Literature Review of Flow past a Cylinder with a Flexible Splitter Plate

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1 Introduction

Flexible structures deform and deflect due to fluid forces acting on them when exposed to fluid. In the meantime, structural displacement affects the flow. That leads to the coupling process between fluid and structure, which is referred to as fluid-structure interaction (FSI). The fluid-structure coupling phenomenon can be seen in almost all engineering fields. With the development of computers, numerical simulation techniques are increasingly used in modern industrial design. At present, FSI numerical simulation has become an important tool for solving such problems. In order to ensure the reliability of numerical computation, this study provides a challenging and well-defined validation test case (FSI-PfS-1a) for FSI in turbulent flow [1]: The benchmark case presented (FSI-PfS-1a) is derived from the experiment of Gomes and Lienhart [2, 3], but is somewhat simplified. The configuration is made up of a flexible membrane-like rubber tail attached to the back of a stiff cylinder that is subjected to a uniform inflow with low turbulence. The flexible structural deformation is described using the St.Venant-Kirchhoff material model.

This study begins with a detailed experimental study using particle-image velocimetry (PIV) and laser triangulation techniques. The structural deformation modes of the flexible cantilever plate under different incoming flows are analyzed by experiment. The final selected inlet flow velocity is $u_{\text{inflow}} = 1.385\,\text{m/s}$. At this time, the deformation of the flexible rubber plate is in the first swiveling mode and is quasi-two-dimensional. The flexible structure presents quasi-periodic oscillations, and the structural displacement is large enough and symmetrical. According to the selected inflow velocity and cylinder diameter, the Reynolds number is equal to $Re = 30470$. At this inflow velocity, the flow around the cylindrical front is in a sub-critical regime. At this time, the boundary layer at the front cylinder is still laminar flow, but a transition to turbulence occurs in the free shear layer. The free shear layers are separated and evolved from the boundary layer behind the cylinder vertex. From the separation point, laminar flow transits to turbulence, and the flow becomes three-dimensional and chaotic.

In this study, the simulation is carried out by the coupling partitioned FSI algorithm with the large eddy simulation (LES), and the results in the subset case and the full case are compared simultaneously. For the subset case, periodic boundary conditions are applied to the lateral sides of both the structure and the flow. For the full case, the normal displacement of the boundary node on the lateral sides is forced to be zero. In the full case, due to the wider structure and less constraints on the lateral side nodes, the deformation in the span-wise direction is relatively larger. However, compared with the phase average flow field and the deformation of the structure in the cross-stream direction, there is no significant difference between the two cases (only a small local error exists behind the structure in the vortex shedding area). The phase average flow field predicted in the subset case is very similar to that in the full case. The subset case consumes less CPU time, but the results are almost the same as those of the full case. Therefore, the periodic boundary conditions can be used to simplify the computation.

In addition, the sensitivity of parameters is studied. The results show that Young's modulus is the most important parameter, which controls the deformation mode of flexible structures. In addition, it can be observed that the slight modification of plate thickness has some influence on the prediction of FSI. On the contrary, the change in density has little impact on the FSI prediction.

By comparing with the experiment, it is found that the structural damping of the rubber material cannot be ignored in the current case. And the structural damping will significantly affect the deflection of the structure. Classical Rayleigh damping is used in the study. Rayleigh damping assumes that the damping matrix of the structure is a combination of a mass matrix and a stiffness matrix. Without considering damping, the structural deflection will be overpredicted. A simple structural damping model can improve the results.

In the end, for the instantaneous results under the phase average, the FSI simulation calculation is very consistent with the PIV experimental measurement. The frequencies obtained by FSI simulation match the measured frequencies (including flexible structure vibration frequency and vortex shedding frequency) in particular. At the same time, FSI simulation correctly predicted the vortex shedding phenomenon behind the structure and the location of the downstream shedding vortex.

References

[1] G. De Nayer et al. "Flow past a cylinder with a flexible splitter plate: A complementary experimental–numerical investigation and a new FSI test case (FSI-PfS-1a)". In: *Computers & Fluids* 99 (2014), pp. 18–43. ISSN: 0045-7930. DOI: `https://doi.org/10.1016/j.compfluid.2014.04.020`. URL: `https://www.sciencedirect.com/science/article/pii/S0045793014001583`.

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[3] Jorge Pereira Gomes and Hermann Lienhart. "Fluid–structure interaction-induced oscillation of flexible structures in laminar and turbulent flows". In: *Journal of fluid mechanics* 715 (2013), pp. 537–572.