Atmospheric Entry Conditions for Planetary Missions: Implications for Thermal Protection Systems Material Development

Planetary Science Program Support

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Topics

- Introduction
- Thermal Protection Systems – Historical Survey
- Entry Circumstances and Entry Conditions
- Findings and Recommendations
- NASA OCT Technologies for Atmospheric Entry
- Conclusions

Introduction

- This report resulted from concerns about requirements for heat shields for future planetary missions adopted at the Second Carbon Phenolic Workshop held at Ames Research Center, April 2012
- NASA PSD has been considering an investment in an alternative to heritage carbon phenolic for high energy entry missions.
- This analysis was led by Tom Spilker of JPL and facilitated by dialogs between mission designers, technologists & engineers at the 9th International Planetary Probe Workshop (IPPW-9) in June 2012.
- The complete report written by Tom Spilker was recently submitted to NASA. Spilker has recently retired from JPL and is not available to give this briefing.

Planetary Heat Shields
Thermal Protection Systems
Historical Survey

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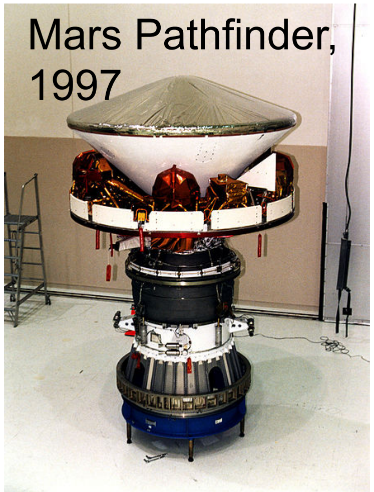
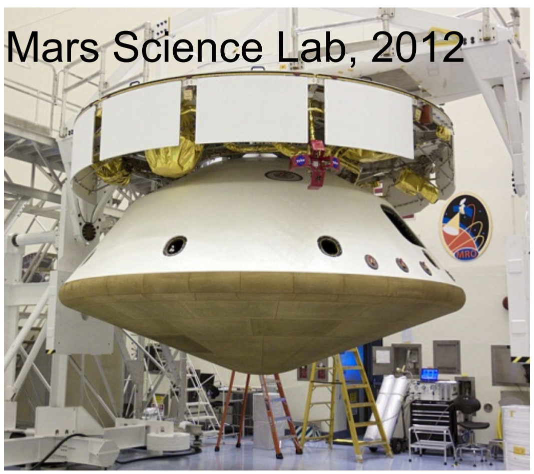
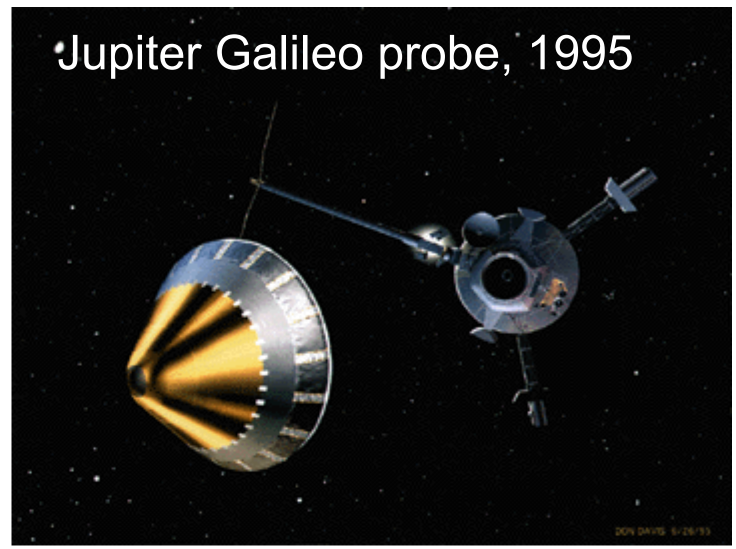

Mars Pathfinder, 1997


Stardust, 2006


Pioneer Venus 1978


Mars Science Lab, 2012


Jupiter Galileo probe, 1995

Low to Moderate heating rates
Low density materials – e.g. SLA, PICA

High heating rates.
Fully dense carbon phenolic

Entry Circumstances and Entry Conditions

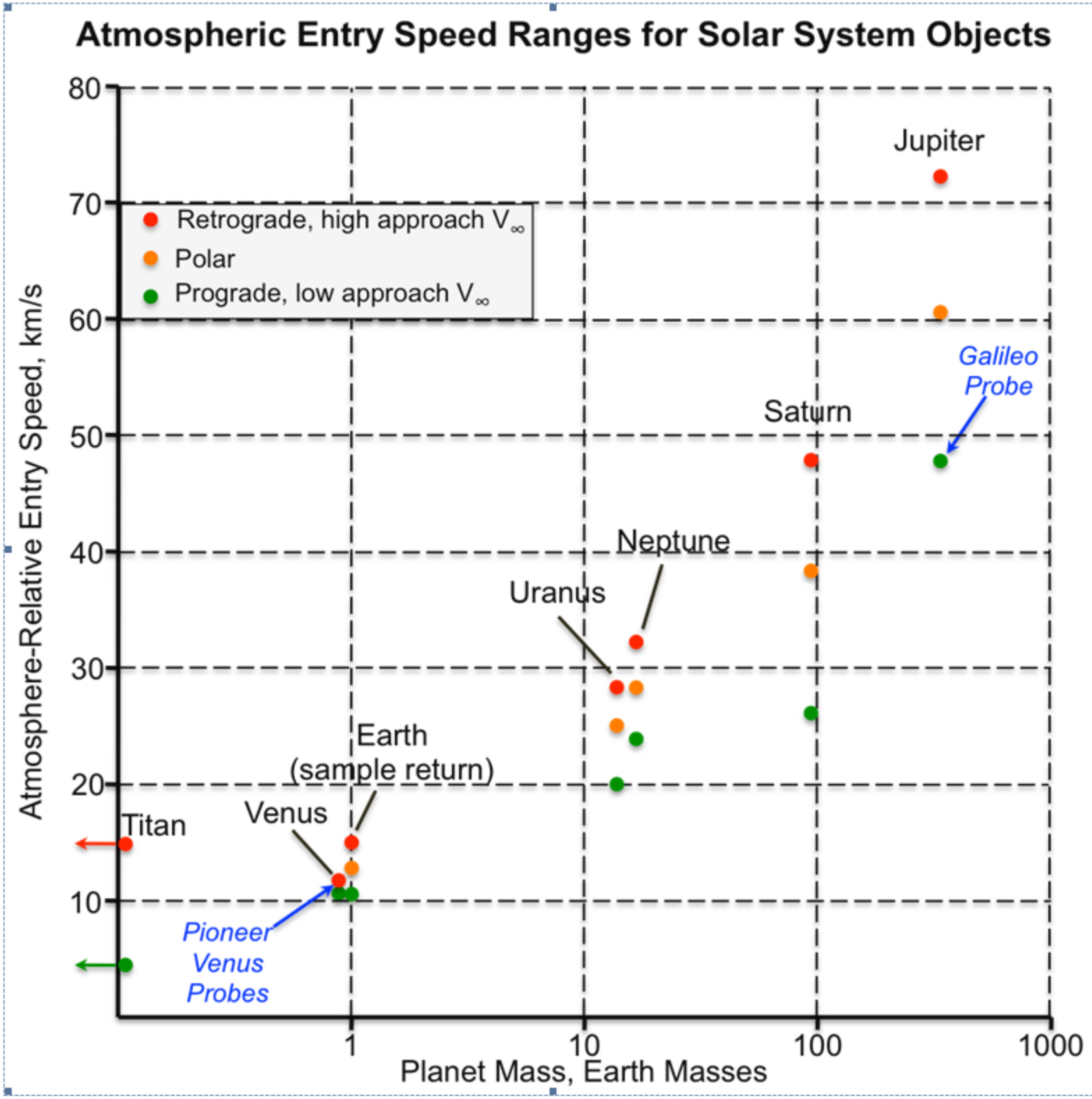
Entry Circumstances

- Characteristics of the destination planet
  - Mass (gravitational parameter μ)
  - Radius, oblateness (planetary shape)
  - Atmospheric composition
  - Rotation rate, winds (if significant)
  - Vertical profile of atmospheric mass density
  - Heliocentric distance
- Characteristics of the trajectory
  - V_∞ of approach for the (hyperbolic) entry orbit inclination
  - Flight path angle at entry
  - Latitude of entry site
- Heat shield geometry
- Entry vehicle ballistic coefficient (M/C_DA)

Entry Conditions

- Atmosphere-relative entry speed
- Time profile of flow enthalpy
- Peak heating rate
- Time profile of heating rate
- Radiative & convective components of heating rate
- Integrated heat load
- Time profile of stagnation pressure
- Peak inertial load
- Time profile of inertial load
- Spatial profile (across a heat shield) of shear loads
- Time profile of shear load

The study focused on the parameters highlighted in blue which determine the entry speed at the planet



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Comparison of this study with NASA Request for Information (RFI) of Jan 22, 2012

	Units	Source	Venus	Saturn	Uranus	Neptune	Jupiter
Entry conditions			Direct entry	Prograde	Prograde	Prograde	Prograde
Entry Velocity	Km/sec	RFI	11.6	26.8	29	29	47.4
Entry Velocity	Km/sec	This study		26	20 to 25	24 to 27	48

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Entry conditions			Direct entry	Prograde	Prograde	Prograde	Prograde
Entry Velocity	Km/sec	RFI	11.6	26.8	29	29	47.4
Peak Stagnation Heat Flux	W/cm2	RFI	4,700	3000	12,000	12,000	48

Adoption of high values for Uranus Neptune entry velocities places unrealistically high requirements on the TPS heating rate

Finding 1 Correction of inaccurate information in RFI

Finding

- The recent RFI for TPS materials (*RFI "Alternate TPS to Carbon Phenolic / Alternate Architectures for Thermal Protection Systems for NASA's Atmospheric Entry Heat Shields," Jan. 22, 2012*) includes some misleading information.
- It greatly overstates the conditions associated with trajectories available for direct probe entries into the atmospheres of Uranus and Neptune
- It may significantly understate the conditions associated with a retrograde Saturn entry

Recommendation

- In the short term, NASA should update the requirements specifications given in the recent RFI to more accurately reflect the conditions expected for missions to the listed destinations

TPS-CP Study
Findings and Recommendations
Finding 2: Define more accurate requirements for future solicitations

Findings

- NASA should ensure that future requests to potential contractors contain information accurately reflecting requirements.
- Specialists in mission design should define the appropriate ranges of entry circumstance parameters to be used in defining requirements.

Recommendations

- NASA should perform analyses that verify the feasible ranges of *entry circumstances* for high priority targets, including the seasonal variability of the range (Note 1)
- To define the specific TPS requirements for future probe missions to these targets, NASA should use these entry circumstance parameters to generate data on the corresponding range of entry conditions

For some mission options, there may be combinations of shallow entry angles and lower ballistic coefficients that could further ease requirements on a new material

TPS-CP Study
Findings and Recommendations
Finding 3 Development[1] of alternative TPS material(s)

Findings

- NASA PSD should develop alternate TPS materials focused on future probe missions to Saturn, Uranus, Venus, as well as future sample return missions involving Earth entry *other than MSR*
- Missions to Neptune should not be considered a driver for near term alternate TPS development by PSD but they should be a driver for game changing technologies developed by NASA's Office of the Chief Technologist

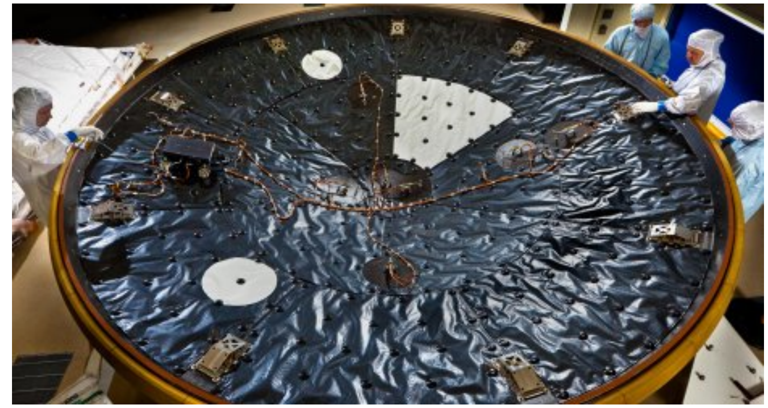
Recommendations

- NASA should initiate a program to test and flight qualify alternate TPS materials applicable to the candidates for missions in this decade
- NASA should conduct a survey of facilities capable of testing these alternate TPS materials and where gaps in capability exist implement facility upgrades

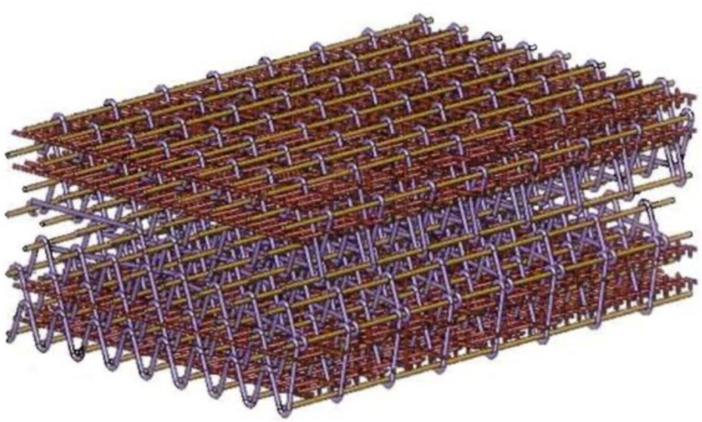
Note 1 – Development in this context includes qualification. In fact, a number of potential materials exist and may just need to be qualified

NASA Office of the Chief Technologist (OCT) Advanced Technologies for Atmospheric Entry

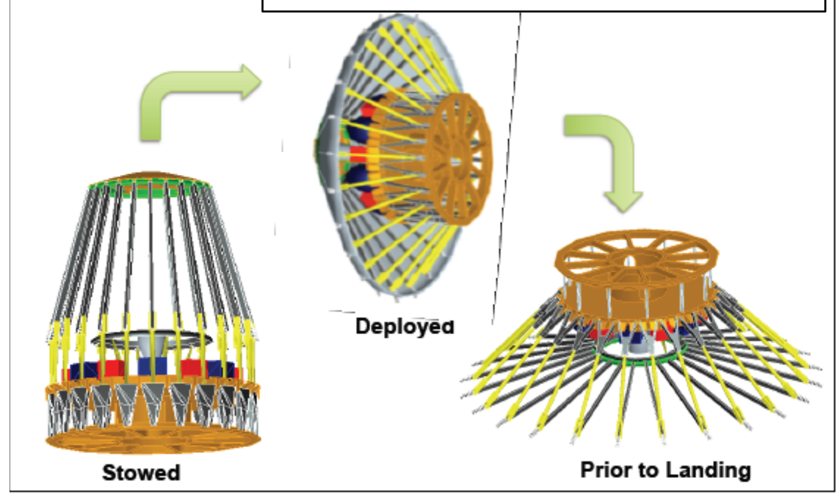
Hypersonic Inflatable Aerodynamic Decelerator (HIAD, LaRC)



MSL Entry Descent and Landing Investigation (MEDLI, LaRC)



Woven Thermal Protection Materials (ARC)



Deployable Aeroshell Concepts Conformal TPS (ARC)

Three of the four technologies are in the game changing technology program

Conclusions

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- The VEXAG community needs to be aware that although some qualified Thermal Protection System (TPS) materials (e.g chop molded carbon phenolic) cannot be reproduced, there are industrial materials that could be qualified for Venus Missions.

- Test facilities are the key to qualification. Validation of TPS material does not necessarily require new facilities and could be subjected to piecewise qualification/validation through test and analysis that has been successfully used on previous missions and is accepted in other areas of technology.

- The TPS requirements for the Decadal Survey Saturn probe and Uranus missions are similar to those of Venus missions and a common materials test/qualification effort could meet those needs

- The OCT technology developments are to be strongly encouraged but may not yield a practical solution in time for the next round of Discovery and New Frontiers missions

- A program of TPS qualification, focused on less ambitious approaches than the Game Changing technology program could reduce the risk for nearer term Venus, Saturn and Uranus missions