6th European Conference on Computational Mechanics (ECCM 6)
7th European Conference on Computational Fluid Dynamics (ECFD 7)
11-15 June 2018, Glasgow, UK

EIGENMODE OPTIMIZATION OF A CONTRACTION CHANNEL BASED ON STABILITY ANALYSIS

Yinzhu Wang[1,3], Alejandro Martínez-Cava[1], Eusebio Valero[1,2], Yao Zheng[3], Esteban Ferrer[1,2]

[1] ETSIAE-UPM - Universidad Politécnica de Madrid - Plaza de Cardenal Cisneros 3, 28040 Madrid, Spain

[2] CCS-UPM - Centre for Computational Simulation - Universidad Politécnica de Madrid, Boadilla del Monte, 28660 Madrid, Spain

[3] CESE-ZJU - Centre for Engineering and Scientific Computation - Zhejiang University, Hangzhou, Zhejiang 310027, P.R. China

Keywords: *GEOMETRIC OPTIMIZATION, EIGENVALUE PROBLEM, CONTRACTION CHANNEL, LINEAR STABILITY ANALYSIS*

There are many applications in which the flow meets a sudden geometry contraction, an example is provided by the cooling flow in a compressor turbine blade. Evidence has shown that such contractions may cause some unfavourable pressure perturbations downstream, affecting the next blades and causing fatigue and loss of efficiency [1].

There have been several investigations aiming at understanding the flow behaviour in sudden contractions both numerically and experimentally. In numerical simulations carried out by Chiang and Sheu [2], and experimental investigations carried out by Cherdron and Soby, two recirculation bubbles of different sizes were observed on the two tip corners downstream the contraction stage. This flow configuration is unstable for certain flow parameters (Reynolds number and contraction ratios) which control the instabilities leading to the observed unsteady flows.

Computational investigations have been performed to study flow bifurcation in the symmetric planar contraction channel. CFD simulations at different Reynolds numbers for 3 contraction ratios have been carried out, which confirm the presence of the pitchfork bifurcations. The critical Reynolds numbers of bifurcations are obtained.

In this framework, the DLR-TAU code is employed to obtain the compressible base flow solution, from which the critical Reynolds numbers for the bifurcations have been found. This non-symmetrical flow topology can be analysed using global stability analysis, evaluating the influence of the Reynolds number of the flow as the main parameter that triggers the unstable phenomenon [3]. The eigenmodes responsible for the flow bifurcations are identified using stability analysis, and their amplification rates analysed.

The real part of the eigenvalue stands for the amplification rate of the corresponding eigenmode, the optimization problem is simplified as minimizing the real part of the corresponding eigenvalue of a specific eigenmode of interest. Based on this assumption,

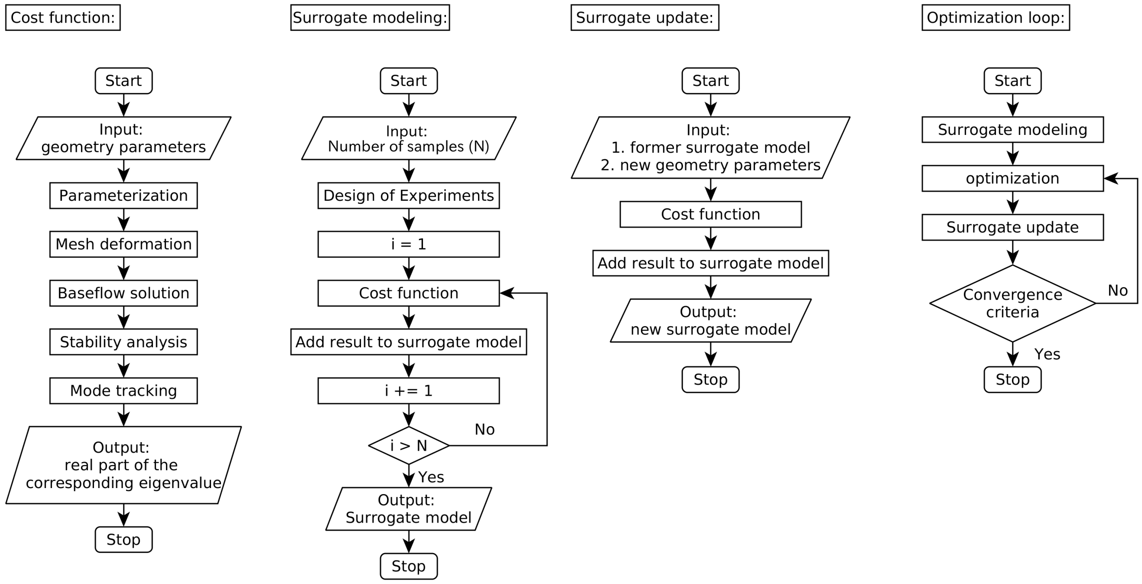


Figure 1: The optimization loop

the optimization problem is modelled as follows.

$$\begin{aligned} & min_{d\in D} \quad \boldsymbol{g}(\boldsymbol{d},\boldsymbol{\theta}) \\ & subject \quad to: \quad h_i(\boldsymbol{d},\boldsymbol{\theta}) >= 0, \quad for \quad i=1, \quad ..., \quad N \end{aligned} \tag{1}$$

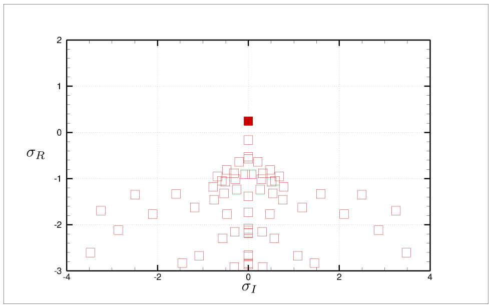
in which, $\boldsymbol{d}$ is the geometry parameters and $\boldsymbol{\theta}$ is the model parameters in the flow field.

The objective function $g(\boldsymbol{d},\boldsymbol{\theta}) = \omega_r(\boldsymbol{d},\boldsymbol{\theta})$, which is dependent on the geometry parameters $\boldsymbol{d}$ and the model parameters $\boldsymbol{\theta}$ are minimized over all possible designs, subjected to constraints imposed on both geometry and the flow field.

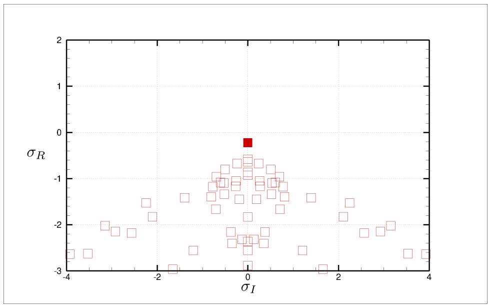
The optimization loop consists of surrogate model building and updating, geometry parametrization, mesh deformation, base flow solution, stability analysis and mode tracking. The main loop is started by building the initial surrogate model. Then, followed by the loop of optimization and surrogate model updating. The flowchart of the optimization is shown in figure 1.

We can see in the eigenvalue spectrum shown in figure 2b in comparison with figure 2a that the amplification rates of the most unstable asymmetric mode is reduced and below zero after the optimization. The corresponding eigenvector is shown in figure 2d in comparison with figure 2c, from which we can find that the modes have been relocated from behind the tip corners to around the corner. And as shown in figure 2f and figure 2e, after the optimization, the flows are all symmetric and the sizes of the recirculation bubbles are either reduced greatly.

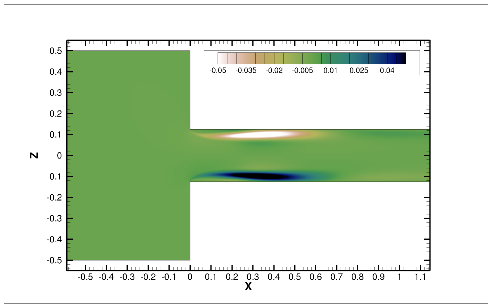
In this study, an efficient optimization method based on stability analysis is developed for investigations on suppressing the modes responsible for unstable flow. The method consists of an optimizer, a dynamic updating surrogate model [4], a geometry parametrization method, a CFD solver, a stability analysis tool, an eigenmode tracking scheme and a mesh deformation module. This procedure is successfully applied to suppress the unfavourable modes in channel flows with geometry contraction. The optimised geometry, with rounded corners, is stable for critical Reynolds number that are 654% larger than for the original geometry.



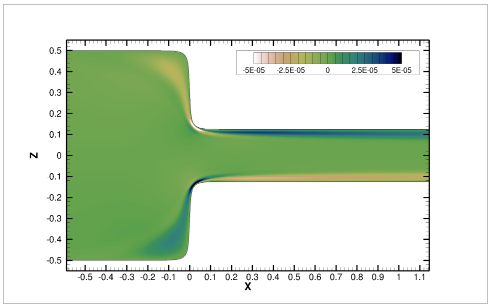
(a) Original eigenvalue spectrum



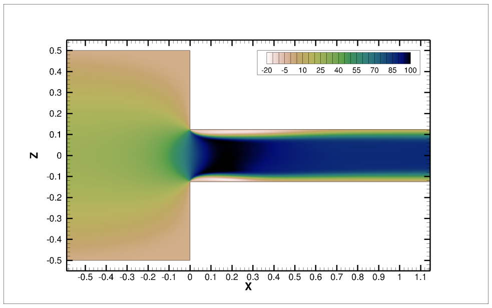
(b) Optimized eigenvalue spectrum



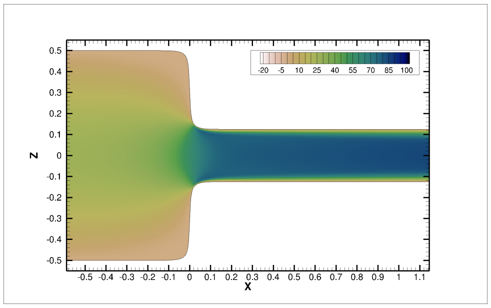
(c) Original eigenvector



(d) Optimized eigenvector



(e) Original velocity contour



(f) Optimized velocity contour

Figure 2: Comparison between original and optimized geometry configuration

References

[1] Gorbachova, Y., González, L. M., and Martínez-Cava, A., Global Stability Analysis of a Compressible Turbulent Flow around a High-Lift Configuration. *AIAA Journal*, Vol. 54, No. 2, pp. 373-385, 2015.

[2] Chiang, T. P. and Sheu, T. W. H., Bifurcations of Flow Through Plane Symmetric Channel. *Journal of Fluids Engineering*, Vol. **124**, pp. 444–451, 2002.

[3] Iorio, M. C., González, L. M. Ferrer, E., Direct and Adjoint Global Stability Analysis of Turbulent Transonic Flows Over a NACA0012 Profile. *International Journal of Numerical Methods in Fluids*, Vol. 76, Issue 3, pp. 147-168, 2014.

[4] Queipo, N. V., Haftka, R. T., Shyy, W., Goel, T., Vaidyanathan, R., and Kevin Tucker, P., Surrogate-based analysis and optimization. *Progress in Aerospace Sciences*, Vol. 41, No. 1, pp. 1-28, 2015.