Application of a slender vortex filament code to the study of a four-vortex wake model

October 26, 2001

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1 Introduction

The potential hazard related to the two-vortex aircraft wake induces separation distances between aircrafts and associated delay at landing and take-off, which contributes to the congestion of airports. Rennich and Lele [1] have shown that the destruction of aircraft wake vortices can be accelerated by adding two flap-vortices between the trailing-edge vortices. Their results were obtained both from a Navier-Stokes spectral code and from a *simple* vortex filament code. We have implemented [2] a *slender* vortex filament (SVF) code based on asymptotic equations of motion [3, 4, 5] derived by Callegari and Ting from the Navier-Stokes equations in the slenderness limit. It allows us to improve the previous results of Rennich and Lele [1] .

2 Methodology

Using the Callegari and Ting's equation Klein and Knio [4] have shown that it is not correct to compute a vortical flows composed of several thin vortex filaments by a standard vortex filament (VF) method with only one *numerical filament* per section of the thin vortex filaments (the so called thin-tube model): more than one numerical filament per section is needed to insure the convergence of the numerical scheme. However, as it would save computation time to have only one numerical filament per section, Klein and Knio [4] proposed a cure: they have shown how to adjust the numerical desingularization parameter (the so called thin-tube thickness) to real thickness of the slender vortex filaments so that the method gives correct results. As the corrected thin-tube model is still stiff to be solved numerically Knio and Klein [5] removed this stiffness in the *improved thin tube models* that they proposed.

We have adapted this numerical scheme for open vortex filaments which are periodic with a characteristic wavelength and we have implemented it in a code named EZ-Vortex. The fluid may be viscous or inviscid; the relative velocity field (*i.e.* velocity field minus filament velocity) is axisymmetric and may be similar (*i.e.* Gaussian) or not (it can be a Rankine vortex or any axisymmetric vorticity profile). The evolution of the core structure (diffusion and stretching) is taken into account in the asymptotic equation and so in the implemented code.

3 Results

For a chosen wavelength we reproduce numerically the results of Fabre and Jacquin [6], who generalized to four vortices the linear stability analysis of Crow [7]. We recover both the growth rate and the geometry of the linear modes. We also obtain the motion and the temporal behaviour of these modes in the non-linear regime up to the merging stage. Numerous tests have been done on convergence of the numerical parameters.

We have five-hole rake experimental data[8] in a cross-section at several wing-spans behind aircraft-models. They are analysed to find initial parameters of a simulation: position of the vortices, circulation, core radius, non-similar moments. The 2D data are extended to 3D to have straight filaments and give the initial configurations for the temporal simulations. A study of the validity of this extension is under way.

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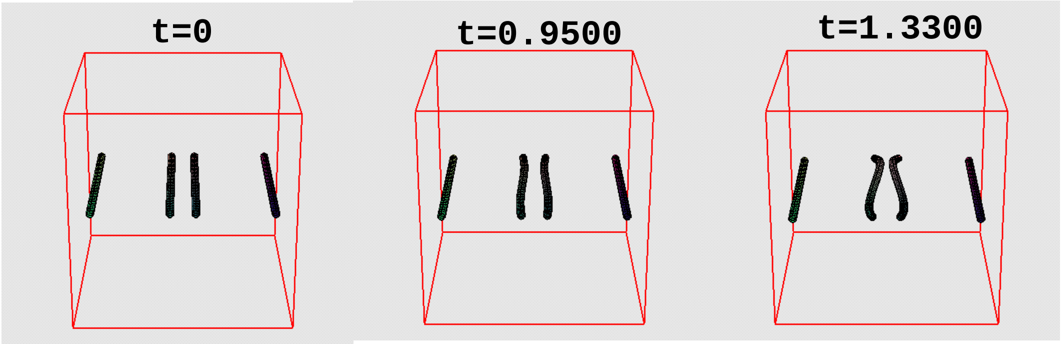

Figure 1: Vortex Filament Simulation of the non-linear instability regime of the most amplified symmetric mode of wavelength $\Lambda = 0.8976$ for the four-vortex wake. Initial amplitude $\rho_0 = 0.001$ and initial thickness $\varepsilon = 0.1$.

4 Conclusions

The computation with the SVF code EZ-vortex has been validated against linear stability results. It is faster than Navier-Stokes spectral codes or than standard VF methods. It allows us to compute the temporal evolution of initial conditions built from experimental data. Simple reconnection models [9] may be implemented to go through the reconnection stage.

5 Acknowledgements

This work, performed within the C-Wake project, was supported by the European Community in the frame of the fifth Framework Research Program under contract #GRD1 - 1999 - 10332

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