Sensitivity analysis of limit cycles of Navier–Stokes equations by the Harmonic–Balance method

Javier Sierra*
UNISA – University of Salerno, Fisciano Italy
UPS-IMFT – Paul Sabatier University – Institute of Fluid Mechanics, Toulouse France

Pierre Jolivet
CNRS-IRIT, 2 rue Charles Camichel, 31071 Toulouse Cedex 7, France

Vincenzo Citro, Flavio Giannetti
UNISA – University of Salerno, Fisciano Italy

Sensitivity of periodic solutions of time-dependent partial differential equations are commonly computed using time-consuming direct and adjoint time integrations. Particular attention must be provided on the periodicity condition in order to obtain accurate results. Furthermore, stabilization techniques are required if the orbit is unstable. In this talk we will discuss an alternative methodology to evaluate the sensitivity of periodic flows via the Fourier–Galerkin method. Unstable periodic orbits are directly computed and continued without any stabilizing technique. Stability of the periodic state is determined via the Hill's method: the frequency-domain counterpart of Floquet analysis. Sensitivity maps, used for open-loop control and physical instability identification, are directly evaluated using the adjoint of the projected operator. Furthermore, we propose an efficient and robust iterative algorithm for the resolution of underlying linear systems. The problem is solved with the FreeFEM library, in particular block matrices are interfaced with PETSc/SLEPc. Efficient preconditioning techniques are implemented to solve the underlying linear systems of the Newton iteration and they are put into test in the transition to a three-dimensional state in the periodic vortex-shedding past a circular cylinder. In addition, such a flow case allows the validation of the sensitivity approach by a systematic comparison with previous results presented in literature.

Keywords: Sensitivity, Fourier–Galerkin method, Floquet stability analysis, unstable periodic orbits

* javier.sierra@imft.com