Nonlinear optimization of a separated boundary-layer flow

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ABSTRACT

Transient growth associated with the non-normality of the linearized Navier-Stokes equations has recieved a lot of attention among the fluid dynamics community over the last decade. However only the linearized perturbation dynamics in more or less arbitrary geometries has been considered, see [1] for a comprehensive study. We address the question of transient growth and control of the nonlinear dynamics for a wall bounded separated flow and as an example we consider the detached boundary layer flow over a shallow bump studied in [2]. This configuration combines a convectively unstable region and it is subject to a global instability giving rise to a low frequency flapping of the recirculation bubble. The optimal growth and the control of the linear perturbation dynamics were already investigated in [2] and [3] for the same flow configuration using a projection based on global modes. Recently the possibilities of nonlinear optimal growth was investigated in the case of the flat plate boundary layer [4] where the optimization of the fluid flow governed by the incompressible Navier-Stokes equations is formulated using the Lagrangian approach. This gradient-based method introduces adjoint variables, also called Lagrange multipliers which provide a general formulation for optimization problems with constraints. In this approach, the question of appropriate outflow boundary conditions is essential.

In our numerical simulation procedure, the influence matrix technique has been implemented in order to ensure a divergence free velocity field as well as compatible stress free outflow conditions. The problem is marched in time and the optimization problem is solved. The structure of the optimal perturbation provides the regions where the flow is the most sensitive to any perturbation or control device. While the linear analysis indicates that only the region near the bump summit is optimal for flow control, the nonlinear results clearly show that possible actuators have rather to be distributed within the shear layer of the bubble as well as upstream the bump. Thus a blowing/suction control device has been introduced on the bump, where the nonlinear optimal disturbance dominates. A receding-horizon predictive control algorithm is used in order to make the control problem feasible over a long time horizon. The control is able to decrease the flow energy down to the level of the mean flow and the possibilities of controlling the entire dynamics are being investigated.

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