Outline

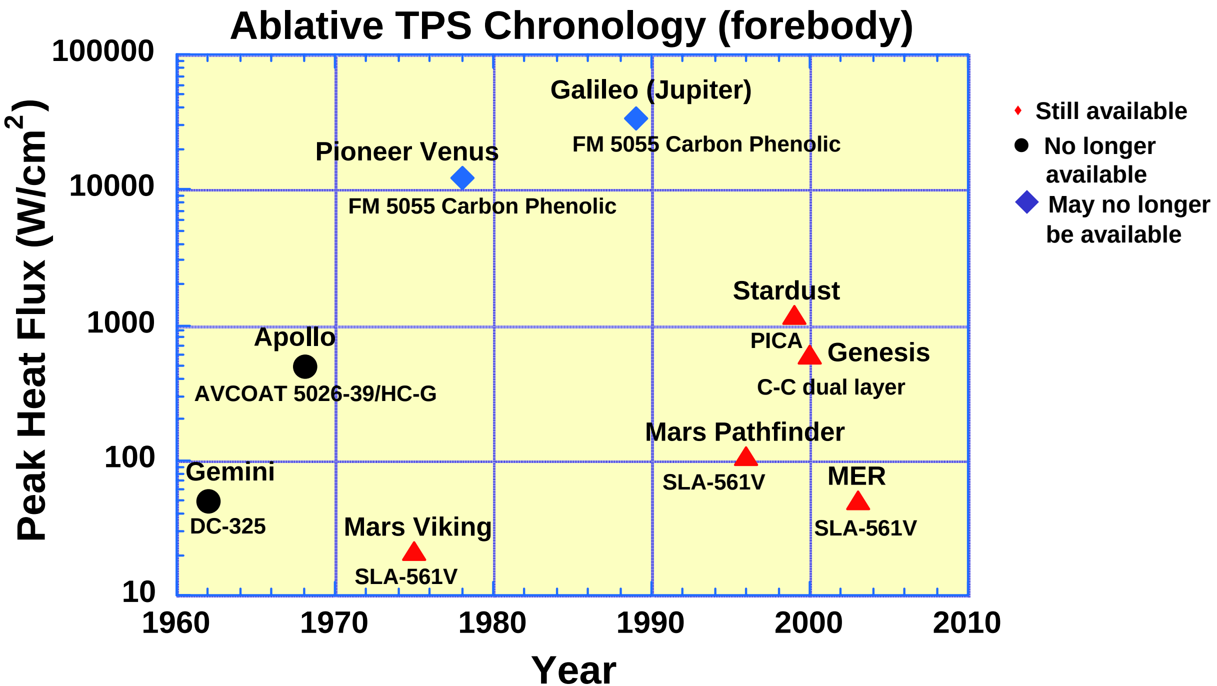
- Why this tutorial?
- Ablative TPS - early studies
- Organic resin composites
- Surface recession mechanisms/modeling
- High fidelity model development
- Testing approaches/requirements
- **Future needs**

Ablative TPS - a short NASA history

- Early NASA missions (Gemini, Apollo, Mars Viking) employed <u>new</u> ablative TPS that were tailored for the entry environment
- After Mars Viking, NASA-sponsored ablative TPS development essentially ceased
  - Focus shifted to reusable TPS (Shuttle)
  - Pioneer Venus and Galileo employed fully dense carbon phenolic (developed by USAF)
  - NASA adopted a “risk averse” philosophy relative to TPS
  - Use what was used before, even if it isn’t optimal
  - Ablative TPS community slowly disappeared
- Stardust and Genesis were exceptions that employed <u>new</u> ablative TPS
  - Missions could not be accomplished with existing TPS materials

NASA's Entry Probe History

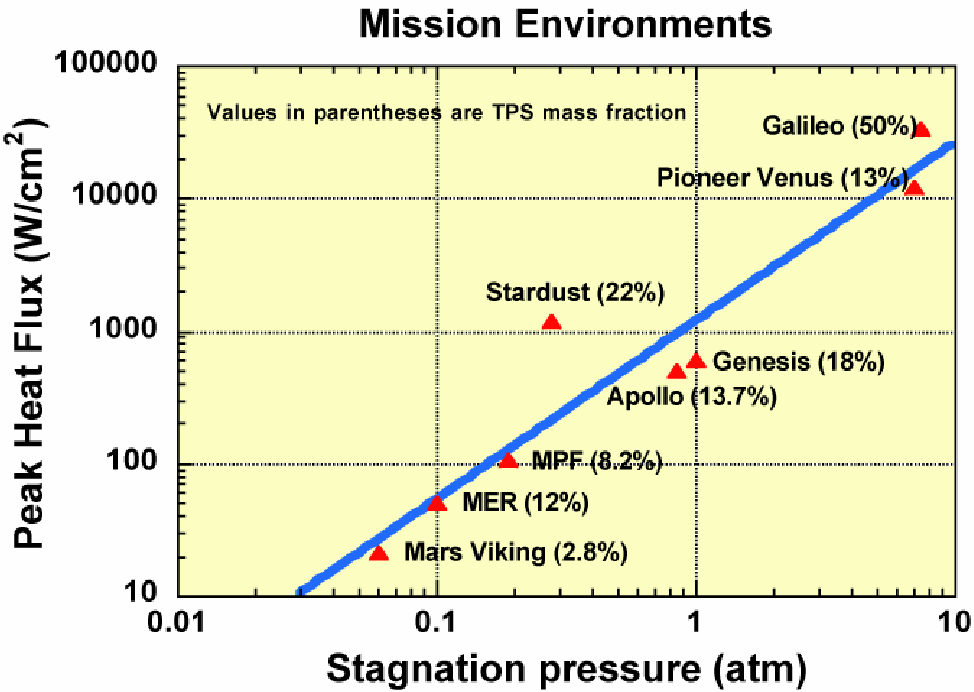
Space Technology Division



In over 40 years, NASA entry probes have only employed a few ablative TPS materials. Half of these materials are (or are about to be) no longer available.

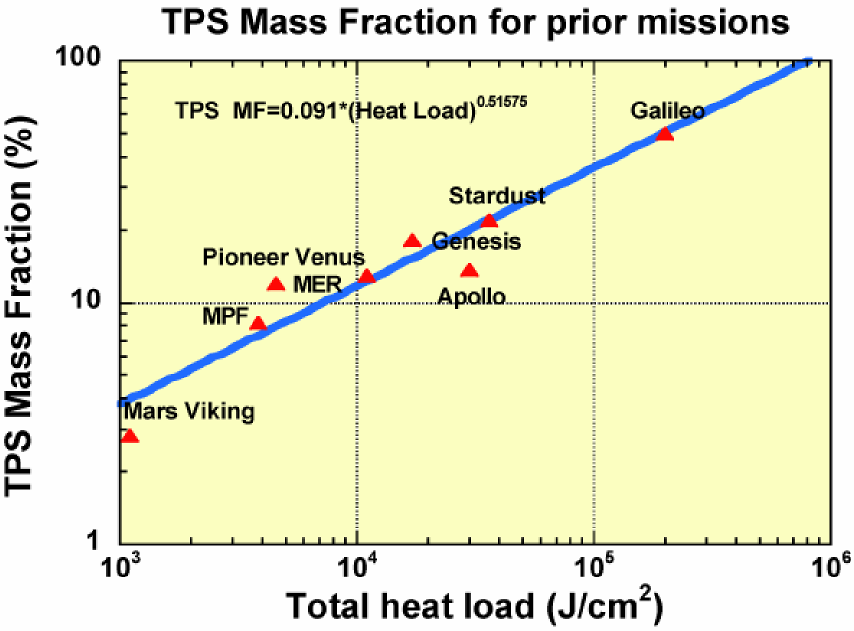
Broad Range of Entry Environments

Space Technology Division



NASA entry probes have successfully survived entry environments ranging from the very mild (Mars Viking ~25 W/cm^2 and 0.05 atm.) to the extreme (Galileo ~30,000W/cm^2 and 7 atm.)

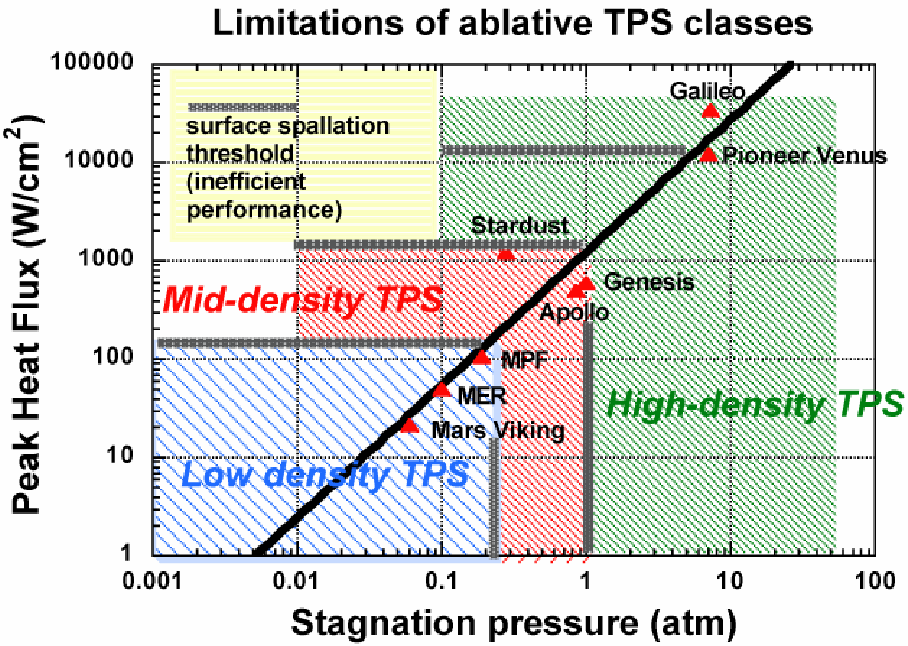
TPS Mass Fraction



- TPS material selection requires an assessment of the entry environment and trade between ablation and insulation performance
- Pioneer-Venus with 13% TPS mass fraction is an excellent example of TPS optimization for a very demanding mission
  - High heat fluxes
  - High pressures
  - Relatively modest total heat load
  - Carbon phenolic (not a very good insulator but an excellent ablator) was a good choice.

The TPS mass fraction for an entry probe is a strong function of the total integrated heat load (e.g., ≈ 50% for Galileo) and the TPS material optimal performance characteristics.

Material Performance Limits



Optimal performance regime is balanced between ablative and insulation efficiency. When material is used outside of optimal zone, inefficient performance leads to non-minimal mass fraction.

TPS for Planetary Probes

Space Technology Division

SSE Missions	Sample Return Missions			Direct Entry						Aerocapture					
Ablative TPS Material Classes	Lunar SR	Comet SR	Mars SR	Mars	Titan	Venus	Saturn	Neptune	Jupiter	Mars	Titan	Venus	Saturn	Neptune	Jupiter
Low-density silicones	X	X	X	●	◗	X	X	X	X	◗	◗	X	X	X	X
Low-density phenolics	◗	●	◗	❍	❍	X	X	X	X	❍	❍	X	X	X	X
Mid-density phenolics	◗	●	◗	❍	❍	X	X	X	X	❍	❍	X	X	X	X
Carbon-based multilayer	◗	●	◗	❍	❍	◗	◗	◗	◗	❍	❍	❍	❍	❍	❍
High-density phenolics	❍	❍	❍	❍	❍	●	●	●	❍	❍	❍	❍	❍	❍	❍

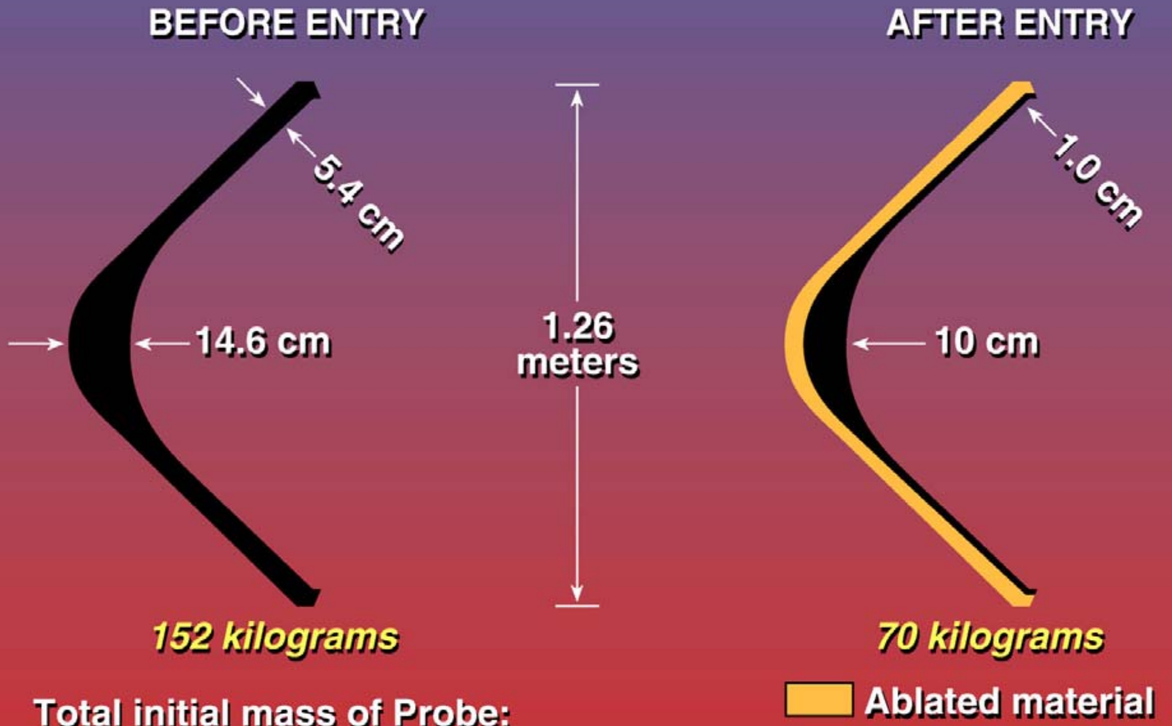
● Fully capable
◗ Potentially capable, but not demonstrated
❍ Potentially capable but with large TPS mass penalty
X Not applicable; conditions too severe

No human-rated ablative TPS available today!

Aerothermal Environment

- **Primary Uncertainties:**
  - Boundary layer transition and turbulent heating levels
  - Shock layer radiation
  - Coupled convection/radiation/ablation, including shape change effects on aerodynamics and trajectory
- Improvements in current models required
  - Different atmospheres (air, CO_2/N_2, N_2/CH_4, H_2/He)
    - Each planet has different physics that govern aerothermal heating
  - Large range of potential entry velocities (6-50 km/s)
    - Flow complexity is a strong function of velocity
- Ground test facilities cannot simulate all aspects of environment
  - In-situ flight data are essential for model improvement and validation, particularly for non-Earth entries

Galileo Probe Heat Shield Ablation: The Most Difficult Atmospheric Entry in the Solar System



Total initial mass of Probe:
335 kilograms

Ablation temperature = 3900° C

TPS Ground Test Facilities

- Existing arc plasma facilities
  - Operate with air (or N_2)
  - Limited gas enthalpy
  - No combined convective/radiative capability
- NASA Ames designed, built and utilized the Giant Planet Facility in support of the Galileo probe development
  - Operated on H_2/He; capable of high pressures & heat fluxes
  - Decommissioned/disassembled after project completion
  - Would require significant time and money to re-establish
- Facility upgrades needed to support TPS development/ qualification for many planetary probe missions

In conclusion

- Discussed the state-of-the-art (from a NASA perspective) in modeling aerothermal environments
- Described approaches to ablative TPS testing, modeling, and qualification (including historical)
- Defined requirements for further development in aerothermal modeling, ablative materials, ground test facilities

We appreciate your participation and hope you found this informative and useful