Realistic simulations of delta wing aerodynamics using novel CFD methods

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Abstract

The overall goal of the research presented in this thesis is to extend the physical understanding of the unsteady external aerodynamics associated with highly maneuverable delta-wing aircraft by using and developing novel, more efficient computational fluid dynamics (CFD) tools. More specific, the main purpose is to simulate and better understand the basic fluid phenomena, such as vortex breakdown, that limit the performance of delta-wing aircraft. The problem is approached by going from the most simple aircraft configuration - a pure delta wing - to more complex configurations. As the flow computations of delta wings at high angle of attack have a variety of unusual aspects that make accurate predictions challenging, best practices for the CFD codes used are developed and documented so as to raise their technology readiness level when applied to this class of flows.

Initially, emphasis is put on subsonic steady-state CFD simulations of stand-alone delta wings to keep the phenomenon of vortex breakdown as clean as possible. For half-span models it is established that the essential characteristics of vortex breakdown are captured by a structured CFD code. The influence of viscosity on vortex breakdown is studied and numerical results for the aerodynamic coefficients, the surface pressure distribution and breakdown locations are compared to experimental data where possible.

In a second step, structured grid generation issues, numerical aspects of the simulation of this nonlinear type of flow and the interaction of a forebody with a delta wing are explored.

Then, on an increasing level of complexity, time-accurate numerical studies are performed to resolve the unsteady flow field over half and full-span, stationary delta wings at high angle of attack. Both Euler and Detached Eddy Simulations (DES) are performed to predict the streamwise oscillations of the vortex breakdown location about some mean position, asymmetry in the breakdown location due to the interaction between the left and right vortices, as well as the rotation of the spiral structure downstream of breakdown in a time-accurate manner. The computed flow-field solutions are visualized and analyzed in a virtual-reality environment.

Ultimately, steady-state and time-dependent simulations of a full-scale fighter-type aircraft configuration in steady flight are performed using the advanced turbulence models and the detached-eddy simulation capability of an edge-based, unstructured flow solver. The computed results are compared to flight-test data.

The thesis also addresses algorithmic efficiency and presents a novel implicit-explicit algorithm, the Recursive Projection Method (RPM), for computations of both steady and unsteady flows. It is demonstrated that RPM can accelerate such computations by up to 2.5 times.
Keywords
Space and plasma physics, CFD, aerodynamics, flow physics, steady, unsteady, delta wing, vortical flow