Oral presentation | Higher order methods
Higher order methods-I
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[3-C-02] Successive correction h-p adaptation for k-exact FV schemes in compressible flow simulations

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Keywords: h-p adaptation, finite volume methods, compressible

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Successive correction h-p adaptation for k-exact finite volume schemes in compressible flow simulations

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An h-p-adaptive strategy for high-order k-exact finite-volume methods is presented. The suitability of the strategy is assessed by analyzing the benefits in terms of accuracy and computational efficiency on compressible and laminar configurations.
Keywords : Finite-volume methods, mesh-adaptation, p-adaptation.

1 Introduction

The demand for efficient and accurate Computational Fluid Dynamics (CFD) simulations of turbulent flows in industrial environments, together with the evolution of data-driven approaches, has spurred the development of more reliable and automatic numerical methods. On one hand, the generation of computational meshes that accurately represent the characteristics of complex fluid flows is a time-consuming and tedious task. On the other hand, fluid flows such as scale-resolving simulations of turbulent flows (for instance Large Eddy Simulation, LES, or hybrid Reynolds-Averaged Navier–Stokes (RANS)/LES methods, HRLES), require high-order numerical methods to accurately capture the finest resolved grid scales. Traditionally, second-order finite volume methods have remained the preferred choice for industrial numerical simulations of flows characterized by strong compressibility effects because of their inherent ability to handle flow discontinuities. However, when further accuracy is required, the solution becomes very reliant on grid size and numerical errors. Using mesh adaptation to locally adjust the mesh alongside high-order methods enhances the solution accuracy, however, the latter comes with higher computational costs and memory requirements. On the other hand, p adaptation, mostly in the context of Discontinuous Finite Element schemes, can alleviate the computational overcost of higher-order reconstructions and improve shock-capturing capabilities by locally increasing or lowering the solution reconstruction order. However, p-adaptation efficiency may be strongly dependent on the computational mesh in use. To combine the advantages of both approaches, $h-p$-adaptive methods have been proposed, adjusting both the local mesh size (h) [1, 2] and the order of the numerical scheme (p) [3, 4] based on specific refinement criteria. These adaptative methods have been extensively studied for continuous or discontinuous finite-element methods [5, 6], however, some studies [4] have proved their potential advantages also for finite volume methods (FVM).

2 Methodology

This study represents a first step toward the development of h-p-adaptation strategies for a family of high-order k-exact FVM. Specifically, we focus on the successive-correction k-exact scheme of [7], which relies on the recursive correction of reconstruction errors to progressively increase the order of accuracy while only using communications with a cell direct neighbours at each correction step. The successive correction strategy also offers a natural error estimator, consisting in the reconstruction error between a second-order (1-exact) and a third-order (2-exact) approximation. We consider 1- and 2-exact Godunov-type schemes using a polynomial reconstruction of the solution over each cell in which every required derivative is calculated by a successive corrections algorithm (SCA). Shock capturing is ensured by the application of slope limiters. This avoids to lower the reconstruction order down to 0-exact around flow discontinuities, while still ensuring sharp and non oscillatory shock profiles. For p adaptation, we use the error criterion to tag cells for order 2 or 3, based on a predefined error threshold. For h-adaptation, we consider dynamic mesh adaptation (DMA) based on isotropic splitting of hexahedral elements (quadtree/octree refinement).
The same criterion drives the h-p adaptation process. Based on an error threshold, we tag cells for increasing order or h refinement. The simulations start with a coarse mesh and a 1-exact (second-order) scheme, and h-p refinement is performed according to the following policy:

$$C_i < M_1 \quad \text{marked for refinement and } 3^{rd} \text{ order accuracy} \tag{1}$$

$$C_i > M_1 \quad \text{marked for } 2^{nd} \text{ order accuracy only} \tag{2}$$

Full details of the numerical scheme and adaptation algorithm will be provided at the conference.

3 Results and outlook

The preceding successive correction p-adaptation and h-p-adaptation strategy is applied to configurations of increasing complexity. The effectiveness of the p-adaptation strategy will be evaluated on three benchmark cases: inviscid transonic flow (Mach 0.8) over a NACA 0012 airfoil at an angle of attack of $\alpha = 1.25°$, transonic compressible laminar flow around a circular cylinder (Figure 1), and a 3D inviscid transonic flow over the Onera M6 wing (Figure 2). The assessment will include a detailed comparison of the results obtained using the 1-exact and 2-exact schemes against those from the p-adaptation strategy, with a particular focus on the computational time efficiency.
Finally, the h-p-adaptation strategy will be assessed on a two-dimensional test case featuring the impingement of a shock wave on a mixing layer (Figure 3). This assessment aims to demonstrate the capability of the h-p-adaptation to achieve results comparable to those obtained with a refined mesh using the 2-exact scheme.

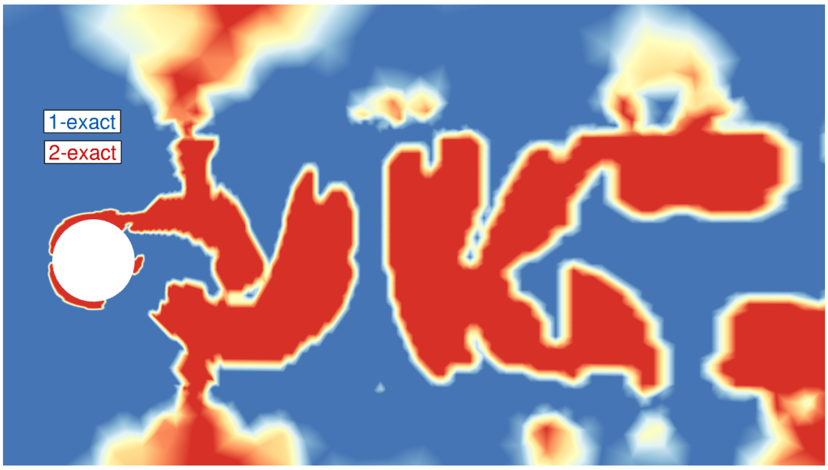


Figure 1: Order distribution for the 2D cylinder test case

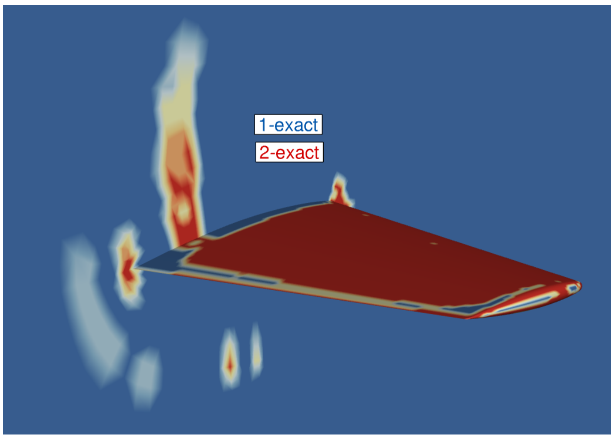
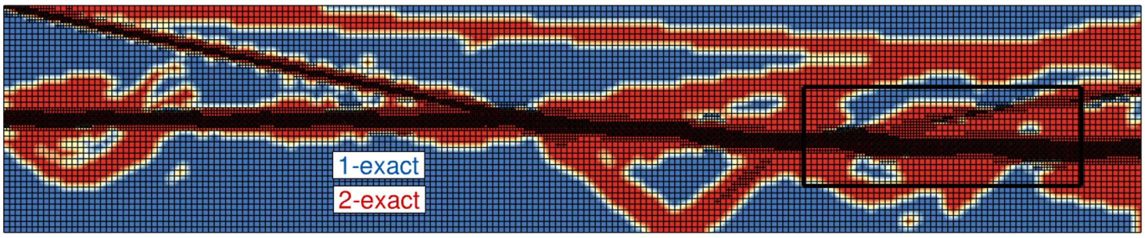
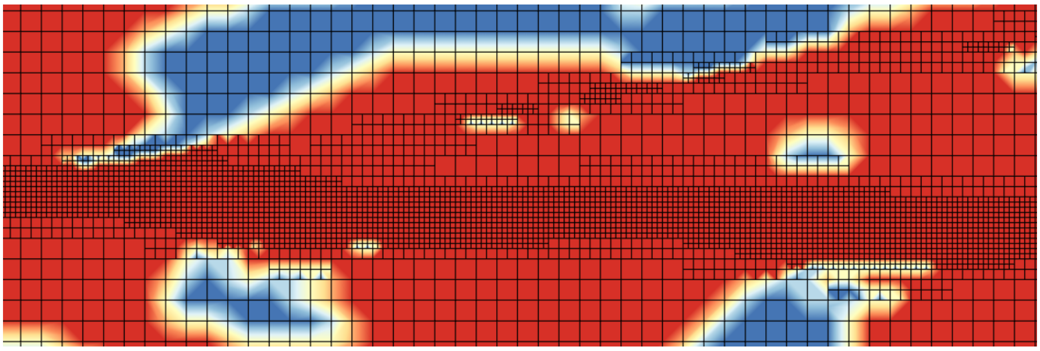


Figure 2: Order distribution for the M6 transsonic test case



(a) Mesh and order distribution on the whole domain



(b) Zoom on the mesh and order distribution

Figure 3: Mesh and order distribution for the Yee test case

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