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CFD simulations of wake flows in the FAR-Wake project

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Within the 6th Framework EU co-funded project FAR-Wake, fundamental aspects of wake vortex physics of potential importance to the alleviation of wake vortices behind civil aircraft were studied by a consortium of 17 partners. Work included sub-scale tests, theoretical modelling and advanced CFD with the objective to improve physical understanding of aircraft wake vortex formation and decay under realistic conditions, focussing on the effects of vortex instabilities, jet-vortex interaction, wake-vortex interaction, ground proximity and effects of turbulent head- and crosswinds. The paper only deals with the numerical simulation results.

Travelling waves along vortices were simulated with LES. UCL used a Vortex-In-Cell method combined with a Parallel Fast Multipole Method (VIC-PFM). Figure 1 shows iso-vorticity contours from a spatial simulation of a suddenly accelerated elliptically loaded wing. CERFACS made temporal LES simulations. Perturbations in a single vortex were created by a local change in vortex core size. Reynolds number and disturbance magnitude was varied. Figure 2 shows helical instabilities developing in the presence of weak random excitation. UCL made pseudo-spectral temporal LES simulations of counter-rotating 4-vortex systems. Figure 3 shows the development of “omega” loops and a rapid growth of short wavelength instabilities thereafter. A pioneering space-time developing LES simulation of the same flow (using the VIC-PFM method and $111*10^6$ grid-points) was also made.

CERFACS did a parametric LES study of hot and cold jets interacting with a vortex, showing a rapid growth of vortex core size when the jet is sufficiently close and strong (see Figure 4). UCL used the VIC-PFM method for an aircraft configuration in high lift with 4 engines. These simulations were initiated from near-wake wind tunnel data, provided by Airbus.

The complex flow in the immediate region behind a fuselage was simulated with RANS by DLR and CENAERO and compared with hot-wire data from TUM. Fine grid resolution and adequate (low artificial dissipation) numerical methods and turbulence modelling are needed. Since the main flow structures are steady, the unsteady DES simulation by CENAERO did not perform significantly better than RANS.

Wake roll-up simulations for an elliptically loaded wing were made by UCL. For the same llift distribution different initial conditions were used: a) without axial velocity defect, b) with axial velocity defect due to viscous wing wake, as b) but including two simulated jets.

In a collaborative effort by UPS-IMFT and CENAERO-UCL, vortex evolution in ground effect was studied with- and without turbulent head or cross-wind (see Figure 5). A vortex pair was released in a fully developed turbulent boundary layer at one vortex spacing above the ground. The vortices rapidly interact with the separating shear layer from the ground, promoting wake decay and an asymmetric rebound in cross-wind. Results of UPS-IMFT and CENAERO-UCL compare very well and agree well with real wake observations. UCL also did a space developing simulation of a wake created in ground effect.

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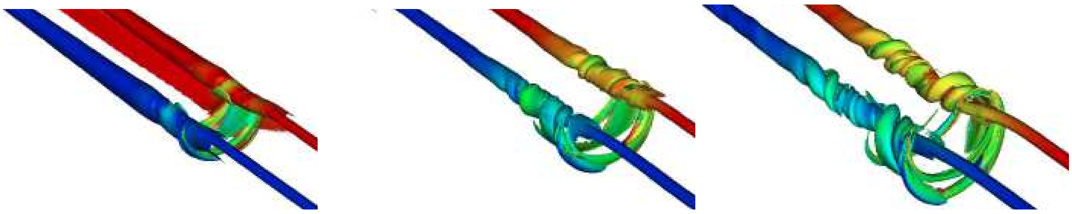
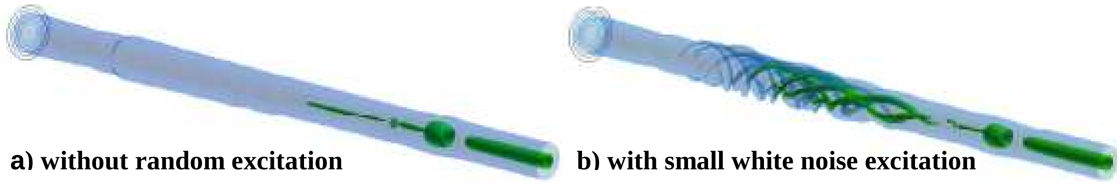


Figure 1: 3-D view of space developing simulation of the wake of an accelerated wing (LES by UCL)



a) without random excitation **b) with small white noise excitation**

Figure 2: A travelling wave initiated by a sudden increase in vortex core radius (LES by CERFACS).

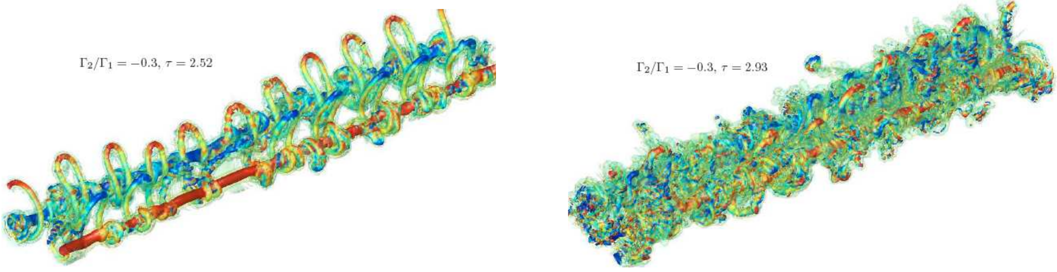


Figure 3: Iso-vorticity contours from temporal LES of a 4-vortex system by UCL at dimensionless time τ= 2.52 (left) and 2.93 (right) (Γ_2/Γ_1=-0.3 , b_2/b_1=0.3).

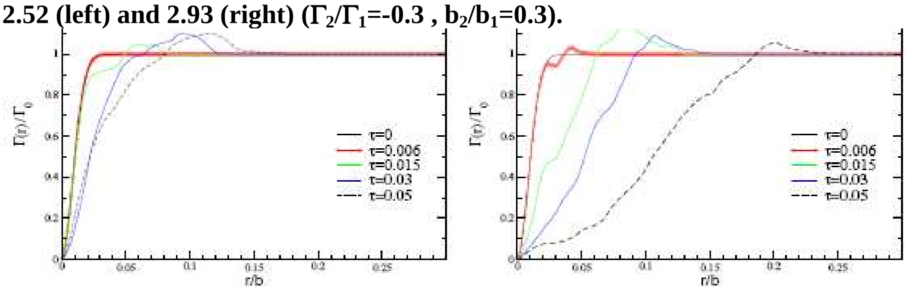
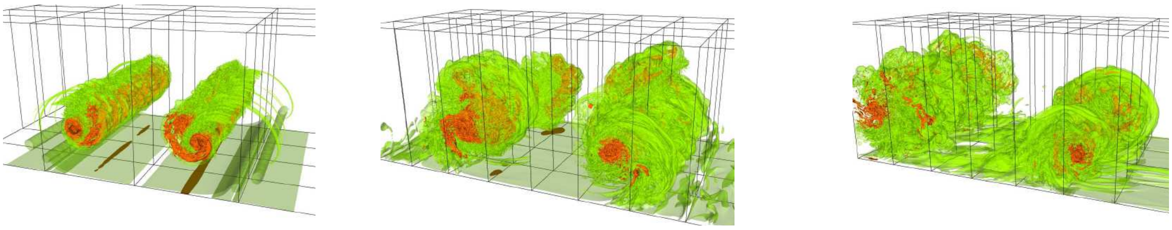
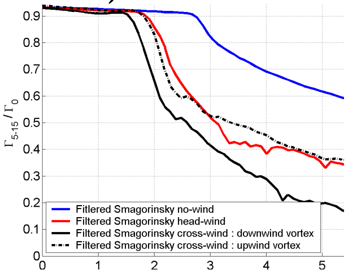


Figure 4: Development of vortex circulation profile for approach-idle (left) and take-off conditions. LES by CERFACS for cold jet-vortex interaction.



a) no wind **b) headwind** **c) cross-wind**



d) circulation decay as function of τ.

Figure 5: Iso-vorticity surfaces for 2-vortex system in ground effect, without wind, with headwind and with crosswind (LES by CENAERO-UCL) and vortex decay versus non-dimensional time τ.