Use of direct and large eddy simulations for the development of multicomponent reacting compressible turbulent boundary layer wall model

O. Cabrit[a,b]**, F. Nicoud**[b]

a. CERFACS, 42 avenue Gaspard Coriolis, 31057 Toulouse, France
b. Université Montpellier 2, Place Eugène Bataillon, 34095 Montpellier, France

Abstract :

The use of high energy propellants in Solid Rocket Motors (SRM) requires to understand the interactions between structural components and high energy fluids. The turbulent boundary layer of such devices is submitted to chemical reactions and significant temperature gradients which makes harder its modeling. Full-scale motor firings are very expensive and do not provide sufficient information to understand the whole phenomenon. Numerical simulations can then be used to generate precise and detailed data set of generic turbulent flows under realistic operating conditions.

To answer the question of wall modeling for such boundary layers, a study of multicomponent reacting channel flows with significant heat transfer and low Mach number has been performed using a set of direct and wall-resolved large eddy simulations. The Reynolds number based on the channel half-height and the mean friction velocity is $Re_\tau = 300$ for DNS, and $Re_\tau = 1000$ for wall-resolved LES. Two temperature ratios based on the mean centerline temperature, T_c, and the temperature at the wall, T_w, are investigated : $T_c/T_w = 1.1$ for DNS, and $T_c/T_w = 3$ for wall-resolved LES. The mass/momentum/energy balances are investigated, specially showing the changes induced by multicomponent terms of the Navier-Stokes equations. Concerning the flow dynamics, the data support the validity of the Van Driest transformation for compressible reacting flows. Concerning heat transfer, two multicomponent terms arise in the energy conservation balance : the laminar species diffusion which appears to be negligible in the turbulent core, and the turbulent flux of chemical enthalpy which cannot be neglected. The data also show that the mean composition of the mixture is at equilibrium state ; a model for the turbulent flux of chemical enthalpy is then proposed and validated. Finally, models for the total shear stress and the total heat flux are formulated and integrated in the wall normal direction to retrieve an analytical law-of-the-wall. This wall model is tested favorably against the DNS/LES database.

Mots clefs : DNS, turbulence, reacting flow, compressible flow, wall model