11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

TRANSITION-ORIENTED SHAPE OPTIMIZATION FOR LAMINAR FLOWS

Christophe Hennekinne[1]*, Matthew P. Juniper[2]

[1] University of Cambridge, Cambridge, UK, ch561@cam.ac.uk
[2] University of Cambridge, Cambridge, UK, mpj1001@cam.ac.uk

Key words: *Shape optimization, Laminar flow, Stability analysis, Transition*

In every fluid flow, a transition from laminar to turbulent flow occurs as the Reynolds number is increased. In most hydrodynamic applications, this transition to turbulence is not desired as it is often accompanied by an increase of the dissipated energy. Numerous active and passive control strategies have been considered to delay this transition [1, 3] but one of the simplest passive control strategies, boundary modification has received less attention, possibly because it is challenging to analyse and implement.
Finding the optimal shape given a cost function and some constraints is the role of a shape optimization algorithm. These algorithms have flourished in recent years and are now well used within the fluid mechanics community [2, 4]. However, as it stands, the constraints cannot include information related to the stability of the flow. We present some advances to introduce this information.

In some flows such as the flow around a cylinder, transition to turbulence starts with a modal instability. This first instability can be accurately predicted by performing a linear stability analysis. The growth rate of the leading mode provides then a scalar measure of the instability, a measure that can be included in the optimization problem. The shape gradient of the growth rate, required in a descent method based algorithm, can be computed using a double-decker algorithm that relies greatly on adjoint methods.
This algorithm has been implemented using low order finite elements and tested on the flow over a backward facing slope. By changing the shape of the slope, the three-dimensional instability that grows on top of the two-dimensional flow is delayed.

In other flows like the flow over a flat plate, the transition is triggered by disturbances such as noises in the inlet or imperfection of the surface. Such transition is more difficult to simulate and requires an accurate stochastic description of the disturbance. The non-modal instability can then be identified by performing a dynamical stochastic simulation of the flow, as transition will be characterized by a large variance of the final solution. The shape gradient of the final variance can be computed using an adjoint-looping algorithm in which both the direct and adjoint equations are stochastic.

REFERENCES

[1] C. W. Rowley and D. R. Williams. *Dynamics and Control of High-Reynolds-Number Flow over Open Cavities*. Annual Review of Fluid Mechanics, vol. 38, pp. 251–276 (2006).

[2] S. Schmidt, C. Ilic et al. *Airfoil design for compressible inviscid flow based on shape calculus*. Optimization and Engineering, vol. 12, issue 3, pp. 349–369 (2011).

[3] D. Sipp, O. Marquet et al. *Dynamics and control of global instabilities in open-flows: a linearized approach*. Applied Mechanics Reviews, vol. 63 (2010).

[4] A. Stück and T. Rung. *Adjoint RANS with filtered shape derivatives for hydrodynamic optimisation*. Computers & Fluids, vol. 47, issue 1, pp. 22–32 (2011).