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. In arc jet tests one replicates – at the stagnation point of an axisymmetric blunt body (such as, a hemisphere, or a flat-faced cylinder, etc), or at a point on a three-dimensional blunt wedge or swept cylinder imbedded in a free jet, or at a point on flat panel washed over by the shear layer that develops on the wall of a nozzle – a partial set of aerothermal environment parameters (combination of pressure and heat flux, or pressure, shear, and heat flux) *predicted* along flight trajectories. Regardless of what partial combination of aerothermal environment parameters is chosen for replication, a single arc jet test is for a single point on the TPS, and at single point on a candidate flight trajectory. Since the materials are tested at a constant condition (i.e., for fixed arc heater settings), the heat load of flight is replicated by varying the time interval of exposure of the material to the arc-heated stream. Therefore, a comprehensive materials test and qualification campaign will have a large test matrix which includes both a collection of points on the TPS and a collection of points on a flight trajectory.

A key point to note is that an arc jet test does not demand that there be a complete set of flight/flight-like environments, or complete similitude (both geometric and dynamic) between the test article and flight. As a result, ground based test campaign does not follow a "test like you fly" paradigm. A second key point to note is that the material performance measurements, such as, bondline temperature and recession, help anchor/calibrate software tools developed to model and simulate a material's thermal response. These calibrated tools are then used to assess the performance of (or optimize) the TPS for flight. Due to paucity of flight data and the fact that most probes are not always recovered on Earth for post-flight analysis, there is a gap in traceability of simulation tools from ground to flight – a gap that is covered by design margins/conservatism, which prevents to some extent, optimization of the TPS.

One strategy to strengthen the ground to flight traceability of a TPS qualification program is to develop an inexpensive small scale test platform, i.e., small probes that are fully instrumented. The proposed paper presents the results of a focused systems study of a class of small probes (8-16 kg entry mass and less than 40 cm in diameter) that are launched as secondary payloads, deployed in orbit, de-orbited and recovered on Earth. The TPS employed on the probes could consist of materials of flight heritage, or even new types of materials. By de-orbiting the probe, its TPS will experience aerodynamic heating, whose magnitude will depend on the orbit. With suitable selection of orbits, the TPS can be stressed to desired levels of aerodynamic heating, and help establish the flight performance envelopes of materials. In addition to being a flight test bed for TPS materials, the small probes can be used to understand material failure modes, local heating due to cavities (representative of damage due to micro-meteorite/orbital debris strike). Furthermore, the paper will show that such small probes can be tested at full scale in an arc jet, changing the paradigm to one of "test what you fly". Furthermore, recovery of the flight article on Earth will enable examination of the TPS and assessing material thermal response, thus not only enabling traceability from ground to flight, but also enabling the assessment of practices/margins policies used in the design of the TPS of large scale entry vehicles such as Orion.

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