National Aeronautics and Space Administration

Entry, Descent and Landing (EDL)

A Personal Look at Capabilities and Our Community

July 20, 2021

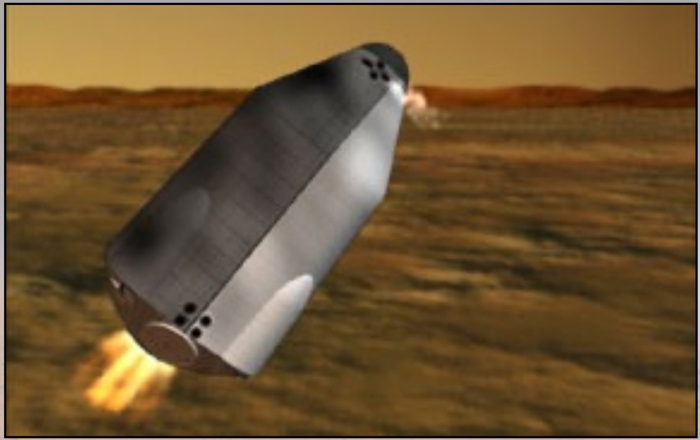
Michelle M. Munk – Entry, Descent and Landing Systems Capability Lead
NASA – Langley Research Center | Hampton, VA

IPPW 2021 • Al Seiff Award Lecture

Outline

- Experience is Everything
- EDL Community Origins
- Two Examples of Technology Evolution
  - Aerocapture
  - Heatshield Instrumentation
- Closing Thoughts

Image Credits: NASA/JPL-Caltech



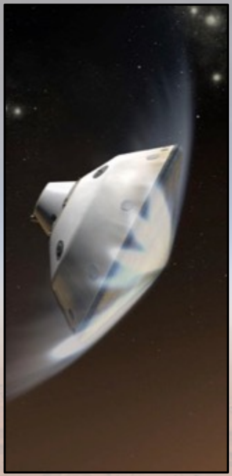
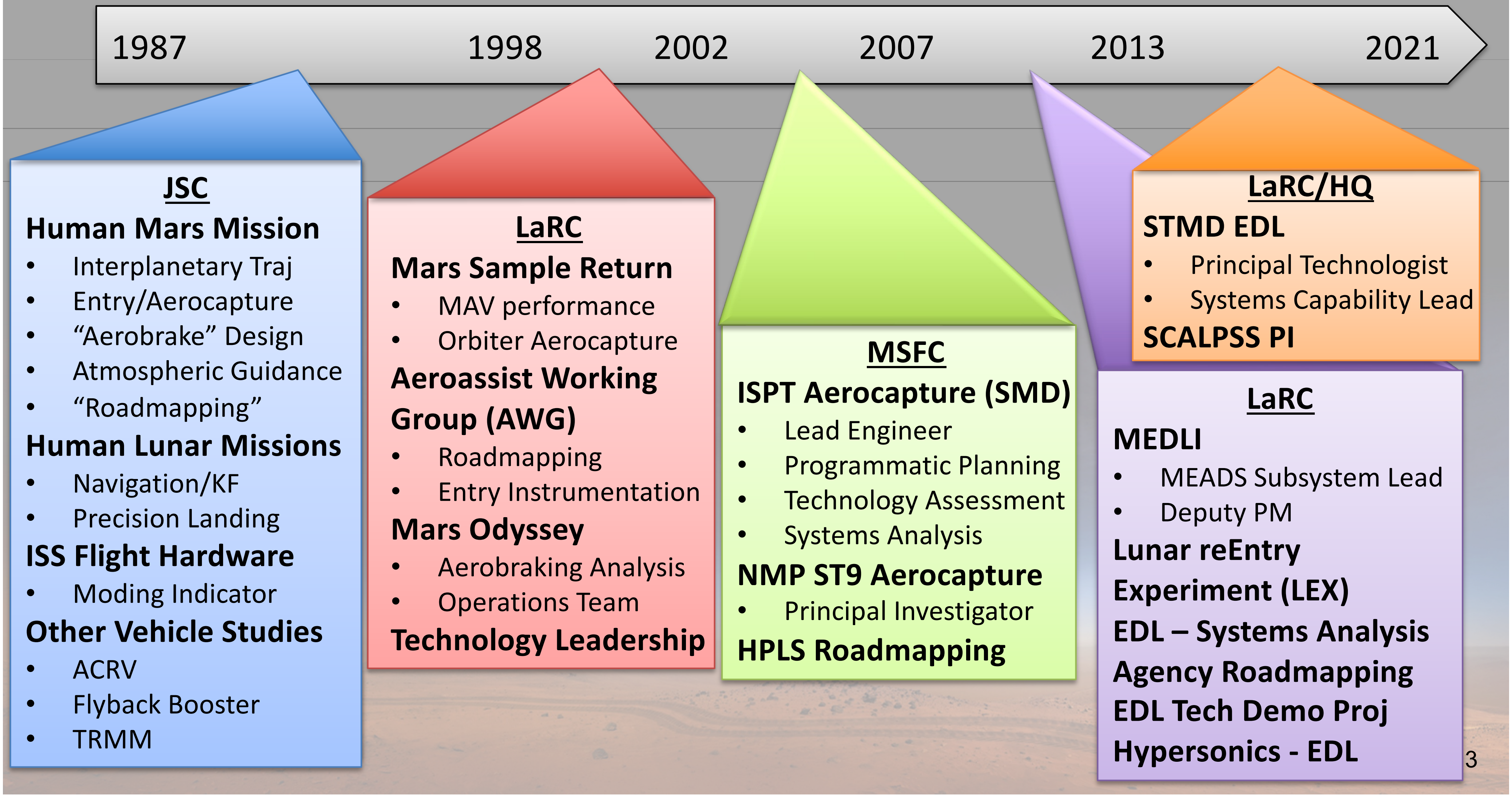


Photo Credit: NASA/JPL-Caltech

Culminating Experiences



JSC

Human Mars Mission
- Interplanetary Traj
- Entry/Aerocapture
- “Aerobrake” Design
- Atmospheric Guidance
- “Roadmapping”

Human Lunar Missions
- Navigation/KF
- Precision Landing

ISS Flight Hardware
- Moding Indicator

Other Vehicle Studies
- ACRV
- Flyback Booster
- TRMM

LaRC

Mars Sample Return
- MAV performance
- Orbiter Aerocapture

Aeroassist Working Group (AWG)
- Roadmapping
- Entry Instrumentation

Mars Odyssey
- Aerobraking Analysis
- Operations Team

Technology Leadership

MSFC

ISPT Aerocapture (SMD)
- Lead Engineer
- Programmatic Planning
- Technology Assessment
- Systems Analysis

NMP ST9 Aerocapture
- Principal Investigator

HPLS Roadmapping

LaRC

MEDLI
- MEADS Subsystem Lead
- Deputy PM

Lunar reEntry Experiment (LEX)

EDL – Systems Analysis

Agency Roadmapping

EDL Tech Demo Proj

Hypersonics - EDL

LaRC/HQ

STMD EDL
- Principal Technologist
- Systems Capability Lead

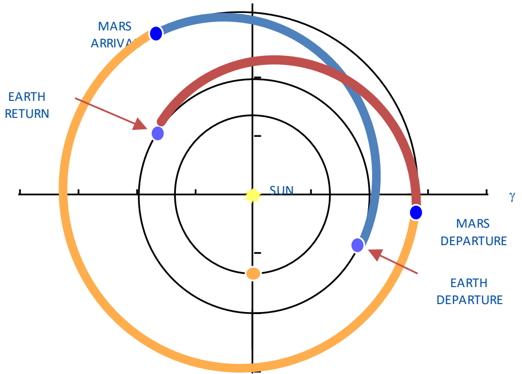
SCALPSS PI

Origins of the NASA EDL Community

JSC-led Human Mars Mission ~1996

Conjunction Class ("Long-Stay") Missions:

- "Minimum Energy" transfers both outbound to, and inbound from, Mars
- Stay times at Mars (typically 500 days) adjusted to minimize energy of the transfers



Interplanetary Design

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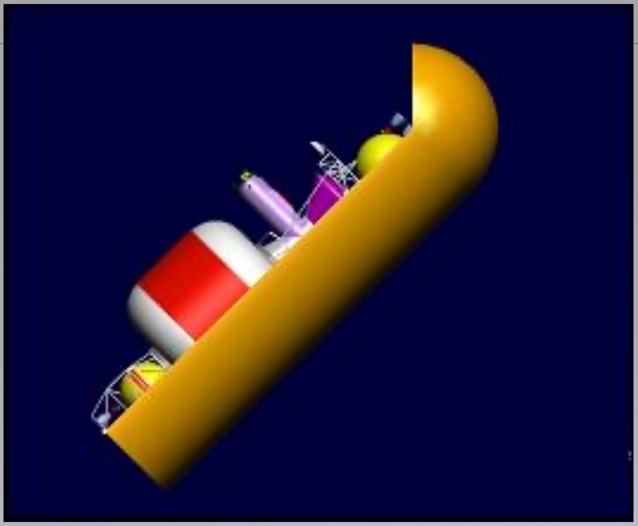
Other Groundrules

Transit Habitat size

Entry Speed

Human Mars "Transhab Aerobrake" (= "Ellipsled")



Needed Additional Expertise (ARC and LaRC):

- Aerodynamics
- Aerothermodynamics
- Structures
- Thermal Protection System

Aeroassist Working Group Charter (2001)

- The Aeroassist Working Group (AWG) shall provide **leadership for the Agency activities in technologies for aeroassist**, that is, technologies for the use of aerodynamic forces during atmospheric flight to accomplish transportation functions. The AWG shall draw on the expertise of its members and other sources to **provide advice and recommendations to NASA's programs, projects, and mission directorates**. *Vehicle and system requirements* and *technology implementation* will be the focus of the AWG efforts.

Original AWG membership was
from JSC, LaRC, ARC, and JPL.

These functions are very close to the System Capability Leadership role of today.

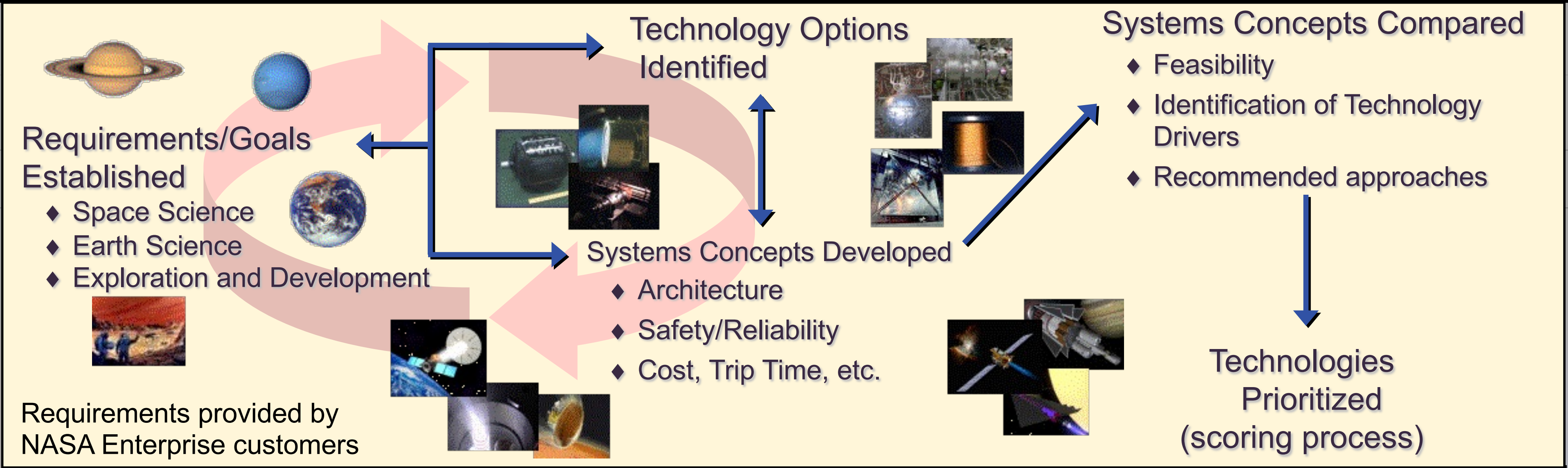
Aeroassist Working Group Charter (2001)

The AWG shall:

- **Integrate aeroassist efforts across the Exploration, Science, Space Operations, and Aeronautics Mission Directorates to achieve maximum value for the Agency.**
- **Support ongoing robotic and human mission activities including support of human mission architecture development.**
- **Develop approaches to integrate robotic and human exploration with respect to aeroassist.**
  - Identify innovative aeroassist concepts
  - Develop aeroassist approaches which are beneficial and common to both types of exploration
  - Identify robotic mission enhancements to support human missions
  - Differentiate Robotic/Human/Both Requirements
  - Identify and quantify the vehicle and mission impacts of aeroassist
- **Formulate aeroassist technology development strategies and roadmaps**
  - Develop High Priority Technologies -"Top 3"
  - Generate proposals for completing milestones on the roadmaps
- **Advocate Aeroassist technologies to NASA management (HQ)**

- **The AWG will draw members from the NASA field centers as appropriate to include expertise in aerodynamics and aerothermodynamics, guidance navigation and control, structures, thermal protection systems, engineering performance sensors, and vehicle design and systems analysis.**

In-Space Propulsion Technology Prioritization Process



Requirements/Goals Established

- Space Science
- Earth Science
- Exploration and Development

Requirements provided by NASA Enterprise customers

Technology Options Identified

Systems Concepts Developed

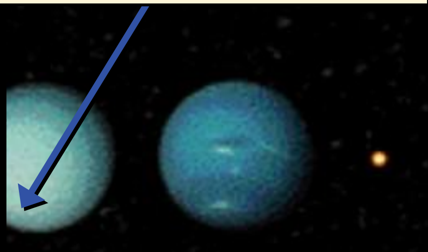
- Architecture
- Safety/Reliability
- Cost, Trip Time, etc.

Systems Concepts Compared

- Feasibility
- Identification of Technology Drivers
- Recommended approaches

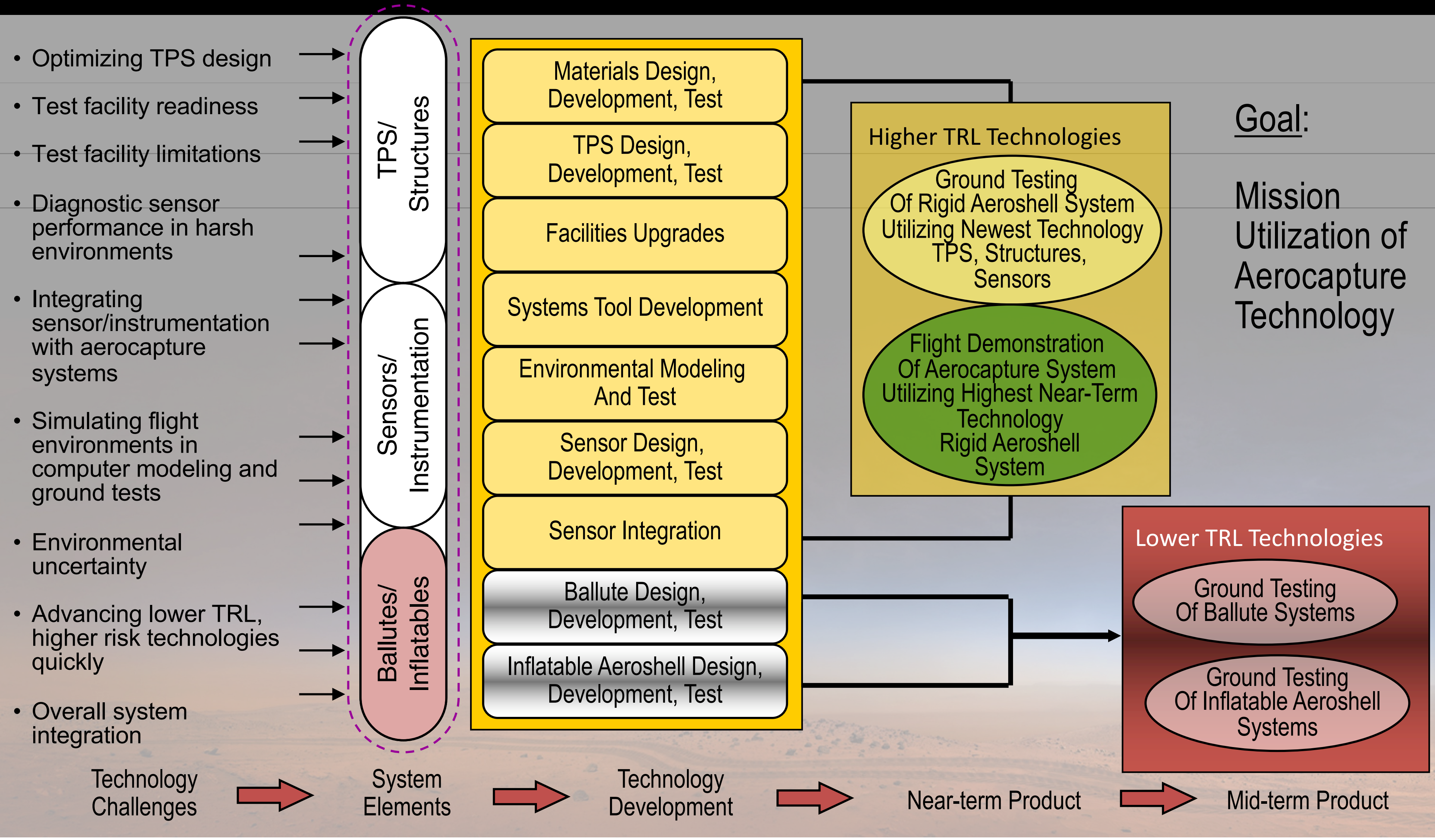
Technologies Prioritized (scoring process)

High Priority	Medium Priority	Low Priority	High Payoff / High Risk (Low TRL)
Aerocapture (robotic to human mission evolvable)	Advanced Chemical	Solar Thermal Propulsion	Momentum Exchange Tethers
Next Generation Ion Propulsion (5/10 kW)	Solar Electric Propulsion (Includes Hall)		Plasma Sails
Solar Sails			Solar Sails (1 g/m^2)



Cross-Enterprise In-Space Propulsion Priorities

FY02 Aerocapture TAG Output



- Optimizing TPS design
- Test facility readiness
- Test facility limitations
- Diagnostic sensor performance in harsh environments
- Integrating sensor/instrumentation with aerocapture systems
- Simulating flight environments in computer modeling and ground tests
- Environmental uncertainty
- Advancing lower TRL, higher risk technologies quickly
- Overall system integration

TPS/ Structures

Sensors/ Instrumentation

Ballutes/ Inflatables

Materials Design, Development, Test

TPS Design, Development, Test

Facilities Upgrades

Systems Tool Development

Environmental Modeling And Test

Sensor Design, Development, Test

Sensor Integration

Ballute Design, Development, Test

Inflatable Aeroshell Design, Development, Test

Higher TRL Technologies

Ground Testing Of Rigid Aeroshell System Utilizing Newest Technology TPS, Structures, Sensors

Flight Demonstration Of Aerocapture System Utilizing Highest Near-Term Technology Rigid Aeroshell System

Lower TRL Technologies

Ground Testing Of Ballute Systems

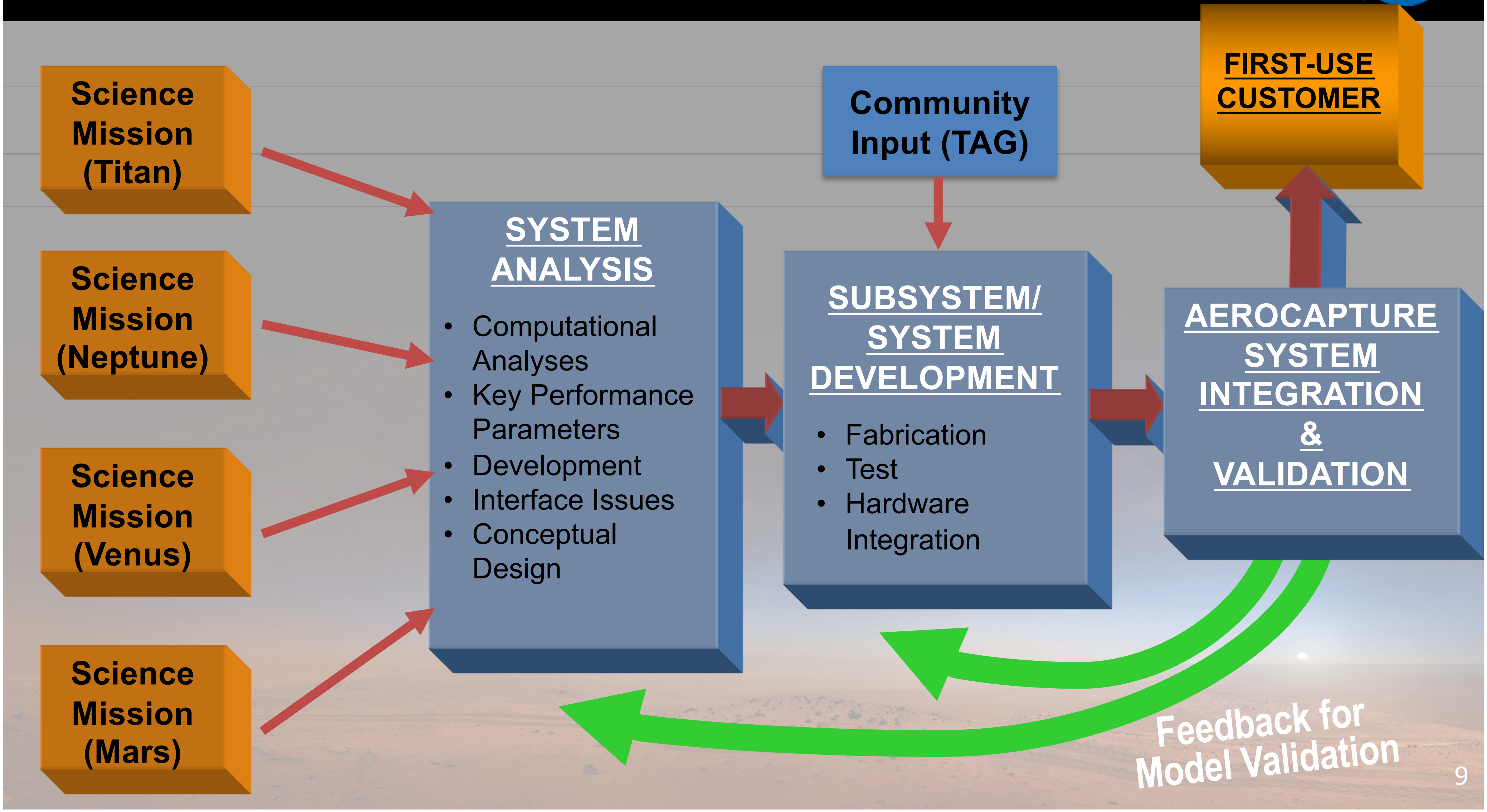
Ground Testing Of Inflatable Aeroshell Systems

<u>Goal</u>:

Mission Utilization of Aerocapture Technology

Technology Challenges → System Elements → Technology Development → Near-term Product → Mid-term Product

ISPT Technology Development Strategy



Science Mission (Titan)

Science Mission (Neptune)

Science Mission (Venus)

Science Mission (Mars)

SYSTEM ANALYSIS

- Computational Analyses
- Key Performance Parameters
- Development
- Interface Issues
- Conceptual Design

Community Input (TAG)

SUBSYSTEM/ SYSTEM DEVELOPMENT

- Fabrication
- Test
- Hardware Integration

AEROCAPTURE SYSTEM INTEGRATION & VALIDATION

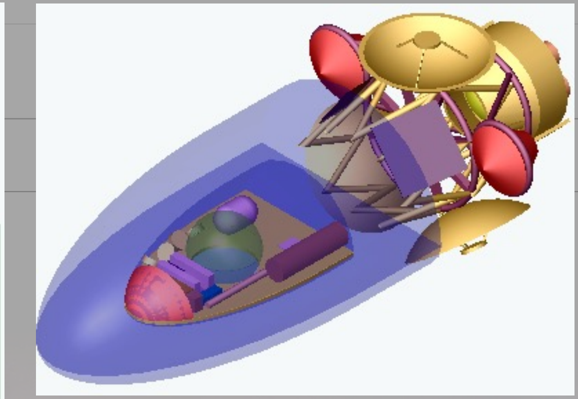
FIRST-USE CUSTOMER

Feedback for Model Validation

Aerocapture Systems Analysis Studies

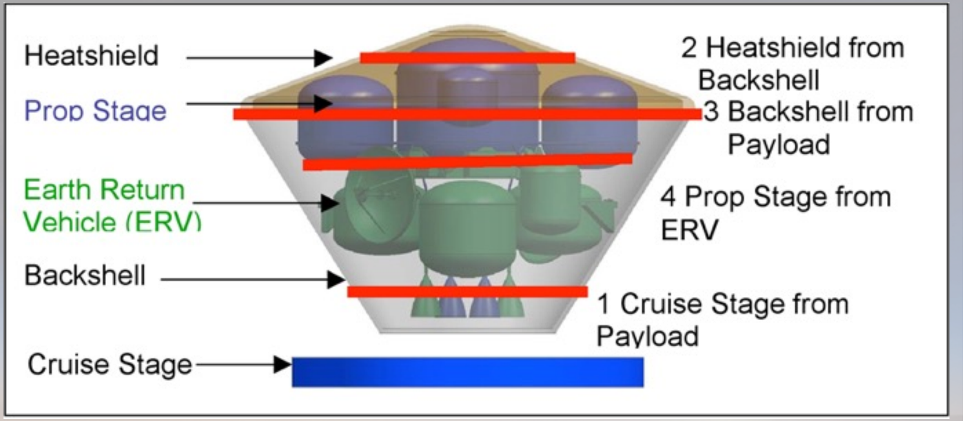
The ISP Aerocapture Systems Analysis Team involved expertise from 5 NASA Centers

FY02 - Titan

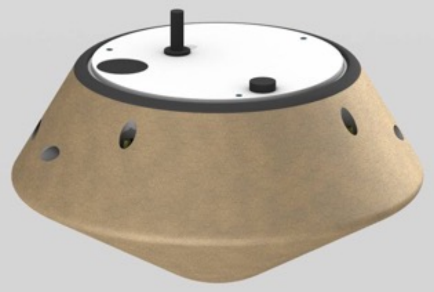


FY03 - Neptune

FY04 - Venus



FY05 – Mars (MSRO)



FY06 – Earth (NMP ST9)

Each study documented by NASA-TM and/or conference papers.

Aerocapture Competed Content (FY02)

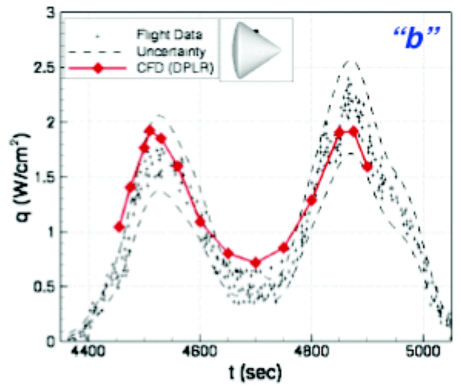
Title	Center Awarded	Contract Awarded	Major Products
Aeroshell Development for Aerocapture	Ames		Fully characterized TPS materials and response models for Titan TPS concepts and heating predictions for Neptune
Advanced Ablator Families for Aero-assist Missions		Applied Research	Fully tested and characterized ablator options utilizing low-cost manufacturing techniques Tests of integrated low-mass structures and ablators
Microsensor & Instrumentation Technology for Aerocapture	Ames	ELORET Corp	Heat flux and recession microsensors for use in Titan and Neptune aerocapture environments Fully integrated aeroshell instrumentation system
High-Temp Structures for Reduced Aeroshell Mass	Langley		Reduced mass aeroshell composite structures, tested for aerocapture environment Validation of ablator/structure interface using high-temp adhesives 2 (1 meter) rigid aeroshell test articles
Aerocapture Technologies		Lockheed Martin	Development of 3 structural/TPS concepts using traditional and advanced materials and manufacturing techniques 1 (2 meter) rigid aeroshell test article

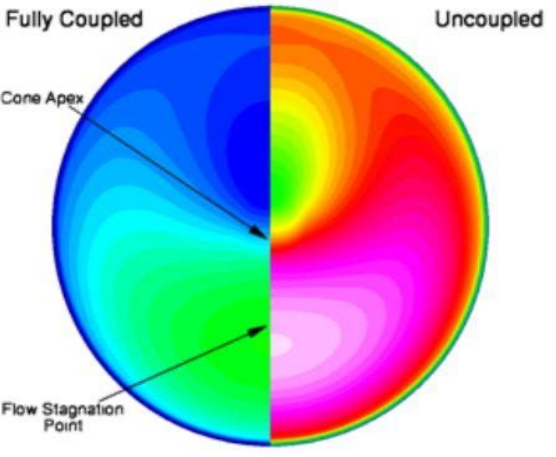
Ames TPS and Aerothermal Modeling

Aerocapture planetary TPS assessments and aerothermal modeling improvements

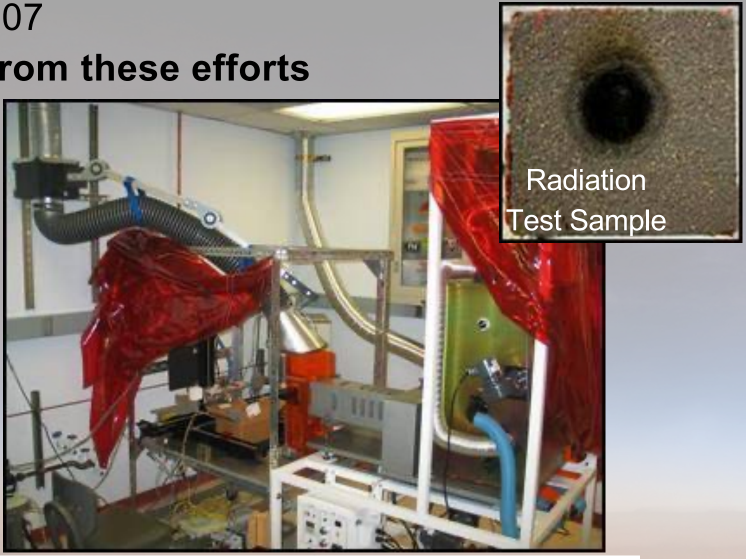
- ❑ Completed arc jet tests in a nitrogen atmosphere on candidate TPS materials
- ❑ Completed testing candidate TPS materials in ISPT-funded Radiative Lamp Facility
- ❑ Demonstrated coupled convective and radiative heating solutions for Titan
- ❑ Completed tests in the EAST shock tunnel to measure shock layer radiation in a simulated atmosphere at Titan relevant conditions
- ❑ Devised Monte Carlo approach to aerothermal uncertainty analysis
- ❑ New release of NEQAIR in summer 2007
- ❑ **Over 50 published papers resulted from these efforts**

Arc jet testing of ablative TPS at Ames





Impact of Coupling on Centerline Radiative Heating



Radiation Test Sample

ISPT-Funded Radiant Lamp Test Facility at ARC

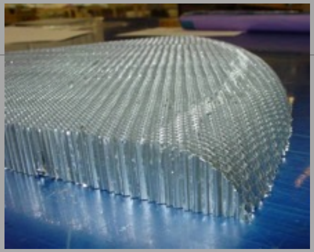
These are the roots of Entry Systems Modeling.

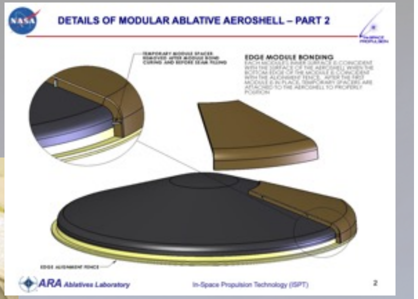
ARA Advanced Ablator Families

Raise TRL of family system of ablators, including manufacturing at “large” scale on lightweight aeroshell structures (Langley/ATK)

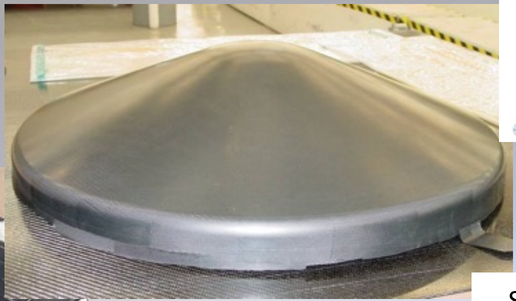
- Convective heating (arcjet) tests at the Ames Research Center
- Radiative screening of TPS coupons at Sandia Solar Tower
- Updated TPS thermal response models
- Solar Thermal testing of 12” square and 24” square panels
- New TPS applied to 1-meter, 70 deg cones from ATK
- Thermally tested 1-meter aeroshell at Sandia Solar Tower
- Updated TPS/system thermal response


Arcjet ablator coupons, post test


Aluminum flex core machined for insertion into outer skin




Tested Solar tower ablator coupon


SRAM-20 on 1-m ATK aeroshell


Solar tower test of ablator panel


Solar tower test of ablator coupons


PhenCarb-28 (150W/cm^2 for 200 sec)

Produced a 2.65-m heatshield using block/modular TPS.

Highlight: Sandia Solar Tower Testing of ARA Ablator

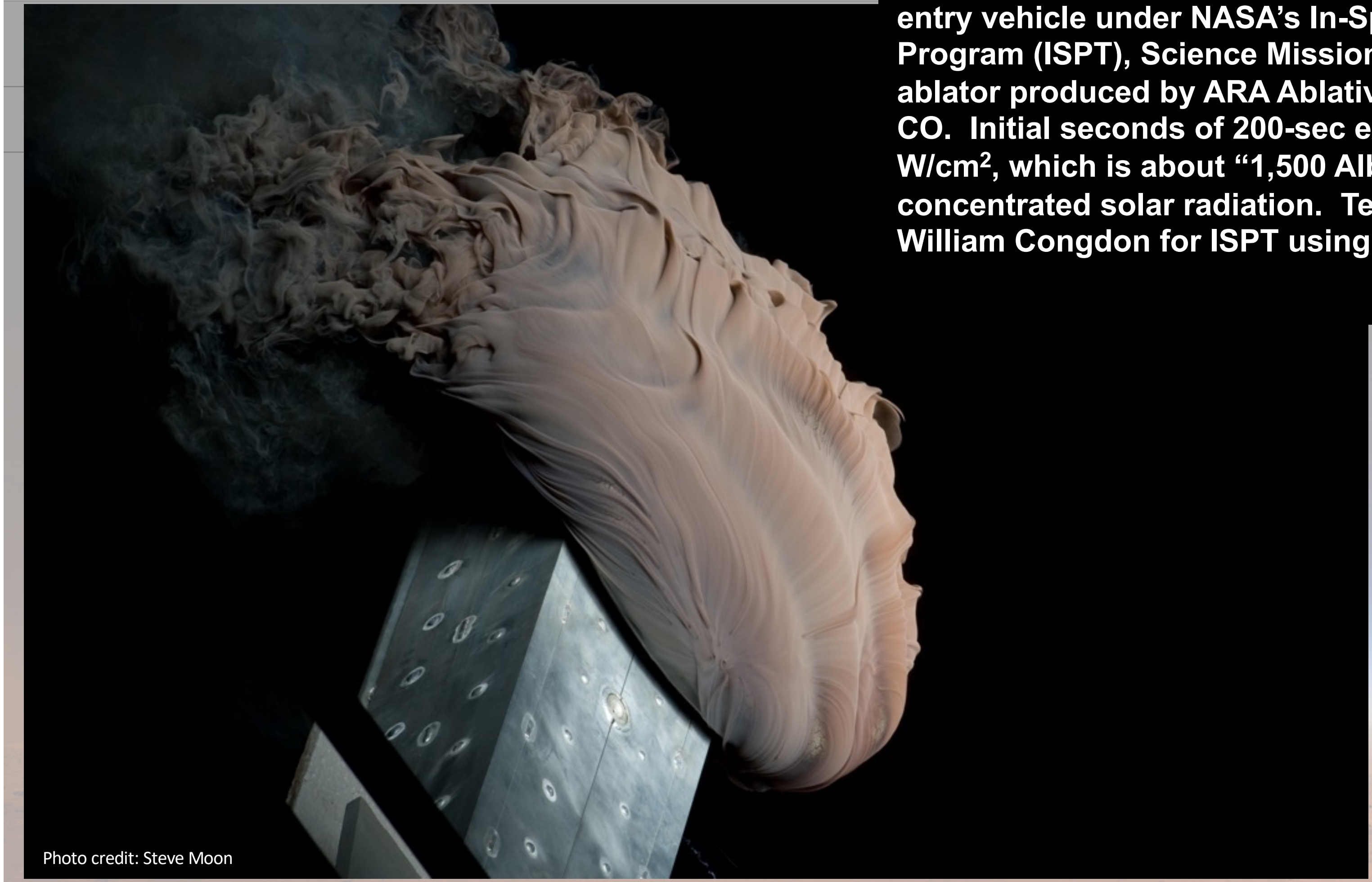


Photo credit: Steve Moon

Aviation Week First Place Winner for Category of “Space Technology and Missions”

Ground testing of advanced heatshield-aeroshell for planetary entry vehicle under NASA’s In-Space Propulsion Technology Program (ISPT), Science Mission Directorate. Phenolic-carbon ablator produced by ARA Ablatives Laboratory in Centennial, CO. Initial seconds of 200-sec exposure at heating rate of 150 W/cm^2, which is about “1,500 Albuquerque suns” of concentrated solar radiation. Test program run by ARA’s William Congdon for ISPT using Sandia’s Solar Tower Facility.

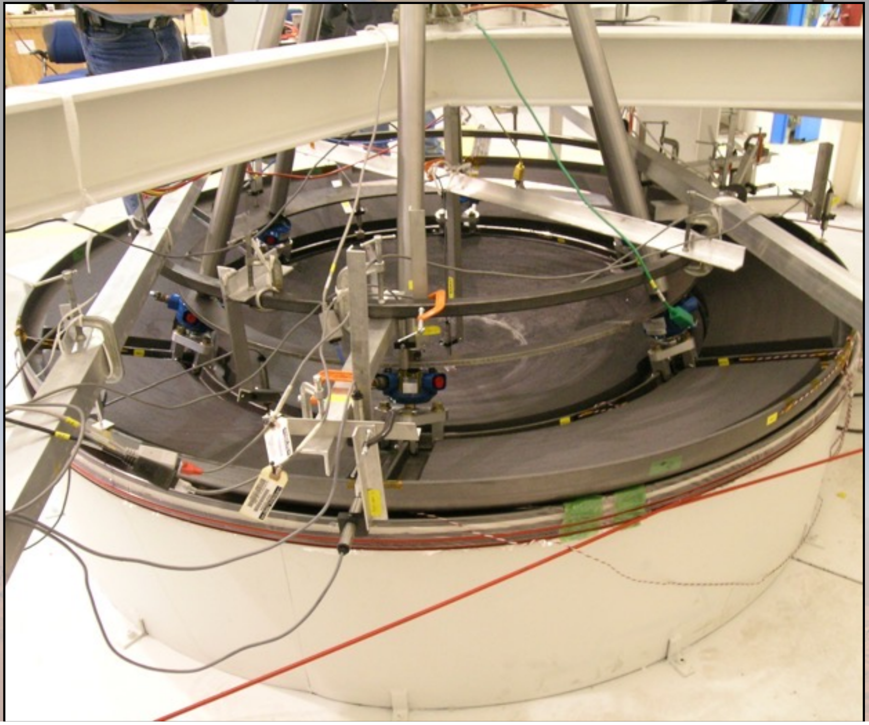
The TPS PI for this effort was Bill Congdon of ARA. His “family” approach to ablators and his block construction techniques, although never flown, had a lasting impact on the industry.

https://www.drinkwinemortuary.com/obituary/William-Congdon

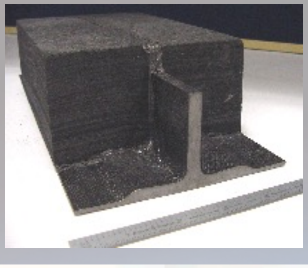
Lockheed Martin Aeroshell Development

- Full static load test to acceptance levels successfully completed on May 31, 2006
- Deflection and strain recorded at multiple locations; agreement with FEM to within **10%**, with the model a bit conservative
- C-CAT conducted detailed post-test NDE; no anomalies
- Over 250 arcjet tests at NASA ARC for warm structure and C-C system (up to 1300 W/cm^2)
- Radiative testing on warm and hot structure coupons


LMA 2 m Aeroshell in Test Fixture




2m C-C Hot Structure Aeroshell

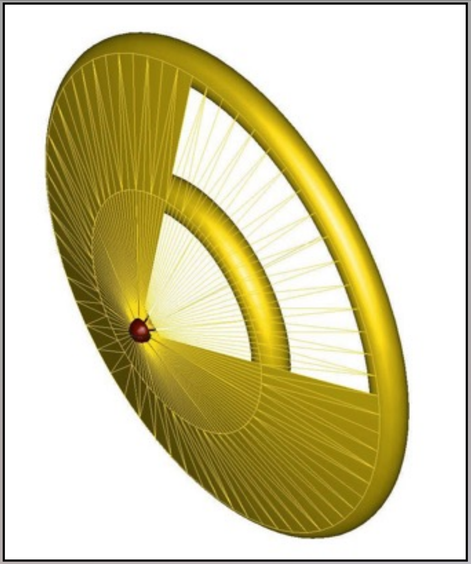


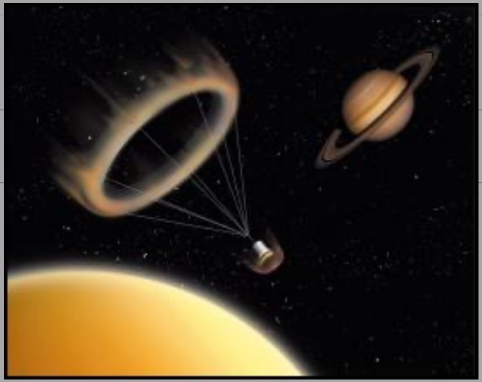

Carbon-Carbon SiC Coated Arc Jet

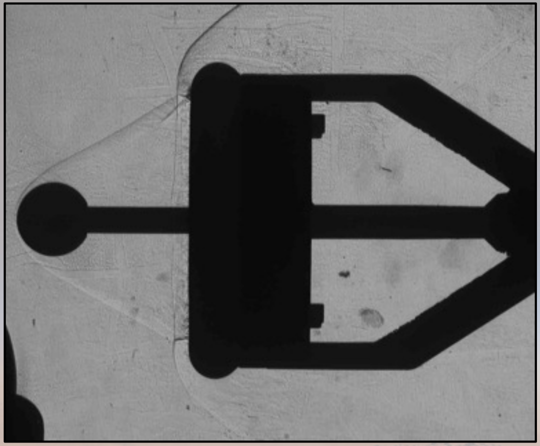
Technology infused on DAVINCI+

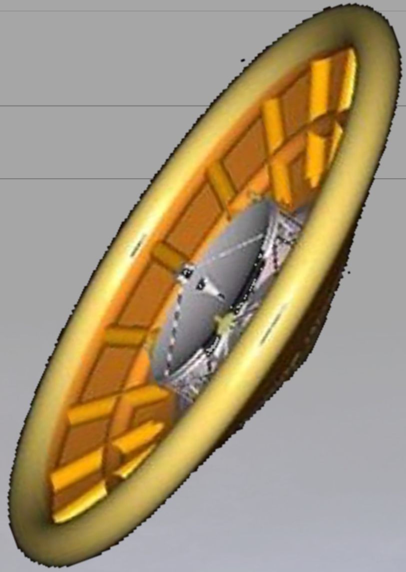
ISPT Ballute Investments (2004-2006)

Ball Aerospace Concepts









Lockheed Martin Concept

These are early examples using drag modulation and toroids.

The Spark for MEDLI

- **Mike Griffin, National Space Society (NSS) Speech, 2006: "With respect to aeronautics, we <u>missed a great opportunity</u> with our recent Genesis and Stardust missions. <u>We could have instrumented these spacecraft</u> to gather information useful for aeronautical science at the highest Mach numbers ever recorded during atmospheric entry. So think about the kinds of synergies that we can achieve between the science, aeronautics and exploration *if we can obtain on our next Mars missions a better characterization of its atmosphere*."**

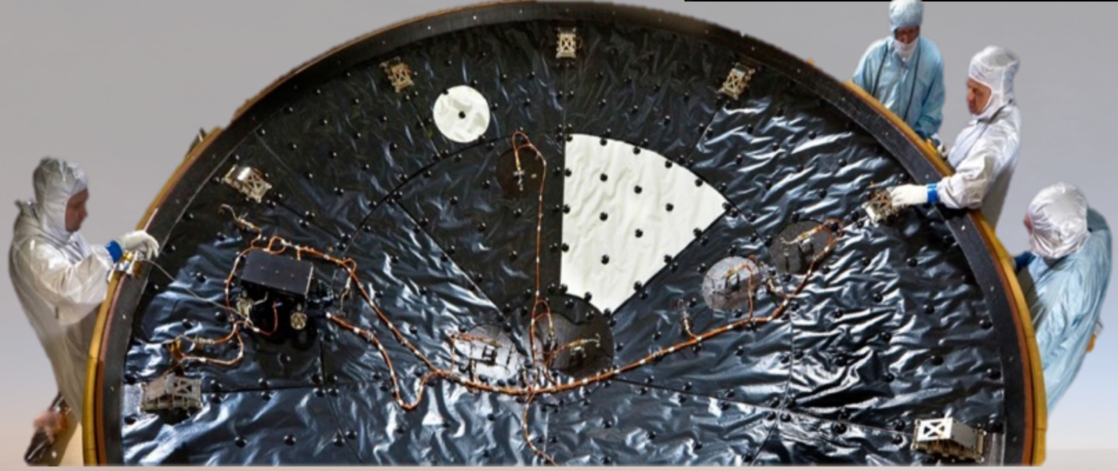
MEDLI: MSL Entry, Descent and Landing Instrumentation

- MEDLI consisted of 7 pressure ports, 7 integrated sensor plugs, and support electronics
- Gathered engineering data during entry and descent for future Mars missions:
  - Aerothermal, aerodynamic, and thermal protection system performance
  - Atmospheric density and winds

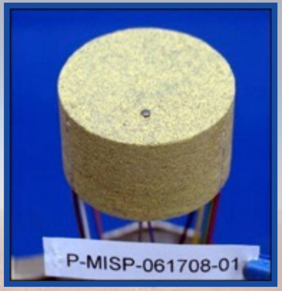
MEDLI measurements successfully completed

Sensor Support Electronics

Mars Entry Atmospheric Data System (MEADS)

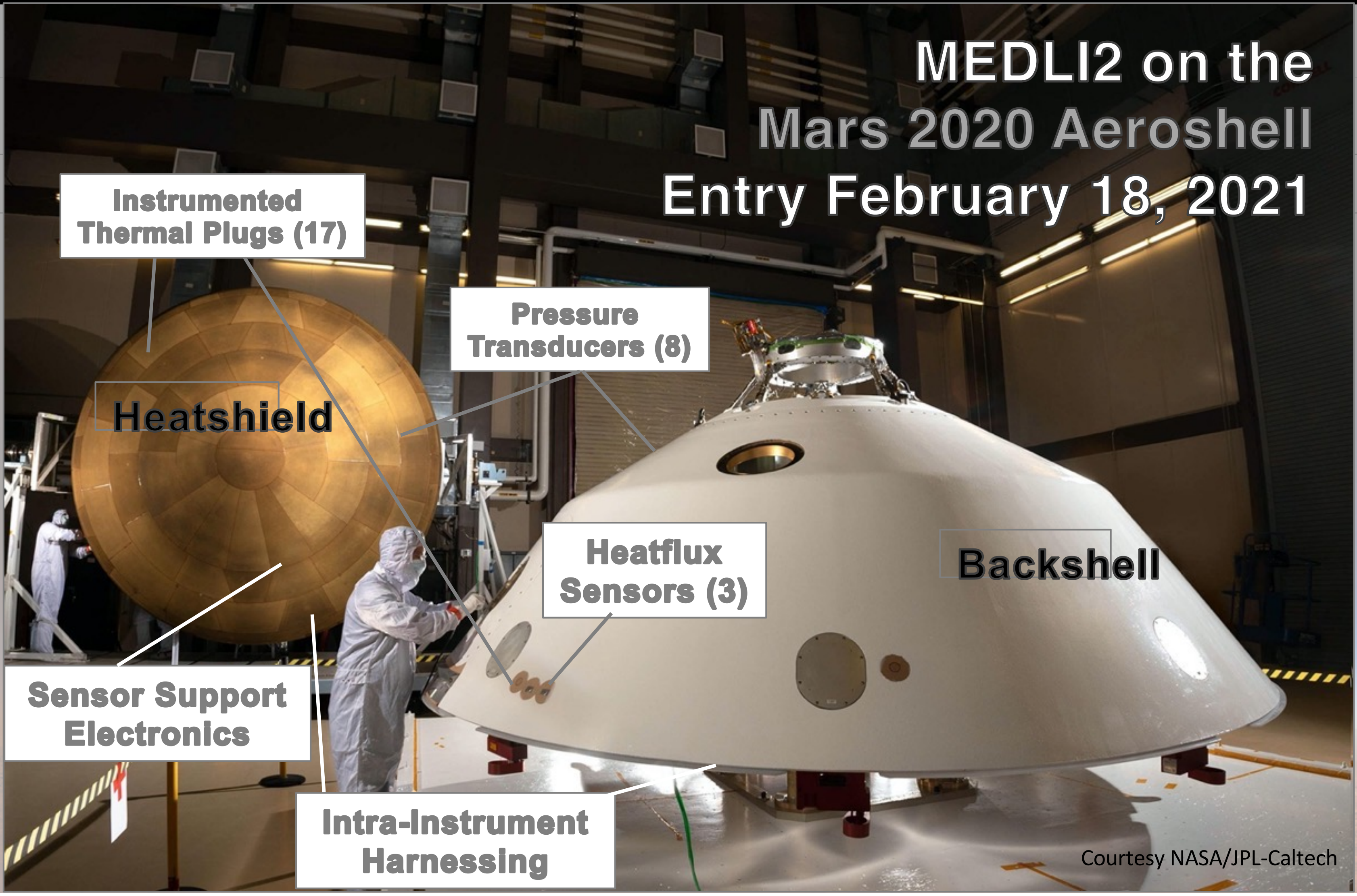


The MEDLI instrumentation made MSL the first extensively instrumented heatshield ever sent to Mars (entry August 6, 2012)



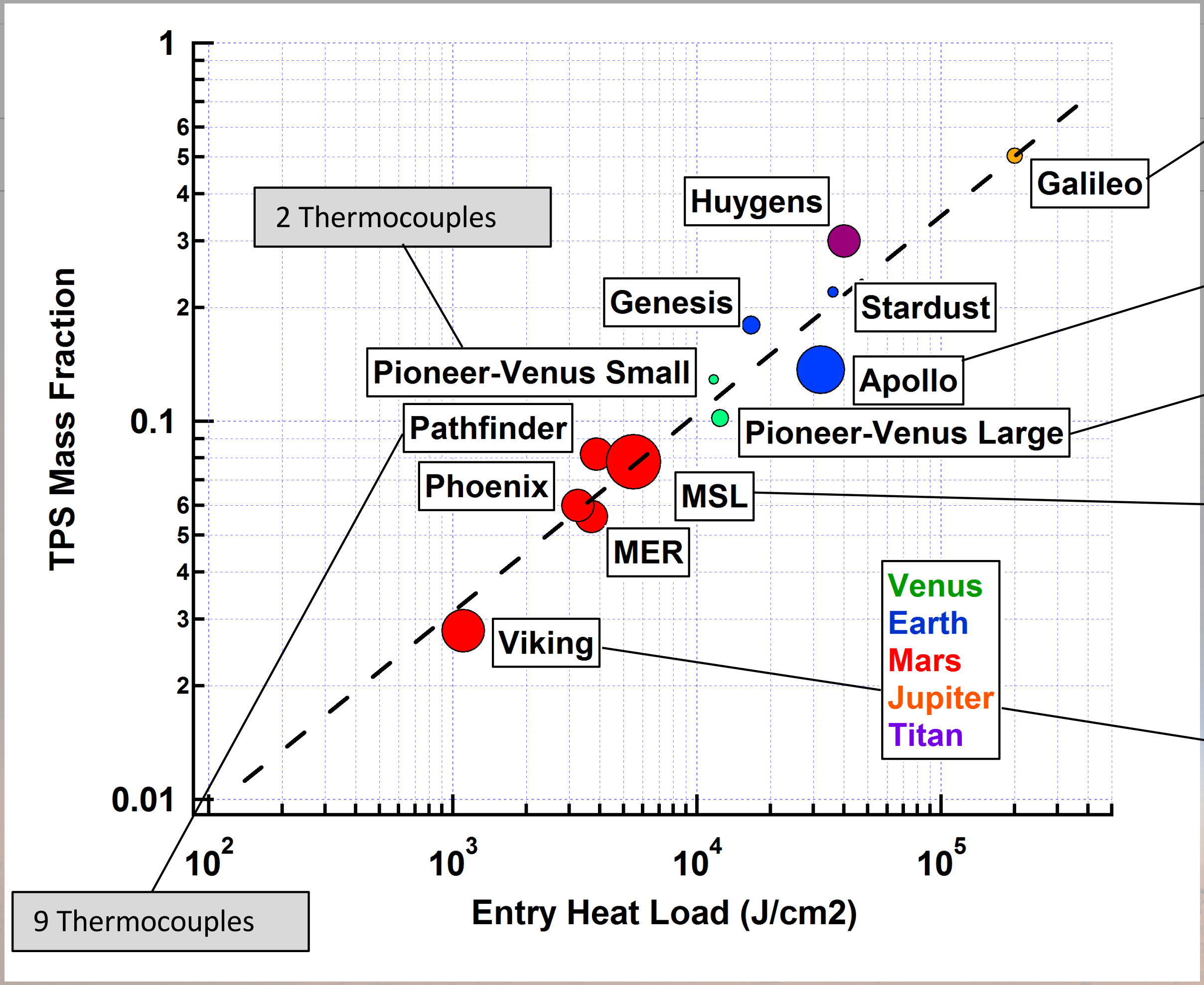
MEDLI Instrumented Sensor Plug (MISP)

MEDLI2 – Continuous Improvement



Courtesy NASA/JPL-Caltech

Entry Flight Instrumentation History (2014)



2 Thermocouples

9 Thermocouples

10 Recession gages, backshell TCs

Several thermocouples, pressure gages, calorimeters, radiometers

2 Thermocouples

24 Thermocouples, 7 Pressure sensors, 6 isotherm sensors

MEDLI

2 Thermocouples, 1 Pressure sensor

Request to NASA Technology Executive Council (HQ) April 30, 2014

- **The EDL community would like NTEC support of an informed decision process, early in the life cycle, for all missions which include EDL:**
  - Decisions by lead Mission Directorate whether or not to capture EDL data will be made, no later than KDP-A, on a mission or opportunity case-by-case basis, in full consideration of cross-Agency needs and in coordination with all Mission Directorate stakeholders.
  - At the time of decision, EDL data capture instrumentation and accommodation cost-sharing arrangements and ground rules for data capture descoping will be established.
  - Mission Directorates will support the generation and exchange of information to support early decisions (i.e. pre-phase A) regarding EDL data capture.
  - There will be off-ramps to protect the lead Mission Directorate in the event of unforeseen circumstances (e.g. instrumentation funding shortfalls, changes in mission risk due to EDL data capture, etc.).
  - The above guidelines include assessing pre-flight and post-flight evaluation (e.g. CT Scan) of Earth return capsules.
  - Implementation decisions must include provisions for post-flight data analysis and/or reconstruction, as appropriate.

SMD AO Requirement
to Instrument (ESI)

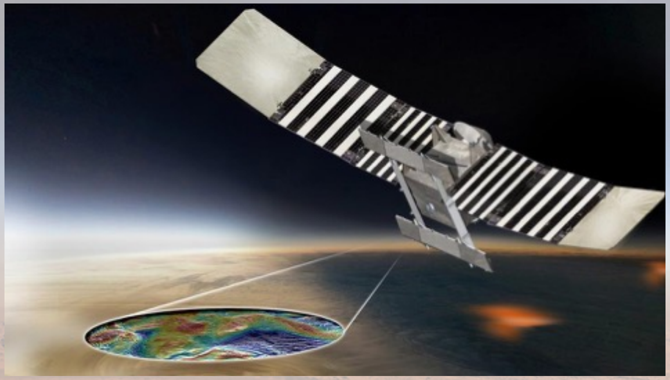
Three New Engineering Science Investigations

Discovery ‘19

New Frontiers-4

Dragonfly – Launch 2027

DAVINCI+



VERITAS

Closing Thoughts

- **Technology development and infusion takes a long time, and is influenced by factors out of individual control**
  - However, individuals make ALL the difference!
  - Patience (perseverance?) frequently pays off
- **Even cancelled projects and abandoned efforts are training tools – disappointing, but still valuable**
  - Document and share findings, lessons learned
  - Sometimes an idea doesn't need to be trashed, just shelved
- **Base technology investments on solid technical data**
- **Use all the tools at your disposal to advance the SOA**
- **Be willing to listen, to learn, and even to go live elsewhere**

The International Organizing Committee (IOC) of the
International Planetary Probe Workshop (IPPW)

presents the

Alvin Seiff Award 2020

To

Ms. MICHELLE MUNK

This award recognizes Ms. Munk's stewardship of NASA's Entry, Descent and Landing capability, ensuring that critical tools in this area are available to meet the agency's needs for current and future missions. These capabilities include modeling and validation of entry aero/aerothermodynamic environments, thermal protection system heatshield development/certification, advocating for deployable heatshields which allow larger payload delivery to the Mars surface, sensors for precision landing and hazard avoidance, and the development of models for retrorocket plume-surface interactions, critical for ensuring safe touch down of both robotic and human-scale vehicles. Also recognized are her leadership and technical contributions in developing understanding of the mass-saving benefits of aerocapture for inserting interplanetary spacecraft into orbit. Ms. Munk was instrumental in establishing NASA policy requiring engineering data collection on all entry vehicles, and contributed significantly to the development of the heatshield sensors flown on the Mars Science Laboratory, important for validating the Mars 2020 entry vehicle design. Finally, it is noted that Ms. Munk is a role model who continually mentors younger researchers and students interested in her field, and that she has supported the IPPW since its early years.

Signed

June 2020

Ashley Korzun / Robert Buchwald
IPPW IOC chairs

Miguel Pérez-Ayúcar
Al Seiff Award Committee chair

I have been honored to serve the EDL community and I want to sincerely thank the IPPW Al Seiff Award Committee and the International Organizing Committee for this prestigious and humbling recognition.

Thank You!