Augmented Lagrangian approach for large-scale linear stability analysis of incompressible flows and its extension to fluid-structure interaction.

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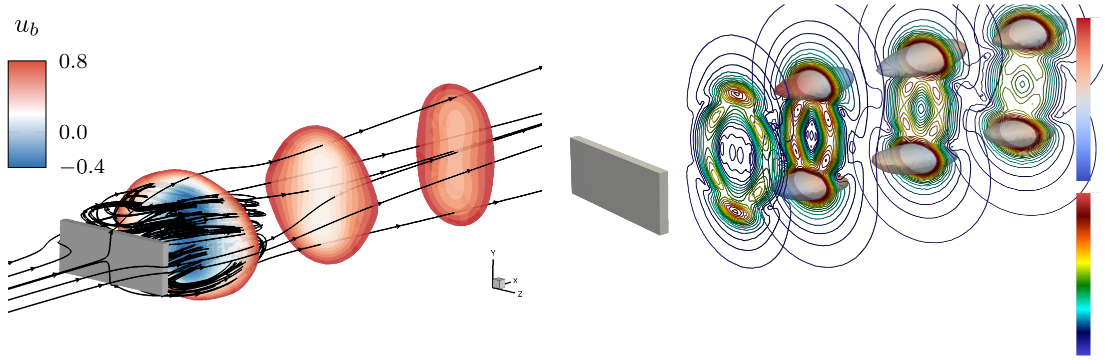
Hydrodynamic linear stability analysis of large-scale three-dimensional configurations is usually performed with a "time-stepping" approach, based on the adaptation of existing solvers for the unsteady incompressible Navier–Stokes equations. We propose instead to solve the nonlinear steady equations with the Newton method and to determine the largest growth-rate eigenmodes of the linearized equations using a shift-and-invert spectral transformation and a Krylov–Schur algorithm. The solution of the shifted linearized Navier–Stokes problem, which is the bottleneck of this approach, is computed via an iterative Krylov subspace solver preconditioned by the modified augmented Lagrangian (mAL) preconditioner[1]. The effect of various numerical and physical parameters is investigated numerically on a two-dimensional flow configuration, confirming the reduced number of iterations over state-of-the-art steady-state and time-stepping-based preconditioners. A parallel implementation of the steady Navier–Stokes and eigenvalue solvers, developed in the FreeFem++ language purposely interfaced with the PETSc/SLEPc libraries is described. Its application on a small-scale three-dimensional problem shows the good performance of this iterative approach over a direct LU factorization strategy, in regards of memory and computational time. On a large-scale three-dimensional problem with 75 million unknowns, a 80% parallel efficiency on 256 up to 2,048 processes is obtained. Finally, an extension of the augmented Lagrangian approach is proposed in order to perform linear stability analysis of three-dimensional incompressible fluid flows interacting with an elastic structure.



(a) Steady solution

(b) Leading eigenmode

Figure 1: Linear stability analysis for the three-dimensional incompressible flow around of plate at Reynolds number $\mathcal{R}e = 100$. Streamwise velocity contours of (a) the steady solution and (b) leading eigenmode are presented.

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[1]Benzi and Olshanskii, *SIAM Journal on Scientific Computing* **28** (2006).