BL1-Laminar Joukowski Airfoil

Li Xiao[1], Shengye Wang [1], Wei Liu, Xiaogang Deng[1]

[1] College of Aerospace Science and Engineering, National University of Defense Technology, Changsha, Hunan 410073, Peoples Republic of China

1. Code description

The current flow solver makes use of a robust 5th-order finite difference scheme WCNS-E-5 [1-4]. The WCNS-E-5 is a typical explicit fifth-order one of weighted compact nonlinear schemes (WCNSs) which were first derived by Deng [1]. To address the question of efficiency, 2nd-order scheme MUSCL [5] is also used for comparison. The procedure of discretization for both WCNS and MUSCL consists of three components: (i) cell-center to cell-node differencing, (ii) flux evaluation at the cell-center, and (iii) cell-node to cell-center interpolation of conservative variables. For this test case, Roe's flux difference scheme is used.

For finite difference scheme, a grid transformation from the Cartesian coordinates to the curvilinear coordinates is required. For the satisfaction of geometric conservation law (GCL), SCMM [6,7] is used for the calculation of grid metrics and Jacobian. For temporal integration, the LU-SGS method is adopted.

2. Case summary

In this test case, the L2 norm of the density residual is monitored and the residual tolerance is set to be 10^{-10}, which is shown in Figure 1. All grids are computed on 1 processor. The CPU time running the TauBench is 8.50s on 1 core.

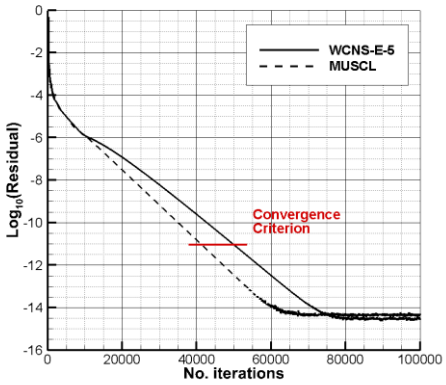

Figure 1. Convergence history for WCNS-E-5 and MUSCL on the coarse grid.

3. Meshes

On the web site, a python script is provided that generates the grids. The plot3d type of grids are chose in our computations. Q is the degree of the polynomial used to represent elements in the python script. For finite difference codes, it is set to be 1 for linear elements. Five grids are generated, which contain 33×17, 65×33, 129×65, 257×129 and 513×257 points respectively. Figure 2 shows the extra-coarse grid. A reference drag is computed on extra-fine (513×257) grid with 5th-order of accuracy scheme WCNS-E-5.

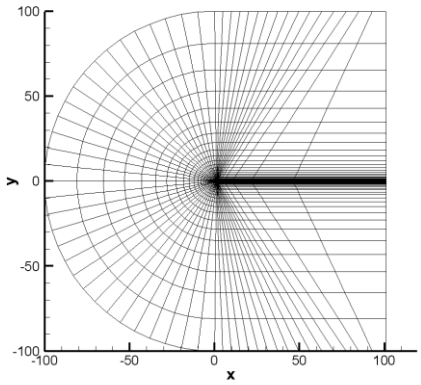

Figure 2. The extra-coarse (33×17) grid.

4. Results

The simulation starts with uniform flow with Mach number of 0.5. The contour plot of the Mach number for WCNS-E-5 on the extra-fine grid is shown in Figure 4. The reference drag is 0.121924008 obtained on the finest (513×257) grid using WCNS-E-5. Both the Cd errors against the grid size and work units are shown in Figure 4. Table 1 and Table 2 show the detail of the results.

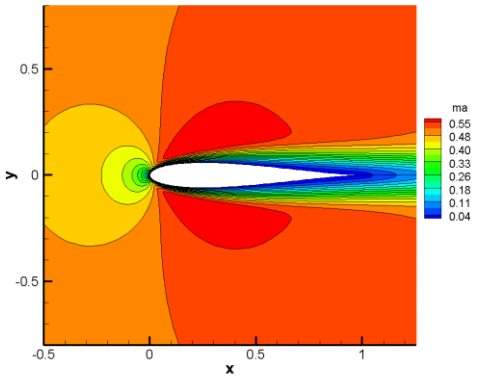

Figure 3. Contour plot of the Mach number for WCNS-E-5 on the extra-fine (513×257) grid.

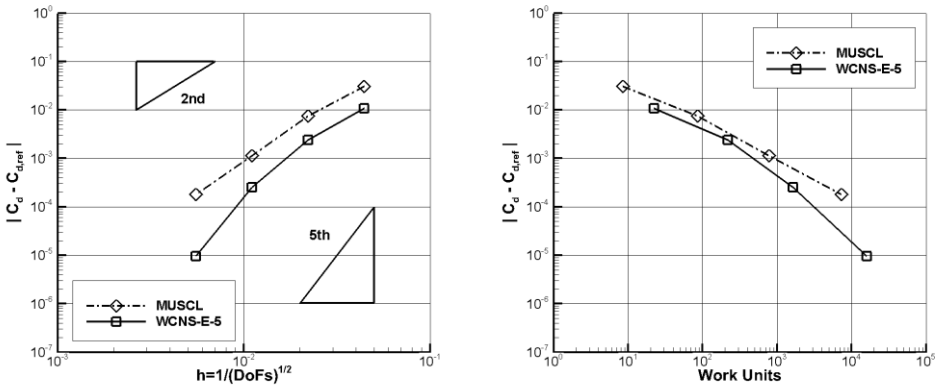

Figure 4. Drag coefficient error for WCNS-E-5 and MUSCL.

Table 1. Detail results obtained by WCNS-E-5.

Grid	h	Cd	Work Unit
33×17	0.044194174	0.132770685	2.22E+01
65×33	0.022097087	0.124319501	2.19E+02
129×65	0.011048543	0.122174018	1.64E+03
257×129	0.005524272	0.121933489	1.60E+04

Table 2. Detail results obtained by MUSCL.

Grid	h	Cd	Work Unit
33×17	0.044194174	0.152166449	8.51E+00
65×33	0.022097087	0.129446575	8.59E+01
129×65	0.011048543	0.123043609	7.73E+02
257×129	0.005524272	0.122104342	7.34E+03

5. References

[1] Deng X, Zhang H. Developing high-order weighted compact nonlinear schemes. Journal of Computational Physics 2000; 165:22–44.

[2] Liu X, Deng X, Mao M. High-Order Behaviors of Weighted Compact Fifth-Order Nonlinear Schemes. AIAA Journal 2007; 45(8): 2093-2097.

[3] Deng X, Mao M, TU G, Zhan Y, Zhang H. Extending Weighted Compact Nonlinear Schemes to Complex Grids with Characteristic-Based Interface Conditions. AIAA Journal 2010;48(12): 2840-2851.

[4] Xu C, Deng X, et al. Collaborating CPU and GPU for large-scale high-order CFD simulations with complex grids on the TianHe-1A supercomputer. Journal of Computational Physics 2014; 278: 275–297.

[5] van Leer B. Towards the ultimate conservative difference scheme V : A second-order sequal to Godunov's methods. Journal of Computational Physics 1979; 32:101–136.

[6] Deng X, Min Y, Mao M, Liu H, Tu G, Zhang H. Further study on geometric conservation law and application to high-order finite difference schemes with stationary grids. Journal of Computational Physics 2013; 239:90–111.

[7] Deng X, Zhu H, Min Y, Liu H, Mao M, Wang G, Zhang H. Symmetric conservative metric method: a link between high order finite-difference and finite-volume schemes for flow computations around complex geometries. ICCFD8-2014-0005, 2014.