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NUMERICAL MODEL FOR THE PREDICTION OF THE REGRESSION RATE IN HYBRID ROCKET KICK-MOTORS WORKING WITH LIQUID NITROUS OXIDE

Abstract

Hybrid rockets are chemical propulsion engines employing propellants in two separate phases. In the classical system arrangement, namely, the fuel is stored in the combustion chamber in the solid state and a gaseous or liquid oxidizer is injected in a port obtained in the solid fuel grain. This propulsion configuration results in a number of advantages over either the conventional solid- or liquid-propellant rockets, which include, among the most interesting ones, the re-ignition and throttling capabilities combined with the possibility of embedding environmentally sustainable propellants and, of the utmost importance, its intrinsic safety and lower development cost. CFD modeling of the flowfield in the combustion chamber of a hybrid propellant rocket has been the subject of considerable interest recently, but for the huge computational cost and very challenging task, comprehensive models to describe the complex interactions among fluid dynamics, solid fuel pyrolysis, oxidizer atomization and vaporization, mixing and combustion in the gas phase, nozzle thermochemical erosion, particulate formation, and radiative characteristics of the flame are still lacking, and numerical simulations are rather considered as a qualitative tool to afford the thermo-fluid-dynamics of the rocket. The main issue of the present work is the definition of a suitable numerical apparatus able to reproduce the motor internal flow-field with the aim of predicting the solid fuel regression rate experimentally achieved in different test cases. The fuel regression rate is the main parameter that governs hybrid rocket performance and is basically determined by the ratio between the heat flux input to the solid grain coming from the combusting flow and the heat of gasification of fuel. Following a common approach the Reynolds averaged Navier-Stokes with suitable turbulence model are solved. Combustion of oxygen and gaseous ethylene injected from the fuel wall and the turbulence/chemistry interaction are modeled by means of the probability-density-function approach coupled to chemical equilibrium. Fuel regression rate is calculated with an improved wall treatment at the gas/surface interface based on local mass, energy and mean mixture fraction balances and the polyethylene pyrolysis model. The task is extremely complicated by the injection of nitrous oxide in the liquid phase. Firstly, the injected liquid droplets' lifetime has been investigated by employing a discrete phase model (DPM) coupled with the gaseous phase thermo-fluid dynamic model. Then, simulations focused on the combustion chamber have been carried out with the aim of evaluating the regression rate.