COUPLED COMPUTATION OF FLUID AND MATERIAL RESPONSE FOR
NON-CHARRING ABLATIVE MATERIALS IN HYPERSONIC FLOW

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Hypersonic vehicles are subjected to high heat loads throughout their flight trajectories, and as a result, some form of thermal protection system (TPS) is required to ensure the vehicle’s survival. Accurate prediction of the behavior of these materials in a hypersonic environment is crucial to the efficient design of a hypersonic flight vehicle. It can be very costly and difficult, however, to experimentally replicate the flow conditions found in many hypersonic regimes, and for this reason it is desirable to be able to simulate the behavior of TPS materials under these flight conditions. This study aims to improve the modeling of the coupled fluid-material response problem for TPS materials in realistic hypersonic flows by coupling a hypersonic CFD code with an axisymmetric material response code.

TPS materials can be broadly classified into two main categories: ablative, where there is a mass loss from the material, and non-ablative where there is no mass loss. Ablative materials can be further divided into charring and non-charring materials. Charring ablators undergo internal decomposition of a resin material, which produces a gas that flows out of the material. After the resin has decomposed, a char material is left behind which may begin to recess if the heat load is high enough. Non-charring ablators, on the other hand, lose mass directly from the ablator surface without first undergoing resin decomposition, and so there is some surface recession of the material. The goal of this study is to develop a material response code for non-charring ablative TPS materials that is capable of handling axisymmetric geometries. This material response code is then coupled to LeMANS[1], a hypersonic computational fluid dynamics code, to predict the behavior of non-charring TPS materials in hypersonic flow conditions. This work extends the previously shown coupling of LeMANS with the one-dimensional material response code, MOPAR [2], also developed at the University of Michigan.

The material response code developed in this study uses the Control Volume Finite Element Method [3] (CVFEM), and is designed for analysis of non-charring ablative materials. This code solves the energy equation, shown below in integral form (Eqn. 1) and includes a term to account for energy convection due to grid motion during ablation. Newton’s method is used to solve the energy equation and restarted GMRES [4] is used to solve the associated linearized system of equations. In order to deform the geometry during ablation the mesh is treated as a linear elastic solid and the equilibrium solid mechanics equations are solved. This method has previously been used for axisymmetric ablation problems by Hogan, Blackwell, and Cochran [5], and for fully 3D problems by Dec [6].

\[ \int_{\text{cs}} q'' \cdot dA - \int_{\text{cs}} \rho h v_{cs} \cdot dA + \frac{d}{dt} \int_{\text{cv}} \rho e dV = 0 \]  

The material response code is coupled to LeMANS, a hypersonic CFD code developed at the University of Michigan, in order to simulate realistic flight conditions. The coupling is accomplished through an aerodynamic heating boundary condition where LeMANS supplies the material response code with the flow temperature and recovery enthalpy, and the material response returns the updated surface temperature and surface geometry. This coupled simulation approach is applied to the IRV-2 vehicle[7] during its reentry trajectory.
1. REFERENCES


