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3D CFD Simulation of Vortex-induced Vibration of Cylinder

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The 3D flow around a circular cylinder free to oscillate transversely to the free stream was simulated using Computational Fluid Dynamics (CFD) and the Spalart-Allmaras Detached Eddy Simulation (DES) turbulence model for a Reynolds number $Re = 10^4$. Simulations were carried out for a small mass-damping parameter $m^*\zeta = 0.00858$, where $m^* = 3.3$ and $\zeta = 0.0026$. We found good agreement between the numerical results and experimental data. The simulations predicted the high observed amplitudes of the upper branch of vortex-induced vibrations for low mass-damping parameters.

INTRODUCTION

The simulation of the vortex-induced vibration (VIV) phenomenon is a subject that has been defying CFD experts. The vortex wake of the high Reynolds number flow around bluff bodies is in general turbulent and 3D, requiring huge computational resources and fine meshes to accurately capture its physical behavior. As was pointed out by Shur et al. (2005), even when the geometry suggests that 2D simulations should be successful, as is the case with the flow around a circular cylinder, the lack of 3D effects generates results that are not in 2D experiments. For this reason, we can hardly expect 2D RANS simulations to produce meaningful results for higher Re numbers.

Due to the difficulties, the vast majority of CFD VIV simulations of the flow around circular cylinders that can be traced in the literature are concerned with low Reynolds flows. For $Re < 180$ the wake is laminar and 2D, simplifying the numerical approach and avoiding the need of expensive hardware. But, as pointed out by Williamson and Govardhan (2004), these simulations in general predict peak vibration amplitudes around $0.6D$ (where D is the cylinder diameter) when experiments for higher Re produce amplitudes well over $1.0D$. The usefulness of low Re simulations is arguable, once the flow around oil risers and other structures is in general in the range $10^4 < Re < 10^6$.

Some of the few 3D simulations of the VIV phenomenon for higher Re numbers can be found in the works of Dong and Karniadakis (2005) and Dong et al. (2006). The first work presents results of DNS simulations of the flow past a stationary cylinder and a cylinder undergoing forced harmonic oscillations using a spectral element method at $Re = 10000$; the second work presents similar DNS simulations and PIV measurements of the flow past a stationary cylinder at $Re = 4000$ and 10000. Results of the simulations are in close agreement with the experiments, but the use of the spectral element method to perform DNS required large computational resources.

A better alternative for practical engineering simulations seems to be to rely on Large Eddy Simulation (LES) or hybrid RANS-LES methods, such as Detached Eddy Simulation (DES). According to Shur et al. (2005), these methods are better suited for the simulation of the flow around bluff bodies because they are less dissipative than RANS, and so do not damp the development of 3D turbulent structures in the wake. For this reason we decided to carry out simulations of the 3D flow around a circular cylinder free to vibrate in the transverse direction using the Spalart-Allmaras DES model, from Spalart (2000), for a Reynolds number $Re = 10^4$.

It can be argued that the VIV of a cylinder is strongly affected by the vibrations in the streamwise direction, and that 2 degrees of freedom VIV simulations would be more interesting for practical applications than simulations with the cylinder free to vibrate only in the transverse direction. When experimentally studying 2 degrees of freedom VIV for mass parameters $m^* < 6.0$, Jauvtis and Williamson (2004) found what they called a super-upper branch of cylinder response, with the streamwise vibration deeply affecting the modes of vortex shedding and the transverse vibrations, which resulted in cross-flow VIV amplitudes near $1.5D$. Dahl et al. (2007) found through PIV visualizations that when the inline and transverse natural frequencies are close to the 2:1 ratio, the motion of the structure near resonance is strongly affected, and the 2P and 2S modes of vortex shedding seen in transverse-only oscillations are replaced by more complex patterns consisting of vortex triplets and quintuplets that cause high-amplitude harmonics in the lift force.

The study of 2 degrees of freedom VIV is more relevant, from an engineering point of view, than the transverse-only VIV, but it is a more complex subject. For this reason we decided to focus the present simulations on the simpler problem of transverse-only VIV in order to validate CFD procedures and acquire a better assessment of mesh requirements, turbulence models and computational resources, and to leave 2 degrees of freedom VIV simulations for future work.

So, for our 3D simulation of the VIV response of a cylinder free to vibrate in the transverse direction at $Re = 10^4$ we used a low mass-damping parameter, with $m^*\zeta = 0.00858$, where $m^* = 3.3$ and $\zeta = 0.0026$. The mass parameter $m*$ is equal to the mass of the cylinder divided by the mass of displaced fluid, $m^* = m/m_d$,

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