Assessment of High-Order Finite Volume Schemes for Turbulent Flows around a Multi-Element Airfoil (case 3.1).

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1. Code description

Results from Reynolds-Averaged Navier-Stokes (RANS) computations are presented using the CFD software *Azure* [1, 2] which comprises unstructured- and structured-grid based modules called UCNS3D and CNS3D, respectively. Azure is based on high-resolution and high-order methods, which are briefly described below. UCNS3D solves the compressible Navier-Stokes equations using a 'k-exact' cell-centered finite volume formulation on mixed-element grids. The discretization of the convective terms is obtained by either Monotone Upstream Schemes for Conservation Laws (MUSCL), or Weighted Essential Non-Oscillatory (WENO) schemes (see [3-6] for more details). The MUSCL schemes can be second or third-order accurate satisfying the Total Variation Diminishing (TVD) condition, thus leading to a MUSCL-TVD formulation. The WENO schemes are used in conjunction with 3rd and 5th orders of accuracy.

The inviscid fluxes are approximated by either the HLLC or Roe's Riemman solvers, and the viscous terms are approximated by a central averaging procedure, where the gradient reconstruction can be based on the Green-Gauss or the least-square method. UCNS3D has been extensively validated over a wide range of cases with particular emphasis on aeronautical applications for flow speeds ranging from Mach numbers as low as M=0.08 to supersonic and hypersonic flows, and for Reynolds numbers spanning from laminar to turbulent flows, including transitional flow regimes [1, 2]. The LES strategy is based on implicit LES (ILES) and the RANS approach is based on the Spalart-Allmaras and K-ω SST models. UCNS3D is versatile and portable software using various programming languages including Fortran, C, C++, Python. It is parallelized with MPI directives and achieves high parallel efficiency, particularly for higher order (>3rd) discretization schemes. The convergence to steady-state solutions is accelerated through the use of local-time stepping and the implicit backward Euler LU-SGS scheme, based on a 1st-order Jacobian approximation.

2. Case summary

The test case concerns the C3.1 turbulent flow around a 2D multi-element airfoil. The convergence criterion is to reduce the normalized L2 residual norm of all the conserved variable by four orders of magnitude and/or lift convergence up to the 5th digit. All the simulations have been performed on 1 node of two 8-core Xeon Westmere CPUs (16 cores in total).

3. Meshes

C3.1

2D mixed-element linear unstructured meshes were generated with quasi-uniform refinement with the quadrilateral boundary layer elements doubled during grid refinement. Three meshes were generated, as shown in Fig. 1. The farfield boundary is located 1000 cords away from the airfoil. The grids consist of 34184, 74902 and 192845 quadrilateral and triangular elements. The grid spacing near the wall corresponds to y+ of 2.0, 1.0, 0.6 for the coarse, medium and fine meshes, respectively.

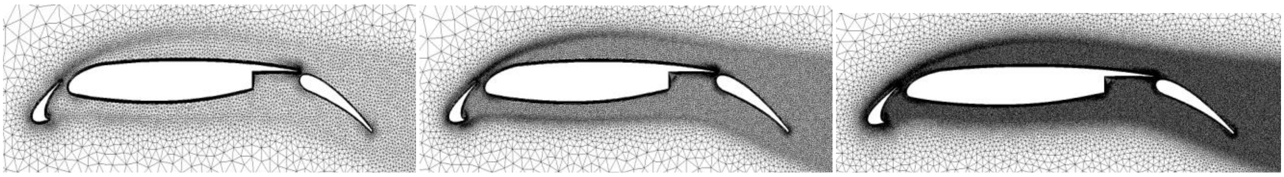

Fig. 1 Computational meshes used for the 2D MDA 30P 30N multi element airfoil (coarse, medium and fine meshes)

4. Results

All the simulations were performed with numerical schemes ranging from 2nd order to 5th order of accuracy. The MUSCL-TVD and WENO type scheme are used in conjunction with an implicit LU-SGS solver and the Spalart-Allmaras turbulence model. Fig. 4 shows the Mach number contours and the ratio of turbulent to laminar viscosity for the WENO 5th order scheme. The results on different grids and for different schemes are shown in Figs. 5. Fig. 6 presents the computed lift and drag coefficients against the work units obtained with the TAU-benchmark for the WENO 3rd and 5th order schemes. The pressure and skin friction coefficients as obtained from the WENO 3rd order computations on the medium grid are shown in Fig. 7. The lift history for the same case is shown in Fig. 8.

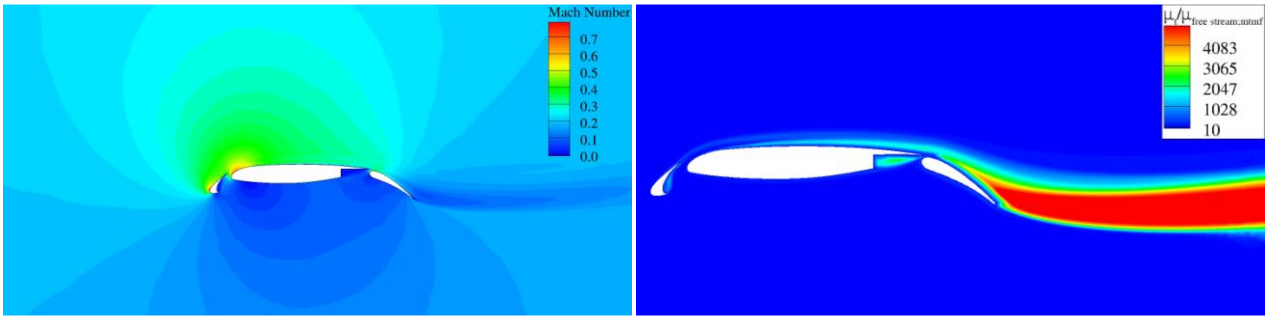

Fig 4. Contour plots of Mach number and turbulence ratio for the 2D MDA 30P 30N multi element airfoil for the WENO 3th order solutions.

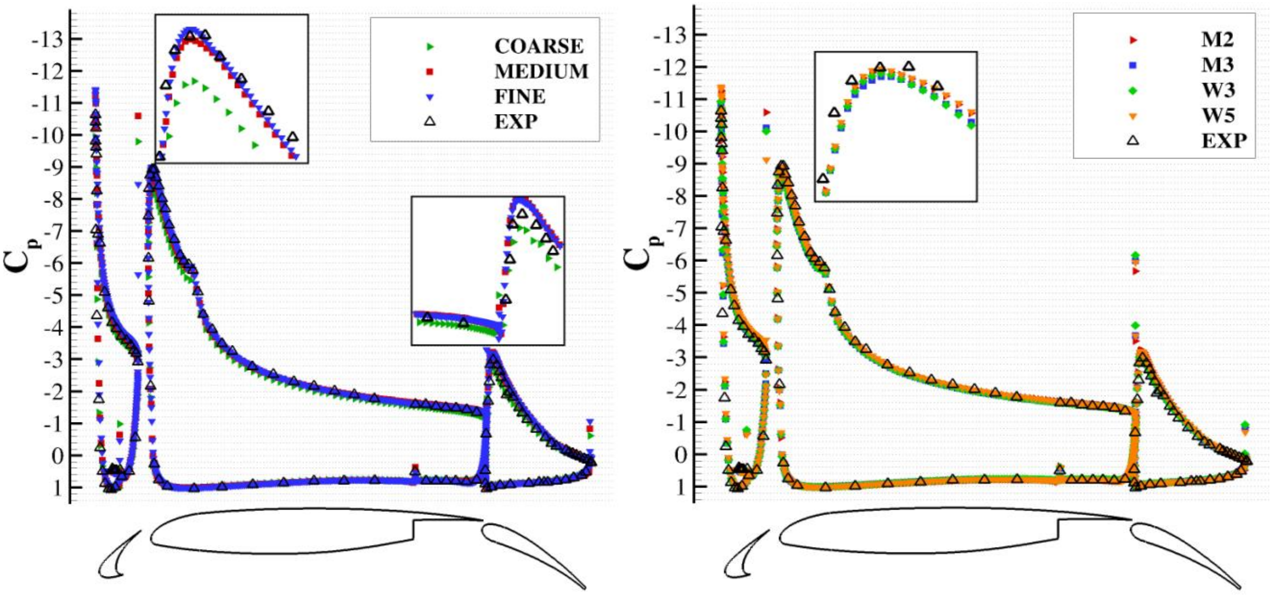

Fig 5. Pressure coefficient distribution using various grid resolutions and numerical schemes for the 2D MDA 30P 30N multi element airfoil**.**

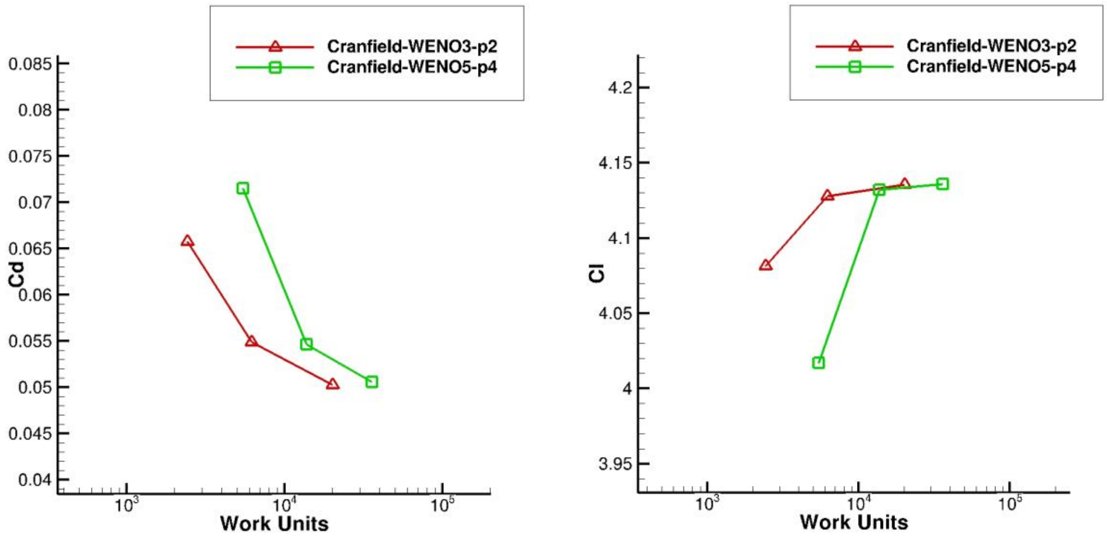

Fig 6. Coefficient of drag (left) and coefficient of lift (right) against work units computed with the TAU-Bench for the WENO 3rd and 5th order schemes on three grid refinements**.**

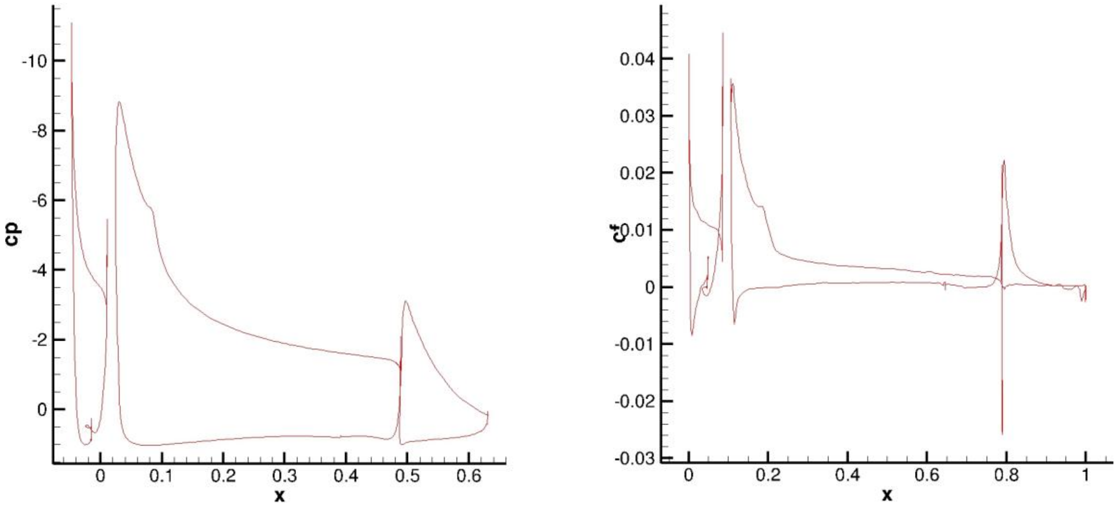

Fig 7. Pressure coefficient (left) and skin friction coefficient (right) for the WENO 3rd order scheme on the medium grid**.**

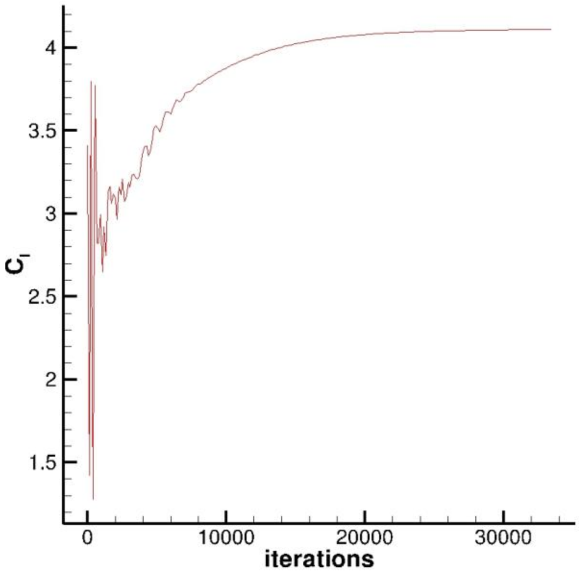

Fig 8. Lift history for the WENO 3rd order scheme on the medium grid.

References

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