CFD Simulation of Regression Rate in Hybrid Rockets

M. Lazzarin\textsuperscript{1}, F. Barato\textsuperscript{2}

\textsuperscript{1,2} Center of Studies and Activities for Space (CISAS)
G. Colombo, University of Padova, Padova, Italy, 35131

and

A. Bettella\textsuperscript{3}, D. Pavarin\textsuperscript{4}

\textsuperscript{3,4} Department of Mechanical Engineering, Center of Studies and Activities for Space (CISAS)
G. Colombo, University of Padova, Padova, Italy, 35131

Abstract

In this work, a CFD code has been used to simulate hybrid rocket motors using O\textsubscript{2} as the oxidizer and HTPB or HDPE as the fuel. Two different kinds of simulation have been performed: a) the first, using pre-defined fuel and oxidiser mass flow rates, and b) the second calculating the fuel mass flow rate as a function of the wall heat flux. For this second type of simulations, regression rate has been determined and compared to the average value derived from the reference experiments; no tuning coefficients nor any other correction parameters have been introduced. The numerical models applied are discussed and a complete description of the set up is given.

First of all, a mesh convergence study is presented, for one of the geometries treated. Then, CFD results are compared with the corresponding experiments described in the literature. In the test cases calculating regression rate as a function of the wall heat flux, the fuel grain has been divided into segments, and the average regression rate resulting from the simulation has been plotted as a function of the average \( G_{\text{ox}} \). Concerning pressure at the head-end of the combustion chamber and \( C^* \), the simulations show a good agreement with the experimental results for the different rocket configurations analyzed.

Regression rate is determined by the CFD with an underestimation around 30\% for HDPE and 50\% for HTPB, if only convective heat exchange is accounted for. It has been proved for the HTPB case, that for relatively low \( G_{\text{ox}} \), the radiative heat transfer contribution to the total heat flux is not negligible and this is confirmed by CFD results: in fact, when the radiative heat flux contribution is added, the error on the regression rate calculated is reduced to around 15\% and in this case the experimental value is overestimated.

Moreover, it is true that CFD does not predict correctly regression rate absolute value, due to a wrong estimation of the wall heat flux, but it calculates correctly the \( n \) parameter of the regression rate formulation: \( r = aG_{\text{ox}}^n \).

I. Introduction

Some of the efforts made since 2001 to create and use numerical tools predicting hybrid rocket performance or analysing the flow field are reported. In 2003, Serin and Gogus \cite{1} studied the HTPB/O\textsubscript{2} reacting flow field inside the hybrid rocket motors and the corresponding regression rate. They used a commercial Navier-Stokes code, CFD-ACE to understand the mechanisms affecting regression rate. In 2005, Antoniou and Akyuz\cite{2} published a mathematical model predicting the entire hybrid rocket performance. Guobiao and Hui wrote a paper \cite{3} about their theoretical analysis of propellant performance, solid fuel regression rate, combustion and flow in hybrid rockets. Recently, a paper has been presented by Astrium about CFD simulations of GOX/HTPB lab-scale rockets \cite{4}, where axisymmetric motors are analysed using a steady-state approach. In 2010 and 2011, two papers have been presented by Lazzarin et al. \cite{5,6} concerning CFD simulations of hybrid rockets employing diaphragms inside the combustion chamber and using liquid oxidiser: the main interest was to prove that CFD tools are able to predict the efficiency of different motor configurations.

For this paper however, not only numerical work and experience is important, but also the experiments conducted on hybrid rockets. In fact, the study carried out is validated against some experimental results obtained for specific lab-scale rockets.

Concerning experimental work and results, Carmicio and Russo Sorge \cite{7} published a paper about the effects of different kinds of injection on hybrid rockets performance. In 2009, Carmicino et al.