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Comparative Analysis of Wind Load Application Techniques for Aeroelastic Analysis of Hard Wing Sails

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ABSTRACT

Reliability analysis of a mechanical system requires an accurate evaluation of the structural responses of critical components. In aeroelastic analysis, the fidelity of these responses depends on the modeling and transfer of aerodynamic loads between aerodynamics solvers and computational structural mechanics solvers. This study investigates the aeroelastic behavior of hard wing sail components using three aerodynamic load modeling approaches, alongside their associated computational costs. The first approach employs a Lifting-line model, transferring aerodynamic loads directly to the load reference axis. The second method uses a panel-based method inspired by the 3D vortex lattice model, integrating computational fluid dynamics and computational structural mechanics via the Dload subroutine in Abaqus v2023. The third method is similar to the second but uses a field mapping technique for load transfer. These approaches are compared for both single-element and two-element wing sails. Aerodynamic pressure coefficients for the single-element configuration are obtained using XFOIL 6.99, while experimental data from the literature is used for the two-element wing sail. Results show that in the root region of the main load-bearing steel component, von Mises stress predictions from the lifting-line method are more conservative than those from the panel-based methods. However, the lifting-line method underestimates stresses in the core and face sheet regions of the leading-edge component of the wing sail. The structural responses obtained using the Dload subroutine method strongly agree with the mapped field method results for both single-element and two-element wing sails. However, the mapped field method is more computationally expensive.

Keywords: Wing sail; Lifting-line method; Vortex lattice method; Field mapping; DLoad subroutine; Finite element analysis; Wind-assisted propulsion