Noncatalytic and Finite Catalytic Heating Models for Atmospheric Re-Entry Codes

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ABSTRACT

The human activity in space has generated a great number of space debris. During the last forty years, 16,000 tons of space debris performed a terrestrial atmospheric reentry, representing a potential threat to ground safety. The total casualty area forecast becomes a major issue for all space actors and especially for CNES which is in charge of ensuring the strict application of the French Space Operation Law by 2021, for both French satellites-and-launchers operators and launch operations from French Guyana spaceport. Space actors have developed tools dedicated to the prediction of the ground risk generated by space debris atmospheric re-entry. However, high fidelity CFD tools cannot be applied to compute a whole trajectory and even less to the multiple trajectories needed by Monte Carlo approaches. Only a strategy based on relevant and reliable reduced models is acceptable for debris risk analysis in terms of computing time and simulation capability. The total wall heat flux is one of the key quantities in the evaluation of the ground risk. The heat flux computed assuming catalytic wall or thermochemical equilibrium gas can be twice as large as the non-catalytic wall heat flux, conducting to underestimate the ground risk. However, most of the models proposed in open literature, such as Detra, Scott, Sutton-Graves, Vérant-Sagnier’s models, allow computing stagnation point heat flux for thermochemical equilibrium gas or chemical nonequilibrium gas with catalytic walls only. Even though Fay-Riddell proposed a formulation to compute stagnation point heat flux for frozen gas with non-catalytic wall, this model requires many local quantities that are not accessible for engineering atmospheric codes. For these reasons, ONERA developed and successfully validated new analytical models (Fig. 1) to compute the total heat flux received by the wall for any inflow gas state and partially and non-catalytic wall properties. These new models have been developed from a large in-house CFD database constructed with the ONERA Navier-Stokes code for various flow conditions (altitude from 70 to 20 km, velocity from 8 to 1 km/s) including different thermochemical flow assumptions in the shock layer (perfect gas, thermochemical equilibrium and nonequilibrium real gas), effects of the nose radius (from 0.01 m to 1 m) and wall temperature (from 300 K to 2500 K). The paper proposes an overview of the present research conducted and focuses on the aerothermodynamic study of the atmospheric entry of a launcher tank and applications of present new models (Fig. 2). A specific attention is given to the influence of the wall catalycity on the thermal degradation of such object.

Fig 1. Comparison between stagnation point heat flux obtained with CFD and the new analytical model for non-catalytic wall.

Fig 2. Influence of the heat flux received by a catalytic (γ = 1), non-catalytic (γ = 0) and partially catalytic (γ = 0.01) wall at stagnation point along three different trajectory entries.