National Aeronautics and
Space Administration

EDL Technology Investments within NASA's Space Technology Mission Directorate (STMD)

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Context: Space Technology Portfolio

Transformative & Crosscutting Technology Breakthroughs

Technology Demonstration Missions bridges the gap between early proof-of-concept tests and the final infusion of cost-effective, revolutionary technologies into successful NASA, government and commercial space missions.

Small Spacecraft Technology Program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.

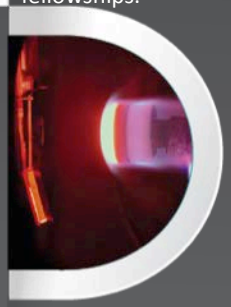
Game Changing Development seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency's broad array of future space missions.

Pioneering Concepts/Developing Innovation Community

NASA Innovative Advanced Concepts (NIAC) nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs—radically better or entirely new aerospace concepts–while engaging America's innovators and entrepreneurs as partners in the journey.

Space Technology Research Grants seek to accelerate the development of "push" technologies to support future space science and exploration needs through innovative efforts with high risk/high payoff while developing the next generation of innovators through grants and fellowships.

Center Innovation Fund stimulates and encourages creativity and innovation within the NASA Centers by addressing the technology needs of the Agency and the Nation. Funds are invested to each NASA Center to support emerging technologies and creative initiatives that leverage Center talent and capabilities.



Creating Markets & Growing Innovation Economy

Centennial Challenges directly engages nontraditional sources advancing technologies of value to NASA's missions and to the aerospace community. The program offers challenges set up as competitions that award prize money to the individuals or teams that achieve a specified technology challenge.

Flight Opportunities facilitates the progress of space technologies toward flight readiness status with testing in space-relevant environments. The program fosters commercial reusable suborbital transportation.

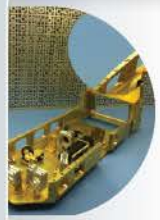
Small Business Innovation Research (SBIR) and **Small Business Technology Transfer (STTR)** Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.

STMD's 8 Thrust Areas

Space Technology will focus investments in 8 key thrust areas that will enable or substantially enhance future NASA mission capabilities.

High Power Solar Electric Propulsion

Deep space human exploration, science missions and commercial applications with investments in advanced solar arrays and advanced electric propulsion systems, high-power Hall thrusters and power processing units.



Space Optical Comm.

Substantially increase the available bandwidth for near Earth space communications currently limited by power and frequency allocation restrictions, and increase the communications throughput for a deep space mission.

Advanced Life Support & Resource Utilization

Technologies for human exploration mission including Mars atmospheric In-situ resource utilization, near closed loop air revitalization and water recovery, EVA gloves and radiation protection.

Mars Entry, Descent and Landing Systems

Permits more capable science missions, eventual human missions to Mars including hypersonic and supersonic aerodynamic decelerators, a new generation of compliant TPS materials, retro-propulsion technologies, instrumentation, and modeling capabilities.

Space Robotic Systems

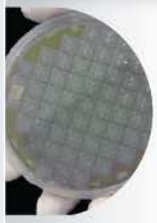
Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.

Lightweight Space Structures

Targets substantial increases in launch mass, and allow for large decreases in needed structural mass for spacecraft and in-space structures.

Deep Space Navigation

Allows for more capable science and human exploration missions using advanced atomic clocks, x-ray detectors and fast light optical gyroscopes.



Space Observatory Systems

Allows for significant increases in future science capabilities including, AFTA/WFIRST coronagraph technology to characterize exo-planets by direct observation and advances in the surface materials as well as control systems for large space optics.

THRUST AREAS

STMD's Entry, Descent and Landing (EDL) Investments

- STMD has active EDL investments in 7 of its 9 Programs
- This diversity enables us to mature several multi-use technologies, using efficiencies and leveraging collaborations across the TRL scale

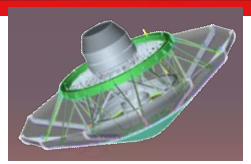
CIF	ESI/ECF/ STRG	NIAC	SBIR	GCD	FO	SSC	CC	TDM
Nano-ADEPT Lifting ADEPT	ESI Sub-topic out for proposal ------- 17 NSTRF past/active, 4 pending	Regolith heat shield ------- Titan Aerial Daught-ercraft ------- Titan Submar-ine	HEOMD: TPS, Instru-ments --------- SMD: Landing Instru-ments	HIAD HEEET CA-TPS 3-D MAT ADEPT PDT ESM MEDLI2 THOR Disreef	Maraia TVA	Partner-ship with ESM (FY15)	EEV Impact	LDSD MEDLI

Green = previous/completed Black = active FY14 Orange = pending start

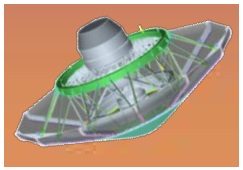
Science Mission-focused EDL Investments

- Woven TPS (HEEET) – sustainable, efficient materials for Venus, Mars & Outer Planets
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD) – increased payload mass and surface access at Mars
- Adaptable Deployable Entry and Placement Technology (ADEPT) – deployable heat shield for Venus provides benign entry loads
- Low Density Supersonic Decelerator – can provide increased mass to Mars surface
- MEDLI and MEDLI2 – provide flight data for aero/aerothermal model improvement and validation
- Entry Systems Modeling – improves models and tools used across all entry missions

EDL for Human Mars Missions



Aerocapture: enables Mars orbit insertion with very little propellant



Entry: The hypersonic portion of EDL requires thermal protection, and a system capable of autonomous guidance as well as predictable aerodynamics. Options include HIAD, ADEPT, and Mid-L/D aeroshells.

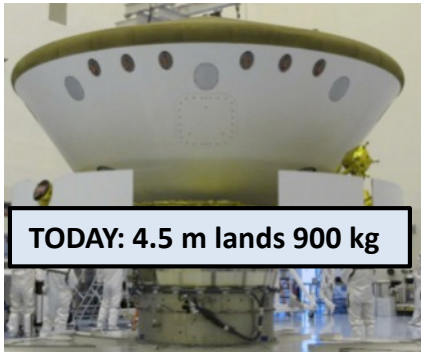
Transition: Extracting the vehicle from the hypersonic decelerator and orienting correctly for supersonic decelerator use

Descent: The supersonic portion of EDL requires slowing from ~Mach 5 to <Mach 1. Options include SRP, SIAD, and parachutes.

Landing: The human-scale payloads must avoid hazards (natural and predeployed assets) as well as land in a precise location close to other mission elements.

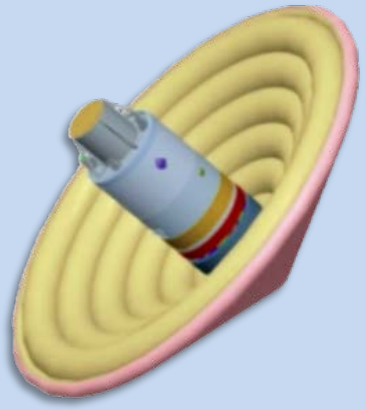
Hypersonic Entry Systems for Human Mars Missions

- **1970's Viking era technology is "broken" beyond MSL-sized spacecraft**
  - Rigid aeroshells constrained by launch shrouds cannot provide enough surface area to slow down a human-scale Mars lander (40,000 kg, 8 x 8 x 20 m)
  - Parachute technology (size and material) is too limited to apply
  - Can only access 30-40% of Mars—need to land below "sea level"



STMD is investing in entry systems to enable Human Mars missions

Hypersonic Inflatable Aerodynamic Decelerator (HIAD)

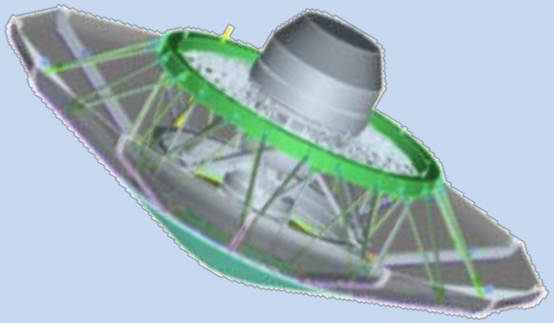


- Inflatable tori with overlaid Thermal Protection System
- Flight tested at 3 m scale (IRVE-II,3)
- ~TRL 4 for human scale

Both systems are folded for launch and deployed before Mars entry, providing the essentially rigid aerodynamic surface and heating protection needed for hypersonic deceleration, at a scale of 25-30 m.

Both systems can be used on robotic exploration missions at 6-10 m scale.

Adaptable Deployable Entry and Placement Technology (ADEPT)



- Mechanically-deployed structure with carbon fabric "skin"
- 6-m ground test planned in FY17
- ~TRL 2 for human scale

Low Density Supersonic Decelerators (LDSD)

Top Left Image: Robotic class supersonic inflatable aerodynamic decelerator prototype after rapid inflation test at China Lake

Top Right Image: NASA's Low-Density Supersonic Decelerator team gathers around the "SIAD-R“ at China Lake

In March 2012, NASA performed a trial run on a rocket sled test fixture, powered by rockets, to replicate the forces a supersonic spacecraft would experience prior to landing.

Project Summary: *Developing technologies to use atmospheric drag to dramatically slow a vehicle as it penetrates the skies over worlds beyond our own. Developing the largest ever supersonic parachute for Mars entry.*

Accomplishments:

- Successful drop test and rocket sled test occurred in 2012 and early 2013, illustrating the ability of the drag devices to slow a spacecraft
- Continue design verification tests of parachutes and supersonic inflatable aerodynamic decelerators in 2013
- All three supersonic deceleration devices -- the two inflatable vessels and the advanced parachute system -- will be the largest of their kind ever flown at speeds several times greater than the speed of sound
- The first supersonic flight tests are set for 2014 and 2015.

Propulsive Descent Technologies (PDT)

Current Mars Capability Limit: ~1t mass surface delivery (MSL)
- Viking derived supersonic chute and retro propulsion (SkyCrane)

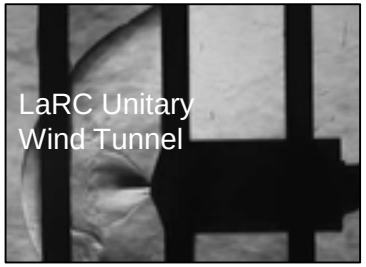
Challenge: Enable new TRL 6 supersonic decelerator capability

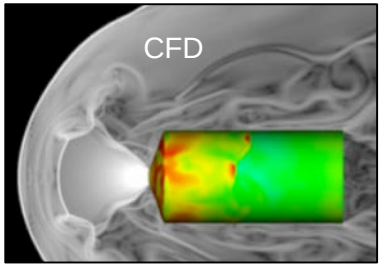
Mission Applicability: Robotic/human precursors >5 mt

Supersonic PDT Challenges

Propulsion system startup
- Rocket engines have been started in an on-coming supersonic flow at Earth

Integrated force and moments at steady state and during startup
- Aero-propulsive interactions
- Real-gas aeroscience effects
- Engine thrust effects due to on-coming supersonic flow
- Uncertainties and design lack supporting ground/flight data and engineering basis





Prior Cold Gas Tests

Project Approach

Acquire Flight Test Data
- SpaceX successful supersonic firings
- Upcoming SpaceX flights

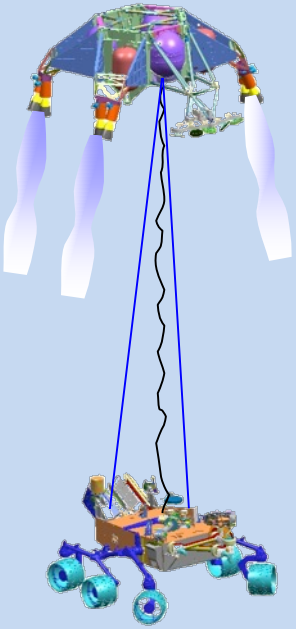
Perform CUBRC Wind Tunnel Testing
- Integrated force & moments, surface measurements
- Computational comparisons to data

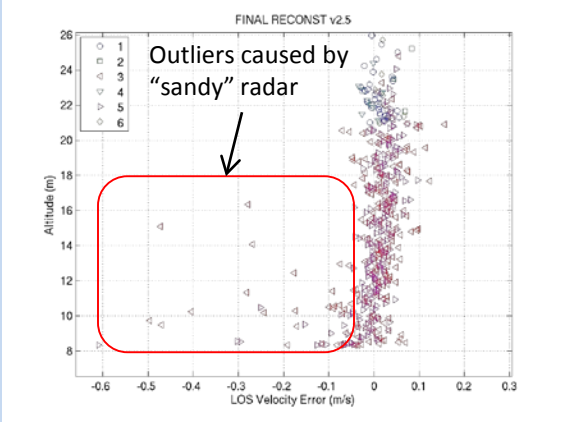
Conduct Vehicle Design Activities
- Conceptual packaging of large payloads; multiple configurations
- Investigate transitions from hypersonic to supersonic systems

Precision Landing/Hazard Avoidance

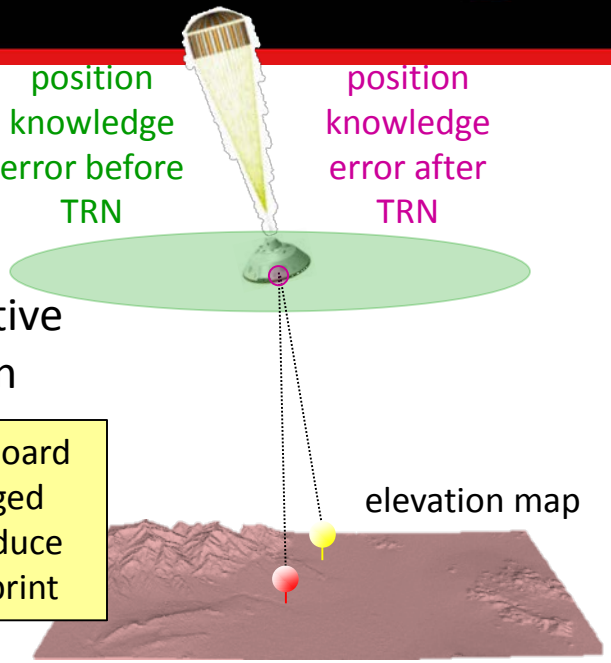
- Precision landing will be required for predeploying critical assets and delivering crews for human Mars missions (current requirement is <100 m)
- Hazard avoidance is needed to meet risk requirements on a given landing, and ensure avoidance of existing assets

State-of-the-Art: MSL Terminal Descent Sensor (Radar)





- Estimating horizontal velocity; propagating vertical velocity
- 25 km x 20 km landing ellipse
- Subject to plume-induced velocity errors

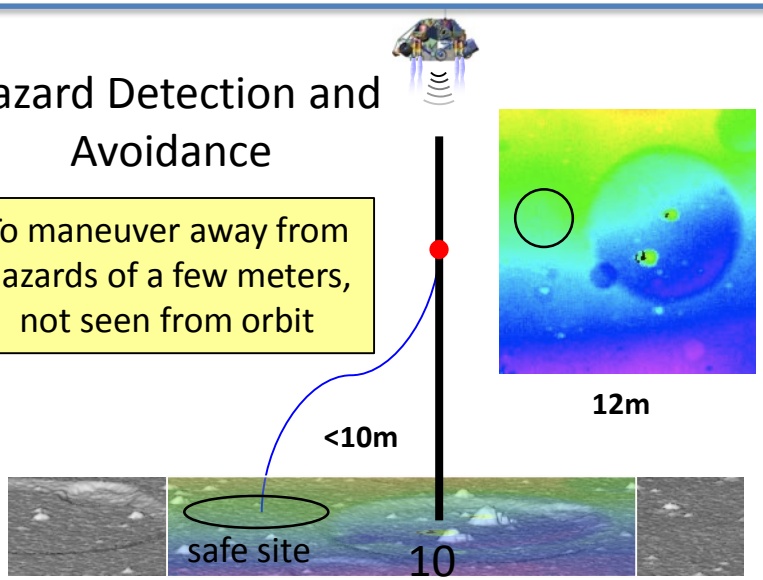


Terrain Relative Navigation

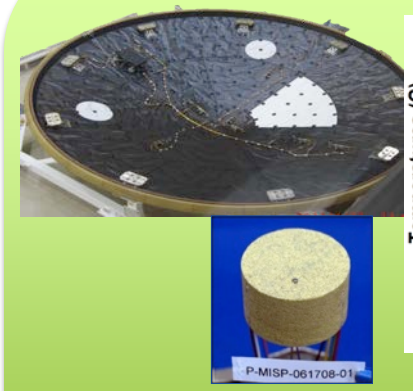
Match an onboard map to imaged terrain, to reduce landing footprint

Hazard Detection and Avoidance

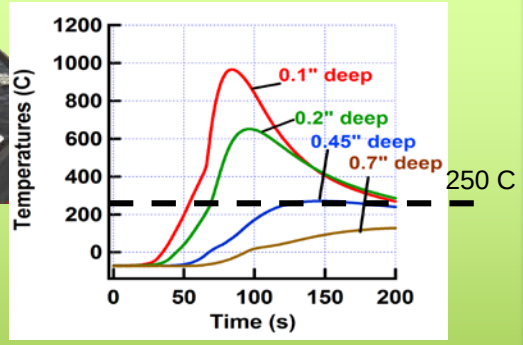
To maneuver away from hazards of a few meters, not seen from orbit

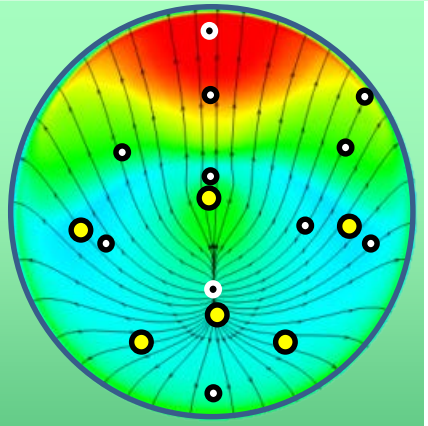


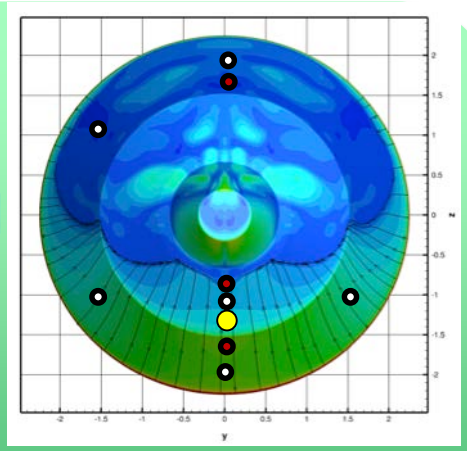
EDL Instrumentation Developments



MSL MEDLI Flight Temperatures







MEDLI data analysis nearly complete

MEDLI2 Authority to Proceed on Mars 2020

EDL flight data return is improving!

- All Mission Directorates and Offices concurred
- States that EDL data capture will be assessed early in mission life cycle
- Decisions will be made case-by-case regarding collaborative funding

NTEC decision memo signed

- Discovery AO released in 2014
- States that missions using EDL are required to propose how they would instrument to return EDL data
- Community will assist as needed; exact relationships to be worked

EDL instrumentation in Discovery AO

Summary

- EDL is a priority investment area in STMD, and one of 8 Thrust Areas
- Progressing towards a portfolio that spans the 9 programs in the Mission Directorate
  - Broadening the TRL of investments
  - Maturing multiple technologies economically by utilizing efficiencies; leveraging partnerships and testing opportunities
- Major strides have been made in EDL instrumentation
  - MEDLI2 approved for Mars 2020
  - EDL Engineering Science Activity in Discovery AO
  - NTEC decision memo on EDL data capture
- New partnerships with SMD – HEEET incentive in Discovery AO
- Multiple University collaborations and training for new engineers
- These developments will build a stronger technical community, and will mature the capabilities needed to both increase science return and enable human expansion

Acronyms

- ADEPT – Adaptable Deployable Entry and Placement Technology
- CA-TPS – Conformal Ablative Thermal Protection System
- CC – Centennial Challenge (Program)
- CIF – Center Innovation Fund
- ECF – Early Career Faculty
- ESI – Early Stage Innovation
- ESM – Entry Systems Modeling
- FO – Flight Opportunities (Program)
- HEEET – Heatshield for Extreme Entry Environment Technology
- HIAD - Hypersonic Inflatable Aerodynamic Decelerator
- LDSD - Low Density Supersonic Decelerator
- MEDLI – MSL Entry, Descent and Landing Instrumentation
- MEDLI2 – MEDLI for Mars 2020 mission
- NIAC – NASA Innovative Advanced Concepts
- PDT – Propulsive Descent Technologies
- SBIR – Small Business and Innovative Research
- SIAD – Supersonic Inflatable Aerodynamic Decelerator
- STRG – Space Technology Research Grants
- THOR – Terrestrial HIAD Orbital Reentry
- TPS – Thermal Protection System
- TRN – Terrain Relative Navigation
- TVA – Terminal Velocity Aerospace

Questions/Discussion

HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

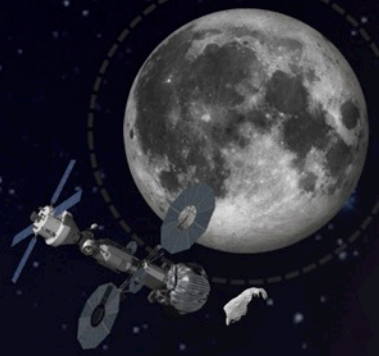
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

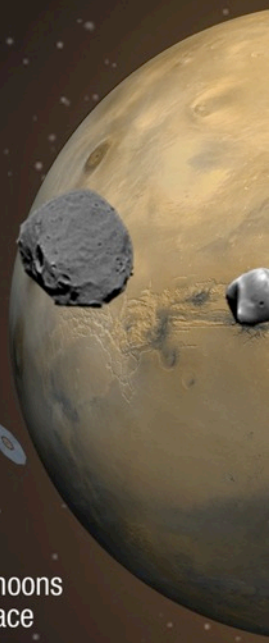


Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

Traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

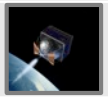


Exploring Mars, its moons and other deep space destinations

STMD Partners with Universities to Solve The Nation's Challenges

U.S. Universities have been *very* successful in responding to STMD's competitive solicitations

- STMD-funded university space technology research spans the entire roadmap space
- More than 120 U.S. universities have led (*or are STTR partners on*) more than 450 awards since 2011
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors

Program	# awards	# University-led awards	Upcoming Opportunities
Space Technology Research Grants	223	223	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC	76	21	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev	32	10	• Various topics released as Appendices to SpaceTech-REDDI ***Annually***
Small Spacecraft Technology 	22	13	• Smallsat Technology Partnerships Cooperative Agreement Notice every two years, with the next opportunity in 2015
Flight Opportunities	114	46	• Announcement of Flight Opportunities - in the future, funded SAAs to U.S. universities, non-profits and industry to pay for flights on their own are planned. ***Twice Annually***
STTR	*169*	*159 w/ univ partners*	• *Annual STTR solicitation*
Centennial Challenges	*3 Challenges (1 Challenge university-run)*	*23 teams competed (4 univ-led)*	• *One or more challenges annually* • *Starting in FY14: challenge competitions with a **procurement track** to fund **university teams** via grants*