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Fluid-Structure Interaction on sail fabric type structures

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Sail analysis is a rapidly evolving field of engineering, since it has a big impact in the performance of yachts. In the presented approach, a weak coupling in Arbitrary Lagrangian Eulerian (ALE) configuration has been chosen. The flow is analyzed with a Reynolds Averaged Navier Stokes (RANS) solver, whereas the structural analysis is performed with Shell Finite Elements.

The flow is analyzed with OpenFOAM, and the PimpleDyMFOAM Finite Volume Reynolds Averaged Navier Stokes (RANS) solver has been chosen for its dynamic mesh capabilities. SST turbulence model has been chosen, since this is generally considered as the most computationally efficient solution for sail type flows [1].

From a structural point of view sails are constituted by thin laminates. Traditionally membrane models have been used for the simulation of sail type structures [5]. However here it has been chosen to use shell elements for the structural deformation analysis. This allow the direct representation of wrinkling, a buckling related phenomenon which is often encountered for downwind sails. Wrinkling determines the formation of oscillations onto the fabric surface, entirely controlled by the bending stiffness. Neglecting the wrinkling in the finite element representation may lead to inaccurate predictions or strong singularities of the solution. The suitability of using shell finite elements for such analysis has been proven by several authors [3, 2]. The structural analysis is carried out with shell elements (MITC4) implemented in the program Shelddon [4].

Due to the very thin fabric thickness, convergence issues are often encountered. This has been overcome with the use of a dynamic Newmark type routine for solving a Mass-Stiffness-Damping system. The damping is then defined by a linear combination of mass and stiffness matrices. All parameters have been tuned in order to optimize the convergence rate.

Fluid Structure coupling is performed with an Arbitrary Lagrangian Eulerian (ALE) framework, by taking advantage of the dynamic mesh capabilities of OpenFOAM. The solver PimpleDyMFOAM has then been modified in order to allow the communication with the structural solver, managed via an MPI communicator.

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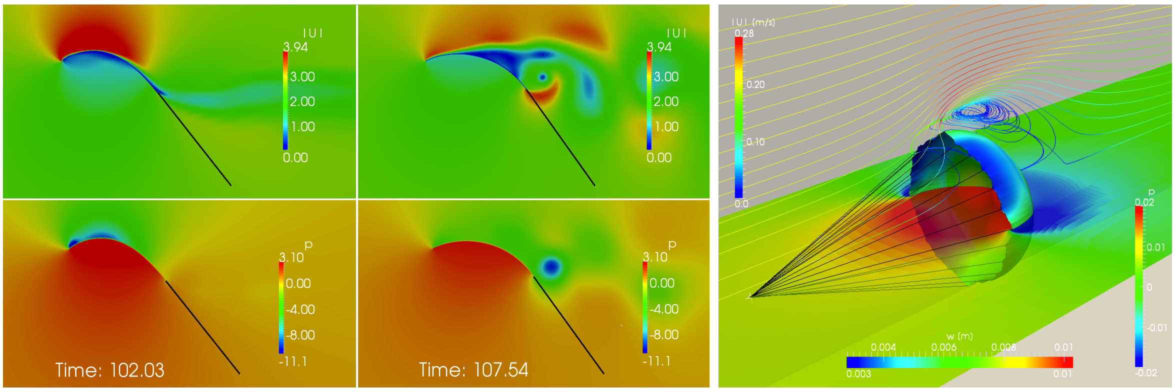

Figure 1: *Left:* Fluid structure interactions for a 2d sail section, supported on one point and a cable. The images report the extremes of a load cycle. *Right:* Fluid structure interactions for a 3d parachute, used for validation purposes.

The coupling is actually performed under the assumption of *'quasi static'* structure. The fluid load is then applied to the structure as a static load; the deformed shape is then assigned to the fluid domain, where the fluid is evolving in time. This explicit uncoupled strategy has been chosen in order to overcome stability issues in the coupling. Due to the very limited thickness of the fabric however oscillations are likely to form, expecially in the the first part of the structural deformation path. Investigations are going on in order to understand if the fabric mass is small enough to make the adopted coupling approach acceptable.

By the time of the workshop some calculation routines will be hopefully ready, allowing the use of non-conforming meshes between the structural and the fluid domain. In the present definition the domains are in fact *one-to-one* mapped.

Investigations are also going on in order to understand how to exploit the OpenFOAM parallel capabilities: the current protocol does not allow communication of decomposed cases with the structural solver.

References

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[3] Y. Wong and S. Pellegrino, Wrinkled Membranes: Experiments, analytical model and simulations, *Journal of Materials and Structures*, **1** (2006)

[4] *Shelddon* is a finite element library developped at INRIA and registered at the *Agence pour la Protection des Programmes* under ref: IDDN.FR.001.030018.000.S.P.2010.000.20600. The base of the program is openSource and available online: *http://www-rocq.inria.fr/modulef/*.

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