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Fluid-Structure Interaction of a 3D Finn Dinghy Sail Membrane with Surrounding Viscous Air Flow

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ABSTRACT (DATE OF SUBMISSION: MARCH 15, 2021)
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Structural mechanics and dynamics of membrane structures are based on the in-plane tangential tensile force equilibrium of curved elastic surface structures.

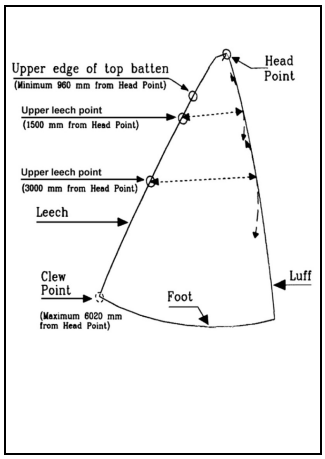
Sailing dinghies are lightweight structures that gain drive by main sail membrane with surrounding air flow. A finn class rules conform plane finn sail with plane curved boundaries is considered.

In a first step, stress-free transformation of the plane finn sail membrane with plane curved boundaries into two different warped configurations to meet beam elastic straight mast at luff and beam elastic boom at foot are determined as two different initial configurations to start finite element modeling of membrane time domain analysis. Structural elastic mast and structural elastic boom are equal-displacement connected to sail luff membrane boundary and sail foot membrane boundary, respectively. Structural boom is joint-connected to structural mast and translational-spring-connected to floor. Structural mast is horizontal-displacement fixed at deck height and fully displacement fixed at mast bottom.

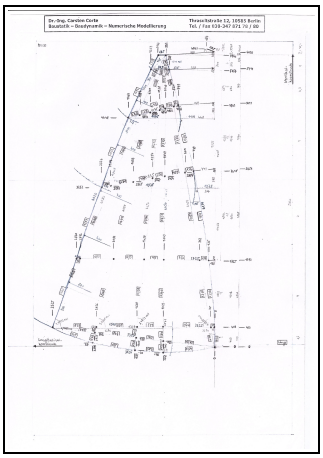
In a second step, translational-spring-connection of boom to floor is spanned to model tightening of the sheet. This membrane-stress inducing transformation is performed from the two different initial stress-free warped membrane configurations and gives large 3D membrane displacement and membrane stress distribution, large 3D mast and boom beam displacement and rotation and 3D mast and boom beam section forces, furthermore floor, mast-at-deck-height and mast bottom support reaction forces.

In a next step, using deformed stress-carrying membrane and beam state as above, surrounding viscous air flow is modeled by Navier-Stokes equations for light wind, average wind, strong wind conditions on close reach in time domain.

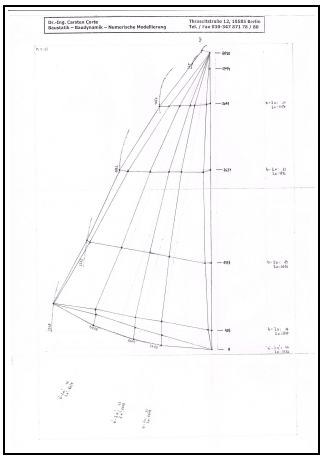
In a final step, strong segregated fluid-structure interaction between sail membrane with added mast and boom beam stiffness and viscous air flow is performed in time domain. Flow state around the sail membrane, membrane, mast and boom deformation, membrane stress and mast and boom beam section forces, floor, mast-at-deck-height and mast bottom reaction forces and resulting driving forces and heeling moment that act onto the hull are evaluated.



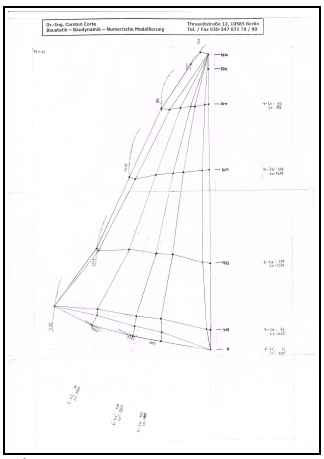
sail measurement [finn class rules]



plane sail shape, curved boundaries



1st warped stress-free configuration



2nd warped stress-free configuration

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