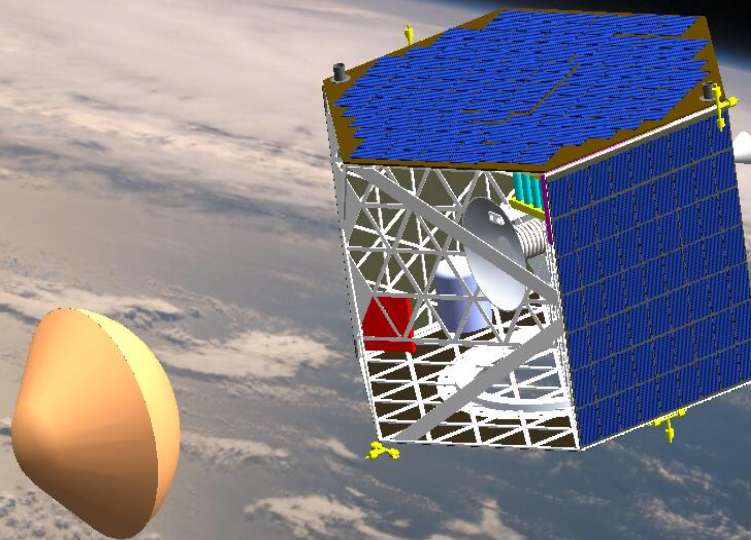


SPRITE: A TPS Test Bed For Ground and Flight

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5th Ablation Workshop, U Kentucky, Lexington
Feb. 28-Mar. 1, 2012

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The hard work put in by the arc jet crew at NASA ARC is gratefully acknowledged

Outline



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- **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?



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Small **P**robe **R**e-entry **I**nteraction for **T**PS **E**ngineering

TPS Design Process



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- 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!

Test & Qualification of TPS Materials: Arc Jets



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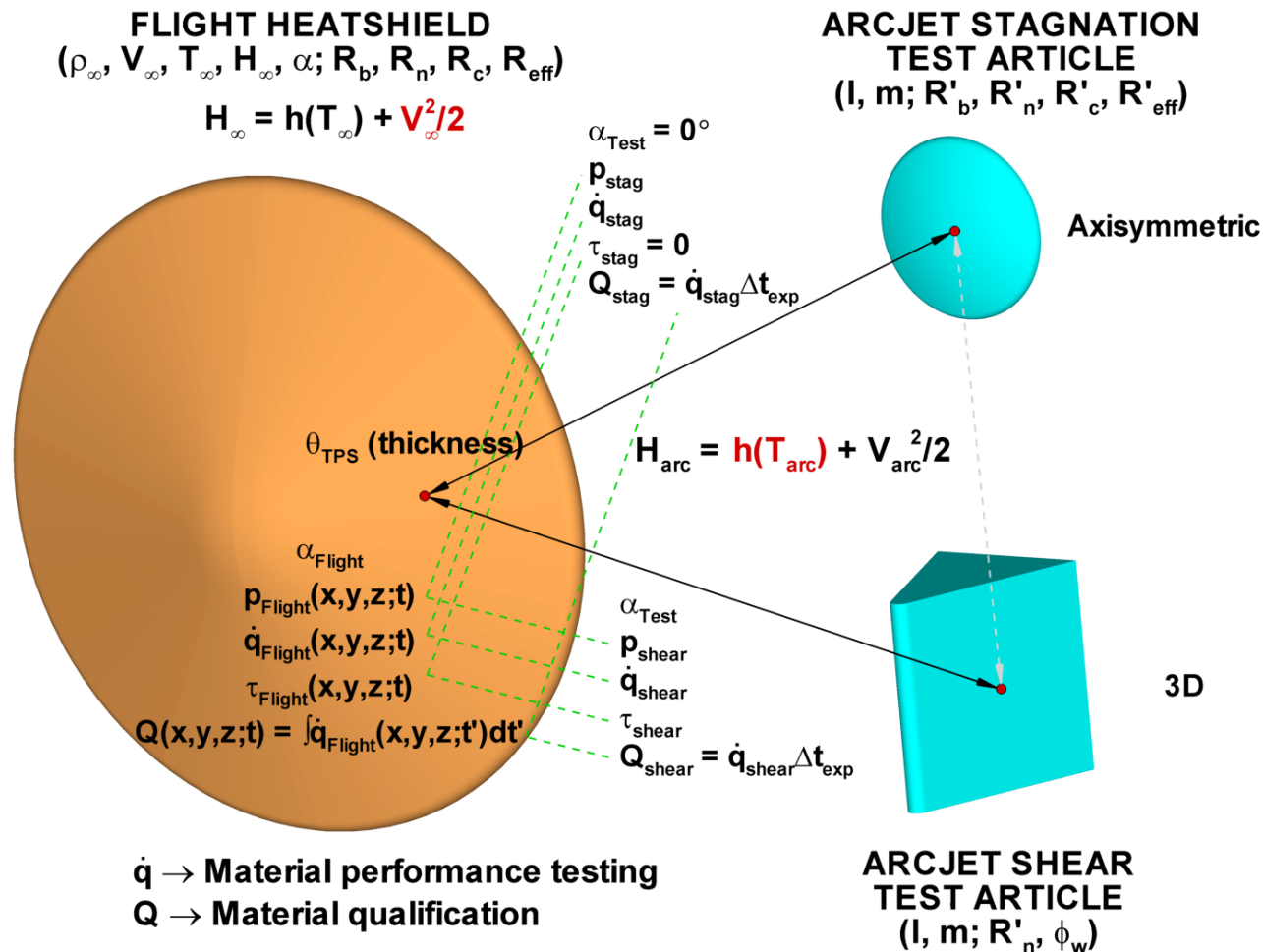
- **Arc jet test gas** (usually air, sometimes N_2) **not necessarily representative of the planetary atmosphere**
 - For Mars entries – enriching air with additional O_2 is one alternative
- **Geometric similitude** is not demanded
 - Flight and arcjet test articles need not be geometrically related (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)



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Matching flight enthalpy in an arc jet means trade between chemical energy ($T_{arc} \rightarrow$ Current/Flow) and kinetic energy ($V_{arc} \rightarrow$ Nozzle Size)

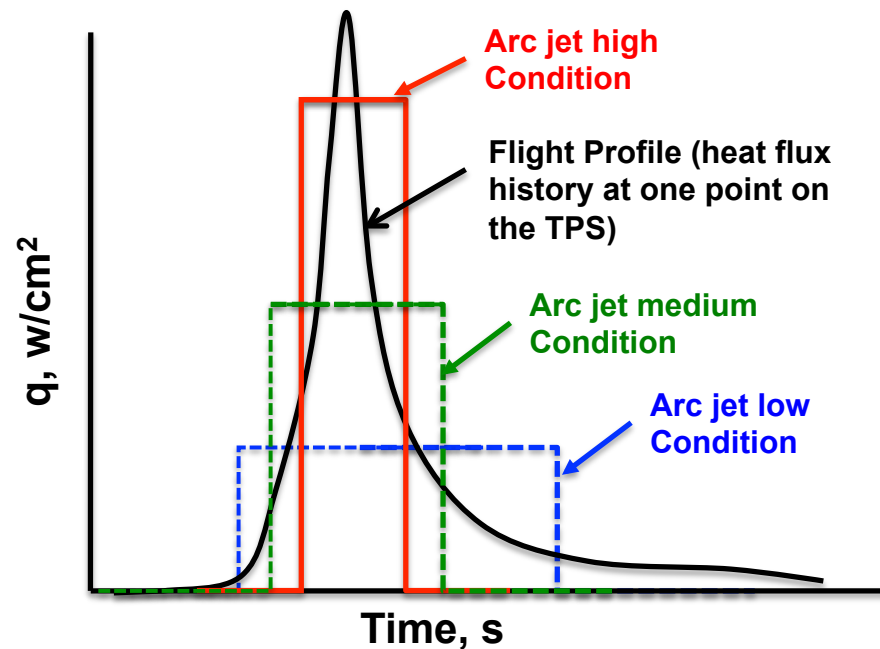
The “Test Like You Fly” Paradigm



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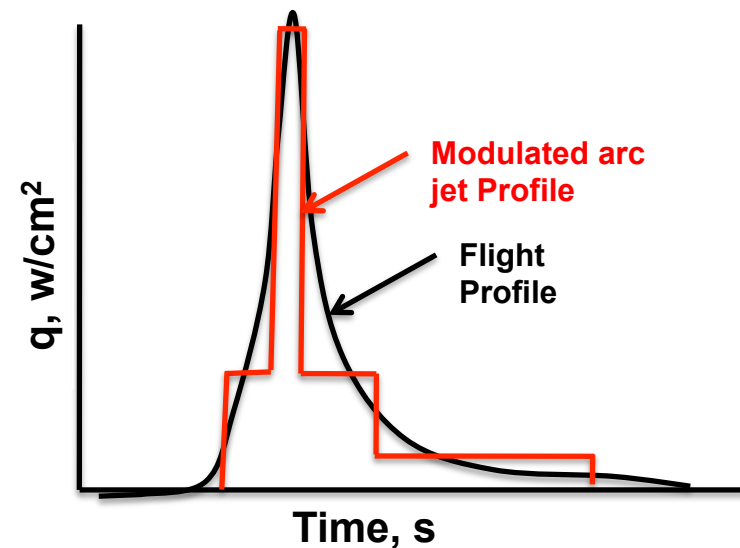
Traditional

(Same heat load at different heat flux levels)



Desirable

(Stepped/Piecewise constant heat load)



- 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

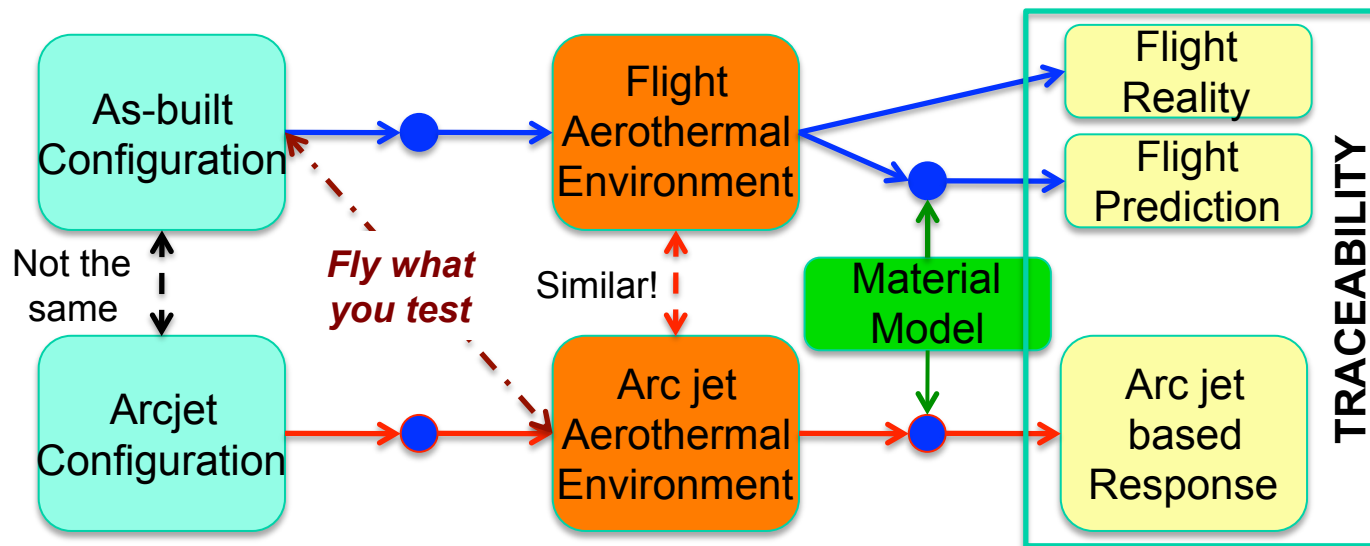


- Do we know how well we have designed the TPS of the flight vehicle
 - Do we have a clear understanding of the *'conservatism' in the design*?
- Can we develop a *low cost flight experiment* to address this 'conservatism'
 - Can we *replicate the design environments* around a concept flight vehicle?
- 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.

Paradigm Shift: “Fly What You Test”



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- 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

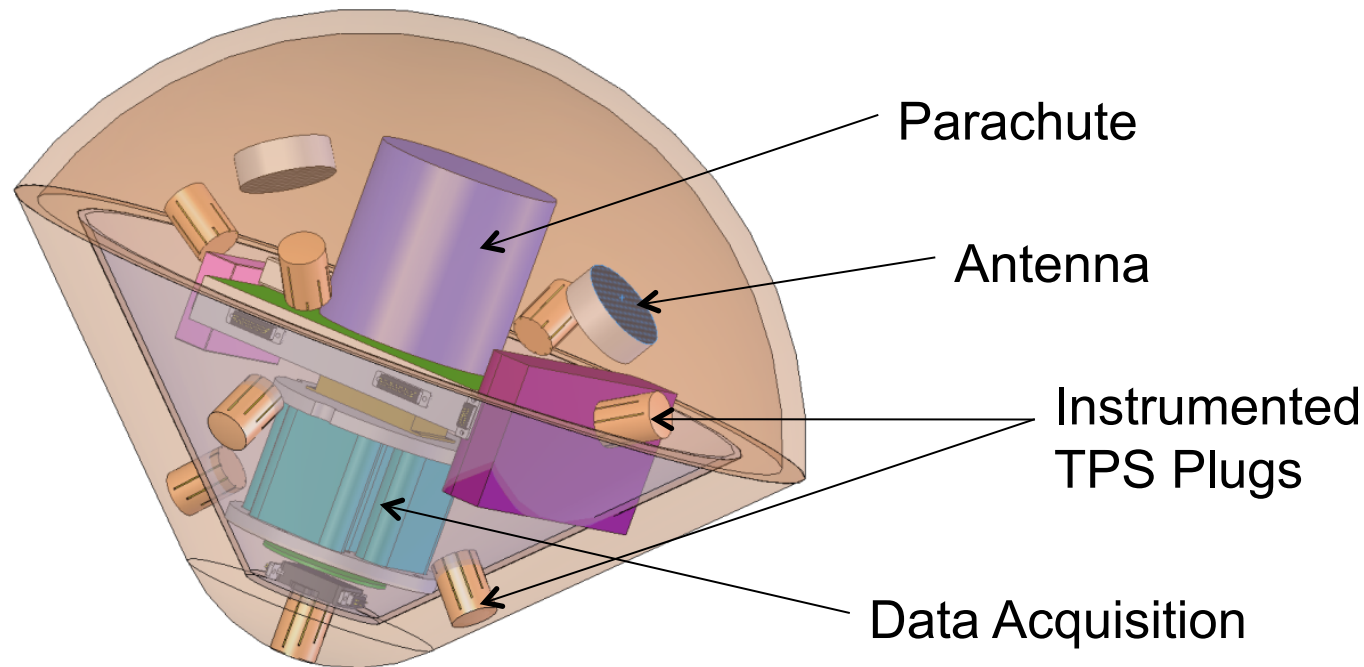


SPRITE as a Flight-Test Paradigm

SPRITE Concept Geometry



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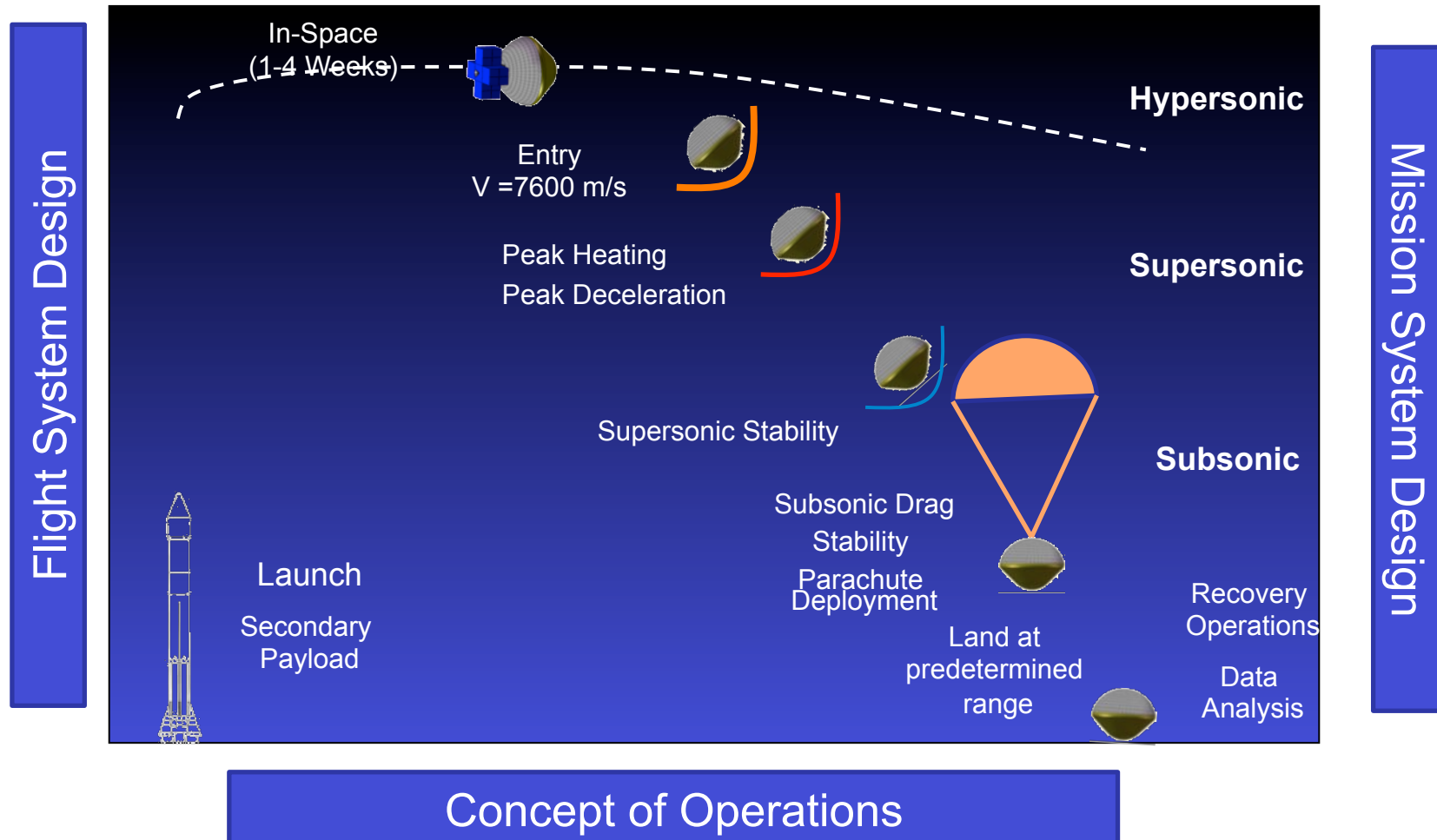


- **Initial SPRITE geometry modeled along lines of Deep Space 2 (DS-2)**
 - 14-inch dia 45° sphere-cone body with rounded back shell for aerodynamic stability
- **Test-what-you-fly paradigm**
 - Test at flight-scale (geometric) in a ground-based facility
 - Attempt to replicate aerothermal environments along portions of the actual flight trajectory by testing in an arc jet

SPRITE Concept of Operations (Con-Ops)



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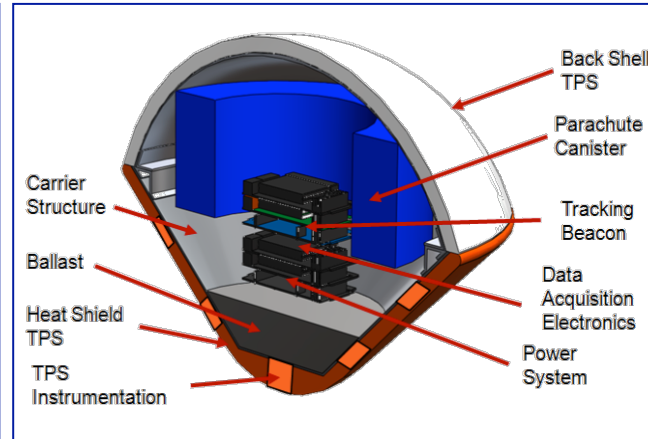
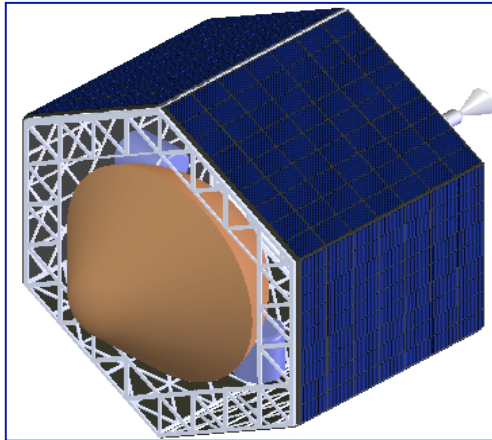


Deorbit, Descent & Landing, and Recovery as important aspects the remain to be addressed

SPRITE (As Secondary Payload) Systems Analysis



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Subsystem	w/ Margin (kg)
Flight Instrumentation	1.807
Communication	0.913
Command & Data Handling	0.480
Electrical Power System	0.922
Recovery System	1.300
Aeroshell	2.909
Structures	2.990
Totals	11.322

	Ground Test	Sub Orbital	LEO	GTO
Entry Velocity, km/s	N/A	2 to 5	7 to 8	9 to 11
Estimated De-orbit ΔV, m/s	N/A	N/A	200-300	<50
Est. Environments	Q:50-400	Q: 100-200	Q: 100-400	Q: 800-1000
Q = Heat flux, W/cm ²	P:0.1-12	P: 15-35	P: 10-25	P: 20-50
P = Pressure, kPa	S:50-250	S:100-200	S:100-300	S:300-600
S = Shear, Pa				

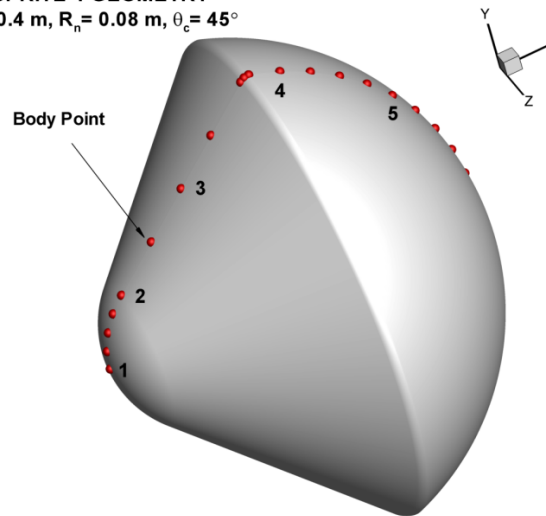
- No choice of orbit as a secondary payload
- Requirements might be imposed by the primary payload

Example: SPRITE Applicability to Orion

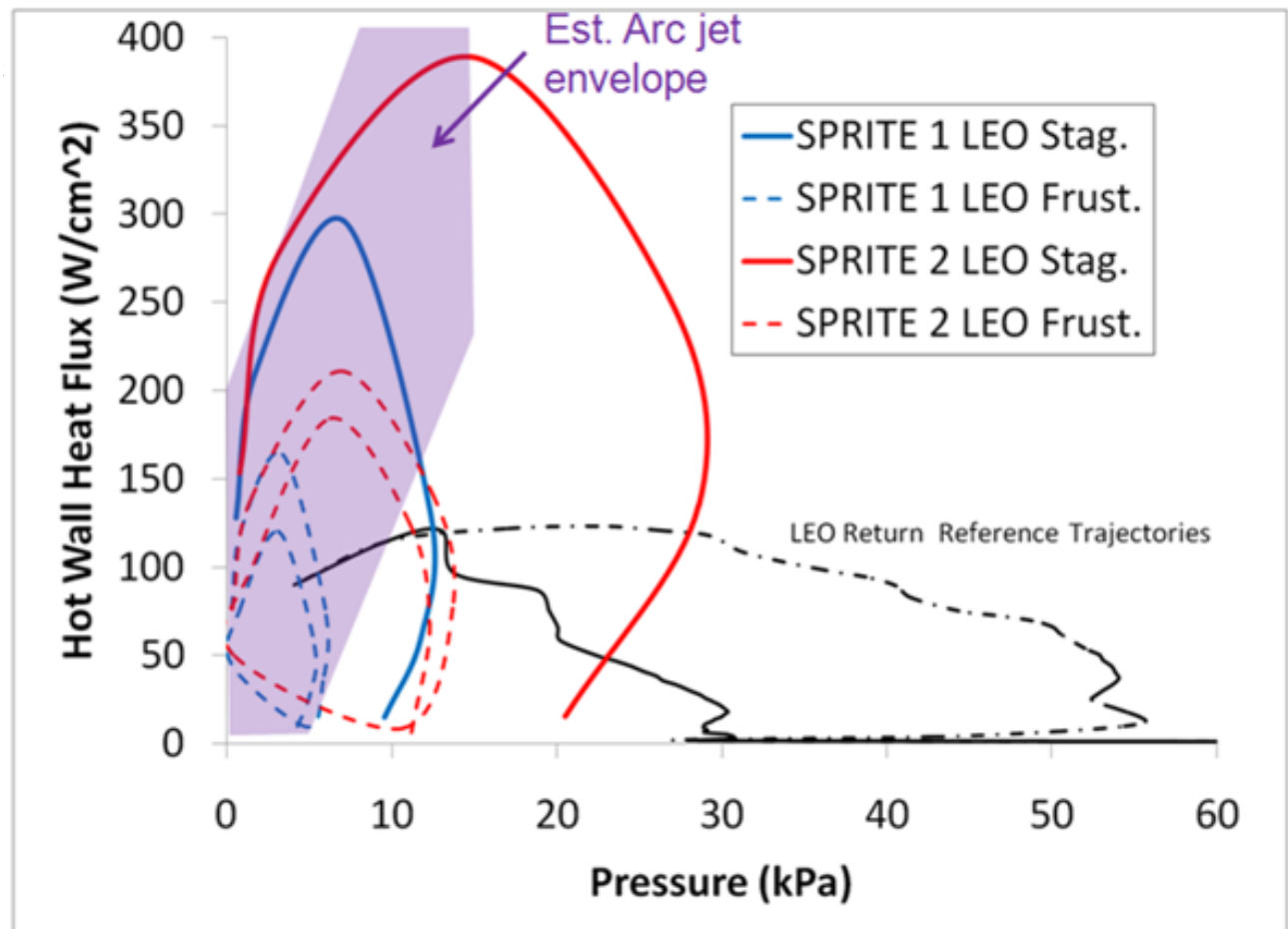


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SPRITE-1 GEOMETRY
 $D = 0.4 \text{ m}$, $R_n = 0.08 \text{ m}$, $\theta_c = 45^\circ$



- 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



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- 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



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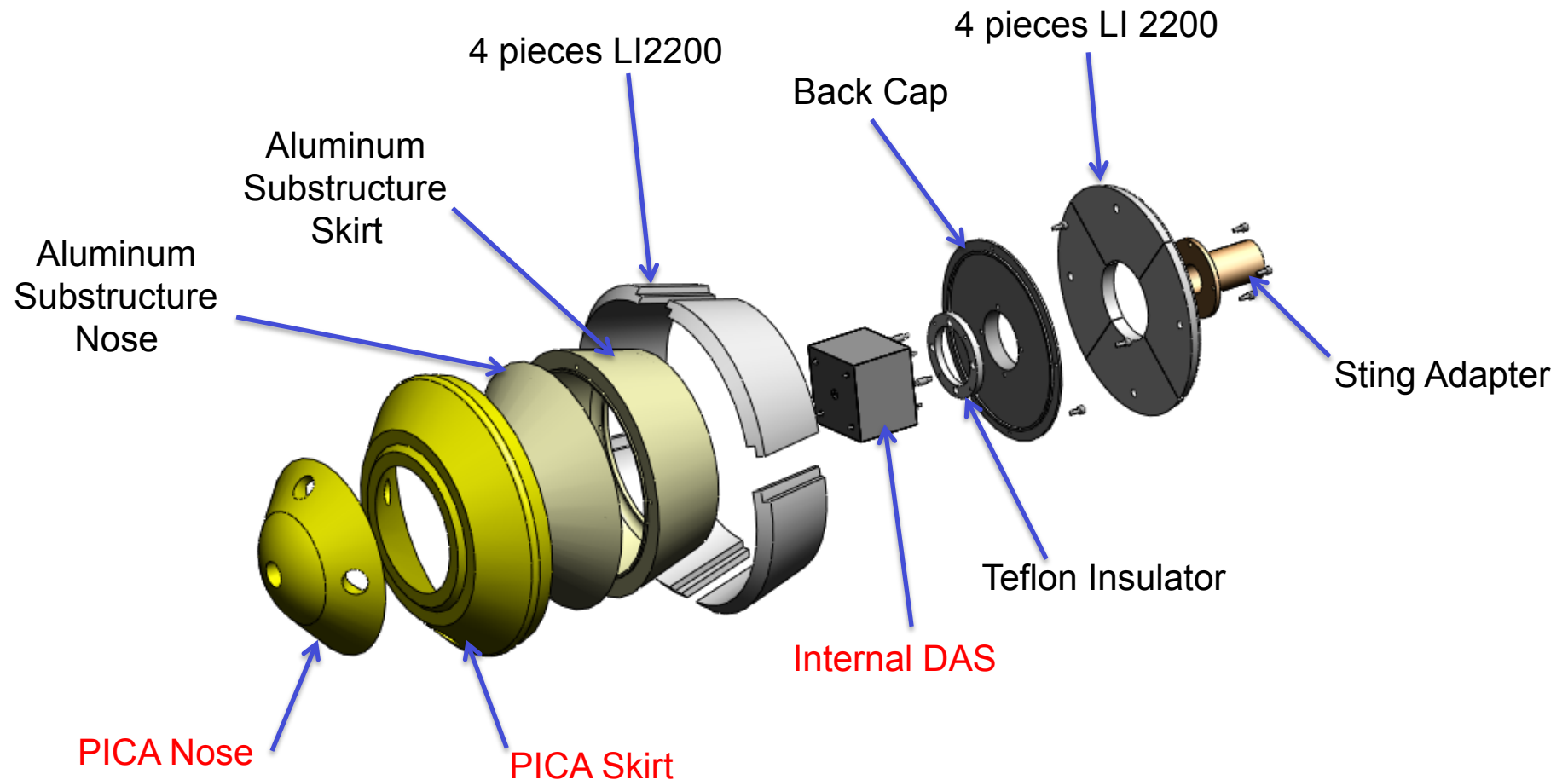
To demonstrate:

- 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



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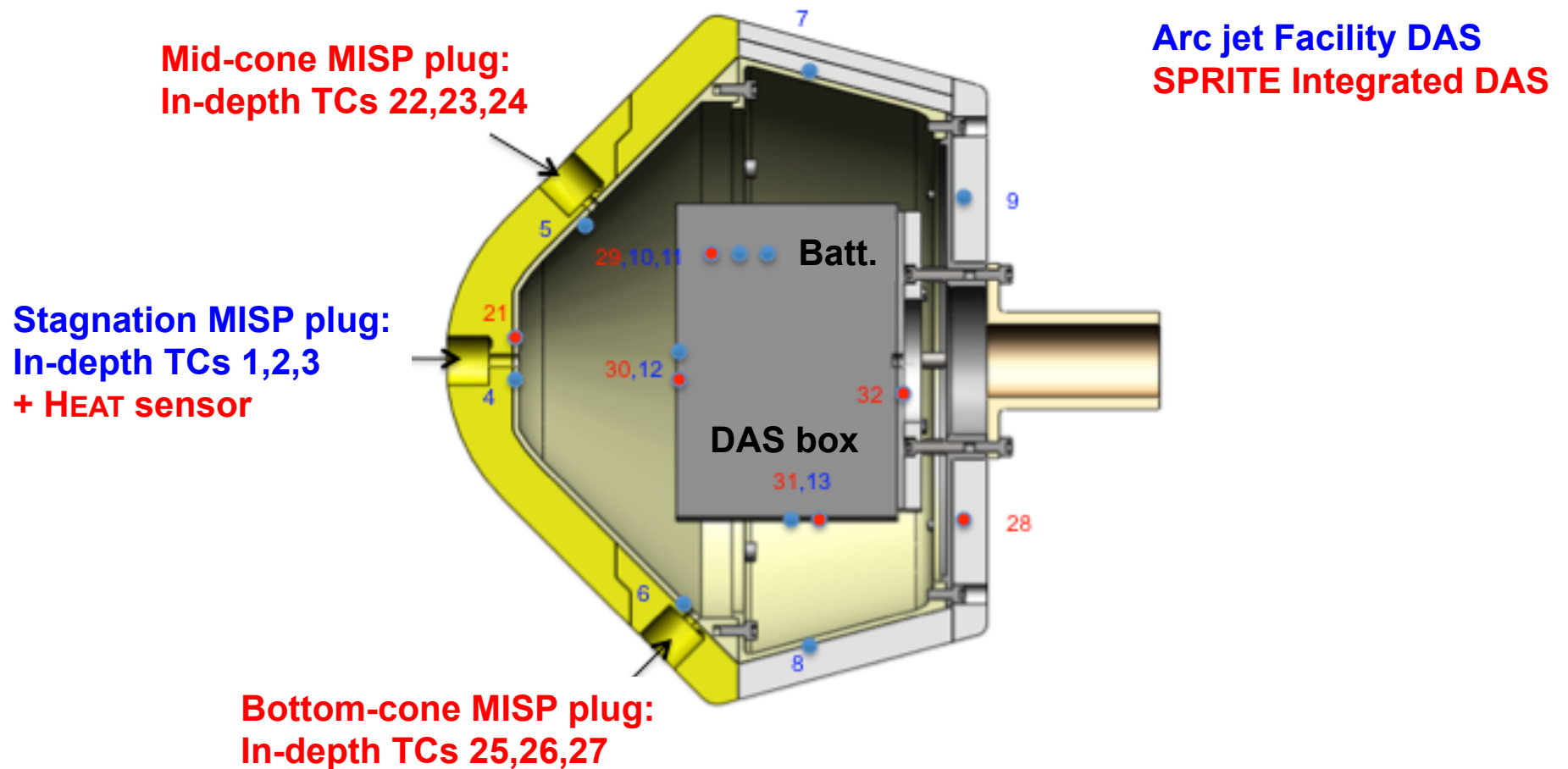


- TPS selected by availability: PICA for heatshield and LI-2200 for aft
- TPS materials not sized for any specific heat load

Distribution of Sensors (K-Type Thermocouples)



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- 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

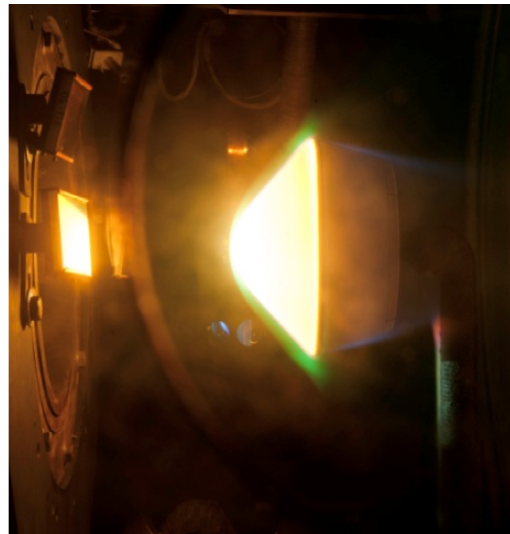


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**Pre-Test
(18-in nozzle AHF)**



**During Test
(Test AHF 295)**



**Post-Test
Charred PICA Heatshield**

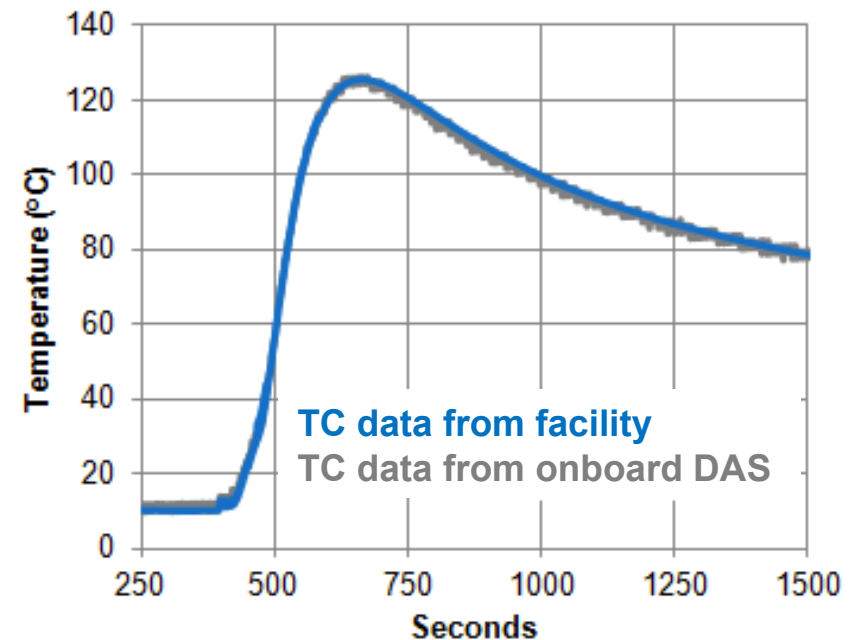
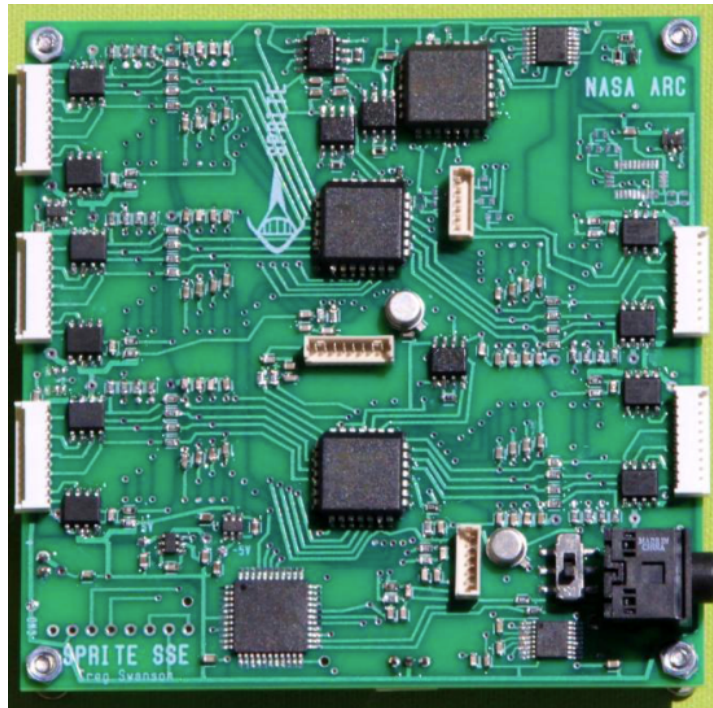


- Two 14-in (36 cm) SPRITE probes designed & tested in AHF (20MW arc jet)
- Demonstrated ability to build a small probe within a small budget
- Demonstrated the survivability of payload
- Demonstrated the ability to obtain data for validation & verification

In situ Data Acquisition System



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- 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.

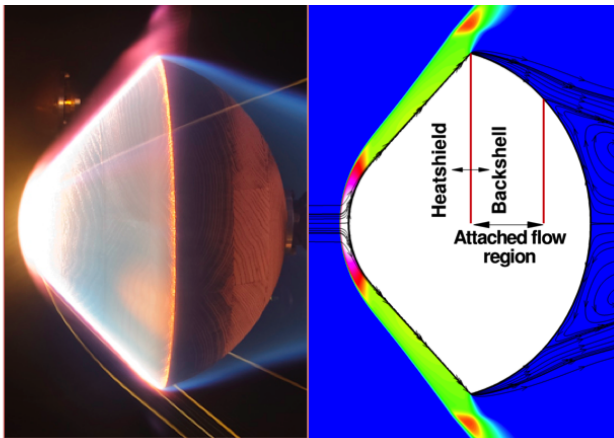
Analysis



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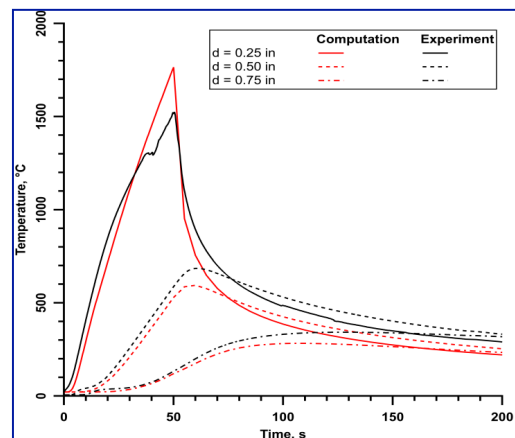
FLOWFIELD SIMULATION

DPLR



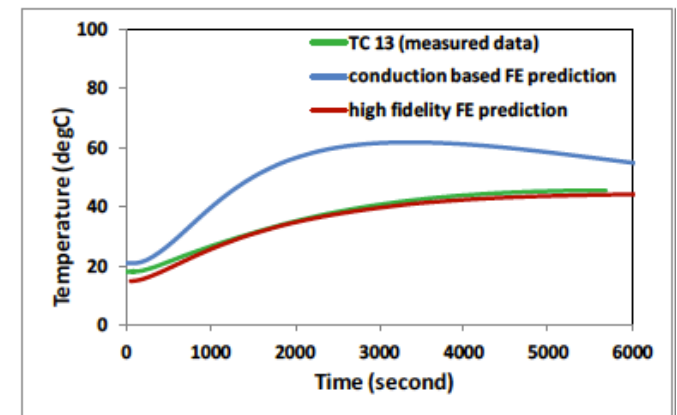
MATERIAL RESPONSE

FIAT



THERMAL ANALYSIS

MARC



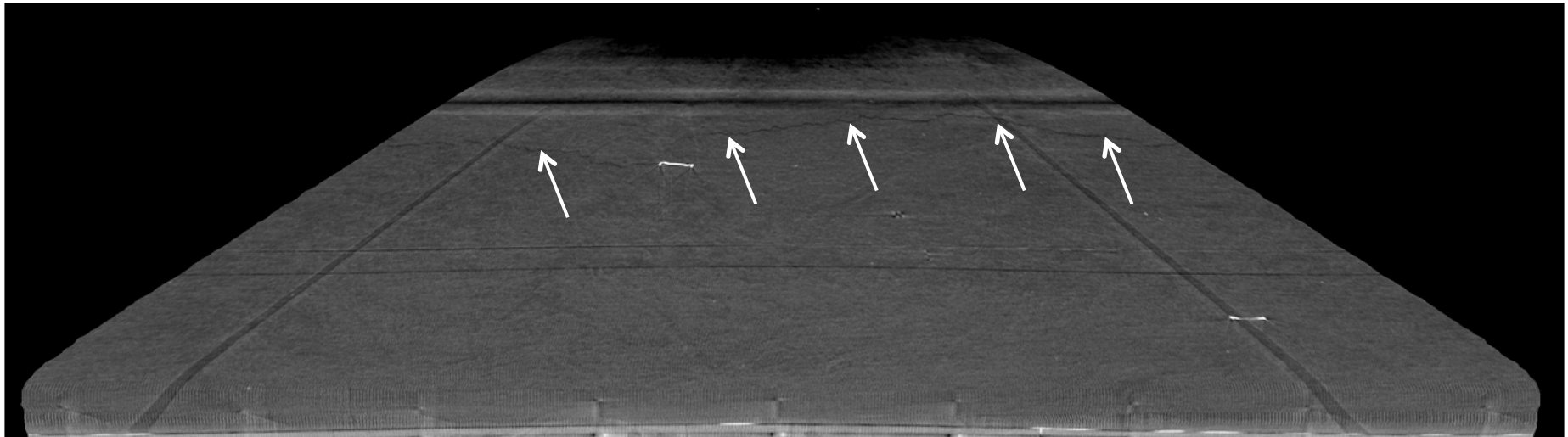
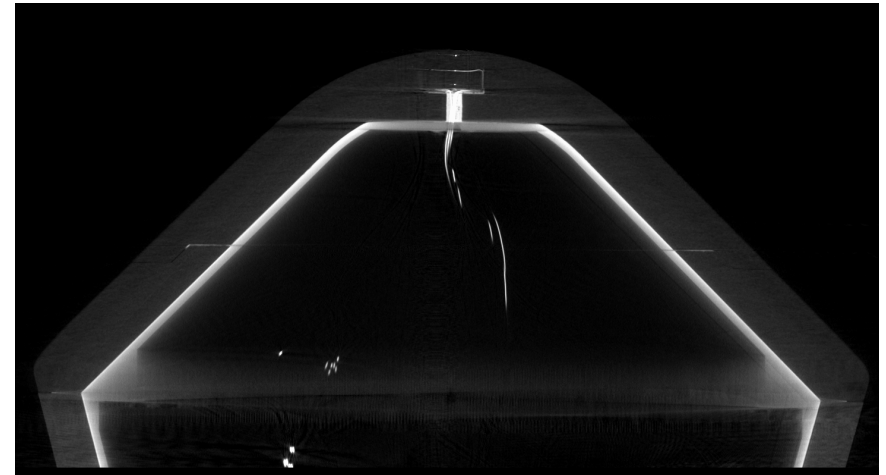
- Proved the predictive capability for aerothermal environments during entry
 - V&V of flowfield simulations with DPLR (Design/Analysis code)
- Established a good approach for thermal soak analysis for sample return missions
 - V & V of thermal predictions for aeroshell, interior and payload with a combination of *MARC* and thermal response tools

NDE of Test Articles: X-Ray CT of SPRITE



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- “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



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- **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



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- **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 *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**