Characterization and Modeling of Spallation in Thermal Protection Systems

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Abstract: The spallation of particles resulting from the breaking of individual carbon fibers within TPS materials results in additional mass loss and reduces TPS efficiency. Understanding this process is crucial to more accurately modeling these TPS, both in the response of the material and the effects on the surrounding flow. Analysis of arc-jet tests investigating these spalled particles have provided insight into their production, size, and quantities. Implementing these results into the existing spallation module of the Kentucky Aerothermodynamics and Thermal-response System (KATS) will allow for a more auntomous modeling of this process.

Keywords: Thermal Protection Systems, Spallation, Computational Fluid Dynamics.

1 Introduction

During atmospheric entry, a thermal protection system (TPS) is used to protect space vehicles from the large amounts of heat incurred when drag forces are used to slow down the vehicle. These TPS are often made of ablative materials, which typically consist of a carbon fiber matrix impregnated with a polymer resin. The ablation process burns up the material so that the heat is absorbed through mass removal instead of conduction through the vehicle. The fibrous nature of these materials, however, result in a very brittle material that is further worn away by mechanical erosion. The process of spallation occurs when pieces of this material break off and are ejected into the flow.

2 Problem Statement

Understanding the process of spallation is important to refining existing models and designing accurate TPS. In current TPS models, spallation is typically modeled using an empirical rate, although there is little experimental data available to use for validation. Analysis from recent arc-jet experiments, however, resulted in a better knowledge of the causes of this process, as well as the types of particles produced. In particular, this provided insight about the size of particles, the number of particles, and how the production of these particles are affected by various factors. This information can be integrated with the existing spallation module of the Kentucky Aerothermodynamics and Thermal-response System (KATS) to model the process of spallation more autonomously. This model is implemented within the computational fluid

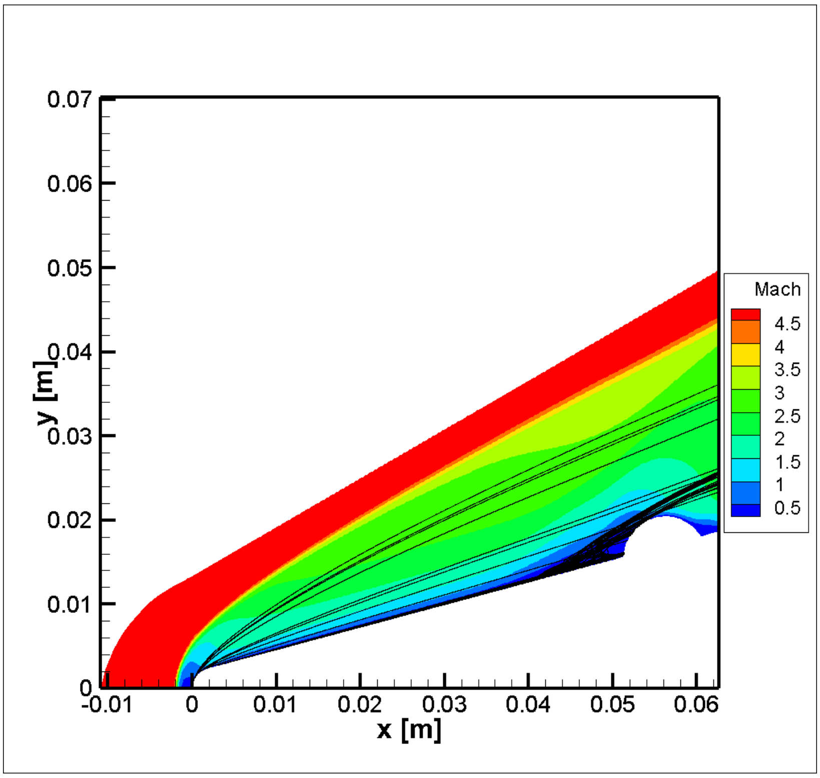

Figure 1: Model of spallation particles in arc-jet sample flowfield.

dynamics module of KATS to incorporate interactions between the particle and flow. The goal of this work is to replace the existing parametric approach for spalled particle modeling with a probabilistic model for the creation of particles that better represents the physical process. For example, the range of particle sizes seen in previous experiments can be used to produce various particle diameters within the model that better mimic the actual statistical distribution of particle sizes occurring.

Additionally, preparations are underway for an additional arc-jet test campaign to be conducted at the Hypersonic Materials Environmental Test System (HyMETS) arc-jet facility at NASA Langley Research Center. The goal of these experiments is to better understand this process and characterize these spalled particles by physically capturing them so that their size and shape can be directly measured. In preparation for these experiments, various sample designs have been modeled using CFD and the spallation code to determine the most effective method of particle capture, as well as any biases in the types of particles being captured. The distribution of particle size found from these experiments, along with additional data found from previous arc-jet tests, can then be implemented into existing spallation models to better improve their accuracy.

3 Conclusion and Future Work

Implementing the results found from arc-jet experimental analysis of spalled particles into the spallation module of the fluid dynamics solver will result in a more thorough and detailed model of the spallation process. Future work includes additional arc-jet test campaigns that will allow for further investigation and validation of these results and their model implementation.