A MONTE CARLO BASED THERMAL MARGIN DERIVATION FOR FLIGHT ENVIRONMENTS
(IPPW-7)

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ABSTRACT

A reentry vehicle that uses Thermal Protection System (TPS) technology for heat management needs to pass through a sizing evaluation process. This process is used to compute the overall required acreage TPS thickness. It considers the inherent various uncertainties and biasses occuring throughout this process such that the final design TPS thickness represents the sum of the nominal and margin components. The primary margin in this process is thermal, i.e. bondline and /or structural interface temperature limit (T_{design}), and its intent is to capture uncertainties due to material response modeling and ground to flight traceability. The usual design requirement is that the not to exceed bondline temperature should be maintained with 3σ probability, requirement which should also be satisfied by the thermal margin since the temperature prediction is in itself uncertain.

Historically, uncertainty levels for TPS sizing estimates, including the thermal margin, have been assigned based on expert judgement. The current work outlines a mathematical methodology by which material specific input uncertainties are converted to a tangible thermal margin. It also tests and validates this method to derive a specific value of the thermal margin, θ_{TM}, for the Avcoat material. The proposed methodology is based on combining ground validation and verification of the STAB/FIAT thermal model against ArcJet test results (σ_{data}) with Monte Carlo simulations considering uncertainties in the ablator material properties for both ArcJet (σ_{ArcJet}) and design (trajectory) environments (σ_{flight}):

$$\theta_{TM} = (T_{design} - T_{initial}) \cdot \sigma_{data} \cdot \frac{\sigma_{flight}}{\sigma_{ArcJet}}$$

The methodology consists of the following three steps:

1. Characterization of the model-test discrepancies, σ_{data}

This step ensures a proper validation of the thermal ablation model in terms of predicted bondline temperature rise versus measured thermocouple data from ArcJet testing of the Avcoat material. A 3σ θ_{TM} is derived.

2. Monte Carlo derivation for ArcJet environments, σ_{ArcJet}

This step verifies that by using uncertainties in the ablator material properties within the framework of a Monte Carlo procedure, the 3σ θ_{TM} corresponding to the dispersion of bondline temperature for ArcJet environments is comparable to that derived at step 1.

3. Monte Carlo derivation for flight environments, σ_{flight}

This step uses the thermal ablation model, the Monte Carlo procedure and the uncertainties in the ablator material properties to derive a value of the thermal margin, θ_{TM} corresponding to flight environments. The ratio of σ_{flight} and σ_{ArcJet} represents the ratio of the sensitivities of the bondline temperatures to flight versus ground environments and as such is equivalent to a ground to flight traceability parameter.