SPRITE: A TPS Test Bed For Ground and Flight

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Outline

- TPS Design Process
- Current Arc Jet Philosophy for Testing & Qualifying TPS Materials
- Motivation for SPRITE
- SPRITE as a Flight-Test Paradigm
- SPRITE as a Ground-Test Paradigm
- Lessons Learned
- The Next Steps
What does SPRITE stand for?

Small Probe Re-entry Investigation for TPS Engineering
The current TPS design process much more sophisticated than before
- Reliance on improved/calibrated *modeling and simulation* procedures
- Fewer, but focused, experiments (ground or flight, esp. flight)

*Predict aerothermal environments* for a given geometry and ref. trajectory(ies)
- Trajectory dispersions
- Shape change
- Uncertainties in aerothermal environments

*Select and size TPS materials for a margined bondline temperature constraint*
- *Heritage, i.e., TRL of TPS material, is important!*
- Choice of materials (nonablative, or ablative: Carbon- or Silicon-based)
- Material stack up
- Choice of bondline adhesives
- Uncertainties in materials properties
- Material thermal response model and its uncertainties

Response models for TPS anchored to arc jet tests & *not flight* experiments!
Arc jet test gas (usually air, sometimes N₂) not necessarily representative of the planetary atmosphere
   - For Mars entries – enriching air with additional O₂ is one alternative

**Geometric similitude is not demanded**
   - Flight and arcjet test articles need not be geometrically related (by scale or shape with surface features)

**Dynamic and boundary layer similitude** between ground and flight is not demanded either.
   - TPS response history or “memory” not considered
   - Attempt to replicate flight-like enthalpy levels
   - Ground tests are “point tests”
     - Usually a single combination of heat flux-pressure
     - For glassy ablators a single combination of heat flux-pressure-shear is important

Arc jets at ARC and JSC currently cannot replicate radiative heating environments, and have limited turbulent flow capabilities
“Point Test” Approach to Materials Test & Qual:
TRL Elevation (to 5, if no flight heritage for material)

Matching flight enthalpy in an arc jet means trade between chemical energy ($T_{\text{arc}} \Rightarrow \text{Current/Flow}$) and kinetic energy ($V_{\text{arc}} \Rightarrow \text{Nozzle Size}$)
• Freestream conditions time-varying in flight, but held constant in arc jet test
• Heat flux modulation is difficult from a facility operations view point
  – Attempted during TPS development program for MPCV
Motivation

- Do we know how well we have designed the TPS of the flight vehicle
  - Do we have a clear understanding of the ‘conservatism’ in the design?

- Can we develop a low cost flight experiment to address this ‘conservatism’
  - Can we replicate the design environments around a concept flight vehicle?

- Can the low-cost configuration be tested in a ground-based facility?

- Three immediate advantages of a low cost flight experiment:
  - Significant reduction in the number of ground-based arc jet tests?

  - A TPS test bed that provides actual flight environment exposure to candidate materials
    - Reference for future TPS designs
    - Risk reduction in technologies
    - TRL elevation of materials

  - The flight experiment(s) can enable/evaluate S&MA aspects of COTS missions
    - PICA-X and gap fillers on Dragon.
• For the case of ablative TPS, material response is the major feedback mechanism

• Arc jet conditions are usually held constant, but imposed flight aerothermal environment and ablator response “memory” can affect flight reality
  • Example: Apollo flight data showed “coking” of char, but coking not observed in accepted pre-flight arc jet results

A flight experiment with capsule recovery back on Earth can help anchor/validate the material model calibrated to arc jet tests
SPRITE as a Flight-Test Paradigm
• Initial SPRITE geometry modeled along lines of Deep Space 2 (DS-2)
  – 14-inch dia 45° sphere-cone body with rounded back shell for aerodynamic stability

• Test-what-you-fly paradigm
  – Test at flight-scale (geometric) in a ground-based facility
  – Attempt to replicate aerothermal environments along portions of the actual flight trajectory by testing in an arc jet
SPRITE Concept of Operations (Con-Ops)

Deorbit, Descent & Landing, and Recovery as important aspects that remain to be addressed.
### SPRITE (As Secondary Payload) Systems Analysis

#### Entry Systems and Technology Division

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<th>Subsystem</th>
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<td>Communication</td>
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<td>Command &amp; Data Handling</td>
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<td>Recovery System</td>
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<th>GTO</th>
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<td>100-200</td>
<td>100-400</td>
<td>800-1000</td>
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<td>P: Pressure, kPa</td>
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<td>15-35</td>
<td>10-25</td>
<td>20-50</td>
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<tr>
<td>S: Shear, Pa</td>
<td>50-250</td>
<td>100-200</td>
<td>100-300</td>
<td>300-600</td>
</tr>
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</table>

**No choice of orbit as a secondary payload**

**Requirements might be imposed by the primary payload**
Example: SPRITE Applicability to Orion

- Body points shown on centerline only
- Body is axisymmetric and the trajectory is ballistic
- Body points can be distributed over the acreage (consider as sensor locations)

Partial coverage of CEV ISS heat flux-pressure space can be achieved
SPRITE as a Ground-Test Paradigm
Engineering of a Small Probe: The First Steps

• Mechanical Design and Fabrication (TPS and Structure)

• *In situ* Data Acquisition System Design and Fabrication

• Thermal Analysis
  – *FIAT* and *TITAN* for the TPS materials
  – *MARC* for Internal Temperatures

• Thermal Structural Analysis (*MARC* and *NASTRAN*)

• CFD (*DPLR*) for predicting aerothermal environments

• No particular flight profile targeted for first ground test of probes
• TPS materials not sized for any specific heat load
• Backshell geometry different from that of flight test for test design simplicity
Objectives of the Ground Test

To demonstrate:

• Feasibility of arc-jet testing flight articles at full scale

• Feasibility of *in situ* measurements of temperature, strain and recession using a data acquisition system mounted inside the test article

• That a combination of simulation tools – primarily DPLR, FIAT, and MARC – can be used to predict material response, thermal environments and thermal structural behavior
Final Design of Small Probe for Arc Jet Tests

Entry Systems and Technology Division

- TPS selected by availability: PICA for heatshield and LI-2200 for aft
- TPS materials not sized for any specific heat load
Distribution of Sensors (K-Type Thermocouples)

- **Mid-cone MISP plug:**
  - In-depth TCs 22,23,24

- **Stagnation MISP plug:**
  - In-depth TCs 1,2,3
  - + HEAT sensor

- **Bottom-cone MISP plug:**
  - In-depth TCs 25,26,27

- **Arc jet Facility DAS**
  - SPRITE Integrated DAS

- **MEDLI-type MISP sensors used (SPRITE is the Maid of the MISP?)**
- **Thermocouple signals acquired by internal DAS and facility DAS, with overlap**
Arc Jet Tests

- Two 14-in (36 cm) SPRITE probes designed & tested in AHF (20MW arc jet)
- Demonstrated ability to build a small probe within a small budget
- Demonstrated the survivability of payload
- Demonstrated the ability to obtain data for validation & verification
In situ Data Acquisition System

- A custom Data Acquisition System (DAS) designed & built using COTS components
- Successful data collection and verification during the tests established the capability for in situ flight data measurement, that could be a powerful tool for future flights.
Proved the predictive capability for aerothermal environments during entry
• V&V of flowfield simulations with DPLR (Design/Analysis code)

Established a good approach for thermal soak analysis for sample return missions
• V & V of thermal predictions for aeroshell, interior and payload with a combination of MARC and thermal response tools
NDE of Test Articles: X-Ray CT of SPRITE

- “Shell Extraction” of a layer of the SPRITE PICA
- Analysis of the CT data indicated the maximum depth of the crack to be 1.5 cm out of 2.5 cm
- From the CT data recession appears to be ~3.1 mm
Lessons Learned

• We can test a probe of a size that could also fly in space and reenter the atmosphere;

• Data can be collected reliably in a small probe by a data acquisition system in the plasma flow;

• The project exercised all the analysis tools that were initially identified; and

• Showed that good predictions of environments, structural and thermal behavior could be made using those tools
The Next Steps

- Converting SPRITE to an arc jet test paradigm which will supplement traditional stagnation and shear (wedge or swept cylinder) testing of materials
  - Leverage the ability to achieve combination of pressure, heat flux \textit{and} shear in a single test
  - SPRITE will prove useful in testing new flexible or conformable ablative materials for which performance under shear loads is important
  - Smaller scale versions of the geometry can be tested safely at angle of attack for back shell materials
  - Cavities representative of MMOD damage can be instrumented and tested

- Build a flight (-like) test article for high-altitude balloon drop or suborbital flight
  - Parachute (or not)
  - Flight data acquisition
  - Locator beacon
  - Validate recovery operations

- Design a flight article & execute a atmospheric re-entry flight test