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An Improved Approach for Hybrid Rocket Injection System Design

Authors : M. Invigorito, G. Elia, M. Panelli

Abstract : Hybrid propulsion combines beneficial properties of both solid and liquid rockets, such as multiple restarts, throttability as well as simplicity and reduced costs. A nitrous oxide (N2O)/paraffin-based hybrid rocket engine demonstrator is currently under development at the Italian Aerospace Research Center (CIRA) within the national research program HYPROB, funded by the Italian Ministry of Research. Nitrous oxide belongs to the class of self-pressurizing propellants that exhibit a high vapor pressure at standard ambient temperature. This peculiar feature makes those fluids very attractive for space rocket applications because it avoids the use of complex pressurization systems, leading to great benefits in terms of weight savings and reliability. To avoid feed-system-coupled instabilities, the phase change is required to occur through the injectors. In this regard, the oxidizer is stored in liquid condition while target chamber pressures are designed to lie below vapor pressure. The consequent cavitation and flash vaporization constitute a remarkably complex phenomenology that arises great modelling challenges. Thus, it is clear that the design of the injection system is fundamental for the full exploitation of hybrid rocket engine throttability. The Analytical Hierarchy Process has been used to select the injection architecture as best compromise among different design criteria such as functionality, technology innovation and cost. The impossibility to use engineering simplified relations for the dimensioning of the injectors led to the needs of applying a numerical approach based on OpenFOAM®. The numerical tool has been validated with selected experimental data from literature. Quantitative, as well as qualitative comparisons are performed in terms of mass flow rate and pressure drop across the injector for several operating conditions. The results show satisfactory agreement with the experimental data. Modeling assumptions, together with their impact on numerical predictions are discussed in the paper. Once assessed the reliability of the numerical tool, the injection plate has been designed and sized to guarantee the required amount of oxidizer in the combustion chamber and therefore to assure high combustion efficiency. To this purpose, the plate has been designed with multiple injectors whose number and diameter have been selected in order to reach the requested mass flow rate for the two operating conditions of maximum and minimum thrust. The overall design has been finally verified through three-dimensional computations in cavitating non-reacting conditions and it has been verified that the proposed design solution is able to guarantee the requested values of mass flow rates.

Keywords : hybrid rocket, injection system design, OpenFOAM®, cavitation
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