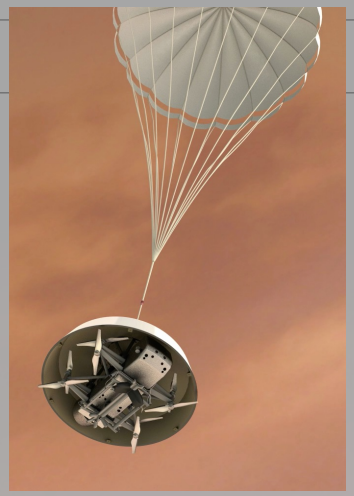
- Improve aerodynamic and aerothermal models
- Establish parachute modeling
- Advance multi-disciplinary, coupled tools
- Instrument EDL vehicles for lower SWaP-C
- Establish & access inexpensive flight test platforms
- Maintain and modernize unique facilities
- Modernize codes to GPU platforms; utilize high-end computing
- Advance flight mechanics/GN&C tools
- Mature TPS performance and reliability modeling

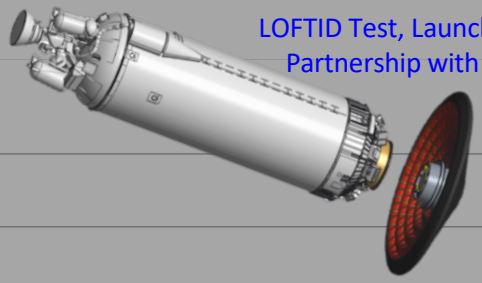
STMD Programs – Means to the End Goal

TECHNOLOGY PIPELINE

Recent EDL Highlights/Activities

Dragonfly, Launch 2027
A Relocatable Titan Lander

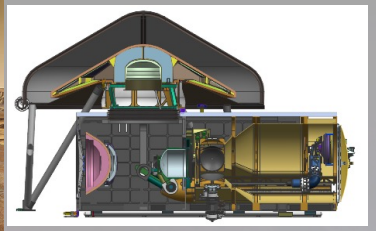




LOFTID Test, Launch 2022
Partnership with ULA

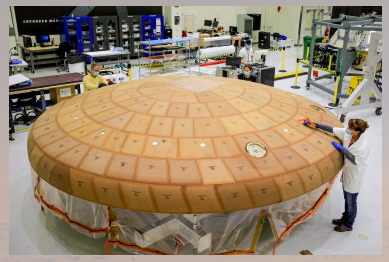
MEDLI2 on M2020
STMD/SMD partnership

Mars 2020 - Perseverance
Landing February 18, 2021

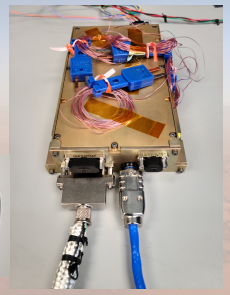


Mars Sample Return Lander &
Earth Return Orbiter, Launch 202x
Technology partnerships with ESM, DLR
MSR EES using STMD-developed TPS

Human Landing System
Mars Assessment updated w/new GRA
Lunar DDL oversight activities

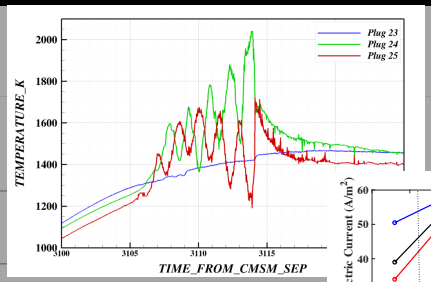


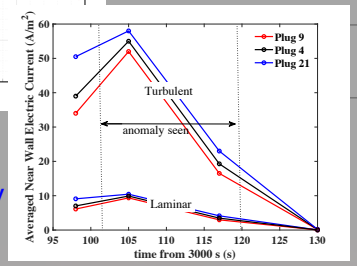
Artemis 1 – Ready to Fly!
NASA instrumentation
SCIFLI aerial imagery



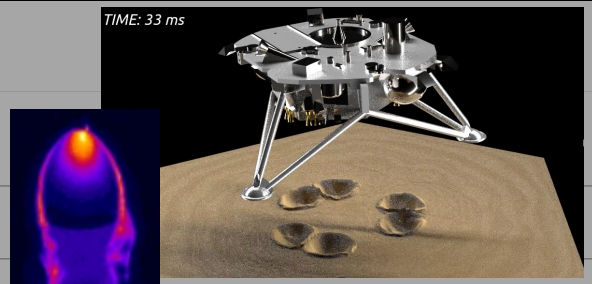
SCALPPS
Delivery to IM in October
for CLPS flight in Jan 2022

Recent EDL Highlights/Activities

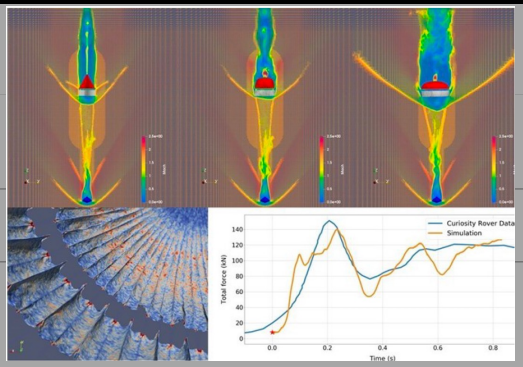




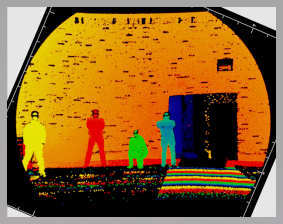
EFT-1 TC anomaly
NESC study informed by ESM methods

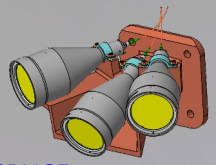


PSI – New Start in GCD
Active partnerships: STTR, SBIR, ESI

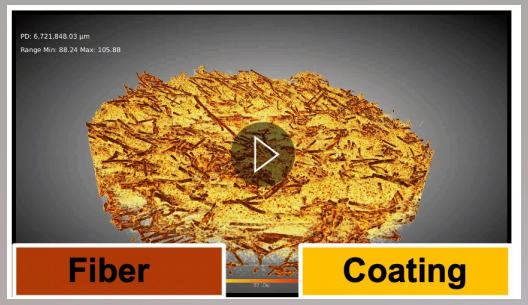


Parachute FSI
Partnership with ESM & STRG
New University Awards

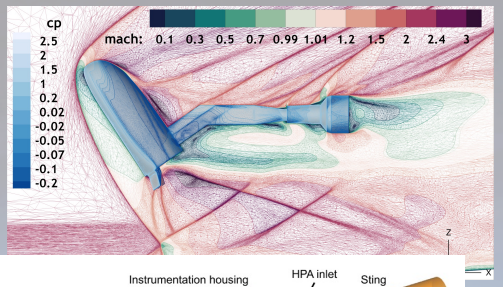




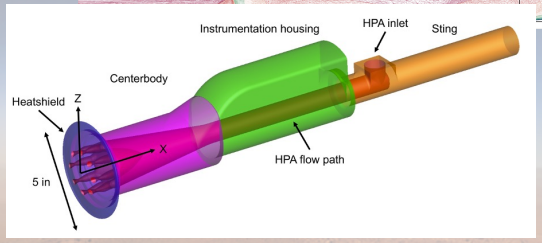
SPLICE
Multiple funded test flights
(Tipping Point, CLPS, FO)



Entry Systems Modeling
Delivery of PICA-NuSil model for MEDLI2



Summit simulation of Supersonic Retropropulsion



Descent Systems Study
Mid L/D testing complete
HIAD testing planned for FY21

What's Next in EDL (2020-30)?

- **We will land precisely on the Moon, first with commercially-provided landers (small), then evolving to human-scale**
  - EDL Challenges:
    - Lightweight, inexpensive sensors for precise landing (feeds to Mars); integrating them on commercial landers
    - Plume/surface/vehicle interactions near touchdown (feeds to Mars)
    - Integrated simulations for assessing landers and sensor suites (feeds to Mars)
- **We want to return rocks 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 $1x10^{-6}$ probability of failure
- **Scientists want to go to Venus, Ice Giants, Ocean Worlds, and Outer Planets**
  - EDL Challenges: rugged terrain, unknown/thick atmospheres, high entry speeds
- **We have the long-term goal of landing humans on Mars**
  - EDL Challenges: high mass, precise landing, risk posture for humans


EXPLORE
MOON to MARS

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