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Simulation of the material response of ablators in atmospheric entry flows: from model development to validation in high enthalpy facilities

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Abstract. *Future space exploration missions, such as sample returns from Mars and asteroids at very high reentry speeds, will use ablative materials for the heat shield protecting the spacecraft from severe heating. Ablative thermal protection systems are able to dissipate the high heat fluxes through chemical and physical decomposition, transforming the thermal energy into mass loss and recession, whilst the remaining solid material insulates the vehicle substructure. To achieve high performance characteristics of ablative materials, mostly composites are used, providing a pyrolysing, ablating, and insulating material at low weight with reasonable mechanical properties due to a carbon-fiber preform. A new generation of low density carbon/resin composite ablators is currently being developed, made of a carbon fiber preform impregnated with phenolic resin. Selection and sizing of the thermal protection material are the two key performance parameters in aerospace design. Engineering prediction inaccuracies can be fatal for the crew or the success of robotic missions.*
The prediction tools for ablative thermal protection system design are still inherited from the Apollo program, and new high-fidelity material response models are proposed here to take into account the porous micro-structure of the new class of materials. In this context, ground testing in plasma wind-tunnels becomes a fundamental requirement for validation of material response codes. We review the effort at the von Karman Institute for Fluid Dynamics to advance the fundamental knowledge of ablation phenomena. Both experimental and numerical studies have been performed to investigate the flow-material interaction. Ablation tests of several materials, from pure graphite to carbon/resin composite materials, have been carried out in the VKI Plasmatron facility. Physico-chemical model data have been implemented in the in-house MUTATION++ library for the thermodynamic, transport, and chemical properties of high enthalpy flows. A numerical procedure has been developed to simulate gas-surface interaction phenomena. As a first step in developing a high-fidelity solver of the flow-material coupled problem, a stagnation-line code has been coupled with a material response code. Comparison with experimental data allows for providing some guidelines for future development.

Keywords: Atmospheric entry flows; ablative material response; gas-surface interaction; multiphysics coupling

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