

## Fluid Structure Interactions applied to Downwind Yacht Sails

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**Abstract** — Sail analysis is a field of engineering which is rapidly evolving, since its big impact in the performances of yachts. Due to the amount and the complexity of involved phenomena, the application of fluid-structure interaction techniques was made possible in recent years only. In the presented approach, a weak coupling in Arbitrary Lagrangian Eulerian (ALE) configuration is presented. The flow is analyzed with a Reynolds Averaged Navier Stokes (RANS) solver, whereas the structural analysis is performed with Shell Finite Elements.

**Keywords**— Sail analysis, RANSE, Finite Elements.

### 1 Phenomena overview and state of the art

Downwind sail analysis is made particularly difficult because the number of complex phenomena and the request of high precision by the sailing teams. In Fig.1-a, a downwind sail profile is represented as a thin and highly cambered wing profile. Due to the size and the relevant wind speed, transition to turbulent flow shows in the very first part of the device. Downwind sails operate at large angles of attack, therefore the driving force is the resultant of an intermediate regime of lift and drag generation, with large regions of separated flow.

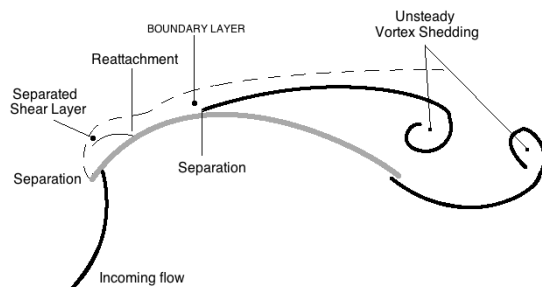


FIG. 1 – Universal flow distribution and flying sail, where wrinkle generation is visible

From a structural point of view sail are constituted by thin orthotropic laminates, which are assumed in large displacements-small strains regime. Some buckling related phenomena are encountered, called ‘wrinkling’. This determines the formation of oscillations and wrinkles onto the fabric surface, where local uni-axial stress concentrations are encountered, as in Fig.1-b. Such phenomena can modify stress distributions, with dramatic impact on the whole deformed shape. One important aspect of sail analysis is then unsteadiness, which can be driven by a composition of fluid unsteadiness (such vortex shedding) and unsteadiness induced by the boat’s motions in seaway.

Downwind sail analysis are can be found in the literature of the very last year only, due to the high computational cost. Generally authors chose to model the flow with Finite Volumes (FV) Methods for the solution of RANS equations [4], and SST turbulence model is preferred. Downwind sail fluid structure interactions have been presented, where a weak steady coupling is performed between RANS and FE solvers. From a structural perspective, the sailcloth is normally analyzed with CST membranes [3]. This is a rather simplified formulation, the reliability of which can be argued. When wrinkling occurs, the membrane model results undetermined, since it does not allow any bending stiffness. The

problem is generally overcome with *ad-hoc* wrinkling models, which modify the constitutive relationship when a wrinkling criterion is satisfied. Another approach is to use a more complete model such as general shells. In this case, all deformation components are considered, and it is then possible to represent directly the wrinkling components.

## 2 Methods

In the present analysis the flow is analyzed with the FV RANSE solver OpenFOAM, where SST turbulence model has been chosen. Results are obtained with an unsteady SIMPLE (Semi Implicit Method for Pressure-Linked Equations) type algorithm. Structural analysis is carried out with shell elements (MITC4) [1] implemented in the program Shelddon. This overcomes the intrinsic lack of determination of the membrane model, thus avoiding the need of a wrinkling model. Due to the very small fabric thickness, the problem results ill posed, thus 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. Rayleigh damping definition has been chosen, therefore Damping is defined by a linear combination of mass and stiffness. All parameters have been tuned in order to optimize the convergence rate. Fluid Structure coupling is performed with an ALE algorithm and dynamic meshes, taking advantage of routines already implemented in OpenFOAM and opportunely modified for dealing with the structural solver.

## 3 Results

In the paper some validation examples will be presented, where numerical and experimental test cases (both in the fluid and the structural domain) will be discussed and used for numerical analysis validation. The structural calculation will be detailed, and encountered problems will be shown and discussed. Results will then be presented about the fluid structure interaction coupling, both for steady (fixed point) and unsteady ALE coupling.

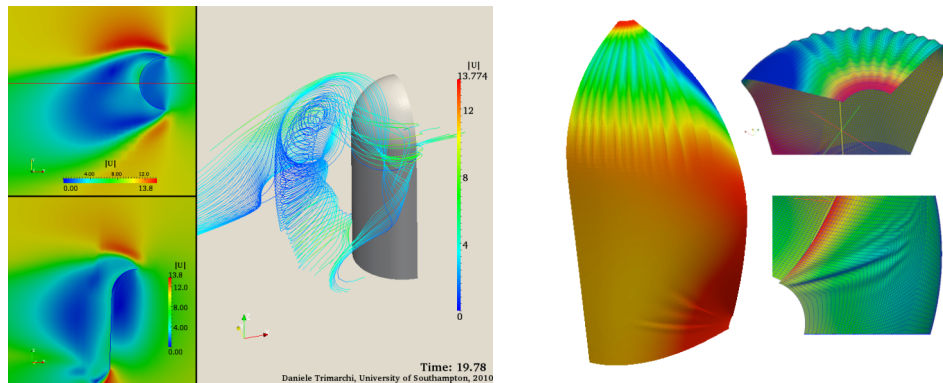


FIG. 2 – Numerical analysis of the flow and the deformation of a wrinkling downwind sail

## 3 References

- [1] D. Chappelle, K.J. Bathe. *The Finite Element Analysis of shells - fundamentals*, Springer, 2003.
- [2] M. Durand, Y. Roux et al., *Unsteady numerical simulations of downwind sails*, *Innov'Sail conference*, 2010.
- [3] J. Li, S. Chan, *An integrated analysis of membrane structures with flexible supporting frames*, *Finite Elements in Analysis and Design*, Elsevier, 2003
- [4] N. Parolini, A. Quarteroni, *Mathematical Models and Numerical Simulations for the America's Cup*, MOX report, 2004
- [5] H. Rensch K. Graf, *Fluid Structure Interaction Simulation of Spinnakers – Getting closer to reality*, *Innov'Sail conference*, 2010.