Aerospace Engineering Doctoral Defense

Investigation of bluff body wakes in incompressible and compressible flows via spectral element and discontinuous Galerkin spectral element method approaches

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Abstract

This thesis focuses on turbulent bluff body wakes in incompressible and compressible flows. The wake flow past a body of revolution at Re=5000 is investigated via a direct numerical simulation. The streamwise velocity profiles in the intermediate wake are found to be self-similar. Three dominant coherent vortical motions are identified in the wake: the vortex shedding motion with the frequency of St=fD/u=0.27, the bubble pumping motion with St=0.02, and the very-low-frequency motion originated in the very near wake of the body with the frequencies St=0.002 and 0.005. The findings show that the helical structure is formed by vortex shedding. Proper orthogonal decomposition (POD) and dynamic mode decomposition (DMD) are further performed to analyze the spatial structure associated with the dominant coherent motions. Results of the POD and DMD analysis are consistent with the results of the azimuthal Fourier analysis.To extend the current incompressible code to be able to solve compressible flows, a computational methodology is developed for a high-order approximation of the solutions of the compressible Navier-Stokes equations with discontinuities. The methodology is based on a discontinuous Galerkin spectral-element method (DGSEM) built upon a split discretization framework with a summation-by-parts (SBP) operator. To extend the split DGSEM framework to discontinuous cases, we implement two shock capturing methods. One is based on the entropy viscosity formulation, the other one is based on the subcell finite volume method. The developed high-order split-form with shock-capturing methodology is subject to a series of evaluation on cases from 1D to 3D, with and without discontinuities. Convergence of the method is demonstrated for both smooth and shocked cases that have analytical solutions. The 2D Riemann problem tests illustrate an accurate representation of all the relevant flow phenomena, such as shocks, contact discontinuities, and rarefaction waves. The test cases have a wide range of mach numbers, from subsonic to hypersonic. The Taylor-Green vortex case and the supersonic sphere wake case show the capability to handle 3D turbulent flows without and with the presence of shocks. We also show that higher-order approximations yield smaller errors than lower-order approximations, for the same number of total degrees of freedom.

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