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Coupled Aero-Ablation Modeling in Free-Flight for Re-Entry Systems

A computational approach for modeling the multi-physical process of hypersonic vehicle re-entry is demonstrated in this work. Time-accurate, three-component coupled solutions for the flow environment and multidimensional ablation of thermal protection systems (TPS) over entire re-entry trajectories will be investigated. An unstructured compressible Navier-Stokes flow code (SPARC) has been integrated with the material response solver (Sierra/Thermal) and 6-degree of freedom (6DOF) trajectory solver (TAOS) in a loosely-coupled fashion. This loosely-coupled approach, which allows for segregated use of high-fidelity Reynolds-Averaged Navier-Stokes solutions, three-dimensional heat conduction and ablation response predictions for decomposing and non-decomposing ablator materials, and a 6DOF free flight prediction provides a comprehensive high-fidelity modeling tool useful for flight test predictions. An interface which communicates the aerodynamic loading from SPARC in-sync with TAOS provides the ability to predict re-entry trajectories for arbitrary vehicle geometries given an initial insertion state. The additional coupling between the aerodynamic heating environment and material response provides ablator performance predictions and induces shape change effects on the vehicle trajectory calculation. Analyses which demonstrate and provide validation evidence for the three-component multi-physics capability will be presented for geometries relevant to hypersonic vehicle re-entry. Shape change effects on the trajectory calculation will be investigated, and insight will be presented regarding the viability and potential drawbacks to utilizing such a coupled approach as a predictive tool.

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