Unified flow-material simulations of light-weight carbon ablators in the VKI Plasmatron: a step forward

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Abstract

Carbon-based porous ablators are used to protect spacecraft during the atmospheric entry phase of interplanetary missions. Advances in modeling the interaction between a chemically reactive boundary layer and the spacecraft heat shield can bring substantial benefits to the overall mission mass budget.

During the last years, a unified approach, which uses a strongly coupled modelization of the flow and the porous material, has been implemented within the multi-dimensional tool Argo developed at Cenaero. The methodology is based on the volume averaging theory applied to the reactive Navier-Stokes equations. This continuum description is flexible enough that it can go smoothly from a plain fluid region to a receding porous medium. The material porosity is itself a variable smoothed on the grid during initialization and then computed to track the evolution of the reactive porous medium. In the present activity we use the developed tool to simulate the experiments carried out in the high-enthalpy Plasmatron facility at the von Karman Institute (VKI) on a carbon-fiber preform. A full Plasmatron experiment is simulated (Fig. 1) and the transient numerical results are compared with the optical measurements performed during the experimental test.

Recent developments of the tool include the possibility of simulating the thermal decomposition of the phenolic resin of charring light-weight ablators. The pyrolyzing polymer is assumed to decompose through a number of pyrolysis reactions, each characteristic of a fictitious solid species composing the resin, and the rate of decomposition of each resin compound is expressed by means of an Arrhenius-type law. Difficulties encountered and solutions applied during the development of this "pyrolysis module" are thoroughly reviewed, and preliminary results are presented.

Finally, updates on the development of the gas-surface interaction (GSI) module of the VKI Mutation++ library are presented. The library has been conceived to be easily integrated within any CFD solver and it currently solves the mass and energy balances at the gas-surface interface featuring several GSI mechanisms for both catalysis and ablation. Argo already makes use of the Mutation++ library for the evaluation of thermodynamic and transport properties of the high-enthalpy flows, as well as for the computation of the chemical source terms in the gas phase. Ideally, in the future, it will make use of the GSI features of Mutation++ as well. This further step will allow the integration of newly developed, and more complex, GSI reaction mechanism with limited effort.

Keywords: Porous Ablators, Volume-Averaged Navier-Stokes equations, Pyrolysis, Gas-Surface Interaction Modeling

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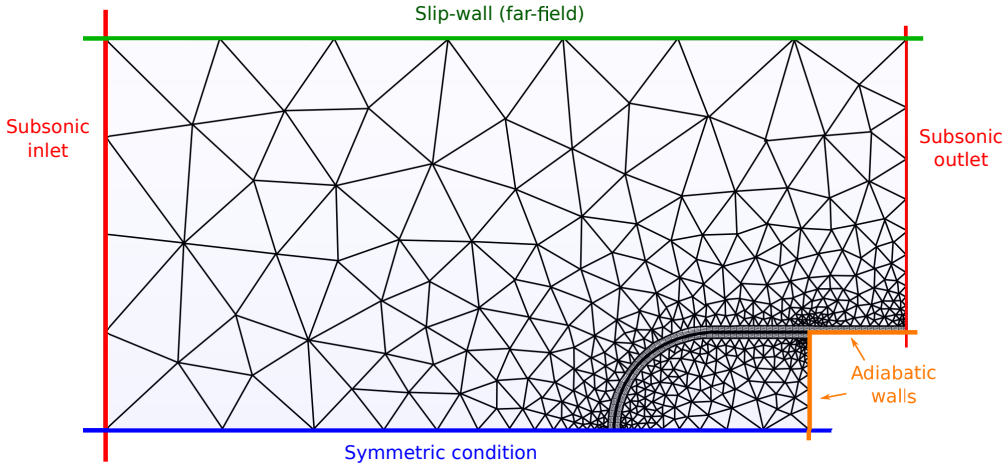
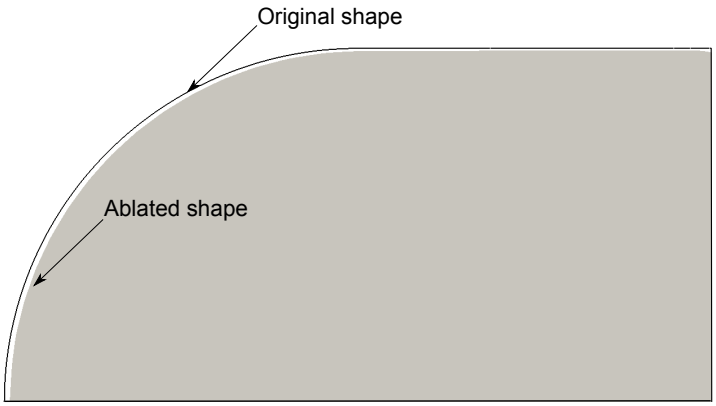


(a)



(b)

Figure 1: (a) Computational domain with boundary conditions for the Plasmatron experiment; (b) shape change of the ablated carbon-preform sample.