Reconstructing Arc-Jet Environments Using 2D Material Response Models

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Abstract: Experiments were conducted using both the Interaction Heating Facility (IHF) and Aerodynamic Heating Facility (AHF), two arc-jet facilities at NASA Ames Research Center. These tests were performed to understand the material response of ablative thermal protection system materials by exposing them to high-enthalpy flows. Using in-depth thermocouple measurements from a graphite test article, test conditions were determined from a 1D inverse heat conduction model. A 2D material response model, the Kentucky Aerothermodynamics and Thermal-response System (KATS), was used to replicate these conditions using several sets of inputs. Each of these cases was compared to determine how to consistently reduce error in temperature and recession predictions.

Keywords: Thermal Protection Systems, Material Response, Arc-jet.

1 Introduction

Thermal protection systems (TPS) are used to protect objects while undergoing atmospheric entry by preventing high temperatures from reaching the payload. Charring ablators are one of the most common TPS materials due to their use of thermo-chemical reaction products to diffuse heat away from the surface. Continued development of these materials requires improvements in experiments and computational fluid dynamics (CFD and material response simulations. Arc-jet tests are useful tools to validate these computational models. Variability in instrument measurements introduce error in model inputs, so additional approaches for deriving conditions such as heat flux are useful.

2 Problem Statement

Many instruments are used in arc-jet tests to provide insight into the flow conditions. In particular, copper calorimeters are exposed to the flow to numerically determine the heat flux. However, these instruments have been shown to consistently over-predict heat fluxes by 50 percent or more [1]. Instead, CFD analysis is often used to determine the target facility heat flux [2]. In this work, the authors will compare this approach with experimental values and validate additional approaches that have a greater degree of accuracy.

In order to validate the expected heat flux values, graphite has been chosen to be tested alongside TPS materials to act as a hot wall calorimeter. Its high thermal conductivity allows it behave similarly to the copper calorimeters, and inverse heat conduction models allow the embedded thermocouple data to be used to back out heat flux values. This heat flux curve is then fit with a function using numerical methods to allow reproducibility for other cases using only the CFD inputs, not temperature data. This approach has been additionally validated with experimental data from tests using export controlled materials, but the scope of this abstract includes only the methodology and application to graphite. Additionally, only only a two-dimensional approach will be presented, though the inputs were originally derived using a one-dimensional approach. The following cases are simulations solved using the KATS Material Response code:

- Step function that reaches the maximum target condition derived from inputs taken from CFD.
- The same maximum target condition with linear ramping to replicate lower heat fluxes while the sting moves the test article in and out of the flow.
- Profile output from NASA's inverse heat conduction model FIAT-Opt.
- Function replicating this profile as a function of the maximum target heat flux and time.

3 Conclusion and Future Work

In order to minimize error in predicting material response of thermal protection systems, graphite models can be used to inversely determine heat fluxes. To replicate this environment in other materials, a function is fit to this heat flux profile. This function provides identical recession and temperature results to the inverse model as well as significantly closer prediction of recession and temperature data than the other cases mentioned. It has also been shown to give improved predictions for other materials as well, though export control prevents these results from being presented here. By applying heat flux as a function of the target value, rather than a step function of this value, reductions in error between simulations and experimental measurements can be introduced.

Several cases have been completed, though additional validating cases must still be implemented. Some additional analysis will likely be done regarding differences between previous 1D work and current work due to 2D phenomena.

References

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