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

2D AND 3D GLOBAL STABILITY ANALYSIS BASED ON THE MODAL DECOMPOSITION OF MARGINALLY STABLE FLOWS

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Key words: *Dynamic Mode Decomposition, DMD, Global stability analysis*

Reduced order models are key enablers of feedback flow control. One of the most popular methods of model order reduction for fluid flows is Galerkin method. It is based on the projection of (approximated) governing equations onto a subspace spanned by mathematical, physical or empirical modes. The right choice of the modal basis has a significant impact on the scope of applicability of the model [6].

In the case of most popular empirical mode bases, resulting from Proper Orthogonal Decomposition [3] of periodic flow undergoing limit cycle oscillations, Galerkin models are unable to capture properly the dynamics of the transition from steady solution to the fully periodic flow (e.g. von Karman vortex street), as well as the influence of the vortex suppression resulting from active flow control. To widen the scope of the model, physical modes, like the ones resulting from global stability analysis [4], have to be incorporated, either as a part of hybrid model [6] or using mode basis parameterization, like continuous mode interpolation [8].

Unfortunately, global stability analysis of general three-dimensional flows is very computationally demanding task. The issues like the solution of large, generalized eigenproblems and the choice of preconditioning making eigenvalues of the real part close to zero the dominant ones result in the very few analysed configurations [5]. These restrictions lead to research on new methods of obtaining physical modes [1, 2].

In this paper, an alternative method of obtaining physical mode basis is presented. The discussed approach is based on Dynamic Mode Decomposition [7] of the snapshots from marginally stable flow, calculated using direct numerical simulation of Navier-Stokes equations. The examples include incompressible, 2D flow past a circular cylinder and a 3D flow past a sphere. The dynamic modes of the flow near fixed-point dynamics (fig. 1) reproduce the structures of global stability eigenmodes, and the eigenvalues of a Companion matrix resemble the ones of generalized eigenproblem resulting from linearization of Navier-Stokes equations.

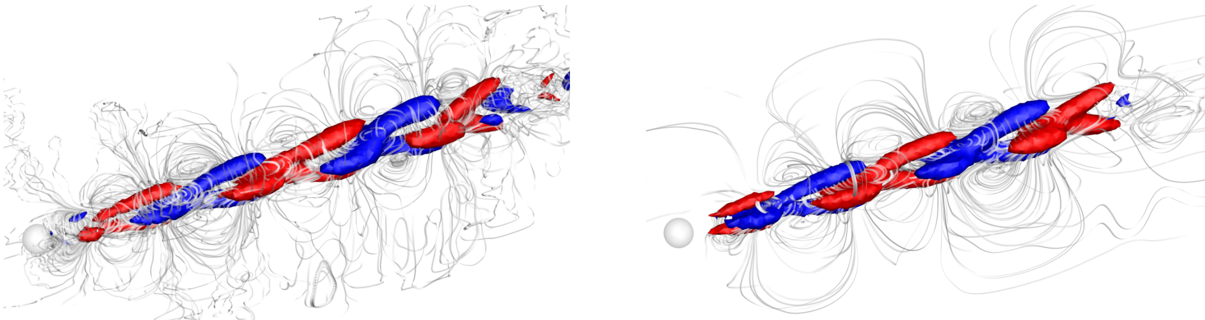

Figure 1: Real and imaginary parts of the most dominant dynamic modes for the flow past a sphere.

Acknowledgment This work has been funded by National Centre of Science under research grant no. 2011/01/B/ST8/07264.

REFERENCES

[1] Garnaud, X. and Lesshafft, L. and Schmid, P.J. and Chomaz, J.M., A relaxation method for large eigenvalue problems, with an application to flow stability analysis, *Journal of Computational Physics*, 231, pp. 3912–3927, 2012.

[2] Gómez, F. and Gómez, R. and Theofilis, V., On three-dimensional global linear instability analysis of flows with standard aerodynamics codes, *Aerospace Science and Technology*, 2013.

[3] Holmes, P. and Lumley, J.L. and Berkooz, G., *Turbulence, Coherent Structures, Dynamical Systems and Symmetry*, Cambridge University Press, Cambridge, 1998.

[4] Morzyński, M. and Afanasiev, K. and Thiele, F., Solution of the eigenvalue problems resulting from global non-parallel flow stability analysis, *Comput. Meth. Appl. Mech. Enrgrg.*, 169, pp. 161–176, 1999.

[5] Noack, B.R and Morzyński, M. and Tadmor, G., Reduced-Order Modelling for Flow Control, *CISM International Centre for Mechanical Sciences, 528*, Springer, 2011

[6] Noack, B.R., Afanasiev, K., Morzyński, M., Tadmor, G. and Thiele, F., A hierarchy of low-dimensional models for the transient and post-transient cylinder wake, *J. Fluid Mech.*, 497, pp. 335-363, 2003.

[7] Schmid, P.J. and Sesterhenn, J. Dynamic mode decomposition of numerical and experimental data, *J. Fluid Mech.*, 656 (1), pp. 5–28, 2010.

[8] Stankiewicz, W. and Roszak, R. and Morzyński, M. and Noack, B.R. and Tadmor, G., Continuous Mode Interpolation between Multiple Operating and Boundary Conditions for Reduced Order Modelling of the Flow, *AIP Conference Proceedings*, 1389 (1), pp. 94–97, 2011.