1st International Workshop on High-Order CFD Methods, Nashville, January 7-8, 2012

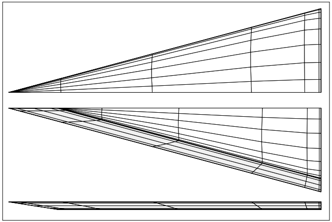
Summary of the C2.4 test case results

Ralf Hartmann
Institute of Aerodynamics and Flow Technology
German Aerospace Center

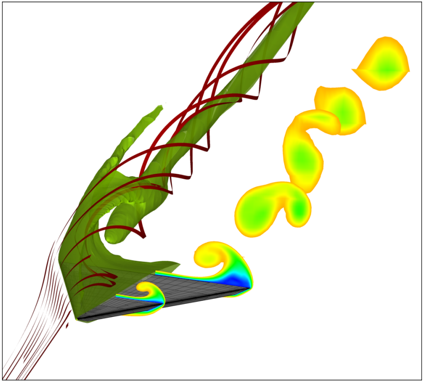
8. Jan. 2012

Test case C2.4

Laminar flow at $M = 0.3$, $Re = 4000$ and $\alpha = 12.5^\circ$ around the delta wing



geometry



Mach number isosurfaces (left) and slices (right) [LH10]

Reference values
(taken from [LH10]):
$C_d^{\mathrm{ref}} = 0.1658$, $C_l^{\mathrm{ref}} = 0.347$.

[LH10] T. Leicht and R. Hartmann. Error estimation and anisotropic mesh refinement for 3d laminar aerodynamic flow simulations. J. Comput. Phys., 229(19), 7344-7360, 2010.

Test case C2.4

Laminar flow at $M = 0.3$, $Re = 4000$ and $\alpha = 12.5^\circ$ around the delta wing

Following nested hexahedral meshes have been provided on the workshop (hiocfd) homepage

- delta.1.msh with 408 cells
- delta.2.msh with 3,264 cells
- delta.3.msh with 26,112 cells
- delta.4.msh with 208,896 cells

"Official" convergence criterion (taken from "Notes for all participants")

Reduction of the density residual to 10^{-10} relative to freestream conditions measured in a normalized L^2-norm, i.e.

$$R/R_\infty < 10^{-10} \quad \text{for} \quad R = L^2(Res_\varrho) = \sqrt{\frac{1}{N}\sum_i^N Res_{\varrho,i}^2}$$

Summary of test case C2.4

Laminar flow at $M = 0.3$, $Re = 4000$ and $\alpha = 12.5^\circ$ around the delta wing

Data available from

- Alessandro Colombo, Francesco Bassi, University of Bergamo, **UBerg**
- Krzysztof Fidkowski, University of Michigan, **UMich**
- Ralf Hartmann, DLR, Braunschweig, **DLR**
- Li Wang, J. Taylor Erwin, W. Kyle Anderson, University of Tennessee, **UTenn**

Summary of test case C2.4

Laminar flow at $M = 0.3$, $Re = 4000$ and $\alpha = 12.5^\circ$ around the delta wing

Case details

	UBerg	UMich	DLR	UTenn
discretization	DG, BR2	DG, BR2 ?	DG, BR2	DG, SIPG
basis functions	$P_p(\kappa)$, orth.norm.	$\sigma(Q_p(\hat{\kappa}))$?	$\sigma(Q_p(\hat{\kappa}))$	$\sigma(P_p(\hat{\kappa}))$?
numerical flux	exact Riemann	Roe ?	Roe+entropy fix	HLLC
farfield	characteristic	Roe + $\mathbf{u}_\infty$?	characteristic	subsonic in/outflow
solver	bw Euler	Newton	Newton	p-MG+el.GS/GMRES
grid	grids (hiocfd)	grids (hiocfd)	grids (hiocfd)	unstruct./tetrah.
convergence criterion	official $R/R_\infty < 10^{-10}$ $\sqrt{\frac{1}{N}\sum_i^N Res_{\varrho,i}^2}$	other $R < 10^{-7}$ $\sum_i^N \lvert Res_{\varrho,i}\rvert$	official $R/R_\infty < 10^{-10}$ $\sqrt{\frac{1}{N}\sum_i^N Res_{\varrho,i}^2}$	other $R < 10^{-11}$ $\sqrt{\frac{1}{N}\sum_i^N Res_{\varrho,i}^2}$?
wall				adiabatic (instead of isothermal)

Note, that work units of UMich & UTenn are not comparable to others.

Summary of test case C2.4

Laminar flow at $M = 0.3$, $Re = 4000$ and $\alpha = 12.5^\circ$ around the delta wing

Case details

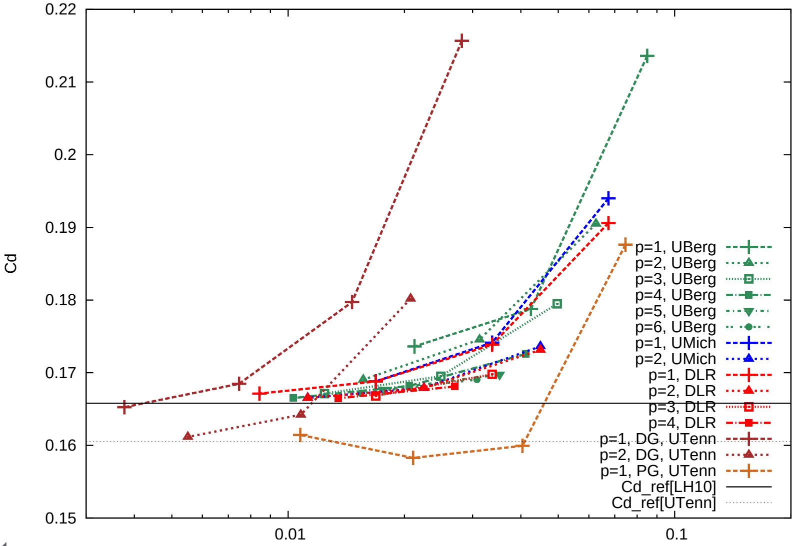
	UTenn
discretization	Petrov-Galerkin
farfield	subsonic in/outflow
solver	approx. Newton
grid	unstruct./tretrah.
convergence criterion	$R < 10^{-11}$ $\sqrt{\frac{1}{N}\sum_i^N Res^2_{\varrho,i}}$?

Summary of test case C2.4

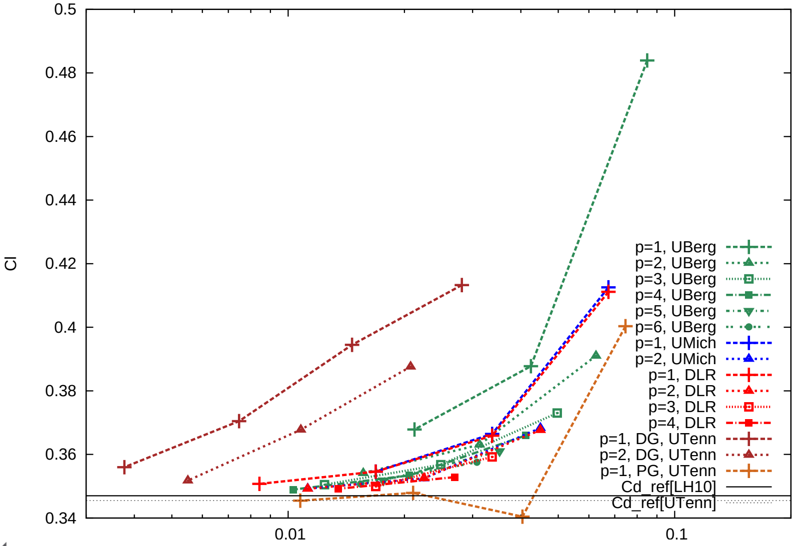
Reference values

- taken from [LH10]: $C_d^{\mathrm{ref}} = 0.1658$, $C_l^{\mathrm{ref}} = 0.347$
  grids (hiocfd), isothermal wall boundary condition
- obtained by UTenn(DG): $C_d^{\mathrm{ref}} = 0.1605$, $C_l^{\mathrm{ref}} = 0.3455$
  unstructured grids, adiabatic wall boundary condition

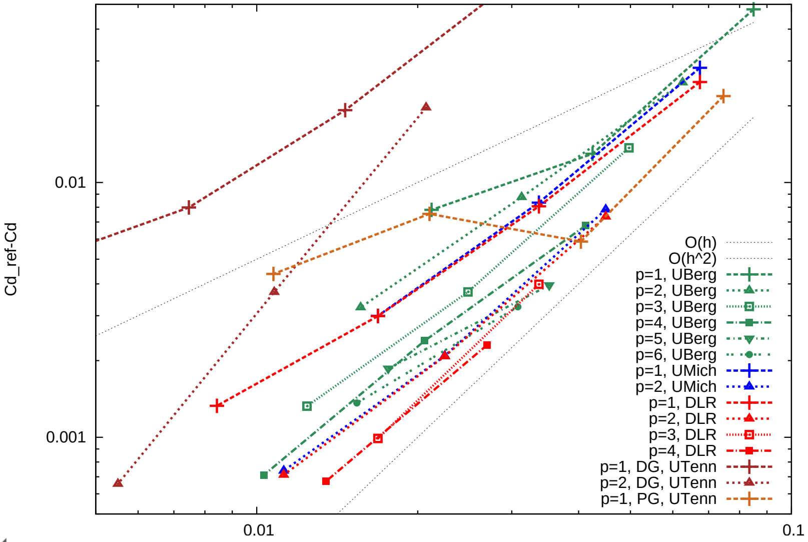
Test case C2.4: C_d vs. h



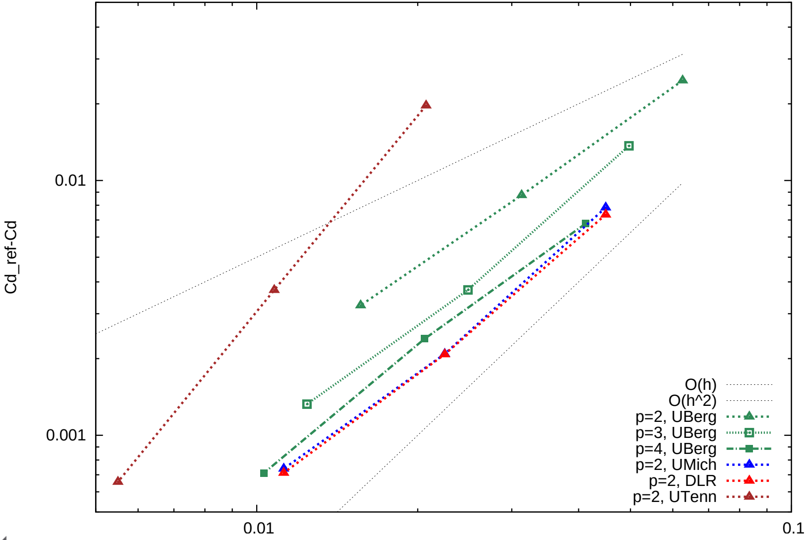
Test case C2.4: C_l vs. h



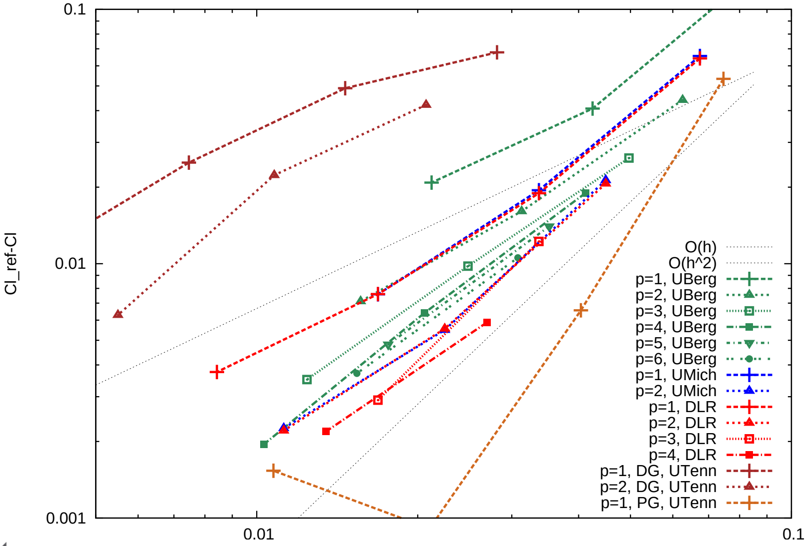
Test case C2.4: Error in C_d vs. h



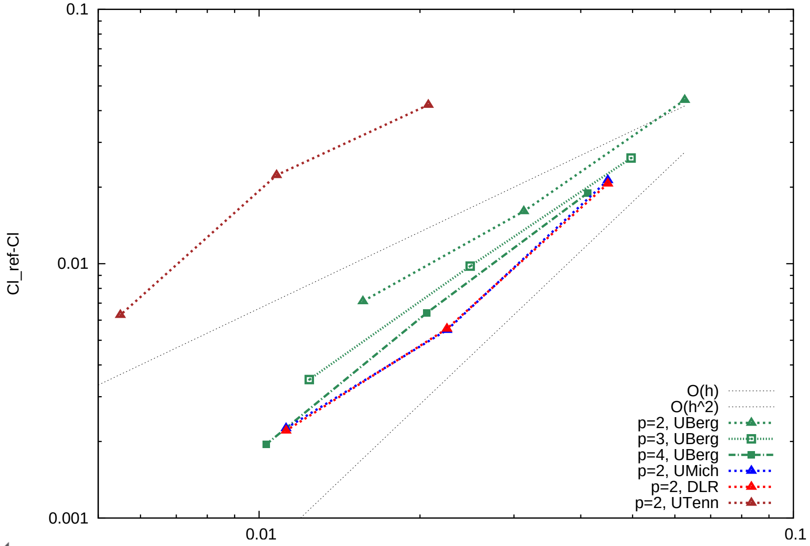
Test case C2.4: Error in C_d vs. h for $p = 2$



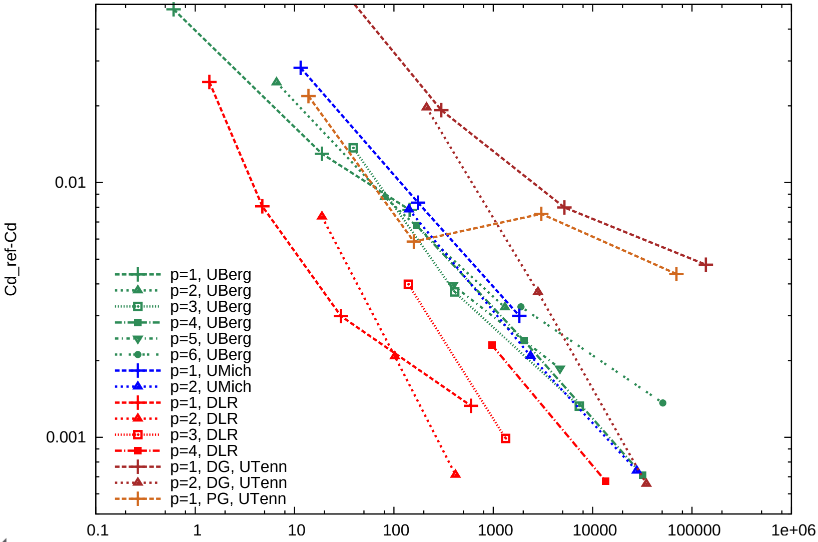
Test case C2.4: Error in C_l vs. h



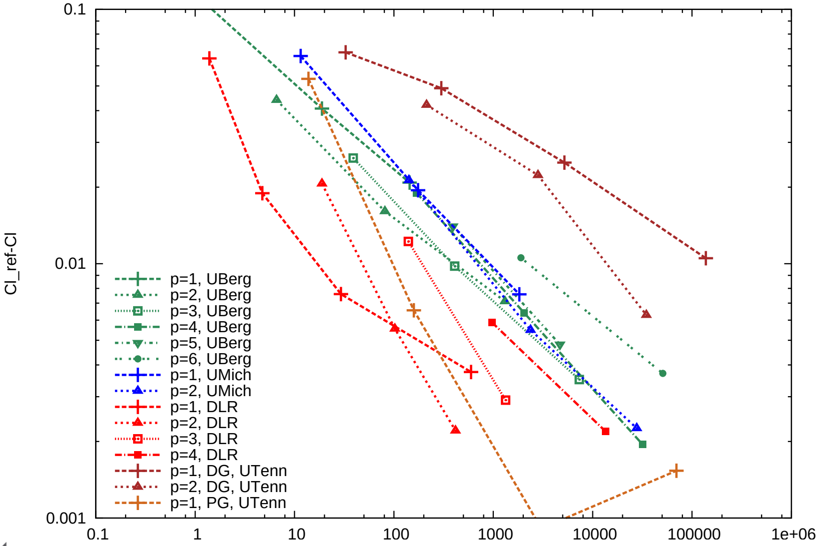
Test case C2.4: Error in C_l vs. h for $p = 2$



Test case C2.4: Error in C_d vs. workunits



Test case C2.4: Error in C_l vs. workunits



Test case C2.4: Summary

- Comparison of results of **UTenn** with the results of the other partners is difficult as **UTenn** computed on different grid sequence with different boundary conditions and different convergence criterion.

Test case C2.4: Summary

- Comparison of results of **UTenn** with the results of the other partners is difficult as **UTenn** computed on different grid sequence with different boundary conditions and different convergence criterion.
- Very good agreement of C_d and C_l values between **UMich** and **DLR** due to the use of very similar numerical schemes.
  - However, **UMich** required a factor of 7–70 more work units than **DLR**.
  - Difference due to parallelization issues and/or different convergence criterion?

Test case C2.4: Summary

- Comparison of results of **UTenn** with the results of the other partners is difficult as **UTenn** computed on different grid sequence with different boundary conditions and different convergence criterion.
- Very good agreement of C_d and C_l values between **UMich** and **DLR** due to the use of very similar numerical schemes.
  - However, **UMich** required a factor of 7–70 more work units than **DLR**.
  - Difference due to parallelization issues and/or different convergence criterion?
- Difference of results between **UBerg** and **UMich**/**DLR** due to different basis functions/discrete function spaces.
  - There is some agreement when comparing results for similar dimension of discrete function spaces instead of for the same polynomial degree.

Test case C2.4: Summary

- Comparison of results of **UTenn** with the results of the other partners is difficult as **UTenn** computed on different grid sequence with different boundary conditions and different convergence criterion.
- Very good agreement of C_d and C_l values between **UMich** and **DLR** due to the use of very similar numerical schemes.
  - However, **UMich** required a factor of 7–70 more work units than **DLR**.
  - Difference due to parallelization issues and/or different convergence criterion?
- Difference of results between **UBerg** and **UMich**/**DLR** due to different basis functions/discrete function spaces.
  - There is some agreement when comparing results for similar dimension of discrete function spaces instead of for the same polynomial degree.
- Due to the non-smoothness of the flow solution there is not much gain (if at all) in computing time using a global p larger than 2.