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NUMERICAL STUDY OF AN ADDITIVELY MANUFACTURED HYBRID ROCKET ENGINE OF 1 KN: A CFD APPROACH

Abstract

The Chemical Propulsion Laboratory of the University of Brasília (UnB) and the School of Aerospace Engineering of Sapienza University of Rome spearhead a cutting-edge research initiative focusing on the detailed numerical analysis of an additively manufactured 1 kN hybrid rocket engine working on N2O-hydrocarbon propellant. This international project is motivated by the increasing interest in leveraging 3D printing technologies for hybrid rocket engines, with specific objectives centered around defining engine characteristics and rationalizing critical design decisions. The study aims to develop and validate a reliable mathematical model of processes inside the combustion chamber and heat exchange with a regeneratively cooled engine's structure. Specific objectives include the development of the reduced chemical kinetic model, coupling mechanism for fluid-solid interaction, mesh sensitivity studies, and other correlated topics. The simulation results will be applied in developing the additively manufactured engine to withstand the thermal and structural loads. As an initial design point, the research adopts classical hybrid propulsion theory for preliminary design and classical numerical tools such as CEA and RPA, further refining the engine model using the CFD approach. The computational study is emphasized by using Ansys Fluent and OpenFoam software. The engine's computational representation involves three-dimensional compressible transient flow equations, turbulence models, combustion via detailed and optimized kinetic models, multiphase simulation, and dynamic meshing for fuel regression law. This approach enables the development of a prototype engine, integrating thermal and structural considerations into the design process. The numerical analysis shows several aspects necessary for the development and optimization of the engine, such as the cooling effect of oxidizer on injectors, droplets behavior, the thermal gradient in nitrous oxide decomposition, recirculation effect in pre-chamber, fuel-rich boundary layer in post-chamber favoring wall protection and cooling, overall engine's performance, highly three-dimensional propellants mixture, and combustion. Several issues in the current research related to the complexity of computational models and the difficulty of their validation were also mapped. The numerical simulations showcased the

overall characteristics of the hybrid rocket engine, providing insights into the performance, reliability, and efficiency of the design. The simulations were rigorously validated against theoretical predictions and experimental data, ensuring the accuracy and reliability of the numerical models.