A FAST IMMERSED-BOUNDARYMETHOD WITH APPLICATION TO LOW REYNOLDS NUMBER AERODYNAMICS

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ABSTRACT

We present an overview of recent developments of a projection approach for implementing the immersed boundary method (e.g. [1]) in a traditional finite-volume, fractional-step algorithm for incompressible flow. Boundary forces and pressure are regarded as Lagrange multipliers that enable the no-slip and divergence-free constraints to be satisfied to arbitrary precision with no associated time-step restrictions [2]. For rigid surfaces, the algorithm can be formulated with a discrete streamfunction, multi-domain approach that provides for a fast algorithm and an FFT-based Poisson equation solution [3]. The method has been verified and validated by solving a variety of stationary and moving rigid surface problems; we provide examples from three-dimensional bluff bodies, flapping wings, vortex-induced vibration, and the collision of a sphere with a planar wall.

Figure 1: Flow (left-to-right) over an inclined flat plate with an aspect ratio of 2 (α= 30º, Re = 300): left, natural flow; center, mid-span actuation; right, trailing edge actuation. For the actuated cases, the (rms) momentum coefficient is 1%. The top row shows isocontours of the vorticity norm and the Q-value to highlight vortical structures, the bottom row shows the corresponding streamlines and pressure contours at a mid-span plane. The actuated cases show a strengthening of the tip vortices near the wing and a concentration and deflection toward the plate of the leading-edge vortex. The lift is increased by about 75% in both actuated flows compared to the natural flow.

Next, we discuss application of the method to low-Reynolds number aerodynamics (for micro air vehicles), and, in particular, active and closed-loop control of the leading-edge vortex (LEV) associated with separated flows on two and three-dimensional airfoils with different aspect ratios, planforms, and angle-of-attack. Some two-dimensional model problems are used to investigate how feedback can be used to phase-lock an actuation signal to the measured forces, in order to synchronize (phase-lock) vortex shedding. Strategies are developed to optimize the lift achieved over a cycle of actuation, by modification of the phase between actuation and the force [4]. Idealized body-force actuators are also applied to three-dimensional, flat-plate airfoils. For certain actuator locations and directions of momentum injection, the actuation can have a strong, stabilizing effect on the leading-edge vortex structure (figure 1), and produce lift enhancement of similar magnitude to that which occurs in the dynamic-stall vortex, or which is associated with the LEV during impulsively-started motion [5].

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