Instabilities in helical vortex systems : linear analysis and nonlinear dynamics

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The near wake behind helicopter rotors, wind turbines and more generally behind rotating devices are dominated by helical vortices. Investigating their stability properties is a necessary step to improve understanding and prediction of their dynamics. This is of importance since coherent structures in the wake are responsible for additional stresses and losses of performance in wind turbine farms for instance. Instabilities can also trigger transition to the highly non-stationary Vortex Ring State which is responsible for some helicopter crashes. The near wake flow can be considered, at least locally, helically symmetric: fields are invariant through combined axial translation of distance Δz and rotation of angle $\theta = \Delta z/L$ around the rotor z-axis, where $2\pi L$ denotes the helix pitch. In order to simulate the evolution of such flows, we use a DNS [1] code based on an original formulation in which the helical symmetry is enforced into the equations. We obtain basic states which consist of multiple diffusing helical vortices with or without a central hub vortex, for various values of the helical pitch and vortex core sizes.

Such vortex systems are subject to multiple types of instabilities which have mainly been studied analytically [2] [3] and experimentally [4] [5]. In the present study we first perform a linear temporal stability analysis of these base flows. In order to extract the dominant unstable modes, we use a linearised version of the helical DNS code coupled to an Arnoldi procedure. In the helical framework, instabilities are dominated by a displacement mode. The influence of the presence of a hub vortex is considered. Nonlinear evolutions are then computed: the unstable displacement mode is shown to be responsible for a leap-frog dynamics which is compared to the one observed in vortex rings. Instability properties as well as nonlinear dynamics are characterized for helical pitch values ranging from large ones (quasi-2D behaviour) to small ones more pertinent for helicopter and wind turbine applications.

Références

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