AN EFFICIENT FSI SOLVER FOR
MULTIPLE-DEGREE-OF-FREEDOM FLOW-INDUCED
VIBRATION

METHMA M. RAJAMUNI*, MARK C. THOMPSON* AND KERRY
HOURIGAN*

*Fluids Laboratory for Aeronautical and Industrial Research (FLAIR),
Department of Mechanical and Aerospace Engineering, Monash University, Clayton, Victoria
3800, Australia
e-mail:methma.mm@gmail.com

Key words: Flow-induced vibration, FSI solver, Vortex-induced vibration, VIV modes

Abstract. A new FSI solver was developed within the OpenFOAM CFD framework to
study the flow-induced vibration of tethered or elastically mounted bodies. It is a fully
coupled fluid-structure solver using a non-deformable mesh. This solver was used to pre-
dict the vortex-induced vibration of a tethered sphere in a uniform current at a Reynolds
number of $Re = 1200$ and mass ratio of $m^* = 0.8$. The sphere experienced similar large
amplitude periodic modes I and II vibration states to those seen in experiments.

1 INTRODUCTION

A new fluid-structure solver was developed within the OpenFOAM package to solve
fluid-structure interaction (FSI) problems of single bodies efficiently without requiring
dynamic meshing/remeshing as part of the solution process. We have applied it to predict
the flow-induced oscillations of a tethered sphere under the assumption of an inextensible
tether. This is a fully coupled solver based on extending the ‘icoFoam’ solver for modeling
time-dependent incompressible laminar flows. A third-order predictor-corrector iterative
method is employed to solve the fully coupled solid body and fluid equations.

2 NUMERICAL METHODS

The fluid flow was modeled in a non-inertial reference frame attached to the center of
the solid body. Therefore, the acceleration of the solid body, $a_c$, appears in the momentum
equation as a source term to account for the acceleration of the reference frame. The
governing equations for an incompressible fluid can be written

$$\frac{\partial u}{\partial t} = -(u \cdot \nabla)u - \frac{1}{\rho} \nabla p + \nu \nabla^2 u - a_c,$$  \hspace{1cm} (1)

$$\nabla \cdot u = 0.$$  \hspace{1cm} (2)

The dynamical equation describing the motion of the solid body was obtained using a
spherical coordinate system with angles $\theta$ and $\phi$ (see equation 3). Here, $f_d$, $f_y$, and $f_z$
are the Cartesian fluid forces, $b$ is the buoyancy force, $m$ and $D$ are the sphere mass and
its diameter, respectively, and \( L \) is the tether length. Also, \( \mathbf{a}_c \) is the linear acceleration vector of the sphere calculated from the angular accelerations obtained from equation 3. Equations 1–3 were solved using a predictor-corrector iterative method, with iteration continuing until the angular accelerations and the fluid forces are within the given error bounds.

\[
\begin{pmatrix}
\ddot{\theta} \\
\ddot{\phi} \\
0
\end{pmatrix} = \frac{L}{m \left( \frac{D^2}{16} + L \right)} \begin{pmatrix}
-\sin \theta / \sin \phi & \cos \theta / \sin \phi & 0 \\
\cos \theta \cos \phi & \sin \theta \cos \phi & -\sin \phi \\
0 & 0 & 0
\end{pmatrix} \begin{pmatrix}
f_d \\
f_y + b \\
f_z
\end{pmatrix} + \begin{pmatrix}
-2\dot{\theta} \dot{\phi} \cot \phi \\
0
\end{pmatrix}. \tag{3}
\]

3 RESULTS

Vortex-induced vibration of a tethered sphere of mass ratio \( m^* \equiv \rho_{\text{sphere}} / \rho_{\text{fluid}} = 0.8 \), was studied at the Reynolds number of \( Re \equiv UD / \nu = 1200 \), for the reduced velocity range \( U^* \in [3, 11] \). Figure 1 compares the computed RMS sphere response amplitude, \( A^* \), with the experimental results of [1] obtained for a sphere of same mass ratio but at higher and varying Reynolds number. Given, the expected variation due to Reynolds number differences, our results compare well with those of [1]. In particular, they identified two different modes of vibrations (modes I and II) in the reduced velocity range \( U^* \in [5, 11] \) also seen in our results.

![Figure 1: The comparison of predicted and experimental sphere response amplitudes.](image)

4 CONCLUSIONS

A new FSI solver was developed in the strongly parallel OpenFOAM CFD framework to study flow-induced vibration of single bodies. Simulations were conducted at \( Re = 1200 \) and mass ratio 0.8 for a vibrating tethered sphere. Mode I and II vibration states were observed computationally to be similar to those seen in previous experimental studies.

REFERENCES