Non-linear fluid-structure interaction of a semi-rigid jib with forestay modeling.

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1 Introduction

This works is a contribution to the SolidSail Performance Oriented Rig Technology (SPORT) project, which purpose is to develop large semi-rigid sails to equip merchant ships. These sails are an assembly of several thin composite membrane panels linked together at the luff and the leech with textile loops and with secondary connections along the battens to facilitate the panels alignment (see figure 1). Each panel is surrounded by reinforced composite battens which ensure rigidity and set the sail profile. A Fluid-Structure Interaction (FSI) model is used to determine sail pressure loads and deformations at a steady state equilibrium. The method is described and investigated in previous works on a mainsail in Sacher et al. [1], and on a jib-mainsail configuration in Morvan et al. [2]. In the current study, a new forestay model combining non-linear deformations and frictionless contacts is suggested. Then the method is applied to the jib configuration of the SPORT project to evaluate the influence of a forestay on the structural stresses in the sail and loops.

Figure 1: Semi-rigid jib.

2 Numerical method

The fluid-structure interaction equilibrium is calculated by coupling a semi-analytic flow algorithm and the Abaqus finite elements structural analysis tool. The aerodynamic code is based on the vortex distribution of the Lifting Line Theory (LLT) model suggested by Katz and Plotkin [3]. The vortex strength, and hence the pressure load distribution, are computed on several 2-D sections of the deformed jib at constant altitudes. The resulting pressure field is then interpolated onto the structural mesh, and given as an input for the next structural analysis step. The detailed procedure is given in Sacher et al. [1].

The forestay cable is modeled in Abaqus as a series of 2-node cubic beam elements to avoid transverse shear strain energy. A toroidal rigid body tied to the luff is used to link the panels to the forestay, as depicted in the figure 2, with a hard frictionless contact settled between the torus external surface and the forestay nodes. To assess the model, a perpendicular load is applied to a single torus in contact in the middle of a pre-loaded forestay, varying the moments of inertia of the forestay denoted as I. The displacement U of the torus is compared to the theoretical displacement U_{th} in the figure 3, assuming a theoretical cable behavior (no bending and transverse shear strain energy) for the real forestay. A convergent trend is clearly noticed around $I/(SL^2) = 10^{-9}$, with S the area of the forestay section and L its length. For moment of inertia lower than this value, bending effects can be neglected. With this method, any cable can be modeled as a beam with an equivalent moment of inertia of $I = 10^{-9}SL^2$.

3 Comparison with and without forestay

The forestay model is then applied on a real jib configuration with eight panels to evaluate its influence on the whole structure. The FSI is conducted with and without forestay with the same inputs, based on experimental data currently being processed, which are the apparent wind angle of 22.09°, a wind speed of 22.53 kts and a clew tension of 1187.2 N. In the simulation without forestay, the tack tension is set to 7062.7 N. In the simulation with the forestay, the forestay tension is set to 5000 N and the tack load is set to 2067.2 N to keep the luff overall tension at the same value of 7062.7 N for both cases. The axial forces in each inter-panel loop of the luff is represented in figure 4. With the forestay, the forces in the loops are much lower than the tension without forestay, and more evenly distributed over the whole luff. It has to be noticed that the luff loop forces are lower than the tack tension because the secondary connections between panels also contain part of the longitudinal forces in the luff. Considering the jib configuration trimmed for a boat sailing upwind with a true wind angle of 38.09°, the driven force in the direction

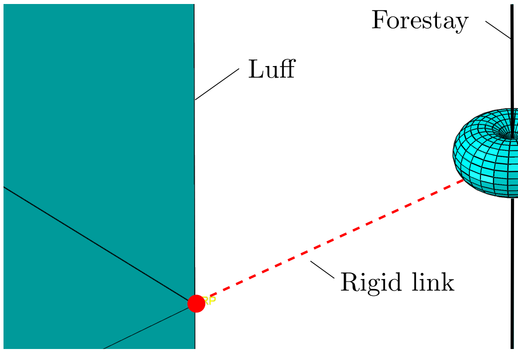

Figure 2: Schematic of the link between the luff and the forestay.

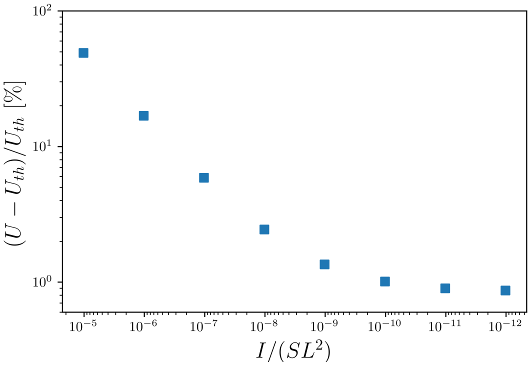

Figure 3: Displacement of the torus as function of the moment of inertia.

of the boat resulting from the LLT is 463.3 N with the forestay and 434 N without. To explain this difference, the maximum of camber at different altitudes on the jib is shown in figure 5. With the forestay, the maximum of camber at the middle of the sail is almost twice higher than without forestay, resulting in a higher lift of the jib with the forestay.

4 Further studies

For the final version of the conference paper, the effects of the forestay will be studied at a constant driven force in the direction of the boat. For that, an iterative procedure will be conducted to find the tack tension equivalent to the non-forestay case, for different forestay loads. This investigation will permit to discuss the benefits of a forestay on the structural stresses on the jib panels and loops at equal performance.

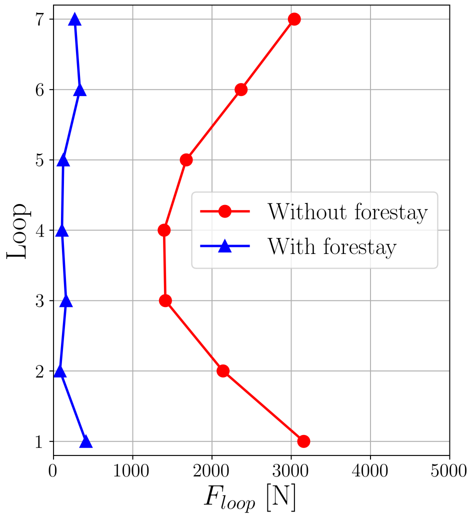

Figure 4: Luff loop axial forces between panels.

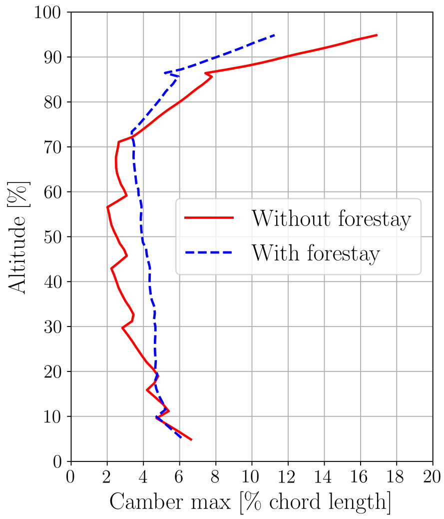

Figure 5: Camber max for different altitudes of the jib.

References

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