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Title

Numerical simulation of flight effect on the afterburning plume exhausting from a solid rocket motor

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Abstract

Afterburning exhaust plumes from solid rocket motors are the main contributors to heat fluxes on the afterbody and vehicle infrared signatures [1], which are major concerns for the design of space launchers, missiles or warning systems. The numerical simulation can provide a reliable prediction of these phenomena in realistic flight conditions with an adequate plume modeling [2] [3]. In particular, attention must be paid to the afterburning mechanism in the mixing layer and the influence of flight conditions on the flame [1] [4] [5].

In this paper, the effect of a supersonic surrounding flow on an afterburning plume exhausting from a non-aluminized composite solid propellant rocket motor is numerically investigated. The case under study match a ground experiment conducted at the ONERA's Rocket Propulsion Laboratory [6]. A motor with a 40mm nozzle exit diameter is placed in the center of a 100mm inner diameter annular pipe generating a Mach 1.5 flow. Firing tests have been carried out with and without the surrounding flow around the motor exhaust plume, respectively labeled as dynamic and static cases. Numerous measurements have been operated with sensors and cameras to characterize the flow properties, including pressures inside the motor and the pipe, heat fluxes on walls near the nozzle exit, as well as plume radiation in visible, ultraviolet and infrared wavelengths [7].

Corresponding simulations are performed with the multi-physics CFD code CEDRE using a Reynold-Average Navier-Stokes $k-\omega$ approach on axisymmetric unstructured grids. The afterburning mechanism is represented by a 12 species – 17 reactions skeletal kinetic scheme [8] associated with a Partially Stirred Reactor (PaSR) combustion model [9] and a flame extinction model based on a local Damköhler number threshold [4]. The computed flow features are discussed and confronted to the available experimental data. In particular, the camera measurements exhibit a lifted afterburning flame in the static case with an ignition zone in the mixing layer that moves closer to nozzle exit in the dynamic case. The comparison with the simulated temperature and heat release fields indicates that only the extinction model allows capturing this behavior, supporting that specific turbulence-chemistry interaction modeling is required for such applications. Perspectives on the assessment of the effect of this CFD modelling improvement on the infrared signature simulation will be finally drawn.

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