A quasi non-dissipative second-order explicit MAC scheme for the large-eddy simulation of compressible flows

B. Gamal[1,2], L. Gastaldo[1], J.-C. Latché[1], D. Trabichet[1,2], D. Veynante[2]

[1]Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Saint Paul Lez Durance, 13115, France
[2]Laboratoire EM2C, CentraleSupelec, Université Paris-Saclay, 3 rue Joliot Curie, 91190 Gif-sur-Yvette, France

Abstract

Large-eddy simulation (LES) has gained a great success in simulating everyday life flows where the Reynolds numbers are usually very high. In such a method, the large scale flow structures are computed explicitly from the filtered Navier-Stokes equations while effects of small-scale ones are modeled. We propose a formally second order scheme, with as low kinetic energy dissipation as possible, dedicated to this purpose, namely the numerical simulation of the filtered Navier-Stokes equations for compressible non reactive flows [1].

The space discretization is staggered and based on the so-called Marker-And-Cell (MAC) scheme. For the energy balance equation, the scheme uses a discrete form of the conservation of the sensible energy. A MUSCL-like technique is used for the convection operators of the mass and the sensible energy balance equations, while the discretization of the momentum convection term is centered. The time discretization is performed with the Heun scheme. The scheme is shown to preserve the positivity of the density and of the internal energy under CFL conditions. In addition, we derive a local kinetic energy balance at the discrete level, which features remainder terms which are shown to be formally of second-order with respect to the time discretization. Building upon this identity, we also show that the scheme satisfies a local total energy balance, which can be made conservative (*i.e.* free of any remainder term) by introducing suitable correction terms in the internal energy balance.

The numerical scheme is implemented in the open-source P^{2}REMICS (Partially PREMIxed Combustion Solver) software [2], developed at IRSN, on the basis of the generic CFD solver library CALIF^{3}S (Components Adaptative Library For Fluid Flow Simulations). Numerical tests confirm the accuracy of the scheme, and obtained kinetic energy residuals are very low. The numerical scheme can be extended to the reactive case and is used for the simulation of turbulent deflagration [3, 1]. The large eddy simulation of an accelerated premixed flame in an obstructed channel [4] is presented in order to illustrate this point.

References

[1] B. Gamal, Development of a Large Eddy Simulation approach for deflagration, PhD thesis of Paris-Saclay University, (2022).

[2] P^{2}REMICS Collaborative website, Physical Modelling in P^{2}REMICS, IRSN, http://gforge.irsn.fr/gf/project/p2remics.

[3] O. Colin, F. Ducros, D. Veynante, T. Poinsot, A thickened flame model for large eddy simulation of turbulent premixed combustion, Phys. Fluids, 12, pp. 1843-1863, (2000).

[4] C.T. Johansen, G. Ciccarelli, Visualization of the unburned gas flow field ahead of an accelerating flame in an obstructed square channel, Combustion and Flame, 156 (2), pp. 405-416, (2009).