Case C1.3

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1 Code Description

The solver utilized in this work is a high-order discontinuous Galerkin(DG) solver. The solver can solve the Euler, Navier-Stokes and RANS equations in two dimensions. The equations are solved using a fully implicit Newton solver which uses preconditioned GMRES as the linear solver. For case B a colored Gauss-Seidel preconditioner was used while case C employed a linear *hp*-multigrid preconditioner. The solver is parallelized using MPI where METIS splits the meshes for parallel processing. Goal-oriented *hp*-adaptation is used for both cases and the adjoint is solved using the same linear solver as the flow for each case.

2 Summary

In all cases the residuals for the flow and adjoint equations are converged 12.5 order of magnitude. The machine used in a Linux workstation with a single Intel Core i7 quad core processor at 2.66 GHz. The taubench timing result for this machine is $T_1 = 9.47$

3 Meshes

- The domain is 120x120 chords with the farfield boundary located at 60 chords from the airfoil surface. The farfield boundary condition is characteristic in/out-flow.
- The meshes are fully unstructured. For case B the mesh is purely triangular and for case C the mesh is mixed-element.
- During refinement the curvature remains constant because the mesh is initially curved to suitably high order($p_{curve} = 5$ for case B and $p_{curve} = 6$ for case C).
- The meshes are curved by using the geometry definition from the mesh generator which gives extra points on the boundary for curvature. Anisotropic meshes are curved by curving the lines used in the line-implicit linear solver.
- Case B Meshes:
  - Initial Mesh contains $N = 1,566$ elements at $p = 1$ for $N_{DoF} = 4,698$
  - Final Mesh contains $N = 8,346$ elements at $p = 1$ to $p = 4$ for $N_{DoF} = 33,060$
- Case C Meshes:

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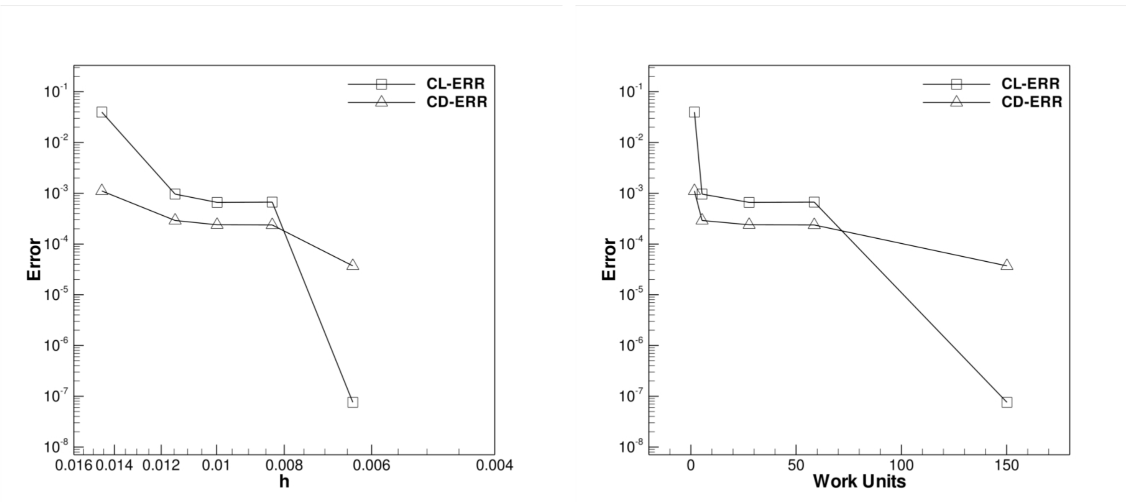
- Initial Mesh contains $N = 1,148$ elements at $p = 1$ for $N_{DoF} = 3,930$
- Final Mesh contains $N = 6,776$ elements at $p = 1$ to $p = 5$ for $N_{DoF} = 196,812$

4 Results

4.1 Case C1.3-B: Transonic Inviscid Flow

The inviscid transonic flow over a NACA0012 airfoil is computed using goal-oriented *hp*-adaptation with lift as the objective. $p = 1$ is the minimum order in the grid and piecewise constant artificial viscosity is employed with pressure as the sensor. The flow conditions are $M_\infty = .80$ and $\alpha = 1.25^o$. The lift and drag errors vs. both h and work units are depicted below in Figure 1(a) and Figure 1(b) respectively. In addition the lift and drag values vs. h are also shown in Figure 2.



(a) Lift and Drag Error vs. h

(b) Lift and Drag Error vs. Work Units

Figure 1: Lift and drag error for the Inviscid Transonic Flow over a NACA0012. Case B.

4.2 Case C1.3-C: Viscous Laminar Subsonic Flow

This test case considers the viscous laminar flow over a NACA0012 with flow conditions $M_\infty = .5$, $Re = 5,000$, and $\alpha = 1.0^o$. Again goal-oriented *hp*-adaptation is employed however drag is now the objective. In addition to the *hp*-adaptation, *h*-refinement using drag as the objective is also employed for comparison. The lift and drag errors vs. h and work units are shown below in Figures 3 and 4 respectively. Additionally the lift and drag values over the refinement process are depicted in Figure 5.

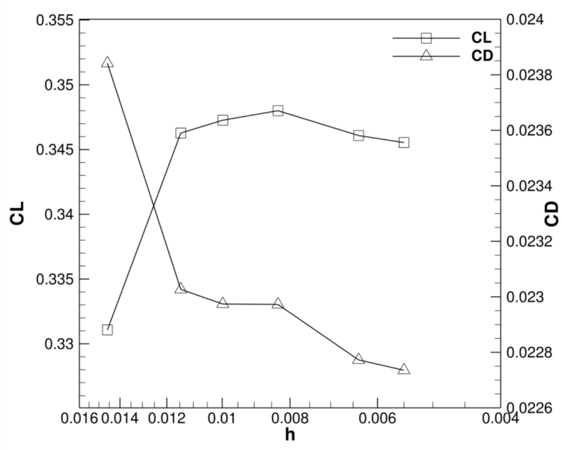
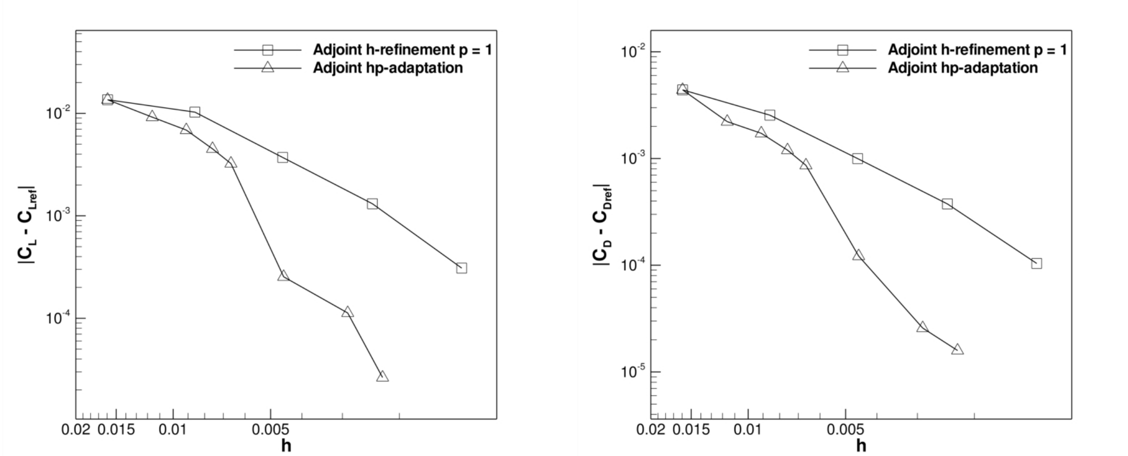


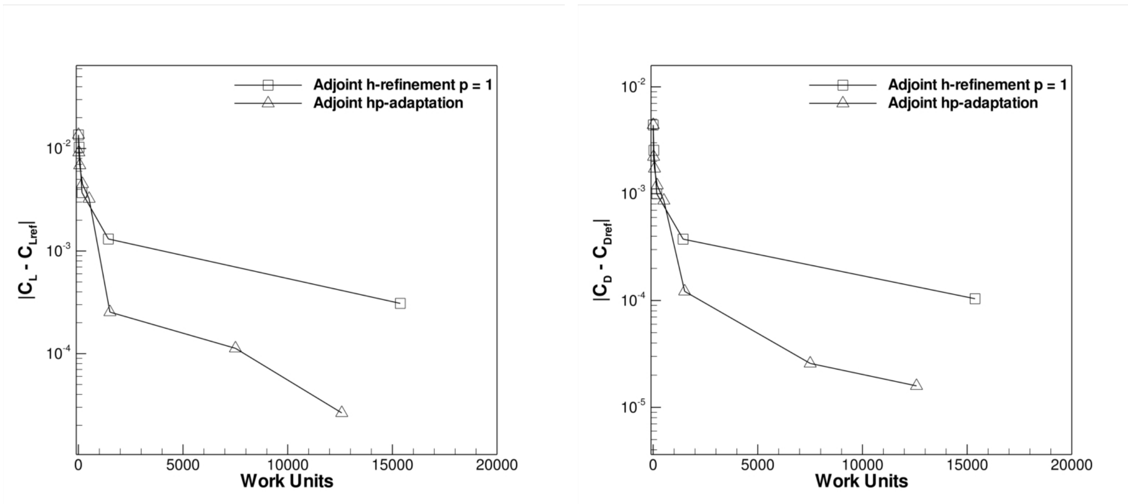
Figure 2: Lift and Drag values as the mesh is refined. Case B.



(a) Lift Error vs. h

(b) Drag Error vs. h

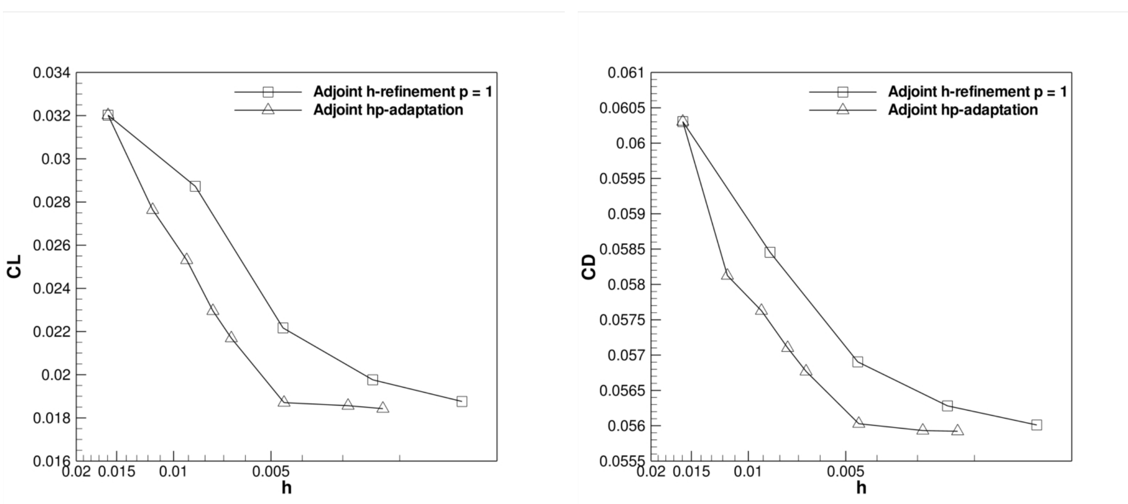
Figure 3: Lift and drag error vs. h for the viscous flow over a NACA0012. Case C.



(a) Lift Error vs. work units

(b) Drag Error vs. work units

Figure 4: Lift and drag error vs. work units for the viscous flow over a NACA0012. Case C.



(a) Lift vs. h

(b) Drag vs. h

Figure 5: Lift and drag vs. h for the viscous flow over a NACA0012. Case C.