Nonlinear dynamics of wake vortices

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Aircraft wakes have been the subject of extensive research for several decades as it poses economic, safety and environmental issues. The wake is composed of powerful counter-rotating vortices that persist long after the aircraft has passed. In this thesis, the nonlinear dynamics of aircraft wake vortices is investigated through Direct Numerical Simulation. The aim is to explore the nonlinear effects on wake vortex behaviour and evaluate the potential for the anticipated destruction of the vortices through optimal perturbation. First the disruptive potential of the linear optimal perturbation of the flow is evaluated by applying it with increasing initial amplitude and observing the nonlinear response of the flow. With sufficient yet reasonable initial amplitude the linear optimal perturbation halves the life-span of the vortex pair by accelerating the loss of coherence of the vortices after the linking phase. Next the nonlinear gradient-based optimisation tool that was developed during the thesis is validated by reproducing existing results concerning a simple vortical flow: an isolated two-dimensional vortex. In doing so new nonlinear optimisation results are obtained and analysed. In particular it is shown that the 2D nonlinear optimal perturbation of an isolated vortex can induce considerably greater transient growth than the linear optimal. In some cases the nonlinear optimal causes a transition to a quasisteady asymmetric state, bypassing the natural axisymmetrisation process. The effect of the vortex vorticity profile on the optimal perturbations is also studied. Vortices with sharper profiles experience far greater linear perturbation growth, however the nonlinear growth is significantly inferior. Finally the nonlinear optimal perturbation analysis of the isolated vortex is extended to three dimensions. Although the 3D nonlinear optimals produce less growth than their linear counterparts, they can lead to quasi-permanent high energy states.

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