Title:

Numerical and Experimental Activities in Support of the Development of Hybrid-Rocket Engine for soft-landing applications

Authors:

Alberto Bettella[1-3], Federico Moretto[1], Martina Faenza[2], Marta Lazzarin[1], Francesco Barato[2], Nicolas Bellomo[2], Enrico Geremia[3], Davide Rondini[2], Daniele Pavarin[1-2]

[1]*Department of Industrial Engineering, DII, University of Padua, Padua, Italy*

[2]*Center of Studies and Activities for Space Cisas G.Colombo , University of Padua, Padua , Italy*

[3]*HIT09 s.r.l., Padova, Italy*

Abstract:

In the framework of the EU FP7 SPARTAN Project , the SPARTAN (SPAce exploration Research for Throttable Advanced eNgine) research aims at developing a throttable propulsion technology, which is mandatorily needed for any planetary soft and precision landing and up to now is developed onlyby the US. It relies on the hybrid engine technology, using HTPB and H_2O_2 with a propellant concentration of 87.5%.

CISAS "G. Colombo" and the University of Padua (UniPd, Italy)are in charge of a dual task: the analysis of the internal ballistics of the engine with a CFD code and the experimental design and ground hot testing of a lab-scale version of the motor.

To overcome issues on handling and storage of high concentration hydrogen peroxide, a specific test bed has been designed to reproduce H_2O_2 in dissociated form,as it behaves after the catalytic bed upstream of the injectors of the combustion chamber: in a specifically designed mixing chamber the required mass flows of H_2O and O_2 are fed, mixed together and heated up by use of a HDPE/GOX hybrid torch, in order to obtain a mixture of 59% of water and 41% of oxygen at 650°C of temperature. This hot gas mass flow enters the hybrid rocket main combustion chamber through a vortex injector. In order to simulate the thrust modulation required for the flight version of the SPARTAN motor, the gas generator is able to work at different mass flow rates, by changing the flows of water and oxygen and the heat flux developed by the hybrid torch: the resulting throttling rate is 1:10.

In a preliminary phase, a calibration of the oxygen and water feed lines into the mixing chamber and for the hybrid torch heater has been conducted. Validation tests have been performed on the integrated simulator, to assess the injected hot mixture characteristics (mainly temperature), ignition (and re-ignition) capability of the HTPB fuel and combustion stability. Finally, whole engine tests have been run with brand new regression rate sensors developed by POLIMI (Poly-technic of Milan, Italy) and integrated into the fuel grain during the casting process, to evaluate the motor performance, to measure the regression rate as a function of time and to characterize the effect of thrust modulation. Preliminary results have demonstrated the high reliability of the developed system, which allows a very fine calibration on the oxidizer mixture composition during thrust modulation. Combustion between simulated hydrogen peroxide and HTPB fuel

resulted to be very stable and the vortex injection technology has achieved high values of regression rate and combustion efficiency.

Both the motor and gas generator flow fields have been investigated, with a dual aim: to evaluate the performance of all the sub-systems and to help in the design process. Numerical simulations have been carried out by means of commercial CFD codes, which have been highly tailored on hybrid rockets combustion description. Various solvers, combustion and turbulence models have been investigated to identify the setup that best fits with the experimental evidence. The flow field has been investigated in its different aspects with these tools, to understand the physics behind the process of vortex injection; cold (injection with and without grain pyrolysis) and burning test simulations (full combustion). A user-defined function has also been developed, in order to calculate regression rate as a function of the wall heat flux, avoiding the necessity for the user to impose a fixed and pre-determined value for the fuel mass flow rate.

In the first section of the paper, a description of the CFD analysis of the internal flow-field of both the motor and the gas generator is reported.The second part details the design of these devices and presents the main results of the testing conducted in the frame of SPARTAN experimental campaigns at CISAS “G. Colombo” hybrid rocket experimental facility, comparing them with the performance predicted by the numerical code.