International Conference on Computational Methods in Marine Engineering
MARINE 2009
T. Kvamsdal, B. Pettersen, P. Bergan, E. Oñate and J. García (Eds)

A CALCULATION/SIMULATION SYSTEM OF SAILS COMMUNICATED IN REAL TIME WITH WIRELESS SENSORS

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Key words: Sails, rigging's configurations, real time data.

Summary. The model presented in this paper is part of the development and integration of a System to Support Decision (SAD) for assistance in the design and actuation of sails. The model is based on the union of a wireless sensor system, continuously connected to a calculation/simulation system. This system will predict the structural behavior and performance of the different configurations of the rigging of a sailing ship.

The simulation software will be communicated in real time with wireless sensors and interfaces through suitable filters. The information gathered by the sensors, which are integrated into the structure of the boat, will be used in numerical algorithms to determine the efforts that are suffering the Structure and evaluate the overall performance of the sailboat.

The system of calculation / simulation is made up of a model of structural calculation based on a quasi-static method with a formulation for large displacement typical of the finite element method, and includes models of membranes, cables and bars. And the starting point of the simulation tool of fluid dynamics is the method of vortices (contour elements). The algorithms are adapted so that they can make real-time data that offers the monitoring system. The software also has algorithms simulation maneuver with which you can change the position of the sails.

1 INTRODUCTION

A complete modeling of sail's steady equilibrium involves a fluid/structure analysis. Moreover, due to the complexity and the diversity of real operating conditions, the usual models are simplified ones, laminar inflow conditions. For steady case, we point out the interaction between the sail and the external flow is to be considered by complete model. The presence of the sail modifies the flow, while the flow applies aerodynamic forces on the sail and modifies its geometry.

The coupled aerodynamics/structural calculation system is continuously connected with a wireless sensor system. The simulation software is communicated in real time with wireless sensors and interfaces through suitable filters. The sensor system is integrated into the structure of the boat, so that gives us information about the forces and their direction, acting in the ropes. We use this information as input to the calculation/simulation system. The interface is programmed to provide the aerodynamic/structural system the inlet data: the strain of the ropes (the trim of the sails), the position of the main car, the velocity and direction of the inlet flow, etc.

2 NUMERICAL SIMULATION

First a sail configuration and an inlet external flow are given. The presence of the sail modifies the flow and a new external flow is then computed, aerodynamic step. The flow modifies the sail and a new configuration of the sail is computed, structural step. The configuration of the sail changes and a new flow is then computed, aerodynamic step. The new flow leads to a new geometry of the sail and so on. The sequence of aerodynamic/structural steps is repeated until the convergence. We consider the sail as an ideally flexible structure submitted to aerodynamic forces resulting from a given flow field.

2.1 Aerodynamic Step

Yacht sails are thin surfaces operating at moderate to high Reynolds numbers in a low speed flow, so it is natural that they should be modeled as thin surfaces carrying vorticity in an incompressible, inviscid fluid, loading to the numerical model of a vortex lattice. The feasibility of this approach was demonstrated over 41 years ago by Milgram[1].

The sails surface are discretized into a set of panels each carrying a locally constant value of doblicity that is identified as the actual value for the doblicity at some point in the panel. This internal point is also chosen at the collocation point for the panel and the boundary condition of tangential flow applied here. With this discretization, the integral giving the velocity induced by the continuous distribution of doublicity is replaced by the line integral around the panel edges. The Biot-Savart result for the velocity induced by a line vortex lying along the edge of a panel with circulation equal to the difference in doublicity of the panels having that edge in common. An “implicit” Kutta condition is used to determine the doublicity distribution in the wake, where the doublicity of a wake strip is set equal to the doublicity of the sail panel abutting the wake strip, removing the line vortex at the function of the surface and wake.

The shedding of a vortex from the leach of the sail, the wake, is an important feature of the real flow. The roll-up of these wakes is an important part of the calculation. The wake roll-up procedure is an iterative one, where an initially prescribed wake shape is relaxed by aligning the wake vortex filaments with the local flow direction.

The RANSE (Reynolds-averaged Navier-Stokes equations) are highly non-linear, so these are expensive in CPU time. The vortex method reduce the aerodynamic solution to a collection of linear equations, that are solved by a iterative process and allow to couple easily to a fluid-structure interaction problems, so this model is more appropriate to calculate during the sail yacht navigation.

2.2 Structural Step

The very flexible behavior of sails leads to large displacement analysis of very thin structures heading to the classical models of membranes, where flexion stresses are neglected. Due to large displacements, these models are geometrically nonlinear, and since deformations in modern sails, variations of lengths and angles in the material, remain low, constitutive laws of the material can be consider as linear, tensions in the structure are linear functions of the local deformations.

Such geometrically nonlinear membranes have been extensively studied and numerical implementation in, but they require important computational efforts compare to sails makers resources. We have been considered this method too expensive, in CPU time, to be coupled with a flow model, so simplified models or different strategies are then necessary. Is necessary a model that allow to compute quickly the solution.

We accept the model presented by Le Maître et al.[2] assume that sails can be correctly considered as structures constituted of elastic string networks. This approximation of the medium using strings is equivalent to consider only elastic deformations (strains) in a finite number of given material directions. Here material direction means that it moves with the structure. The strings network approximation is a simplified form of the nonlinear membrane model and it leads to a variational equation (Principle of Virtual Works) of Minimum of the Energy, which is functionally solved by relaxation.

The structural model also includes all the elements of the rigging system, using a standard FEM beam model. The contribution of the complete system is included in the variational principle and the minimization of the corresponding functional gives the solution of the problem.

3 THE INTERFACE

Investigation of the changes in sail forces due to different sail trim. In addition, the strain of material is responsible for geometry changes in different load distribution.

The system is designed to calculate during the sail yacht navigation. During the navigation the sailors trim their sails in order to optimize the aerodynamic forces and obtain maximum boat speed. They change the position of the cars and the first strain of the ropes, so we have to modelled these changes during the calculation.

The sensor system is integrated into the structure of the boat, and these give us information about the forces acting on the ropes. We use the strain on the ropes as input to the calculation/simulation system.

When some of the initial conditions (velocity, direction of the inlet flow, the first strain of some rope, position of the cars) change, the interface modifies these data in the aerodynamic/structural calculation/simulation system and this program is computed to determine the efforts that are suffering the Structure and evaluate the overall performance of the sailboat.

4 CONCLUSIONS

- With this model we can simulate the movements of the sails during the sail yacht navigation and determine the efforts that are suffering the Structure and evaluate the overall performance of the sailboat.
- This system will predict the structural behavior and performance of the different configurations of the rigging of a sailing ship, which will increase the level of security of this type of craft. It would also allow reliable criteria to optimize the design while increasing the performance of the boat in competition.

5 ACKNOWLEDGEMENTS

This work was partially supported by the DSSAIL Project (TSI-020100-2008-647) of the Ministerio de Industria, Comercio y Turismo, Spain.

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