IAF SPACE PROPULSION SYMPOSIUM (C4)
Hypersonic Air-breathing and Combined Cycle Propulsion, and Hypersonic Vehicle (7)

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PROPULSIVE AND COMBUSTION MODELLING OF SABRE ENGINE IN AIR-BREATHING MODE TO SUPPORT NOX EMISSIONS ESTIMATION IN CONCEPTUAL DESIGN

Abstract

Since its establishment, the space sector has pursued the development of technologies required to further expand the space exploration activities with almost complete focus on performance achievement. With the projected increase in frequency of access to space, it is of utmost importance to evaluate and develop minimization strategies for the environmental impact since the earliest design stages. This work aims at extending the applicability of NOx estimation methods developed for the aviation sector to a Single Stage To Orbit vehicle. This implies an adaptation of already existing formulation to cover propellants (different from Jet-A1 kerosene) and different propulsive technologies and speed regime, ranging from subsonic to supersonic and hypersonic. In particular, this work discloses a new set of emissions' estimation formulations tailored on the Synergetic Air-Breathing Rocket Engine (SABRE) technology, the key element of the future Skylon vehicle. The SABRE engine is designed to power the vehicle, an horizontal take-off and landing single stage to orbit, allowing the transition from air-breathing to rocket mode and employing liquid hydrogen as fuel. A modelling strategy able to capture the complexity of this propulsive system is crucial for the development of a reliable and accurate emissions database, which is, in turn, the foundation for the upgrade of the emissions predictive models. In particular, this work focuses on the analysis and modelling of the air-breathing operating modes. In details, an already existing propulsive model is upgraded (i) by integrating the effect of the regenerative closed-loop helium cycle on the engine performance, (ii) by enhancing the combustion modelling thanks to the integration of 2-phases thermodynamic combustion simulations, and (iii) by increasing the accuracy of the mixing modelling. Both the mixing and the combustion modelling are performed thanks to the exploitation of an open-source suite of tools called Cantera. In addition, Cantera software is used to generate the emissive database starting from the propulsive database , using 0D chemical kinetic simulations. Eventually, new predictive formulations for NOx emissions are developed using the newly defined emissions database as dataset and the P3-T3 and the BFFM2 as reference formulations. The original estimation equations are upgraded by tuning the numerical parameters of the formulations as well as by integrating new variables including the Mach number, the water-to-fuel ratio at the inlet of the main combustion chamber, the air-mass flow ratio in the pre-burner and the helium-to-air mass flow ratio. Discussions on the physical characterization of these parameters are reported.