Numerical Simulation of Combustion Processes in Hybrid Rocket Engines using OpenFOAM and COOLFluiD Codes

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Hybrid rocket engines (HRE) are currently considered one of the most promising propulsion technology for both space and aeronautical applications in the next decades, due to their inherent advantages when compared to standard propulsion systems. These advantages include high flexibility (thrust modulation, possibility of multiple re-ignition and shut down), high reliability, low cost and low environmental impact. A major drawback for HRE is the low solid fuel regression rate, due to the diffusion flame structure typical of this kind of engines. In order to overcome this limit and improve the HRE technology maturity, a deep understanding of the combustion processes is of major importance. To date, a complete knowledge of the complex interactions between physical and chemical processes in HRE is still unavailable.

The aim of this work is to give a contribution to hybrid technology improvement by providing a reliable numerical simulation of processes occurring in the combustion chamber. Two different codes (OpenFOAM and COOLFluiD) are used in this work, in order to evaluate the numerical codes performance for simulation of combustion processes in HRE.

The present work focuses on four main topics.

The first item is the definition and implementation of a suitable computational domain for combustion chamber description. In HRE, the solid grain regression rate is a consequence of a coupling, both in terms of energy and mass, between gas phase and solid phase. This in turn results in a need for remeshing, due to a reduction in the solid grain domain. Moreover, the combustion mechanisms typical of HRE imply a O/F ratio variation during combustion, and local variations due to different boundary layer thickness. The numerical simulation is particularly useful for the investigation of such variations. Moreover, numerical simulation is of major importance for the investigation of the transient phenomena associated to the motor throttling, which is of major importance for HRE. The second topic deals with the numerical simulation of non-reacting flow field in both laminar and turbulent conditions. The study of a cold condition has been carried out for different turbulence models and boundary conditions effects investigation. The third subject is the implementation of a kinetic scheme for the chemical reactions occurring in the combustion chamber. Different global kinetic schemes were investigated in order to select the most suitable scheme for the present physical configuration. Finally, in the fourth topic the numerical simulation of the reacting flow field is addressed. The results presented in this work include the investigation of the effects of several major parameters variation on the global flow field.

The numerical codes, OpenFOAM and COOLFluiD, have been used in this work for the investigation of the aforementioned topics, which are of fundamental importance in HRE.

References

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