Numerical modelling of the radar signature of rocket exhaust plumes

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In this paper, we present a novel multiphysics numerical model predicting the electromagnetic signature of rocket engine plumes. We first describe the physical and numerical model for aerothermochemical physics and for electromagnetic applications. The numerical scheme was applied to simulate the electromagnetic signature of a Black Brant rocket.

The fluid mixture in the plume is assumed to be weakly ionized; we also assume that for the radar frequencies under consideration the electromagnetic field interacts only with the plume electrons and not with the heavier ions. The numerical approach results from the coupling of two models:

- An aerothermochemical numerical code called CEDRE which simulates the fluid flow and the dynamics of the charged species in the rocket plume. We assume that the fluid mixture stays quasi-neutral and we use an ambipolar approximation for the diffusion of the electrons and ions.
- An electromagnetic numerical code called MaxwellAxi which uses the electron density and the electron-neutral collision frequency calculated by CEDRE.

The combined solvers have been used to simulate the electromagnetic signature of a Black Brant rocket launched from NASA's White Sands facility. The exhaust plume of the second stage of the rocket was simulated at altitude 25531 m. Rocket velocity is 1547 m.s-1. US standard temperatures and pressures at this altitude are respectively 222 K and 2350 Pa.

We add 100 ppm of alkali metals Na and K to the propergol, which correspond to the order of magnitude for the concentration of such impurities. We then calculate the chemical equilibrium in the combustion chamber. We force the charged species mass fraction at nozzle entrance to be equal to those in the combustion chamber. A flux of charged species enters the computational domain trough the nozzle.

The CAD model used for the electromagnetic application is automatically deduced from the dielectric permittivity obtained from CEDRE. The large areas with values close to 1 are neglected. The results are then interpolated on a mesh better suited for electromagnetism.

In order to simulate the dynamic radar signature we solve the equations using small perturbations of the mesh associated to the electron velocities. Then the spectral response is obtained using Fourier transforms.