Mitteilung

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Numerical Simulation of a Longitudinal Vortex

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Introduction:
Longitudinal vortices are common flow phenomena in the flow around aircrafts. They develop wherever sharp corners are encountered like on wing tips, tail plane or in the cut-out between surfaces. Of special interest is the longitudinal vortex that is generated at the slat cut-out for the nacelle integration (fig. 1) which produces a loss of maximum lift [1]. To compensate this effect strakes are mounted on the nacelle to generate a longitudinal vortex which helps to improve the stability of the boundary layer. Several numerical investigations about the vortices generated by strakes were performed through RANS models [1][2] showing large discrepancies with respect to experimental data around maximum lift [3]. However, the huge complexity of these configurations makes it difficult to identify if those discrepancies arise from the applied turbulence model.

Numerical methods:
To investigate a suitable numerical approach for the simulation of longitudinal vortices, a simplified model was set up so as to get rid of the numerous uncertainties that carry more complex configurations. This model consists of a single delta wing with sharp-edges. The numerical simulations were performed using the DLR TAU-Code where the low dissipative low dispersion LD2 spatial scheme of the code [4] was applied for the hybrid RANS/LES simulations. The URANS computations were done with the advanced SSG/LRR-ω DRSM [5] which inherently incorporates the effects of rotation and streamline curvature. For the scale resolving simulations, three different positions were investigated to switch from RANS to LES as shown in fig. 2. The wall-modelled LES was performed with a zonal IDDES, while the rest of the hybrid computations with a simple zonal RANS/LES approach. To trigger the buildup of resolved turbulence downstream of the RANS/LES interface, the synthetic turbulence (ST) implementation [6] was extended for free flows. The numerical results were validated against experimental data which was obtained for this purpose at the low-speed wind tunnel of the TU Braunschweig (MUB).

Test case setup:
The delta wing has a chord length of $c = 0.3$m and a sweep angle of $\Lambda = 65°$. The simulations were performed at an angle of attack of $\alpha = 8°$ with a free stream velocity of $U_\infty = 55$m/s which corresponds to a Reynolds number based on the chord length of $Re_c = 0.99\times10^6$ and a Mach number of $M_\infty = 0.155$. Only a half model of the delta wing and the wind tunnel was computed with symmetry boundary condition in the middle span plane of the model. The walls of the wind tunnel were treated as inviscid, and the inflow and outflow were set as farfield. Three different meshes were tested. The coarsest mesh has 6.276.109 points and a resolution of $\Delta x = \Delta y = \Delta z = 2$mm, while the finest mesh has 40.866.816 points and a resolution of $\Delta x=\Delta y=\Delta z= 1$mm. The third mesh has 25.944.921 points with a resolution in the vortex plane equal to the finest mesh ($\Delta y=\Delta z= 1$mm) and the streamwise resolution of the coarsest one ($\Delta x = 2$mm). Further details on the mesh design can be found in ref [2]. The physical time step was set to satisfy the condition CFL = 1, hence $\Delta t = \Delta x/ U_\infty$. For the anisotropic mesh, two different time steps were assessed based on the streamwise mesh resolution $\Delta t=\Delta x/ U_\infty$ and on the vortex plane mesh resolution $\Delta t=\Delta y/ U_\infty$, respectively.

Results:
The RANS solution can satisfactorily reproduce the bulk formation of the longitudinal vortex, but the modeled turbulence at the vortex core strongly decays downstream of the vortex roll-up, impacting on the longitudinal evolution of the vortex. On the other hand, the hybrid RANS/LES simulations are able to resolve the evolution of the bulk flow with sufficient accuracy when the RANS/LES interface is

placed in a suitable location (fig. 3 (b)-(c)). The suitable locations are where the RANS/LES interface with forcing of ST does not interfere with the roll-up process of the vortex which should be completely scale resolved (WM-LES) or completely modeled (Interface I.2). In the latter situation, the RANS/LES interface should be placed where the bulk structure of the vortex is still well resolved by the RANS model with a sufficient amount of modeled turbulence. The final decision of the interface location is a trade off between accuracy and computational cost. The results on the anisotropic mesh provide a similar solution to the one of the fine grid, showing a good compromise between accuracy and saved computational cost and reflecting the relevance of the mesh spacing in vortex plane. All the numerical simulations underestimate the level of turbulent kinetic energy in the vortex core with respect to the PIV data (fig. 3 (a)).

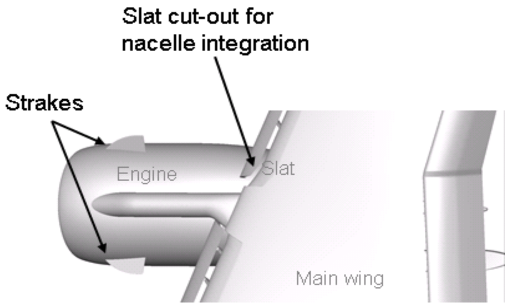

Fig. 1:Sketch of the slat cut-out for the nacelle integration

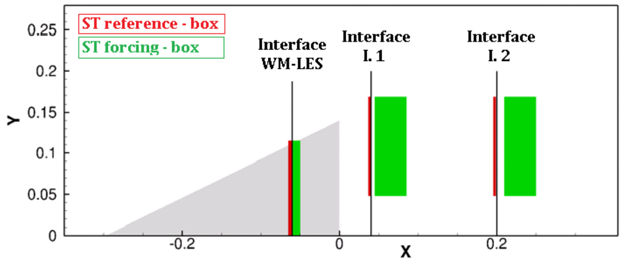

Fig 2: RANS/LES interface locations for the hybrid computations

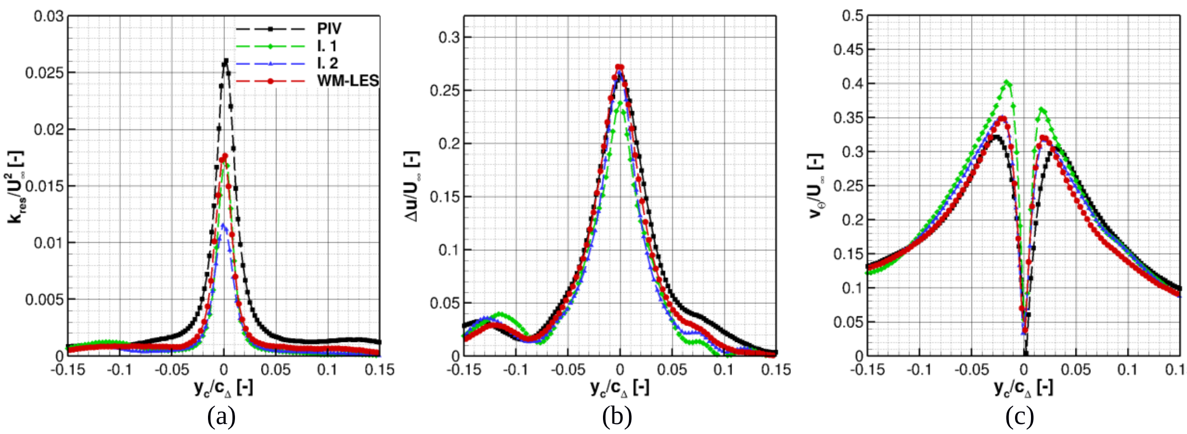

Fig. 3: Mean flow characteristics of the vortex at x=0.8m. (a) turbulent kinetic energy, (b) axial velocity deficit, and (c) tangential velocity

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