Object oriented techniques for the numerical simulation of combustion processes in hybrid rockets

A. Mazzetti, P. Barbante

Politecnico di Milano
Mathematics Department "F.Brioschi"
I-20133, Milano, MI, Italy

Hybrid rocket engines are nowadays considered the new frontier for space propulsion due to their low cost, operational flexibility and intrinsic safety. Their layout implies coexistence, inside the combustion chamber, of three phases of matter: solid, liquid and gaseous (the latter in conditions of turbulent flow). These multiphase and multi-domain characteristics, together with the presence of pre- and post-combustion chambers, convergent-divergent nozzle, liquefying fuels leading to spray formation in the combustion chamber (also called entrainment effect), result in major difficulties in the numerical modeling of the phenomena involved. The investigation of hybrid fuels is currently performed mainly through experimental tests and semi-empirical correlations that provide a quite rough picture of the phenomena happening inside the engine and are still unable to clarify the presence of strong combustion instabilities during the operational phase.

Therefore, a reliable numerical model capable of predicting performance parameters and behavior of hybrid rockets, such as fuel regression rate, would be of major importance for the design of the next generation of hybrid rocket engines.

Within a cooperation between Politecnico di Milano and von Kàrman Institute for Fluid Dynamics, the COOLFluiD object oriented computational fluid dynamics framework is selected, adapted and modified in order to perform numerical modeling and simulation of hybrid rocket engines.

The project involves the simulation of traditional hybrid rocket fuels, such as polymeric rubbers (HTPB), and the model extension to the new generation of paraffin-based fuels, with multi-phase approach for spray/droplets combustion.

In this phase the flow field inside the engine combustion chamber is modeled as a mixture of turbulent chemical reacting gases with an unsteady Reynolds averaged Navier-Stokes (URANS) turbulence model. The set of Favre-averaged governing equation is closed by Wilcox k- ω turbulence model.

Traditional HTPB-based solid fuels were modeled as starting step, with reduced chemical kinetics. 1,3-butadiene is the only gaseous product of fuel pyrolisis.

The computational domain represents the combustion chamber of an hybrid rocket, with an axial inlet for the oxidizer and a transverse inlet for fuel. The dimensions match the lab-scale test combustion chamber of Space Propulsion Laboratory of Aerospace Engineering Department at Politecnico di Milano. Oxidizer inlet constitutes the whole height of the left side wall, while fuel inlet is positioned on the lower wall.

Cell-centered finite-volume method is used and a flux-splitting technique such as AUSM+-up is also applied. Isothermal, no-slip wall boundary conditions were applied in order to reproduce combustor physical walls. Fuel is injected at HTPB pyrolisis temperature of 800 K. Oxidizer is pure oxygen, injected with an axial velocity of 6 m/s at the temperature of 300 K.

Some preliminary results are shown in figures below. Results are displayed or as contour plots in the computational domain or as sections along y-axis. Sections are taken at three progressively

distant locations from oxidizer inlet, along the x-axis: 75 mm (fuel inlet end), 100 mm and 120 mm.

Figures 1a and 1b show the temperature profile in the channel and its sections at the three indicated locations. A wall-detached diffusion flame structure is generated, with a central hotter flame zone. This is confirmed by products mass fractions sections, shown in figure 2a and 2b.

Figures 3a and 3b show how temperature increase from combustion affects the axial velocity component u. In fact, as expected, significant velocity increase is obtained as an effect of temperature increase.

Final paper will present numerical simulation results in conditions relevant for SPLab experiments on traditional HTPB fuels and paraffin-based fuels.

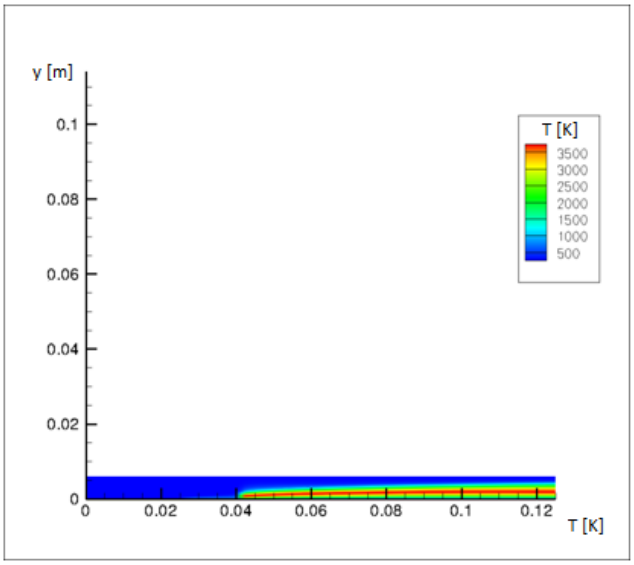

Fig. 1a – Temperature profile

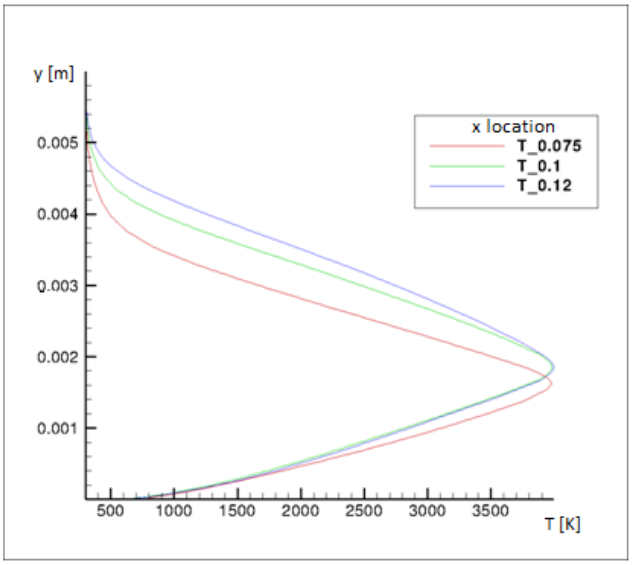

Fig. 1b – Temperature sections

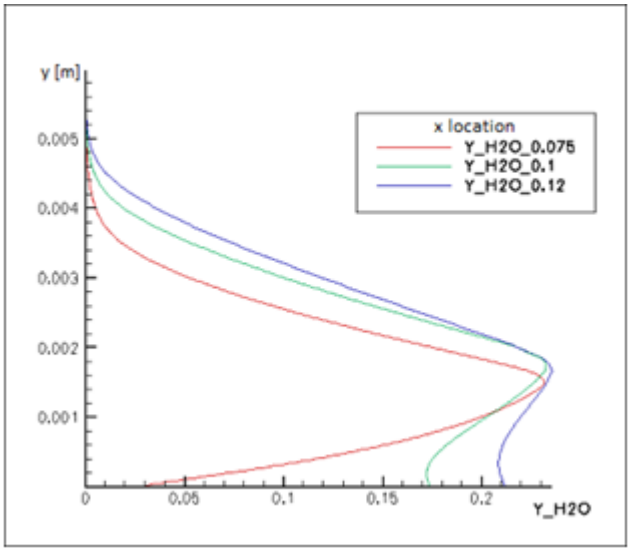

Fig. 2a – H_2O (product) mass fraction sections

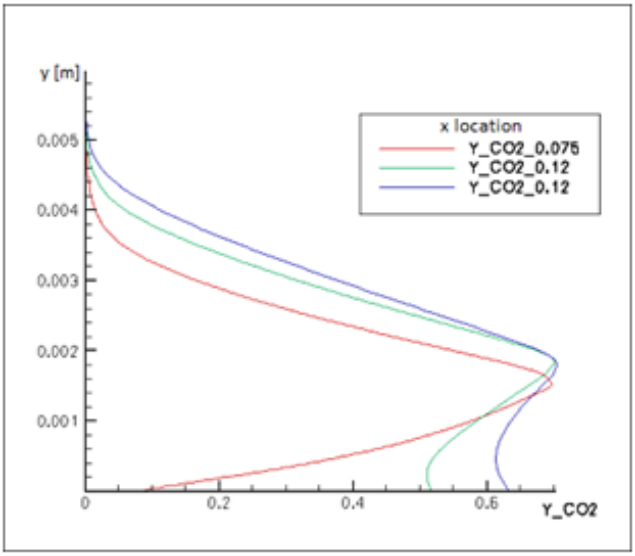

Fig.2b – CO_2 (product) mass fraction sections

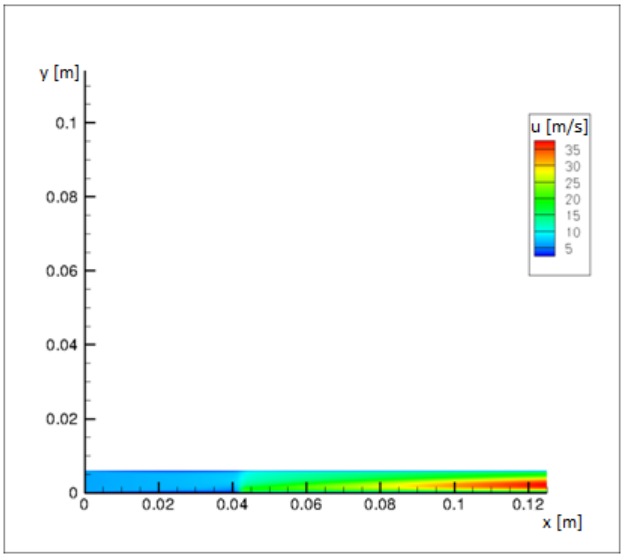

Fig. 3a – u velocity component profile

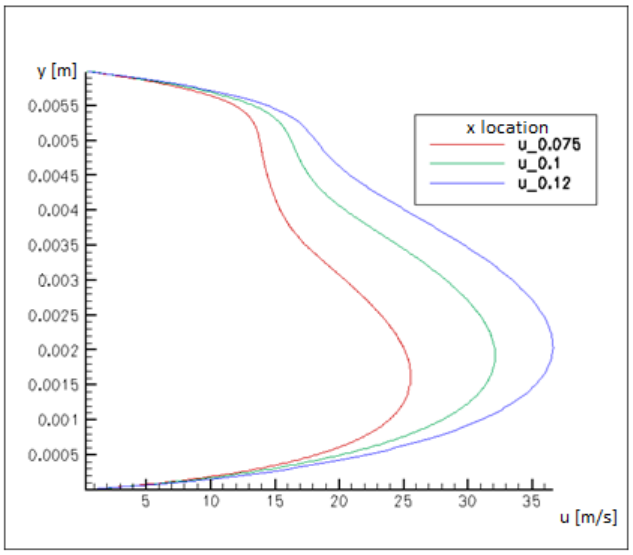

Fig. 3b – u velocity component sections