SMALL PROBES AS FLIGHT TEST BEDS FOR THERMAL PROTECTION MATERIALS

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Thermal Protection System (TPS) materials for atmospheric entry probes are traditionally tested and flight qualified in ground-based arc jet test facilities. Testing is performed using a family of test article geometries including blunt axisymmetric stagnation articles, blunt wedge articles, and large flat panel articles. Together these test geometries partially reconstruct aerothermal environment parameters predicted along a trajectory. The tests attempt to replicate environments predicted at a single location on the TPS, at a single time point on a trajectory. One strategy to strengthen the ground to flight traceability of a TPS certification program is to develop an affordable test platform comprised of fully instrumented small probes. This poster summarizes the results of a focused systems study of a class of small probes (8-24 kg entry mass and < 40 cm diameter) that can be tested on the ground and can be launched as secondary payloads, deployed in orbit, de-orbited and recovered on Earth.

Small Probe Design

The Small Probe Re-entry Investigation of TPS Engineering (SPRITE) concept includes the utilization of a small probe as a flight test bed for TPS technologies. SPRITE represents a compromise between a full-scale flight test and a coupon-scale ground test article. The probe would be designed to be as using existing off the shelf technologies which minimizes cost and risk. Maintaining a 1:1 geometric similitude between the ground test and flight article would allow the same probe to be tested both on the ground and in flight at full scale; an innovative strategy that has the enormous potential to greatly increase knowledge and confidence in the TPS design at an affordable cost.

The SPRITE capsule design concept includes TPS material bonded to a structural shell, a parachute system, TPS performance instrumentation (similar to Mars Science Laboratory TPS instrumentation [1]), data acquisition system, tracking beacon, and power system. See Figure 1. Preliminary estimates indicate a minimum entry mass between 8-12 kg is feasible and by using ballast weights the entry mass can be increased up to 20-25 kg to tailor the ballistic coefficient according to specific test requirements.

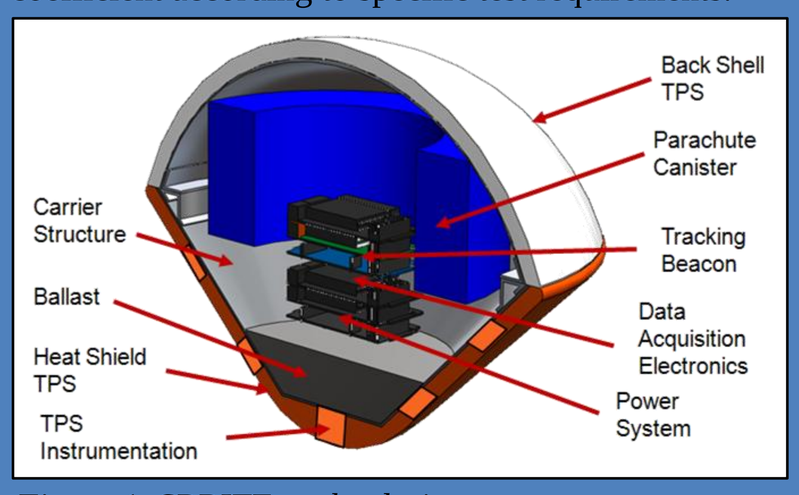

Figure 1. SPRITE probe design concept

The SPRITE platform has four notional design reference missions including a ground test configuration, and three flight test configurations that span a wide range of entry conditions applicable to a multitude of entry vehicle missions. See Table 1, the column headings on the flight test missions indicate the initial orbit prior to entry.

Table 1. Estimated SPRITE entry environments

	Ground Test	Sub Orbital	LEO	GTO
Entry Velocity	N/A	2 to 5 km/s	7 to 8 km/s	9 to11 km/s
Estimated De-orbit Delta V	N/A	N/A	200-300 m/s	<50 m/s
Est. Environments*	Q:50-400 P:0.1-12 S:50-250	Q: 100-200 P: 15-35 S:100-200	Q: 100-400 P: 10-25 S:100-300	Q: 800-1000 P: 20-50 S:300-600

*Q=Stag. Heat (W/cm^2), P=Stag. Pressure (kPa), S=Frust. Shear (Pa)

Thermal Protection Technology Certification

TPS technologies are traditionally developed, qualified, designed, and flight certified based on data collected from ground based tests. This approach is the best strategy available within the constraints of most projects and is an exception to the Test Like You Fly (TLYF) design philosophy (a philosophy in which one attempts to achieve both geometric and dynamic similitude between ground test and flight) because the environments simulated on the ground are only partial combinations of the environment parameters encountered in flight.

One way of relaxing the restrictions imposed by ground test facilities is through flight test programs. However, flight tests are rarely performed primarily because of programmatic cost and schedule constraints. The SPRITE platform is designed to obtain valuable flight test data within the constraints of modern development and flight projects. Data collected from the SPRITE platform will not only help TPS technologies advance in TRL, it will also help verify the relevance of performance measurements recorded in ground facilities (i.e. build ground to flight traceability).

The SPRITE test platform enables testing material performance of shear flows down stream of a stagnation region. This means more relevant combined environments on ground test articles which are traceable to their flight test counterparts. Traditionally shear and stagnation environments are tested using separate test articles. See Figure 2. Large article tests have been demonstrated in test facilities [2], however, the environments achievable in existing ground test facilities are limited. Improvements in test gas flow rate and/or test power would increase the envelope of ground test environments.

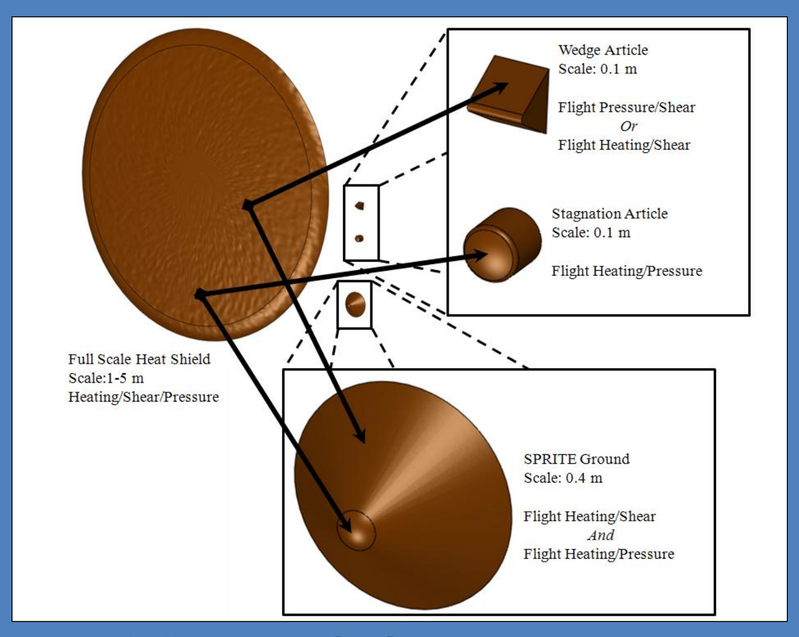

Figure 2. SPRITE probe design concept

Mission Profile

The probe would integrate with a spacecraft on the ground. The spacecraft provides all on-orbit functionality including attitude control and orbital maneuvering (including the de-orbit maneuver directly prior to atmospheric entry). The complete SPRITE probe and spacecraft assembly would then be integrated with a secondary payload adapter and prepared for launch. After launch, the SPRITE probe and spacecraft would remain in orbit until proper alignment with a predetermined landing site upon which time the spacecraft would initiate a propulsive de-orbit burn and release the probe. The SPRITE probe would maintain passive stability through the hypersonic, supersonic and subsonic flow regimes. Once the probe reaches subsonic speeds, a parachute would be deployed to decelerate the probe to its landing velocity. A recovery team capable of tracking the probe would recover the probe hardware for post flight inspection and analysis of flight data recorded during entry. See Figure 3.

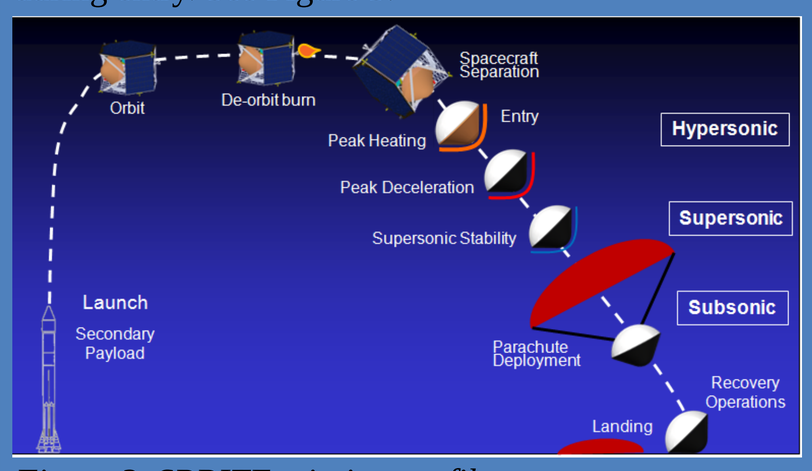

Figure 3. SPRITE mission profile

Thermal Protection Technology Design

The objective of the TPS design process is to develop a design that is not only efficient in terms of mass but also robust enough to survive off-nominal events that may occur during a mission. More often than not, there is a significant amount of engineering judgment involved in reducing and quantifying design uncertainty while trying to strike a delicate balance between performance and reliability. In particular, the TPS sub-system has considerable design uncertainty because of the extreme nature of the environments and the uniqueness of TPS design challenges. The SPRITE platform can provide not only the capability to quantify and reduce design uncertainty, but also to validate and potentially optimize the process through which design uncertainties are treated through one or more relatively inexpensive flight tests.

Summary of Key Benefits

SPRITE is designed to be a flexible, cost effective platform to improve and augment ground test data, provide relevant flight data early in development, and to build direct traceability between ground and flight data all in order to improve reliability and/or mass efficiency of modern TPS designs. The components of the SPRITE test platform include both ground based and flight test articles with the same geometry. Specifically the SPRITE platform provides the tools to:

- Collect reference data to challenge confidence in the thermal models and investigate governing physical phenomena (e.g. glass melt, coking and mechanical erosion).
- Investigate transient material response of in a flight profile test
- Directly correlate ground and flight data in order to qualify the applicability/relevance of ground test data
- Identify unknown failure modes and investigate the behavior of known failure modes
- Demonstrate new TPS instruments and post flight analysis techniques for full scale vehicles and large scale flight tests
- Collect data necessary to develop and validate techniques to model entry vehicle shape change during flight
- Collect statistical material response data and reduce environmental uncertainty from coupon to coupon

Acknowledgements

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References

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