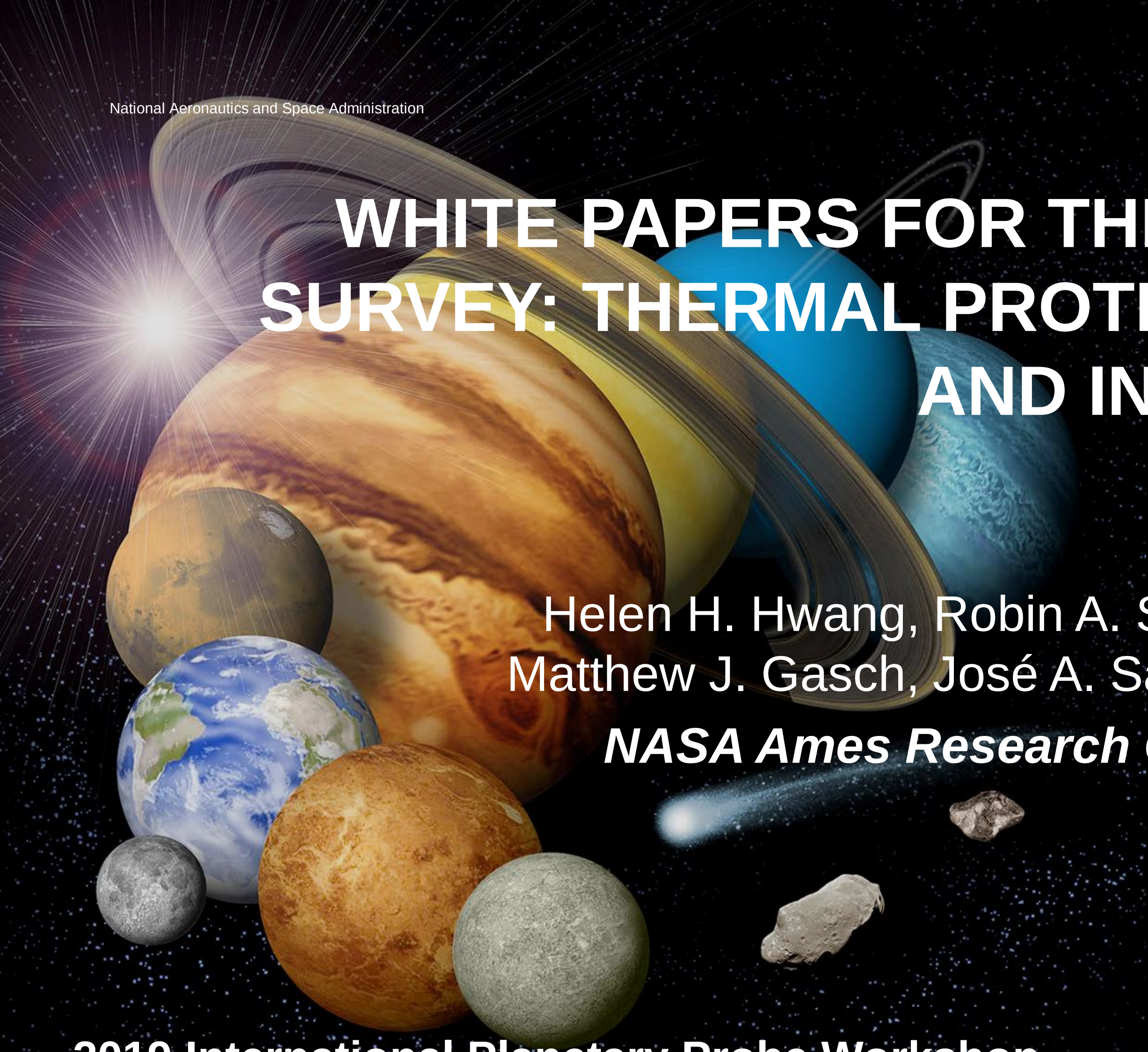

National Aeronautics and Space Administration

WHITE PAPERS FOR THE NEXT DECADAL SURVEY: THERMAL PROTECTION SYSTEMS AND INSTRUMENTATION

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2019 International Planetary Probe Workshop **July 12, 2019**

Introduction

- **For the previous Decadal Survey, white papers were submitted in 2009 that outlined the current status for atmospheric probe missions:**
  - 4 TPS papers categorized by destination (Venus, Earth return, Mars and Titan, Outer Planets)
  - One on TPS instrumentation (before MEDLI and EFT-1 had flown)
- **Scope:**
  - Rigid aeroshells only
  - Direct, aerocapture, and from-orbit entries considered
  - Other entry technologies (such as inflatables/deployables) not considered
- **Broad range of support—over 90 individuals representing 18 organizations as co-authors**
- **These white papers helped the Decadal Survey Sub-panels to identify missions that were feasible based on availability of TPS:**
  - Uranus flagship mission (using carbon phenolic)
  - Jupiter and Neptune probes were not considered as potential flagship missions

Updates required for next round of Decadal Survey

- **Much has changed in the past 10 years**
  - Some materials have undergone little to no development in the past decade
    - Full density carbon phenolic, SRAM, PhenCarb
  - New materials have been developed at varying levels of readiness
    - HEEET, block AVCOAT, 3D-MAT, conformal PICA
  - New ground test capabilities have expanded the achievable testing envelope
    - SMD-funded 3” nozzle in the NASA Ames Interaction Heating Facility (IHF), AEDC H3 arc jet
  - EDL instrumentation has flown and is now a requirement for all missions!
    - MEDLI, EFT-1, Schiaparelli
  - Major investments in inflatables/deployables (HIAD, ADEPT), although these technologies will have separate white papers discussing their suitability for mission implementation
- **Material readiness and availability may influence the ability to construct missions to planetary targets**

Outline for TPS/instrumentation white papers

I. **Introduction**
II. **Background**
    a. Historical Overview of TPS Development specific to mission destination
    b. Anticipated Loads and Environments specific to mission destination
III. **Current Capability**
    a. Materials/Sensors
    b. Ground Test Facilities
IV. **Issues and Challenges**
    a. Materials/Sensors
    b. Technical Engineering Development
    c. Ground Test Facilities
V. **Recommendations (Materials/Sensors, Facilities, Modeling, etc.)**

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V. **Recommendations (Materials/Sensors, Facilities, Modeling, etc.)**

Sample Status Table

Table 2. Candidate ablative heat shield TPS materials for Mars and Titan

Density	TPS	Supplier	Flight Qual or TRL	Potential Limit		Entry at Mars			Earth Return†	Titan	
				Heat flux, W/cm^2	Pressure atm	MPF Class	MSL Class	Aero-capture		Direct	Aero-capture
FOREBODY HEAT SHIELD											
Low-Mid	SLA 561V	LMA	Mars	< 120 (<300)*	< 1	●	✖	◡	✖	●	●
	PICA	FMI	Stardust	~ 1200	< 1	■	●	●	✖	●	●
	BPA	Boeing	TRL 3-4	~ 1000	~ 1	■	◡	◡	✖	◡	◡
	Avcoat	Textron	Apollo	~ 1000	~ 1	■	●	●	✖	●	●
	AQ60#	EADS	Huygens	~ 250	< 1	◡	✖	◡	✖	●	◡
	Acusil® II†	ITT	DOD MSL	100	< 1	✖	✖	◡	✖	◡	◡
	SRAM Family	ARA	TRL 5-6	~ 300*	~ 1	◡	◡	◡	✖	◡	◡
	Lower density Phen-Carb	ARA	TRL 5-6	< 2000	~1	■	◡	◡	✖	◡	◡
Mid	ACC	LMA/C-Cat	Genesis	> 2000	> 1	■	■	■	✖	■	■
	Mid-density PhenCarb	Several	TRL 4-5	~ 2,000-4000	> 1	■	■	■	✖	■	■
High	3DQP	Textron	DOD	~ 5000	> 1	■	■	■	✖	■	■
	Heritage Carbon phenolic	None today but several can	Venus, Jupiter	10,000-30,000	>> 1	■	■	■	●	■	■

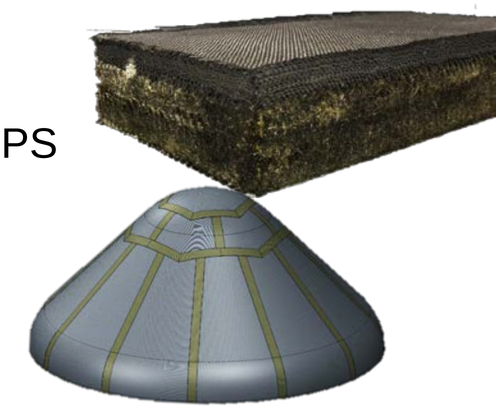
● Fully capable ◡ Potentially capable, qual needed ■ Capable but heavy ✖ Not capable

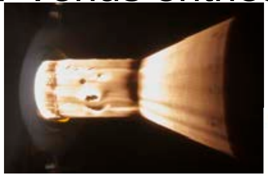
†RF transparent #European Supplier * (heat flux limit is lower with high shear, higher at low shear)

- Table from 2009, will be updated in current round of white papers
- Gives status of TPS materials for missions to each destination
- Updates for 2020:
  - Aerothermal environment range for each mission type
  - Thermal response model availability
  - Manufacturing readiness

Venus

- **Updates from the past decade:**
  - Carbon Phenolic has been de-emphasized
  - Heatshield for Extreme Entry Environment Technology (HEEET) TPS developed and now at TRL 6
  - Both atmospheric probes and large aeroshells for landers will be considered
  - Facility upgrades target conditions applicable for Venus entries
    - NASA IHF 3-inch nozzle
      - ~4000 W/cm^2 @ 5-6 atm (stagnation)
    - AEDC H3 Facility
      - ~ 1,200 W/cm^2 @ 3 atm pressure, 4000 Pa shear (wedge)
      - ~ 1,000 W/cm^2 @ 14 atm (stagnation)



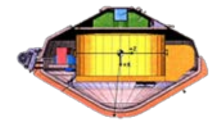


- **Questions for the community:**
  - Is it valid to assume that targeting a particular landing site location is not required?
  - Are there restrictions to science instruments (g-load constraints) that will define the acceptable entry angles?

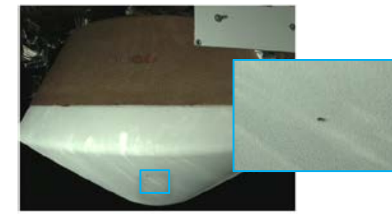
Sample Return (SR) to Earth

- **Updates from the past decade:**
  - Mars Sample Return (MSR) Earth Re-entry mission will be included in the Sample Return paper, not the Mars/Titan paper
  - Planetary Protection class distinction will be made:
    - Class V Unrestricted (Moon, comets, asteroids)
    - Class V Restricted (Mars, other biologically active sites)
  - New materials considered (HEEET), as well as heritage materials (PICA, carbon-carbon)
  - Risk to the TPS as a system (failures due to gap filler issues, micrometeorite and orbital debris damage, etc.) will be a major consideration in material suitability
- **Challenge for the community**
  - What design tools and testing methods are needed to capture complex failure modes in TPS in order to demonstrate robustness?

Heritage SR designs continue to be modified and proposed…



Genesis



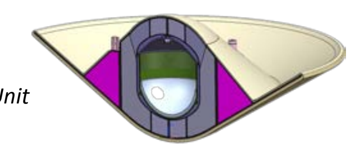
Stardust -> OSIRIS-REx (with Micro-meteoroid damage)

JAXA Hayabusa

…while high reliability for Class V motivates robust TPS selection and advanced modeling.

Tiled HEEET Engineering Test Unit

Mars Sample Return Concept



Mars/Titan

- **Updates from the past decade:**
  - New materials (conformal PICA, Norcoat-Liege, etc.)
  - New arc jet test article designs (SPRITE-shape): representative heating and shear with appropriate pressure gradients w/ internal electronics
  - Inclusion of radiative heating modeling in CO_2 (NEQAIR, HARA)
  - New arc jet test facility: LEAF-lite for combined convective and radiative heating
  - NASA arc jets consolidated into one location
    - CO_2 in TP3 to be available soon
    - Recommend adding N_2–only capability to IHF to better represent Titan at relevant conditions

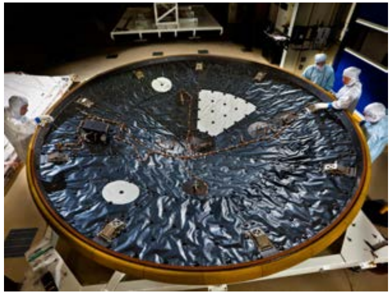
- **Requests for the community:**
  - Information on new materials capable for use at Mars and Titan:
    - Tested heating, pressure and shear values
    - TRL estimates
    - Relevant scale tested or demonstrated to date
  - Updates on data for materials included in the previous white paper

Outer Planets

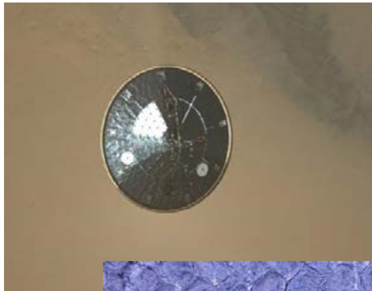
- **Updates from the past decade:**
  - As with Venus, the de-emphasis on carbon phenolic and the maturation of HEEET to TRL 6
  - New aerothermal analysis at Neptune shows entry conditions are lower than in previous decadal survey and comparable to Uranus entry conditions; both fall within ground based test capabilities
  - New arc jet testing capabilities
    - SMD-funded 3” nozzle in the NASA Ames IHF test facility allows testing at mission relevant environments
    - HEEET tested in AEDC H3 facility at ~1200 W/cm^2, ~2.9 atm and ~4000 Pa shear, relevant to Outer Planet missions
    - Recommend N_2-only testing in IHF for oxygen-free testing
  - Need to consider turbulent heating augmentation due to TPS roughness (modeling, testing?)
- **Questions to the community:**
  - Is incentivization of HEEET team support for future mission proposals needed for tech transfer/integration issues?
  - Are there scientific or mission requirements driving to steep entry flight path angles and/or high latitude targets?
    - Equatorial, low entry flight path angles will result in entry environments more consistent with ground based test capabilities

Instrumentation

- **Updates from the past decade:**
  - Successful TPS instrumentation has flown (MSL/MEDLI, Orion EFT-1, Schiaparelli) and collected rich data sets
  - Airborne observations conducted for Earth return missions (Hayabusa, Orion EFT-1)
  - NASA Discovery and New Frontiers mission concepts with EDL must include an Engineering Science Investigation to obtain data about vehicle performance and entry environments.
  - Planned instrumentation on upcoming missions:
    - Mars Entry Descent and Landing Instrumentation 2 (MEDLI2) – launch July 2020
    - Orion Heat Shield DFI – launch 2020
    - Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) – launch 2022
    - Orion Aeroshell DFI – launch 2023
    - Hayabusa 2 (arrives December 2020)
    - Dragonfly (DEDLI) – launch 2026
- **Requests for the community:**
  - More participation from the EDL community – previous white paper only had 2 co-authors!
  - Which physical measurements during atmospheric entry are of greatest interest?



MEDLI



Orion EFT-1 DFI

Closing

- We need your help—we will be instituting telecons for drafting the white papers soon
- Can you help answer/address the questions and requests in this presentation?
- We would like your participation in framing the recommendations
- Other technology-focused papers (ADEPT, HEEET, etc.) need to be written to help Decadal committees plan for new types of mission possibilities
- If you are interested in participating in writing the TPS/instrumentation white papers, please contact me!