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PRELIMINARY DEVELOPMENTS TOWARDS A HIGH-ORDER AND EFFICIENT LES CODE FOR PROPULSION APPLICATIONS

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An advanced LES code, named *SPARK-LES*, is currently under development at CIRA within the frame of the HYPROB program.
The general goal of the HYPROB program, coherently with CIRA programmatic guidelines in the field of Aerospace Propulsion, is to improve CIRA design and research capabilities on Liquid Rocket Engines, and in particular on the LOx/CH4 oxidizer-fuel mixture. One of the objectives of the HYPROB program is to develop enabling qualified technologies and corresponding high-fidelity simulation tools to support the design of propulsion systems.
In this framework, Large-Eddy Simulation (LES) has emerged over the last years as a promising and reliable technique to perform unsteady computations of reacting flows in low- as well as high-pressure environments [1]. In particular, the final goal of SPARK-LES is to perform accurate simulations of liquid-rocket thrust chambers with suitable numerical/physical models.

SPARK-LES is based on a finite-volume approach for structured grids and solves the fully-coupled Navier-Stokes equations in a compressible formulation. It is widely recognized that LES has to be performed with high-order spatial and temporal schemes so that 1) the energy-carrying scales are resolved accurately and 2) the numerical dissipation does not interfere with the subgrid-scale (SGS) model. Therefore, high-order centred schemes for discretization of convection, both explicit and compact, have been implemented [2]. Temporal integration is performed by means of a standard multi-stage Runge-Kutta scheme of arbitrary order. On the other hand, it is well-known that high-order centred schemes are inherently unstable due to the lack of numerical dissipation. As a consequence, high-order low-pass filters and/or artificial viscosity are required in order to suppress numerical instabilities. A sixth-order compact filter is available [3], as well as second- and fourth-order artificial dissipation terms [4]. Another approach aims to prevent spurious production/dissipation of kinetic energy due to discretization of convection. To this purpose, use of skew-symmetric-like schemes [5] to avoid introduction of filters/dissipation is under investigation.

The code handles both two- and three-dimensional grids, while extension to a fully parallel multi-block version is currently in progress. Special attention has been paid to software performances, by both a specific design of code structure (e.g., highly vectorized format) and high-profile optimization. For instance, among the various optimizing stratagems, the analytic solution of circulant tridiagonal systems arising in compact schemes (at least for uniform, periodic meshes) has been used. This allows considerable speed-up in comparison with standard numerical techniques (e.g., LU decomposition or Thomas' algorithm).

In the following, some preliminary results are presented (see Figure 1). Two standard benchmarks have been considered to assess accuracy and performances of the code. First, the preservation of a subsonic vortex travelling over long distances is investigated, for which many results from similar codes are available in literature [6]. Then, the three-dimensional Taylor-Green vortex is simulated, which is a well-defined flow that has been often used as a prototype of dynamics of transition to turbulence and energy decay [7].

The various schemes are compared in terms of accuracy and performances. Results confirm the excellent behaviour of both temporal and spatial integration along with very good performances, if compared to results obtained by other codes.

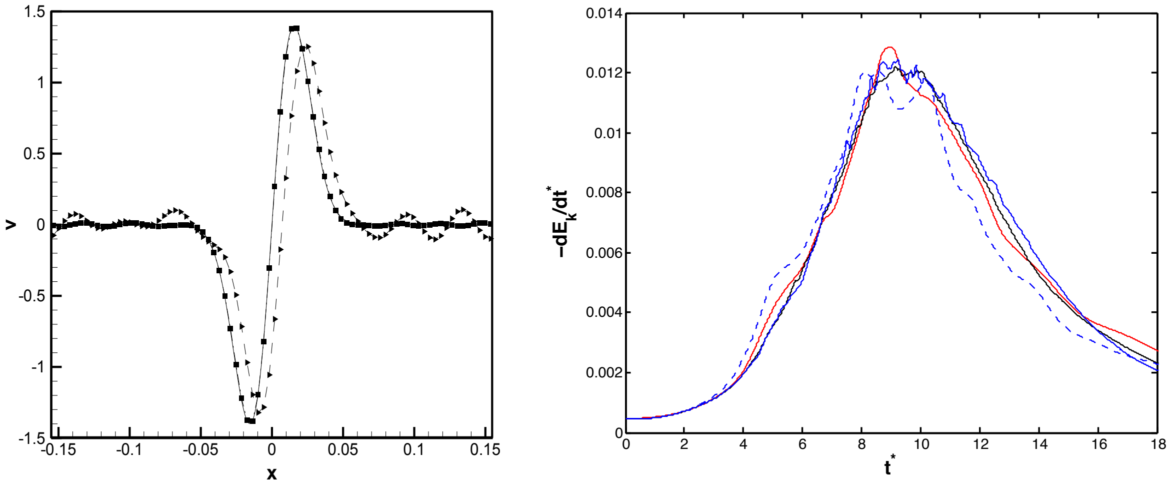

Figure 1: *(left)* y-component of velocity along the centerline for a subsonic vortex after 40 turn-over times on a periodic 80^2 square. ■ 4th order compact scheme; ▶ 4th order centered scheme; —— exact. *(right)* Dissipation rate of a Taylor-Green vortex at Re=1600 on a periodic 128^3 box. —— DNS [8]; —— 4th order compact scheme; —— 4th order centered scheme; ---- 4th order centered scheme with a 6th order compact filter (α = 0.4).

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