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Title

Hybrid NS-DSMC simulation of a full scale solid rocket motor reactive exhaust at high altitude

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Abstract

Rocket propulsion at high altitudes or satellite attitude control systems involve both high density gas in the combustion chamber and low density atmosphere in the surrounding environment. Simulating such flows numerically can be challenging due to the multiple scales involved. In this study, a hybrid approach to accurately simulate both rarefied flow physics and high-density regions is employed, which combines finite volume Navier-Stokes (NS) resolution with Direct Simulation Monte Carlo (DSMC) in a one-way surface based coupling method. The idea is to divide the calculation into two regions. In the first one, the flow is dense and computed using classical Computational Fluid Dynamics (CFD) to solve the Navier-Stokes equations. In the other region the flow is rarefied and computed by the Direct Simulation Monte Carlo method to solve the Boltzmann equation. Information is only transferred from the dense to the rarefied region across an interface located according to a specific rarefaction criterion. The one-way method has previously been used on several nozzle scales: a milimetric thruster from the German Aerospace center (DLR) by Grabe *et al*. [1] and reconsidered by Charton *et al*. [2], a decimetric sized nozzle by Charton *et al*. [3] and a metric sized one by Rasthofer *et al*. [4]. The current work therefore aims to optimize the method for full scale nozzles of solid rocket motors. The studied case is a 2D axisymmetric representation of the third stage of JAXA's MV rocket. All conditions, i.e. pressure and temperature in the chamber, chemical composition of the exhaust, flight altitude and velocity of the stage, are chosen as close as possible to the real rocket published data, particularly by Kinefushi *et al*. [5]. First the effect on the flow field of the NS-DSMC interface definition, i.e. the threshold values for the rarefaction criterion, is evaluated through a parametric study. These results are compared with the study by Charton *et al*. [2] for milimetric nozzles to improve knowledge of the effect of this parameter at different scales. Electron density resulting from the ionization of the flow, which is relevant for predicting radio communication attenuation between the ground station and the rocket, is a particular field of interest for such simulations. Similarly to Charton *et al*. [3], the chemical reactions in the rarefied domain are computed using a Lagrangian post treatment solver along streamlines. The relevance of this approach for full scale solid rocket motor reactive exhaust is investigated.

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