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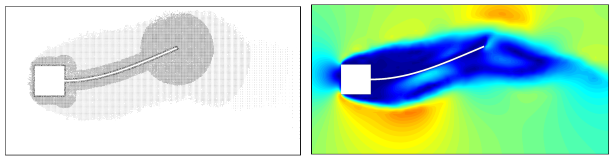
Partitioned vortex methods for fluid–structure interaction of thin-walled flexible structures

Abstract

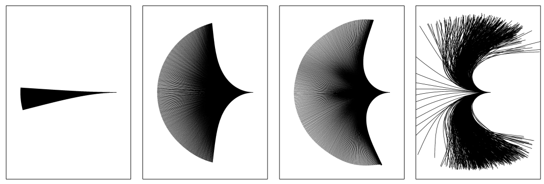
The interaction between a structure and surrounding fluid flow is known as fluid–structure interactions (FSI). In such an interaction, the motion of the structure causes a change in the fluid stresses that act on the surface of the structure, which in turn causes a change in the structural motion. FSI problems are frequently encountered in many areas of civil, mechanical, and aerospace engineering, such as the aeroelastic analysis of long-span bridges, tall buildings, lightweight thin membrane roofs, solar chimneys, the stability analysis of airplane wings, marine risers, and so on. Structural systems under wind loading may experience large amplitude divergent or limit cycle oscillations due to the aerodynamic phenomena such as vortex-induced vibration, galloping, and flutter.

In recent years, the unstable aeroelastic response of thin-walled cantilever systems has been exploited for small-scale energy harvesting. The aim is to supply sustainable green power for portable and wireless electronic devices, especially those expected to operate for a long time with no human intervention. The analysis of FSI problems can be extremely challenging when a thin and flexible body undergoes large deformations. In case of such a flexible energy harvester, the additional electrical damping effects need to be considered in the FSI simulation. The accurate prediction of these coupled large amplitude responses is very challenging, however, necessary to investigate such FSI mechanisms of many similar structures, to quantify essential influencing parameters and, if necessary, to be able to optimize the performance of aeroelastic energy harvesters.

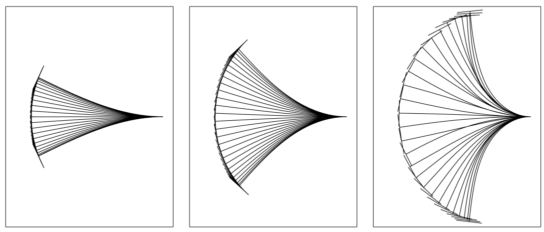
An in-house flow solver based on Vortex particle Method (VPM) is extended for 2D and pseudo-3D FSI simulation of thin-walled systems. Whilst the existing solver is based on linear structural vibration behaviour, the flexible structures or a flexible harvester undergoing large vibrations requires a more advanced structural modelling to accurately predict the system vibrations. A structural solver based on a corotational finite element formulation is coupled with 2D VPM to account the geometrically nonlinear effects accurately. This model is extended further to perform aero-electromechanical coupled simulation for analysing the performance of different cantilever energy harvesters. Furthermore, the existing pseudo-3D multi-slice model is extended to simulate the FSI simulation of thin surface type systems such as cantilever roofs and cooling towers. The novelty of the extension is the consideration of flexibility of the surface geometry at each 2D simulation slice.



FSI simulation of a flexible cantilever in Kármán vortex street



Aeroealstic response of an inverted cantilever in increasing wind speeds



Aero-electromechanical coupled simulation of a flutter-based T-shaped electromagnetic energy harvester under increasing wind speeds

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Related publications

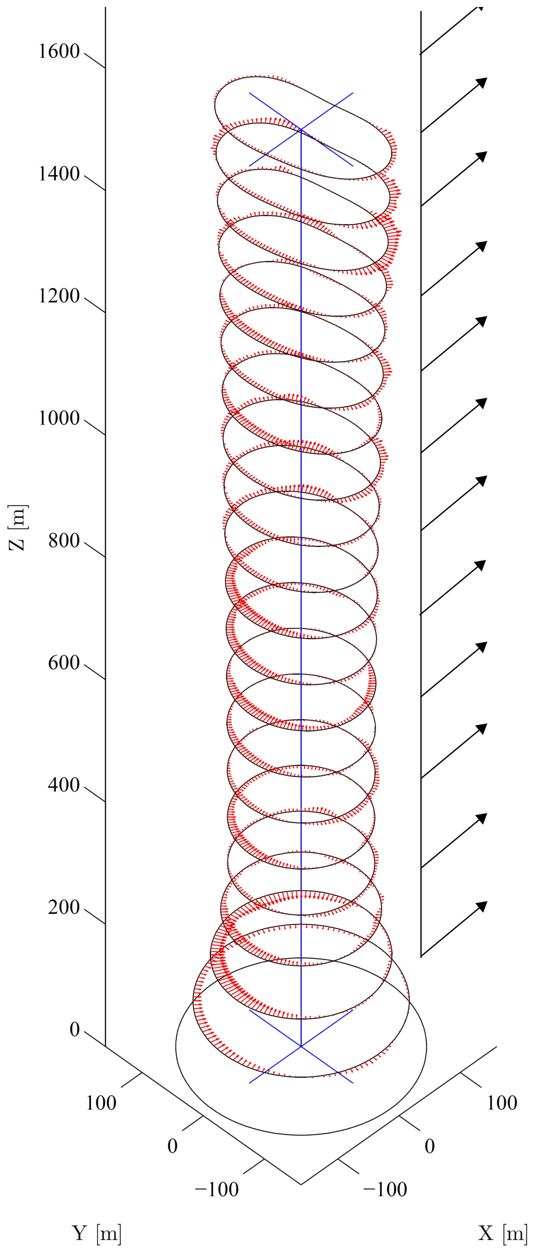
[1] Chawdhury, S., Morgenthal, G., Flow Reproduction using Vortex Particle Methods for Simulating Wake Buffeting Response of Bluff Structures, Journal of Wind Engineering and Industrial Aerodynamics, 151 (2016), pp. 122–136

[2] Chawdhury, S., Morgenthal, G., Numerical simulations of aeroelastic instabilities to optimize the performance of flutter-based electromagnetic energy harvesters,

Journal of Intelligent Material Systems and Structures, 29(4) (2018), pp. 479–495

[3] Chawdhury, S., Milani, D., Morgenthal, G., Modeling of pulsating incoming flow using vortex particle methods to investigate the performance of flutter-based energy harvesters, Journal of Computer and Structures, 209 (2018), pp. 130–149

[4] Chawdhury, S., Morgenthal, G., A partitioned solver to simulate large-displacement fluid-structure interaction of thin plate systems for vibration energy harvesting, Journal of Computers and Structures (2019) (submitted)



Pseudo-3D multi-slice simulation of a 1500 m tall solar chimney under the wind speed of 35 m/s