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MODELING OF WALL-BOUNDED HIGH PRESSURE FLOWS IN LIQUID ROCKET ENGINES

Abstract

With the recent increase of High Performance Computing (HPC) resources, an higher demand of Computational Fluid Dynamic (CFD) investigations have been observed in the context of Liquid Rocket Engines (LRE) combustion chamber simulations. Associated to this technological advancement, the minimum standards of numerical analysis have raised a bar, in terms of reliability, robustness and performance. As an example, Large Eddy Simulation (LES) is nowadays considered the reference numerical framework for unsteady turbulent problems (such as those involved in the turbulent combustion process inside a LRE thrust chamber) in place of Reynolds Averaged Navier Stokes (RANS) analysis, being Direct Numerical Simulations (DNS) still prohibitive for industrial and large scale applications. In particular, the widespread diffusion of wall-modeled LES (WMLES) simulations is nowadays largely discussed, given the computational bottleneck associated to the simulation of wall-bounded flows. However, the intrinsic complexity and interdisciplinary nature of LRE combustion chamber problems, still require proper modeling solutions in order to, on one hand, separately describe the main physical phenomena involved (heat exchange towards the chamber walls, expansion in the nozzle, flame-to-flame and flame-to-wall interactions) and, on the other, let all these models harmonically and consistently play to achieve the final aim: the simulation of the entire injection-mixing and combustion problem in LRE. To this end, this work aims at addressing the main physical aspects beneath the modelization of wall-bounded flows in LRE combustion chambers, and the associated challenges. Concurrently, it presents some of the authors' solutions to two specific issues: the propellants injection problem and the modelization of the wall-heat-transfer at the chamber walls. Regarding the former, effects of heat exchange mechanisms inside the propellants inlet ducts causing a thermal break up of the jet [1] are discussed and associated modeling strategies proposed. Concerning the latter, effects of large stratifications in the near wall region, as for instance those induced by the combustion process or by an isothermal wall, are discussed and some recent advancements [2] with respect to the state of art in the context of wall-models presented.

References:

[1] Banuti, D. T. and Hannemann, "The absence of a dense potential core in supercritical injection: A thermal break-up mechanism." (2016). Physics of Fluids, 28(3), 035103.

[2] Indelicato, G. et al. "An efficient modeling framework for wall heat flux prediction in rocket combustion chambers using non adiabatic flamelets and wall-functions." (2021). International Journal of Heat and Mass Transfer, 169.