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Hybrid RANS/LES Simulations of Multi-Element Airfoil Stall Using Different Flow Solvers

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Numerical simulations of flows with weak pressure-induced separations, which e.g. occur on airfoils and wings at stall, pose a great challenge not only for classical RANS models but also for hybrid RANS/LES approaches such as Detached-Eddy Simulation (DES). Contrary to massive geometry-induced separation, the location of pressure-induced separations strongly depends on the underlying RANS model. Other than that, transition from modelled to resolved turbulence in the separated shear layer may be delayed ("grey area"). For multi-element airfoils, the situation can be considered as less critical, since in this case the geometry-induced separations in the slat and wing coves ensure a switch to the LES mode and forming of resolved turbulent structures which are convected downstream. However, in order to prevent their damping before reaching the critical flap region, thus ensuring consistent modelling of the resolved attached flow, a hybrid RANS/LES approach with wall-modelled LES (WMLES) capabilities is required.

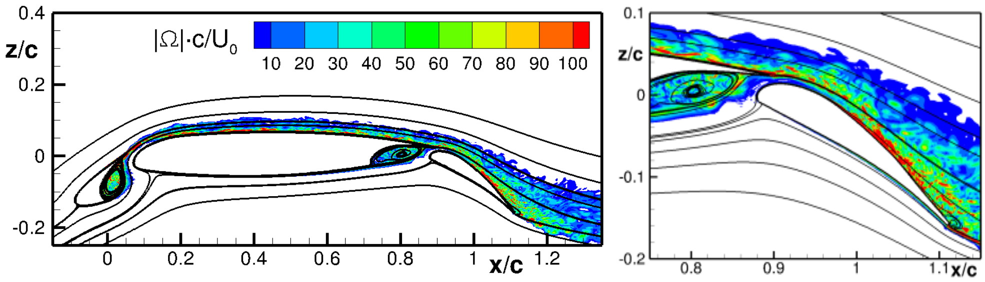

Figure 1: Mean streamlines and instantaneous vorticity magnitude around the DLR-F15 3-element airfoil computed with SST-IDDES using DLR-TAU (left), close-up view of the flap region (right).

In the present work, we apply exactly such a hybrid approach, i.e. the Improved Delayed DES [1], to the flow around the LEISA 3-element airfoil [2] at incipient stall ($Re = 2 \cdot 10^6$, $Ma = 0.15$, $\alpha = 6°$). To assess the uncertainties due to the underlying numerical method, we systematically compare results of two rather different flow solvers: the compressible unstructured 2nd-order DLR-TAU code and the incompressible block-structured 4th/3rd-order NTS code. Both codes are applied to the same block-structured (hexahedral) grids.

In a preparatory study the basic code implementations of the k-ω SST model, which is chosen as RANS background model, are compared between the codes using fully-turbulent RANS computations of the 2D flow. It is shown that both the DLR and the NTS results agree well, as long as the turbulence equations are discretized with 2nd-order accuracy. This underlines the importance of accurate discretization schemes for all considered equations (mean flow and turbulence), even on rather fine grids. On the other hand, compressibility effects are shown to be marginal, justifying the use of the incompressible branch of the NTS solver.

The unsteady simulations with SST.1994-IDDES are conducted on a 3D hexahedral grid with 100 spanwise layers and a total of $27 \cdot 10^6$ grid points. For spatial discretization, the DLR-TAU code applies a 2nd-order central scheme, whereas a weighted 4th-/3rd-order central/upwind scheme is used in the NTS simulations. With a physical time-step size of $2 \cdot 10^{-4} c/U_0$ and sufficiently long time samples in the transient and averaging phases of the simulations, both an adequate temporal resolution and reliable turbulence statistics are provided.

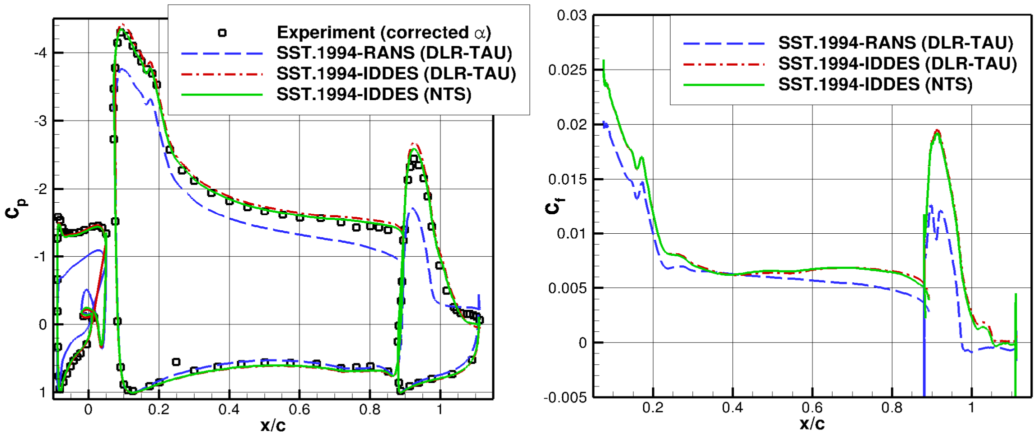

Figure 2: Surface-pressure (left) and skin-friction (right) distributions along the 3-element airfoil.

Qualitative views of the flow field computed with DLR-TAU are provided in Fig. 1. As expected, small-scale vortical structures emerge in the slat-cove region and are transported onto the upper side of the main wing, where the IDDES operates in WMLES mode. Further downstream, additional resolved flow from the wing cove joins the onflow to the upper flap surface, which exhibits a small pressure-induced separation near the trailing edge (see Fig. 1, right). Very similar results are obtained with the NTS code, although finer structures are resolved due to the higher-order discretization scheme. Mean surface-pressure and skin-friction distributions from both flow solvers depicted in Fig. 2 demonstrate a remarkably good agreement between the two codes, even including subtle features of the skin friction. The IDDES results clearly depart from the SST-RANS solution, which yields a much larger separation on the flap. Due to significant experimental uncertainties w.r.t. the (corrected) angle of attack and transition locations, a validation based on the pressure measurements in Fig. 2 (left) should be taken with care. However, convincing agreement of the hybrid simulations with the experiment can be stated for both flow solvers.

The full assessment of the simulations will include more detailed code-to-code comparison (boundary-layer profiles, unsteady RMS data), as well as sensitivity studies w.r.t. the underlying RANS model and the spatial discretization order.

REFERENCES

[1] M.L. Shur, P.R. Spalart, M.K. Strelets and A.K. Travin, A Hybrid RANS-LES Approach with Delayed-DES and Wall-Modelled LES Capabilities. *Int. Journal of Heat and Fluid Flow*, Vol. **29**(6), pp. 406–417, 2008.

[2] J. Wild, M. Pott-Pollenske, An Integrated Design Approach for low Noise exposing high-lift devices. *AIAA paper* 2006-2843, 2006.