C3.1 Turbulent Flow over a 2D Multi-Element Airfoil

I.S.Bosnyakov*

Aerodynamics department, TsAGI

1 Code description

Presented in this work is the implementation of high-order solver for RANS. The solver is based on finite-element, discontinuous Galerkin method. The method is embedded into Numeca Fine/OPEN code. The solution is stored in polynomials with maximum degree $p = 3$, which is expected to provide scheme spatial accuracy order 4.

The solver is intended to solve 3D RANS on unstructured hexahedral meshes. High-order EARSM turbulence model is available. Implemented time-stepping algorithm is explicit 5-step Rhunge-Kutta scheme. The convergence is enhanced with full hp-multigrid. The solver is capable of multi-thread parallel computations. High-order post-processing is limited: high-order value distributions are treated as low order, however forces and moments are calculated with sufficient accuracy using corresponding quadrature rules.

2 Case summary

Solution was assumed converged when forces entered trust range ± 1 count about averaged solution. The machine used for this work was a Linux computer with four AMD Opteron 6272, 2.1 GHz processors. Computation for each mesh and polynomial order p was held on 16 cores. TauBench reference time was $T_1 = 12.6s$.

3 Meshes

A set of 3 meshes was prepared for this case. Portions from the meshes are shown on Figures. 1, 2, 3.

The domain size for all meshes is approximately 1800×1800 chords. The farfield boundary is square and located 900 chords from the airfoil.

The meshes are fully unstructed, linear, with hexahedral elements. The number of hexas is 10907 for coarse mesh, 21970 for medium and 40611 for fine. The corresponding number of degrees of freedom for each polynomial set is listed in the table below. Mesh spacings can therefore be easily calculated using formula $h = 1/\sqrt{ndof}$.

	$ndof$		
degree	coarse	medium	fine
$p = 1$	43628	87880	162444
$p = 2$	109070	219700	406110
$p = 3$	218140	439400	812220

The set of meshes was obtained by refining from coarse to fine. The cells in boundary layer almost form the family of nested meshes. In the other cells the number of cell divisions by 2 was varied. The far field mesh at distance more than 180 chords from the foil surface wasn't refined.

First layer thickness in coarse mesh is $h_{0c} = 4.174 \times 10^{-5}m$, the expansion rate is $c_c = 4.3$. Medium mesh: $h_{0m} = 1.358 \times 10^{-5}m$, $c_m = 2.07$. Fine mesh: $h_{0f} = 5.566 \times 10^{-6}m$, $c_f = 1.44$.

4 Results

The reference values for error calculation have been achieved from Richardson extrapolation. The error is assumed to be the difference between computed value and the reference. c_l & c_d errors versus work units and $1/\sqrt{nDOFs}$ are represented at Figure 4. Here workunits are calculated by formula:

$$T_{computation}/T_{benchmark} \times n_{cpu}.$$

*1, Zhukovskogo st, Zhukovsky, Russia, 140181, bossig@yandex.ru

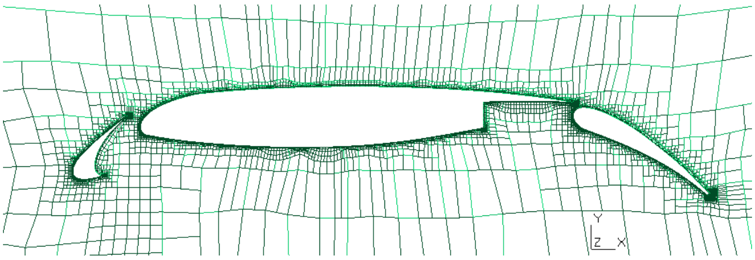

Figure 1: Coarse mesh

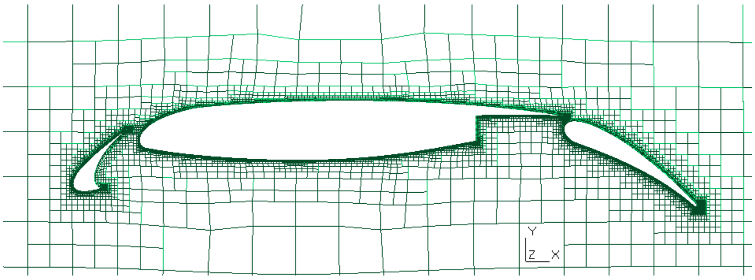

Figure 2: Medium mesh

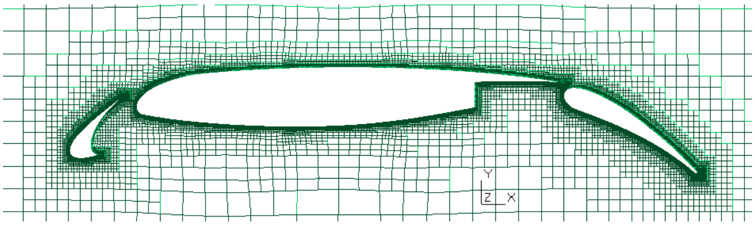

Figure 3: Fine mesh

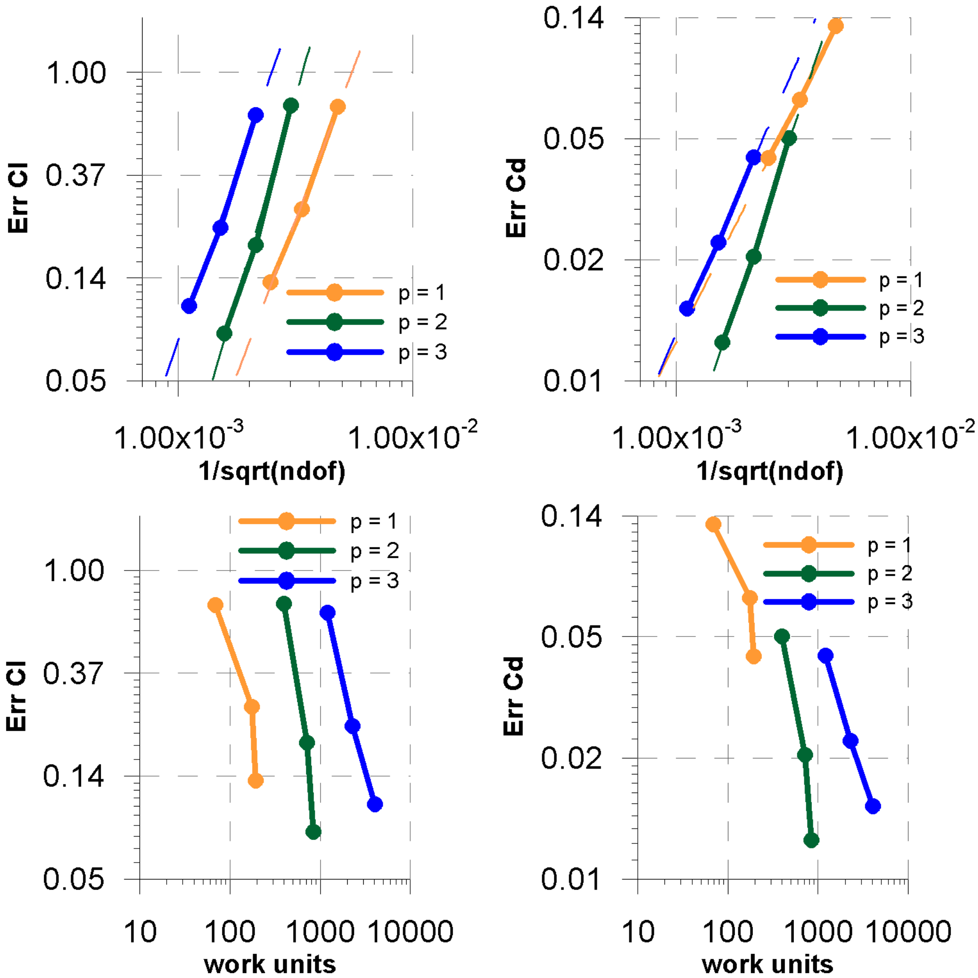

Figure 4: c_l & c_d error versus $1/\sqrt{nDOFs}$ (top) and work units (bottom)