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Interactions of Vortices with Differing Creation Mechanisms in the Wake of a Normal Flat Plate-Delta Flat Plate Couple: A Numerical Study

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Abstract

Fluid flow is characterized by the presence of different physical mechanisms that aide in transfer of mass and energy across space and time. These mechanisms include flow shearing, stretching, convection, diffusion, vorticity generation, and fluid acceleration and physically manifest as large coherent structures in the fluid flow, resulting in the formation of vortical structures such as vortex tubes, vortex streets, and eddies. When these vortical structures interact with each other or other distinct mechanisms in a fluid, they form a chaotic region of mixing where a large transfer of mass and energy is observed; This phenomenon is called a vortex interaction and is commonly observed in nature across large Reynolds number regimes. In Engineering, vortex interactions are an important topic of research in areas such as Mixing, Structural Stability and Vibrational Analysis, Propulsion, Aerodynamics, Convection, Heat Island Effects, Hydrodynamics, and Atmospheric Sciences, to name a few.

This thesis studies a common vortex interaction scenario observed in nature that is often overlooked in research due to its perceived complexity and aims to act as a template for future studies of complex vortical interactions. The interactions of vortices with differing creation mechanisms are studied in the wake of two simplified normal flat plate – delta flat plate coupled solid body models for laminar and transitional wake conditions. A total of 5 CFD simulations are conducted, and findings are presented as three computational studies: 1) vortex interactions in a laminar wake, 2) vortex interactions in a transitional wake, and 3) vortex interactions in the wake of a finite span symmetric model.

The first model couples an infinite normal flat plate to an angled delta flat plate resulting in the creation of, and interaction between, a steady streamwise vortex and a stably shedding spanwise vortex at its leading edge. Findings for the infinite flat plate model are presented in the first two computational studies: Enstrophy (□y) measurements in the plane orthogonal to the interaction planes are shown to be a good indicator of interaction intensities for asymmetric interactions and accurately captures the extent of the interaction region as well. A strong vortex interaction is characterized by the absence of any reconnection of the split spanwise vortex after pinch-off, and furthermore, creates a suction action that destabilizes the trailing edge vortex. Lastly, wake characteristics are quantified by conducting a vorticity transport analysis.

Vortex interactions in nature are created by bodies of finite length and the second solid model provides insights on vortex interactions of such a system. A finite span symmetric model is created by coupling a finite span normal flat plate to a pair of angled delta flat plates to the leading and trailing edge and results in vortex creation in all three axes. These interactions create a coupled shedding pattern in the cross streamwise and spanwise axes, and result in the formation of horseshoe vortical structures with alternating positions in two axes. Again, wake characteristics are quantified by conducting a vorticity transport analysis.