High-Fidelity Simulations and Applications group: overview

Advancing our understanding of engineering problems involving wall-bounded, turbulent shock-laden flows requires the development of high-fidelity computational tools, including robust numerical methods and predictive reduced-order models. Such problems often feature high Mach numbers, flow discontinuities and unsteadiness. Developing and evaluating predictive science tools for these complex flows were the primary focus of the High-Fidelity Simulations and Applications group.

In wall-bounded turbulence, drag reduction is a compelling challenge. Inspired by drag-reducing riblets, Zahtila *et al.* perform direct numerical simulations to quantify the drag-reduction potential of surfaces generated from a Miura-origami basis. The authors attempt to interpret their findings via analogy with drag reduction due to the dynamic oscillation of walls. Their work is a first step toward optimal, dynamic origami surface–based design in the drag-reduction context.

For compressible flows, the wall temperature boundary condition also affects drag. On this note, De Broeck *et al.* investigated the temporal stability problem for a compressible boundary layer over a cooled wall with impedance boundary conditions. Their findings provide an explanation for the stabilization effects of temperature-controlled impedence walls, with additional developments for applications involving porous surfaces.

For robust and accurate simulations and control of shock-laden flows, numerical methods need to be devised that correctly capture shocks and their sensitivity to change. Bodony & Fikl study the adjoint-based sensitivity of shock-driven flows to parametric changes in the governing equations or to internal forcing, with a specific focus on calculating the resolvent and input/output operators for shock-laden flows. Using the nonlinear inviscid Burgers' equation as a guide, they show that localized artificial diffusivity-based methods produce correct discrete adjoints, while stencil-switching schemes like MUSCL and WENO do not.

The large-eddy simulation (LES) paradigm is an attractive approach for studying turbulent flows with increasingly high Reynolds numbers, but the filter kernel–wall interaction has complicated the modeling effort. In this spirit, Ghosal *et al.* propose a new formulation of LES in which the filter width is fixed as the wall is approached. This formulation removes many mathematical inconsistencies in the LES equations, while potentially creating a new approach for constructing a reduced-order model to study near-wall physics. In this work, the unfiltered or primitive field is filtered using a fixed-width filter to generate both an interior closure problem and a surface LES field that interacts with it through surface stresses and source terms.

With the existing combinations of minimum dissipation numerics and phenomenological subgrid-scale models, LES is also used as a predictive and analytic tool for complex engineering systems. Two projects in this group focus on applications of LES, specifically in the flow over an airfoil for noise detection and in rotor-blade applications for hover.

Lee *et al.* perform wall-resolved LES to analyze noise caused on a high angle of attack, NACA0012 airfoil geometry. Using wavelet thresholding, the authors decompose the pressure field to identify the dominant noise source at specific frequencies, such as the noise from low-frequency vortex shedding and from the high-frequency laminar separation bubble and trailing-edge noise. This work advances the value of wavelet-based decomposition as a tool to study mechanisms of airfoil noise generation.

Finally, Stratton *et al.* study the problem of a scaled helicopter rotor in hover, which is one of the most challenging applications in which LES has been used to date. Their systematic analysis quantifies the effects of laminar-turbulent transition over the blade and its impact on integrated forces. Despite the complex flow phenomena involving blade-vortex interactions, the authors demonstrate the ability of LES to accurately predict forces over the blade with as few as 2–7 grid points within the boundary layer. A remarkable feature of this work was that the turnaround times for these simulations were under two days on 40 GPUs, which points to the readiness of LES for widespread use in industrial applications.

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