Detailed modeling of meteor entry at low altitudes

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Introduction

During the atmospheric entry of meteoroids, ablation products interact with the ionized gas surrounding the meteoroids and are driven to the wake, giving a signature that can be detected by radars. Recent efforts have been made by the Belgian Institute for Space Aeronomy to estimate the velocity and trajectory of meteors, by means of an innovative technique based on radio waves. The Belgian Radio Meteor Stations (BRAMS) [1] experiment consists of a series of receivers spread all over Belgium to study the meteor atmospheric entry to collect and standardize meteor observation data. The estimation of meteoroid mass flux is particularly difficult to quantify from radar observations alone, and it is necessary to augment observation data with numerical modeling to have a reasonable estimate of the flux of meteoroid material to the atmosphere. In this project we propose to study the meteor ablation with a numerical approach similar to those used in the aerospace community to model the gas-surface interaction over thermal protection system materials [2].

Methodology

We apply a strategy based on an aerospace-engineering-derived approach (i.e., steady-state CFD with surface ablation model). A boundary condition to describe the interaction between the atmosphere and objects with a complex elemental composition is developed. This interaction is modeled by solving an open-system multi-phase chemical equilibrium problem (i.e., gas-solid) by means of a solver able to handle materials composed by multiple compounds. The boundary conditions consist in solving a surface mass balance and a surface energy balance enabling the solution of the surface temperature and the amount of mass ablated.

The closure of the Navier-Stokes equations is done by computing the thermodynamic and transport properties of the flow field. This is achieved by detailed state-of-the-art models included in the Mutation^{++} library, developed at VKI [3]. A radiation solver is also included, using a Hibrid statistical narrow band (HSNB) method showing an accurate description of the radiative flux with low CPU cost for coupling with CFD tools [4].

The flow governing equations are solved through a 1D Stagnation-line CFD solver coupled with the Mutation^{++} library where the gas-surface interaction boundary condition is implemented.

The melting of the material will be modeled by solving Stefan problem through a coupling of a 1D material code with a flow solver. By this means it will be possible to track the fusion interface and to estimate the amount of mass that is removed by mechanical erosion.

In the final manuscript we will analyze the the ablation of meteors at altitudes at lower than 70 km with low entry velocities. Stagnation-line simulations for meteors of different sizes will be performed accounting for the physical phenomena described above.

References

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