Implementation of Fluid-Structure Interaction Solver in Nektar++

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Nomenclature

DFT	Direct numerical simulation
DNS	Direct numerical simulation
FSI	Fluid-Structure Interaction
GECB	Geometrically exact composite beam
LES	Large-Eddy simulation
VIV	Vortex-induced vibration

1 Outline

Design and analysis of modern engineering systems as well as research and investigation of many physical phenomena requires study and simulation of multidisciplinary problems. Among such multidisciplinary problems, Fluid-Structure interactions encountered in many areas including but not limited to simulation of wind turbines and vortex-induced vibration (VIV) of their blades, flapping hydro turbines, aeroelastic of compliant deformable wings, parachutes cables and marine riser to name a few. This, highlights the necessity of extending capabilities of computational frameworks, such as Nektar++[1], beyond conventional CFD for addressing FSI problems. Further, many of these applications involve FSI of slender structure in high-Reynolds-number anisotropic turbulence due to the motion of the structure as well as large boundary layer separation because of the shape of structure or flow incident angle, where requires high-fidelity numerical method as well as highly scalable computational code for their simulations. In this context, Nektar++ framework is of particular interest due to its formulation based on spectral/hp element method and its high scalability. Nektar++ is an object-oriented C++ tensor-product open-source computational frame work based on spectral/hp finite element where it allows construction of efficient solvers using conventional low-polynomial order h-type formulation as well as higher p-order piece wise polynomial solvers. Nektar++ currently supports the VIV of slender structure via linear DFT (Discrete Fourier Transfrom) solver and coupling with *SHARPy*[2] library (currently under development) which uses non-linear geometrically exact composite beam (GECB) model for single structure. Both FSI approaches are based on *thick strip* method where the $3D$ fluid domain is represented with series of smaller domains, thick strips, each of them have a finite thickness in the spanwise direction of the structure. Having a finite thickness in spanwise direction enables the method to capture the local three-dimensional flow structures and hence capturing the turbulent wake's local three-dimensionality and its effect on the FSI of slender structure. A distinct advantage of such an approach is that while the local 3D turbulence can be captured because of strips thickness, only a fraction of a full three-dimensional fluid domain is modelled which can be simulated efficiently. In this project our plan is to extend the Nektar++/*SHARPy* FSI solver to include more general cases of rotating multi-body FSI simulation of highly deformable slender structures. The outcome of our work helps to extend the Nektar++ capabilities reaches further beyond the conventional CFD simulations and benefits the computational community, both in academia and industry, with an efficient implicit-LES/DNS nonlinear FSI solver with wide range of applications particularly in design and simulation of wind-turbines for harvesting green sustainable wind energy.

2 Project Objective

The end goal of this project of extend the Nektar++/*SHARPy* FSI solver which is currently under development by the same researcher for VIV of slender structure, to include the more general case of FSI of multi-body and incorporate the effect of rotating frame of reference with applications in simulation of turbomachinery and wind turbines.

Rotating frame of reference

In order to incorporate the rotational motion of structure while avoiding the difficulties arises in dynamic remeshing, one can use body-fitted non-inertial rotating frame of

[1] www.nektar.info
[2] www.imperial.ac.uk/aeroelastics/sharpy

reference where the effect of motion of the frame of reference can be reflected in Navier-Stokes equations using proper transformation of the equations and via appropriate source terms. Further, the rotational motion of structure, in general, consists of prescribed rigid-body rotation such as when the turbine blades rotating with a specific angular velocity as well as local rotation of structural sections around the local spanwise direction due to the deformation of the structure. This step consist of implementation of such effect that consistently incorporate both type of rotations in the Fluid solver including both governing equations as well as Dirichlet, Neumann and high-order outflow boundary conditions.

Multi-body

Nektar++/*SHARPy* FSI solver is currently supporting FSI simulation of non-rotating single slender structure while in many practical applications we are interested in simulation of multi-body FSI problems. The structural solver, *SHARPy*, already supports multi-body, however, the coupling interface between Nektar++ and *SHARPy* requires further extension for appropriate set up and force/displacement transfer between the two solvers for case of multi-body FSI. Further, the FSI solver uses several frame of reference in fluid and structural solvers and the multi-body set up requires intermediate functions to appropriately interpret the user inputs in Nektar++ format and set up the problem while maintaining consistency between various frames of references and bodies orientation resulting in a user-friendly interface for the multi-body FSI solver. This step focuses in providing the required functionality and implementation of multi-body-supported coupling interface in Nektar++.

3 Alignment with Prism strategy

Development of key staff: I have a strong background in computational methods with a specific focus on Fluid-Structure interaction. At the present, I am actively seeking a permanent academic position where my efforts in development of Nektar++ FSI solver will plays a central role in my future research targeting applications in wind energy, bio-inspired fluid dynamics and aero/hydro-elastic FSI simulations. This will be beneficial for the dissemination of Nektar++ into other fields and institutions. My expertise in FSI and nektar++ will allow me to finish the goals of the proposal in the 7-month timeframe.

Retention of Knowledge: I am currently the only developer of Nektar++ working on FSI of deformable structure and have been developing the current Nektar++/*SHARPy*. The continuation of my funding will help finalizing the current state of FSI solver, reducing required times and effort for the next developer to focus on developing new features and enhancing the FSI functionality of Nektar++.

Supporting long-term research: In the general scale, this project lays a foundation for the highly-scalable FSI solver with particular application in wind energy and modern wind turbine design. Such FSI simulations are inevitable part of modern wind turbine designs and benefits both academic and industry with an open-source efficient solver for wall-resolved FSI of slender structure. On the personal level, it helps me to establish a concrete foundation and gain an invaluable knowledge and experience in Nektar++ and spectral/hp element method via direct interaction with main Nektar++ developers. This is of upmost importance in my future research as the FSI solver and Nketar++ will be central part of resarch focusing on nature-inspired FSI and fluid dynamics and their applications in modern engineering design and green energy.

Integration with PRISM: Focusing on the Fluid-Structure interaction, this project helps extending the horizon computational package beyond the conventional CFD, providing academic and industrial community with the open-source efficient FSI solver which widens the user community of PRISM tools.

4 Work Plan

As I am already experienced with Nektar++ and the FSI solver, the work can be started immediately. The first step is formulating NS equations in rotational frame of reference and implementing the required source terms in the solver as well as any modification required for handling boundary conditions. The implementation will be tested with several simulations. The next step is to extend the current FSI coupling interface for multi-body which follows by automating the robust setup for the users. A user guide will be prepared and a research paper will be submitted.