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Author: Mr. Alessio Ricca
Turin Polytechnical University, Italy

Ms. Valeria Borio
Politecnico di Torino, Italy
Dr. Roberta Fusaro
Politecnico di Torino, Italy
Prof. Nicole Viola
Politecnico di Torino, Italy
Dr. Guido Saccone
CIRA Italian Aerospace Research Centre, Italy
Mr. Fabrizio Borgna
Politecnico di Torino, Italy

PROPULSIVE AND COMBUSTION MODELLING OF SABRE ENGINE IN ROCKET 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 regimes, ranging from subsonic to supersonic and hypersonic. In particular, this work discloses a new set of emissions' estimation formulations tailored to 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, a 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 rocket operating mode. A propulsive model of the rocket was developed by including (i) the effect of the regenerative closed-loop cycle on the rocket performance, and (ii) a mixing and combustion modelling, overcoming the traditional energy balance approach. Both the mixing and the combustion modelling are performed thanks to the exploitation of an open-source suite of tools, i.e. Cantera. In addition, Cantera software is used to generate the emissive database starting from the propulsive database, using 0D chemical kinetic simulations. Regarding emissions, it is necessary to take into consideration (i) the effects of the recombination process between the rocket plume and the atmospheric air, and (ii) the NOx generation during re-entry due to high temperature reached on the surface of the vehicle. 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. Discussions on the physical characterization of these parameters are reported.