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Three-Dimensional Flow Dynamics in Pumping Wingsail

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This numerical study investigates the three-dimensional flow dynamics of a pumping wingsail, focusing on the formation and evolution of leading-edge vortices (LEVs) and their impact on aerodynamic performance. Pumping wingsails, characterized by angular oscillatory motion could be found in wind-assisted propulsion systems such as windsurfing. This unique angular oscillatory motion could lead to three-dimensional complex interplay between unsteady flow separation, vortex dynamics, and added mass effects. To address this, a wingsail model with a constant NACA0012 airfoil cross-section and an aspect ratio of 3.5 is employed. Using the overset dynamic mesh method and the SST k-ω turbulence model, the numerical study examines the lift and drag characteristics at a 30° angle of attack, reduced frequencies ranging from 0.4 to 1, and amplitudes between 4° and 6°. Reynolds number is 1.6×10^5. The numerical simulation results demonstrate agreement with experimental data in terms of time-averaged load and phase-averaged flow features. Additionally, the study investigates the evolution of the leading-edge vortex (LEV) during the pumping motion and analyzes the influence of added mass and LEV attachment on lift generation across different pumping phases. The findings provide novel insights into the unsteady aerodynamic characteristics of pumping wingsails and offer practical guidance for optimizing wingsail motion profile in real-world applications.

Keywords: Flapping sail; CFD; Added mass; Flow separation; Leading-edge vortex.

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