Mitteilung

Projektgruppe / Fachkreis: T 2.1 Numerische Aerodynamik

Transitional Flow Computations of the NASA Trapezoidal Wing

Simone Crippa and Normann Krimmelbein
DLR Institut für Aerodynamik und Strömungstechnik,
Lilienthalplatz 7, 38108 Braunschweig, simone.crippa@dlr.de

The validation of CFD methods is an important aspect of the tool development cycle, to benchmark the capabilities and identify research priorities. The participation in the first AIAA High Lift Prediction Workshop (HiLiftPW-1) marks the latest step in a long series of validation activities of DLR's TAU code[1]. The configuration chosen for HiLiftPW-1, NASA's trapezoidal wing shown in figure 1, is geometrically relatively simple. Nonetheless, the 3-element wing mounted on a body pod, develops most of the relevant flow features of subsonic transport aircraft high lift configurations. The geometric simplicity allows to perform grid convergence studies to assess the discretization errors, while enabling manageable grid point counts.

The grid generation tool of choice, Solar, resolves the solid surfaces with a quad-dominant mesh. Anisotropic quadrilateral elements enable to discretize simple-curvature surfaces, such as wing leading edges, in an optimal way. The inclusion of some triangles increases surface grid flexibility and improves the mean element quality. Due to the mixed-element surface grid, the advancing-layer step is hexahedra-dominant, with some triangle-based prismatic layer stacks. Solar has been developed jointly by ARA, QinetiQ, BAE Systems, and Airbus. Some of the recent algorithmic developments take place at ARA[2].

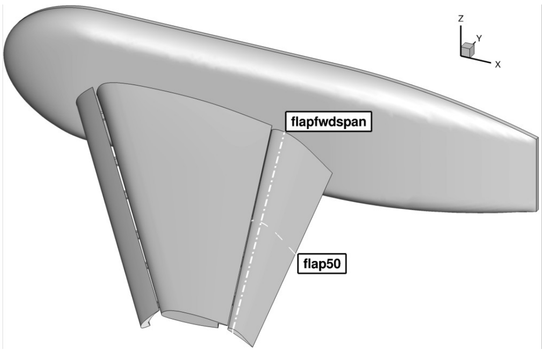
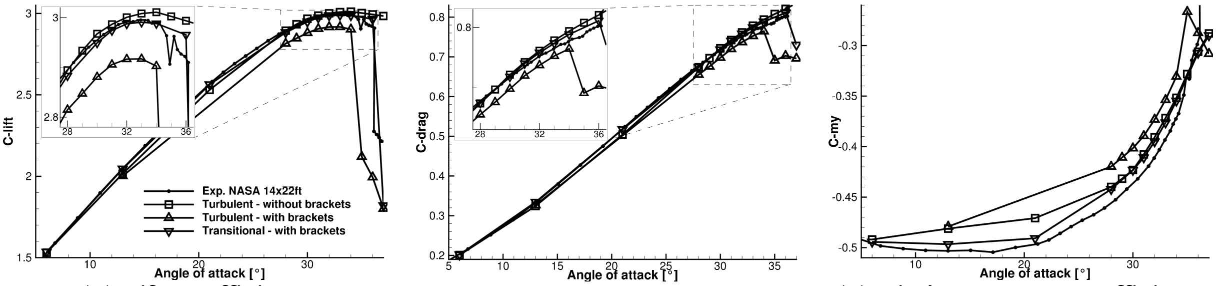


Figure 1: NASA trapezoidal wing with two of the measured surface cut planes.

Only a limited subset of the full contribution by DLR to HiLiftPW-1 is presented here, for the complete set see Crippa et al.[3]. A post-workshop activity to improve the prediction accuracy is presented hereafter. One of the outcomes of the workshop was the insight that the similarity of the discretized geometry to the wind-tunnel geometry plays a vital role in the prediction of maximum lift. Simplifying the geometry by neglecting the slat and flap holding brackets allows for a faster grid generation process, but leads to discrepancies between the computed and measured flow-field in the slat and wing coves, in the wake of the brackets on the suction and pressure sides of the lifting surfaces and ultimately to a substantially different surface loading. Fully turbulent computations, as required by the workshop organizing committee, were also identified as a possible source of discrepancy between computed and measured data. After the workshop, transitional computations on the full geometry were undertaken over the angle-of-attack range of 6 to 38 degrees at a Mach number of 0.2 and Reynolds number of 4.3 million, based on the mean aerodynamic chord.

For each angle of attack, the TAU transition module[4] was used to perform a transition prediction step, based on the turbulent surface pressure data of the simplified geometry, in approx. 80 line-in-flight cuts for each component. The resulting poly-lines are then used to prescribe the transition locations. The experimental free-stream turbulence level is used to determine N_{TS} to 8.5 and data obtained in a comparable wind-tunnel campaign is used to estimate N_{CF} to 8.5.

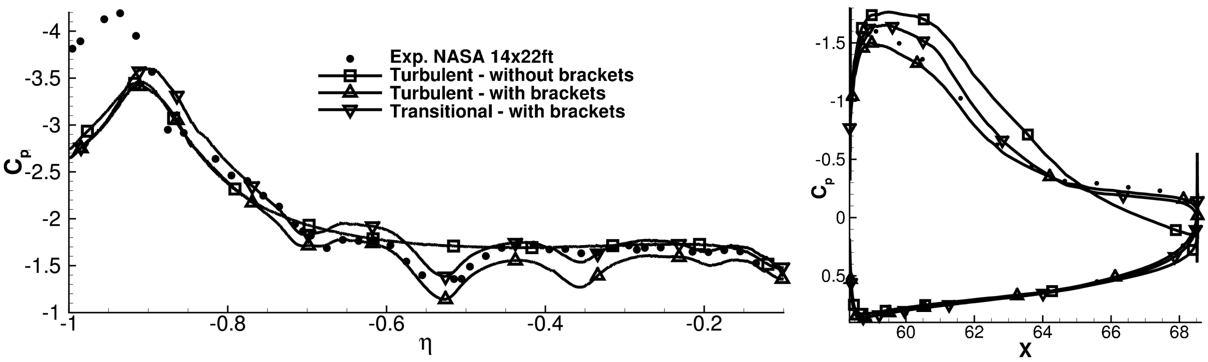
The forces and pitching moment coefficients for the three evaluated cases and the experimental data are presented in figure 2. The seemingly good agreement between the turbulent computations on the simplified geometry to the free-transition, measured data on the full geometry is misleading. The turbulent computations on the full geometry show improvements in some areas, most importantly the flap loading, but fail to match integrated forces and moments. The transitional computations finally deliver a satisfactory match to the experimental data.



(a) Lift coefficient. *(b) Drag coefficient.* *(c) Pitch moment coefficient.*

Figure 2: Forces and pitching moment coefficients over the complete angle-of-attack range, with inserts for the region 28° to 37°.

The detailed analysis of the surface pressure coefficient of the analyzed cases, reveals no drastic differences on the slat and main wing elements, but a substantial difference on the flap. The effect of the missing brackets is clearly seen in figure 3(a), where the C_p loss due to the wakes of the brackets is missing on the clean configuration. By discretizing also the brackets, this effect is captured. The stream-wise surface C_p cut on the flap at mid-span presented in figure 3(b), shows the improved flow prediction on the flap due to the presence of the brackets. From this figure it is also possible to deduce a reason for the seemingly good agreement of the results on the clean configuration to the experimental data. The higher loading of the flap leading edge, together with the lower loading of the flap trailing edge, integrates to a net lift coefficient that compares well to the experimental data. On the other hand, due to the shifted loading towards the front of the flap (closer to the reference point), the resulting pitching moment is higher than measured. Only thanks to the transitional flow computations on the full geometry, it is possible to further improve the predicted forces and moment coefficients.



(a) Span-wise cut (flapfwdspan). *(b) Chord-wise cut at η=50%.*

Figure 3: Pressure coefficient (C_p) on selected surface cuts for the angle of attack of 28°.

A major area of discrepancy between the computations and the experimental data remains in the tip region. This deficiency is conjectured to be attributable to an under-resolved vortical flow system starting at the slat-tip and merging subsequently with the main-tip vortex system. Future activities will focus on improving the computed flow-field in the tip region.

References

1 Schwamborn, D., Gerhold, T., and Heinrich, R., The DLR TAU-code: recent applications in research and industry, ECCOMAS CFD 2006.

2 Leatham, M., Stokes, S., Shaw, J. A., Cooper, J., Appa, J., and Blaylock, T., Automatic mesh generation for rapid-response Navier-Stokes calculations, FLUIDS 2000 Conf. and Exh., Jun 2000, AIAA 2000-2247.

3 Crippa, S., Melber-Wilkending, S., and Rudnik, R., DLR contribution to the first high lift prediction workshop, 49th AIAA Aerospace Sciences Meeting, Jan 2011.

4 Krimmelbein, N., and Radespiel, R., Transition prediction for three-dimensional flows using parallel computation, J. Comp. & Fl., Volume 38, Issue 1, Jan 2009.