MODELING OF RADIATIVE TRANSFER IN HIGH ALTITUDE SOLID PROPELLANT ROCKET PLUMES

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Solid propellant rocket plumes are characterized by a two-phase flow composed of alumina particles and exhaust gases produced by the combustion of an aluminized solid propellant in the combustion chamber and ejected in the atmosphere through the nozzle. At the nozzle exit, the condensed phase, which represents about 30% of the mass flow rate, is composed of liquid alumina particles whose diameters range from 0.1 to 10 μm. Due to expansion in the nozzle, there is a thermal disequilibrium between gases and the different size classes of particles at the nozzle exit.

In the plume nearfield zone (near the nozzle exit), the cooling of alumina particles is mainly driven by the convective transfer with gases, due to the high velocity and temperature differences between both phases. Further downstream, the convective heat transfer becomes negligible as the pressure is very low due to high altitude (atmospheric pressure is about 0.05 Pa at 110 km altitude), and the radiative transfer plays an important role in the cooling and the phase change of the particles. Moreover, alumina particles crystallize following a supercooling process leading to a sudden increase of their temperatures.

Therefore, radiation has to be taken into account in these plume numerical simulations to correctly predict the alumina particle temperatures which have a strong effect on computation of heat fluxes on vehicle walls and of plume signature. Consequently, suitable models for supercooling phenomenon and radiative properties have been selected and implemented in a calculation platform, enabling to couple a Navier-Stokes solver for the gas phase, an Eulerian solver dealing with the dispersed phase and a radiation solver based on a Monte Carlo method.

This poster focuses on radiative property models and numerical methods used to compute radiative transfer. The plume radiation is calculated from infrared to UV range, for wavelengths from 0.2 to 200 μm, taking into account scattering by liquid and solid alumina particles. The main radiating gaseous species are H_2O, CO_2, CO and HCl. Due to the wide range of pressure in these plumes, gas radiative properties are modeled using a statistical narrow band model. Finally, a splitting method of the radiative power has been established to compute all the source terms required in the energy balance equations of the gas phase and the different size classes of particles.

The developed numerical tool has been partly validated comparing our results with the measurements obtained during the BSUV2 experiment. In the conditions of this experiment, particle radiation is shown to be predominant but the contribution of the gas phase is found to be non-negligible. It has been shown that radiative transfer, coupled with the supercooling phenomenon, play a crucial role to accurately compute the particle temperature fields.

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