1st International Workshop on High-Order CFD Methods

Test Case C1.3: Steady Flow over the NACA0012 Airfoil

Georg May, Michael Woopen

Graduate School AICES, RWTH Aachen

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RWTH AACHEN UNIVERSITY

Test Case 1.3: Summary

- Trends in numerical discretization and relaxation procedures
- Summary of results
- This report: Not too heavy on statistics (small sample size)
  - 1.3a (subsonic, inviscid): 6 data sets
  - 1.3b (transonic, inviscid): 3 data sets
  - 1.3c (subsonic, viscous): 5 data sets
- Note: Not all contributions represented (missing data)

Discretization Methods

Method of choice seems to be DG

- This includes many DG-flavors (e.g. CPR-DG)
- Non-DG submissions:
  - Finite-Volume (1)
  - SBP-SAT (1)
- Most use fairly standard DG schemes
  - Winner of popularity contest: DG with BR2 (used by a third of submissions)

Meshes and Fidelity of Results

Meshes

- Very many different meshes found use
  - provided quad meshes
  - self-generated meshes (quad, tri, and mixed)
- Correlation between mesh type and fidelity of results not attempted here
- Submissions include adaptive methods (goal-oriented)

General Remark on Results

- For subsonic cases: Convergence studies reveal superiority of high-order approximation
  - Fewer DOFS for same error
  - Lower CPU time for same error
- Work needs to be done for transonic flow

Solution Methods

This is a steady test case! Look for efficient relaxation methods

- Method of choice seems to be (damped) Newton / Krylov
  - Almost all use GMRES (one BICGSTAB)
- No consensus on preconditioners
  - ILU-n
  - Gauss-Seidel
  - Multigrid

Important note: We do not compare and evaluate efficiency

- insufficient number of samples
- We cannot assume all codes are fully optimized

Convergence Summary
Test Case C1.3a (Subsonic inviscid)

Convergence Towards Truth Solution

Do we agree on the truth solution?

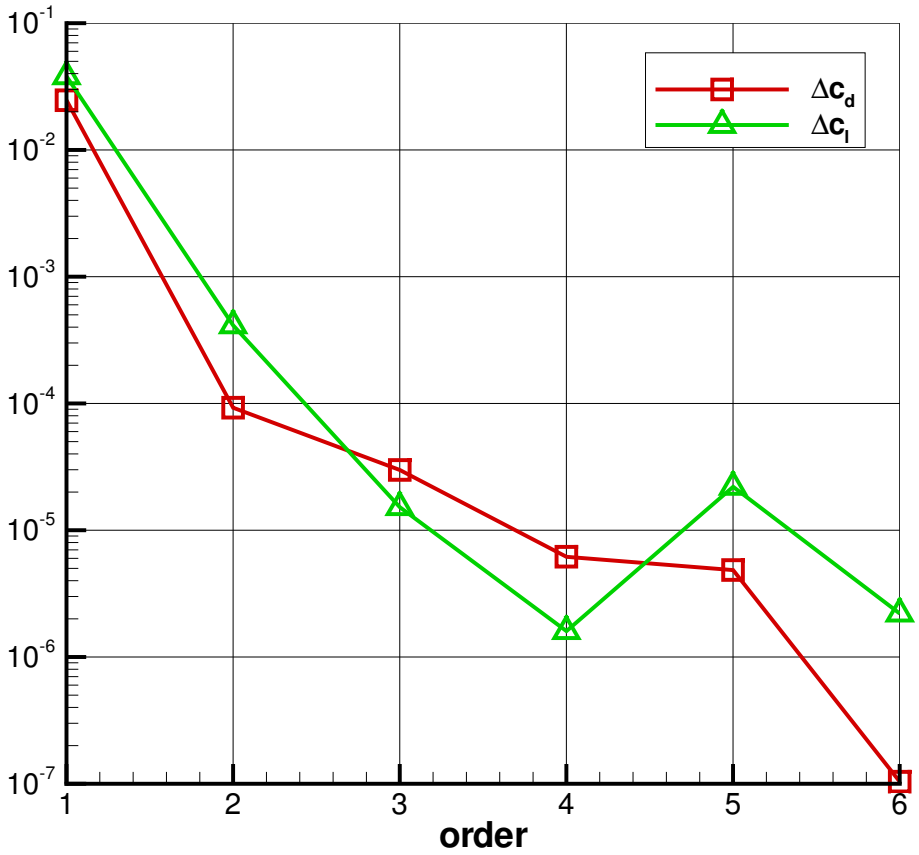
"Truth" lift and drag coefficients

	Average	Standard Deviation
Drag	2.4219E-06	2.0548E-06
Lift	2.865E-01	2.3008E-05

Compare to p=3 solutions

	Average	Standard Deviation
Drag	1.5166E-05	2.4829E-05
Lift	2.865E-01	3.7218E-05

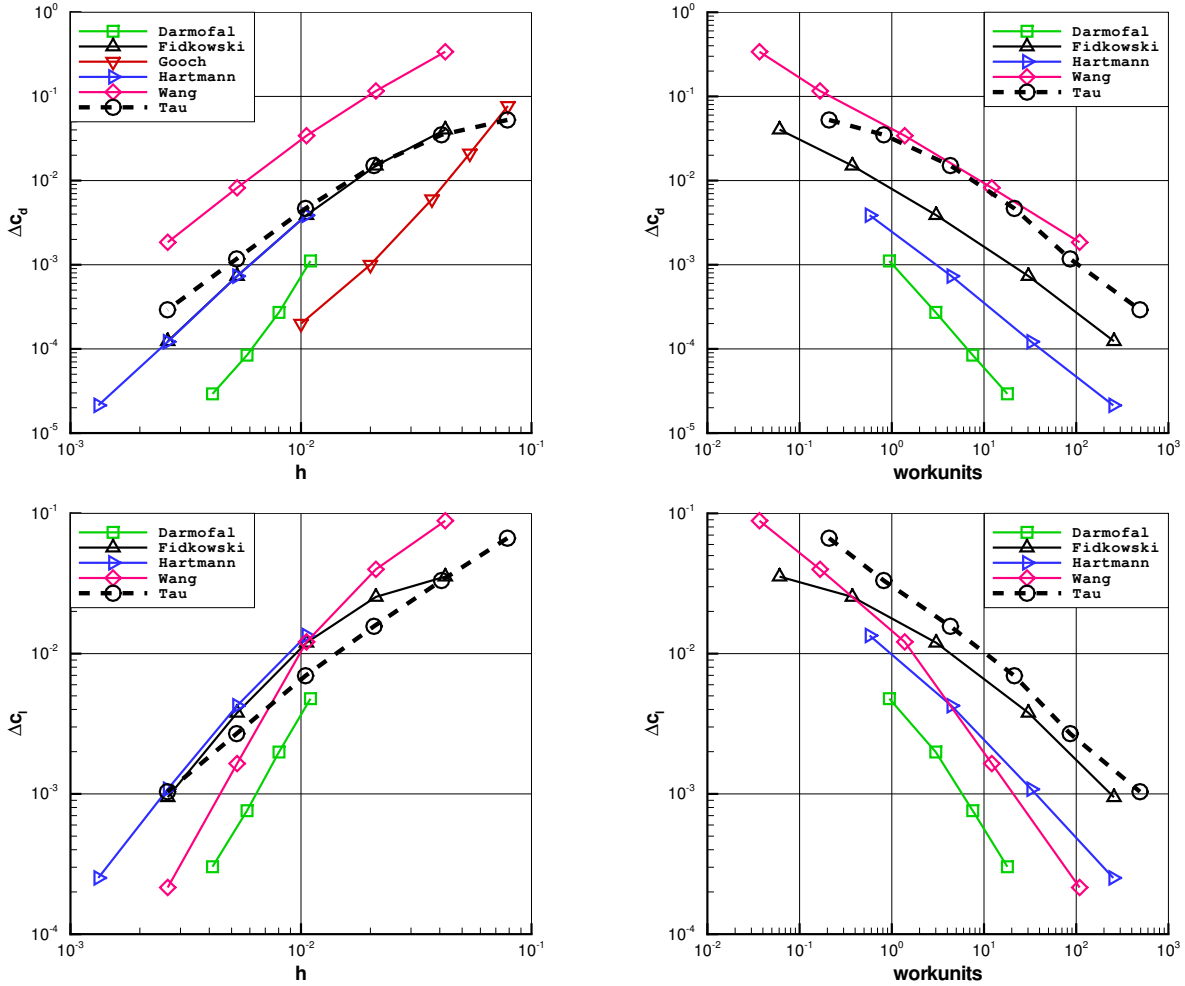
Convergence towards Truth Solution



Mean lift and drag coefficients for each order on the finest mesh approaching the mean reference values

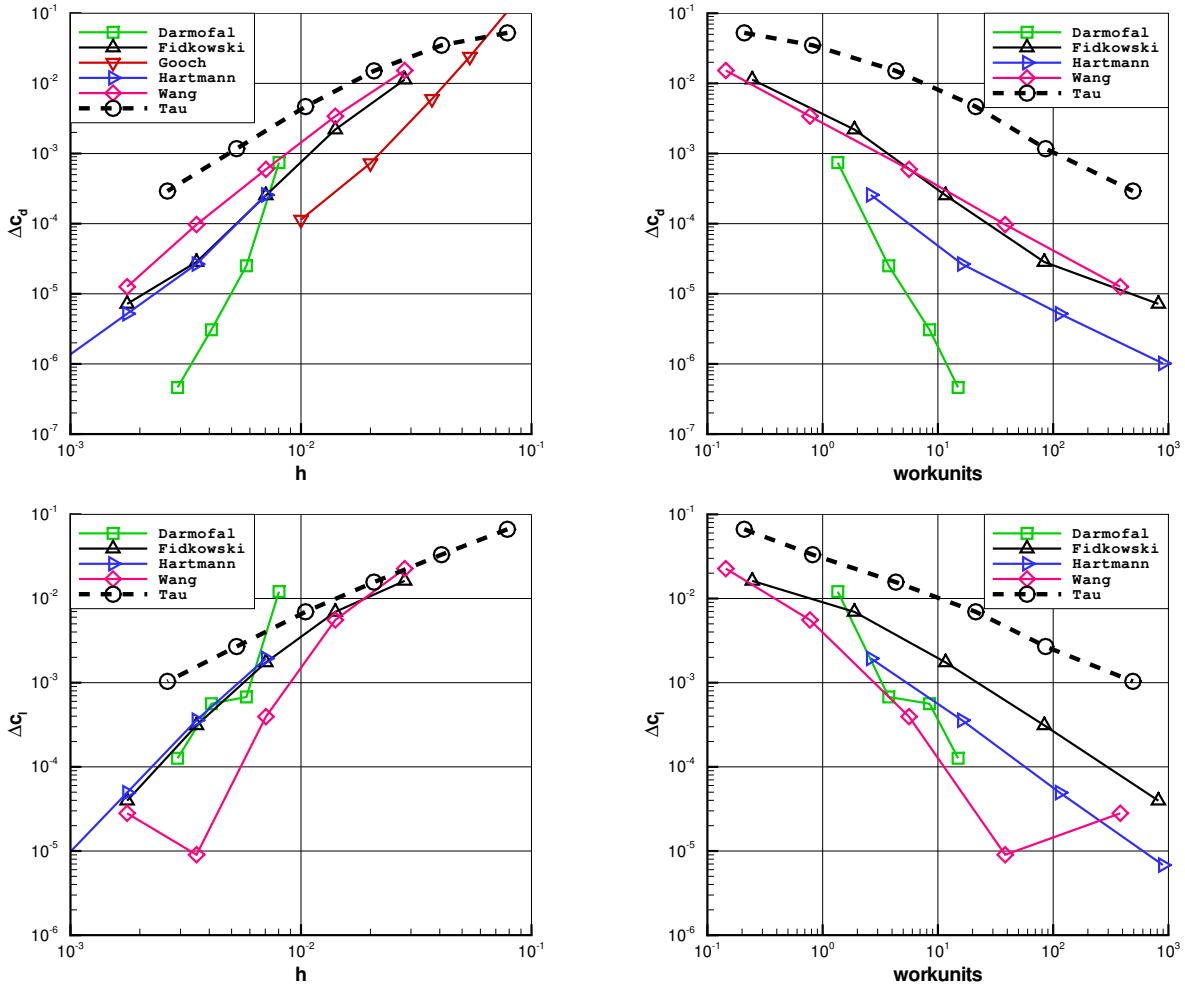
Convergence – Test Case C1.3a (Subsonic Inviscid)

2nd Order (p=1)



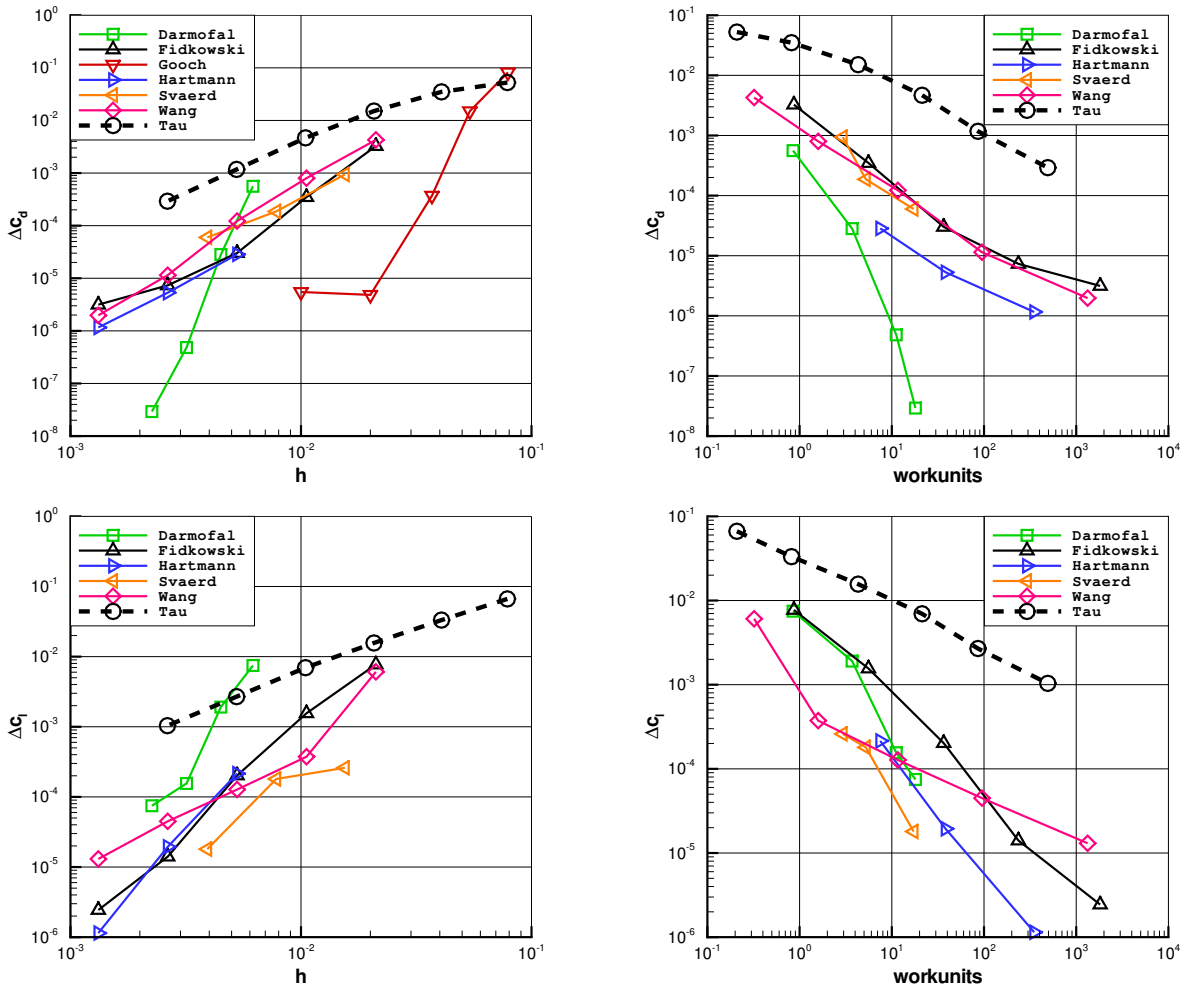
Convergence – Test Case C1.3a (Subsonic Inviscid)

p=2



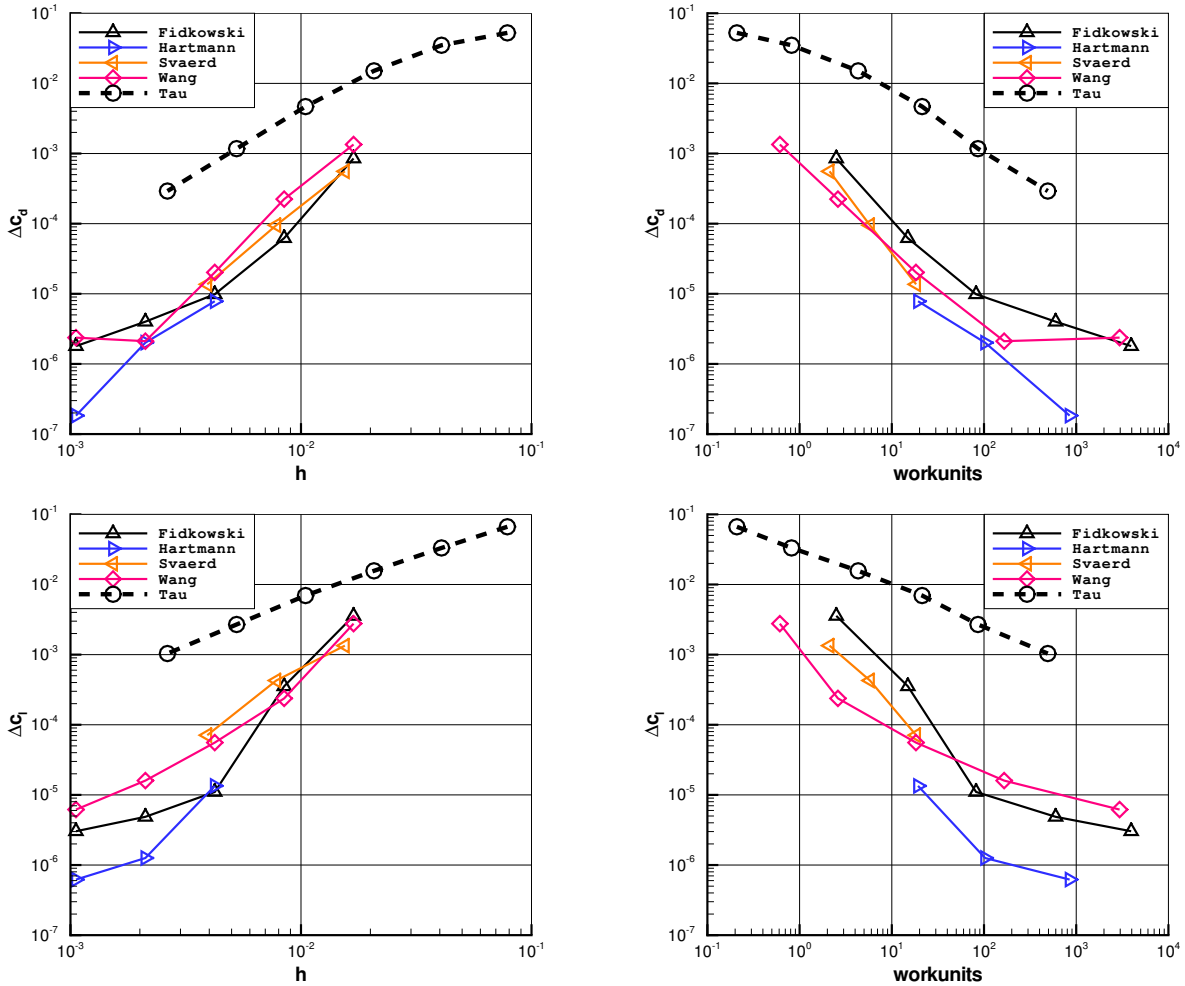
Convergence – Test Case C1.3a (Subsonic Inviscid)

p=3



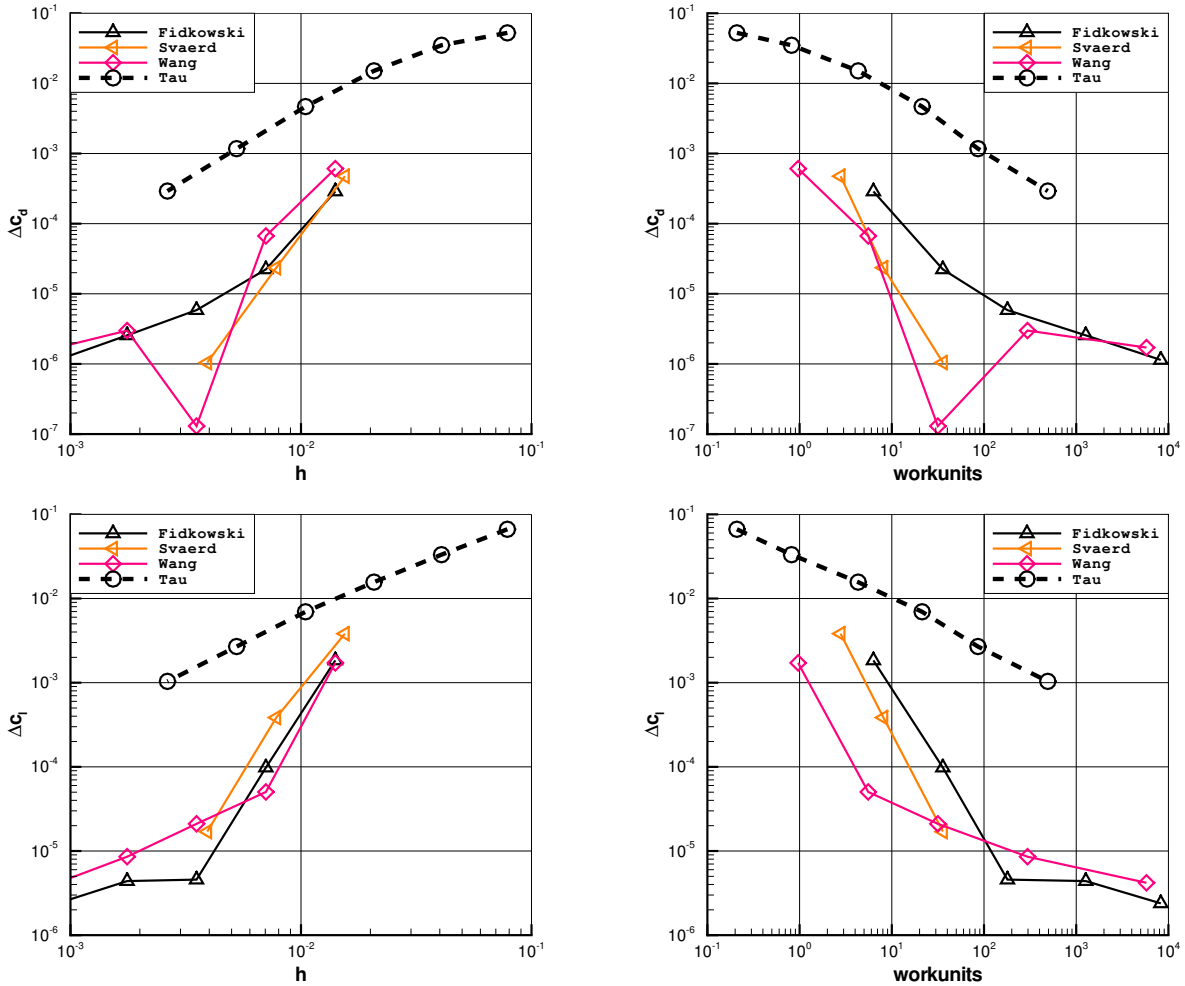
Convergence – Test Case C1.3a (Subsonic Inviscid)

p=4



Convergence – Test Case C1.3a (Subsonic Inviscid)

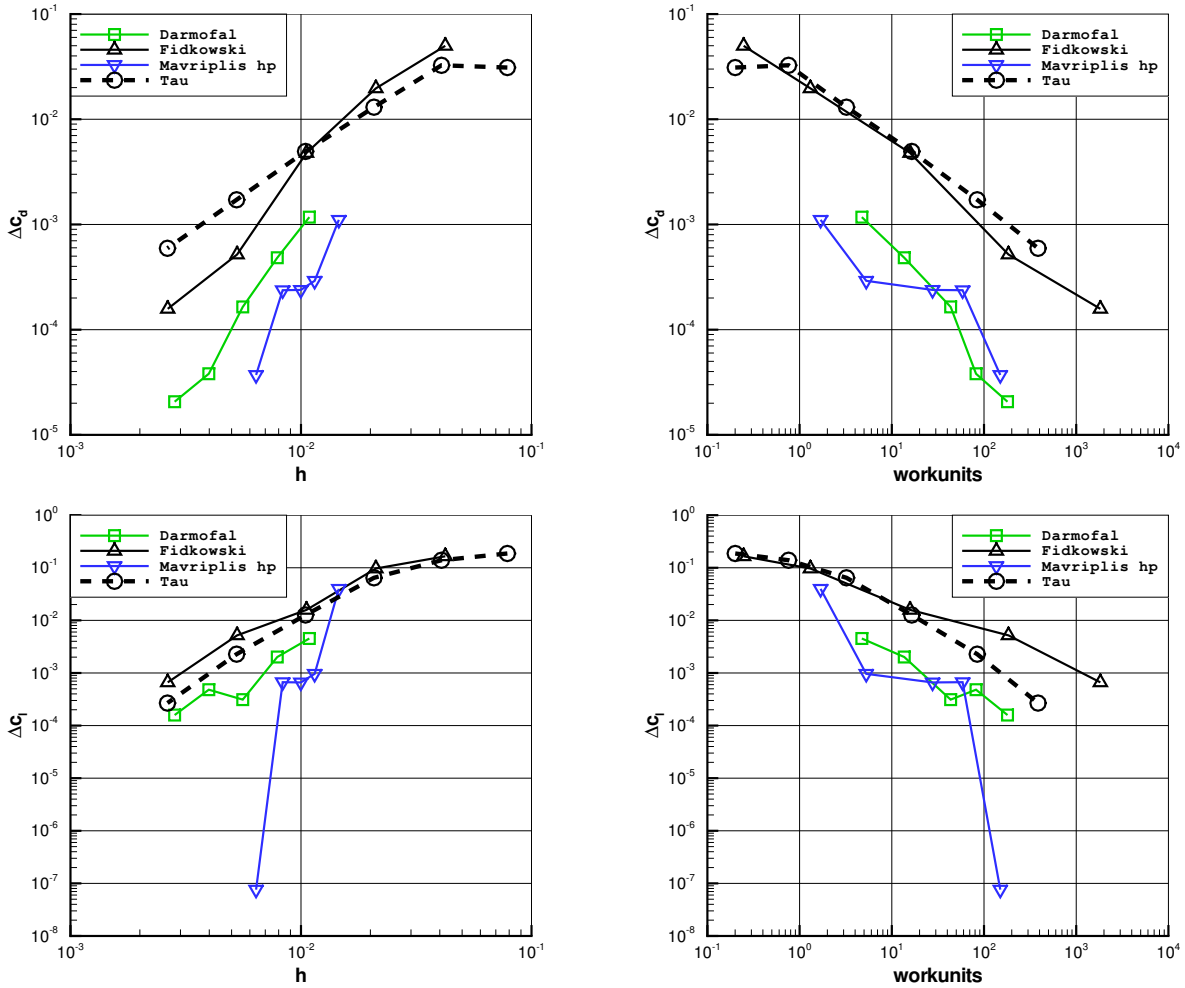
p=5



Convergence Summary
Test Case C1.3b (Transonic Inviscid)

Convergence – Test Case C1.3b (Transonic Inviscid)

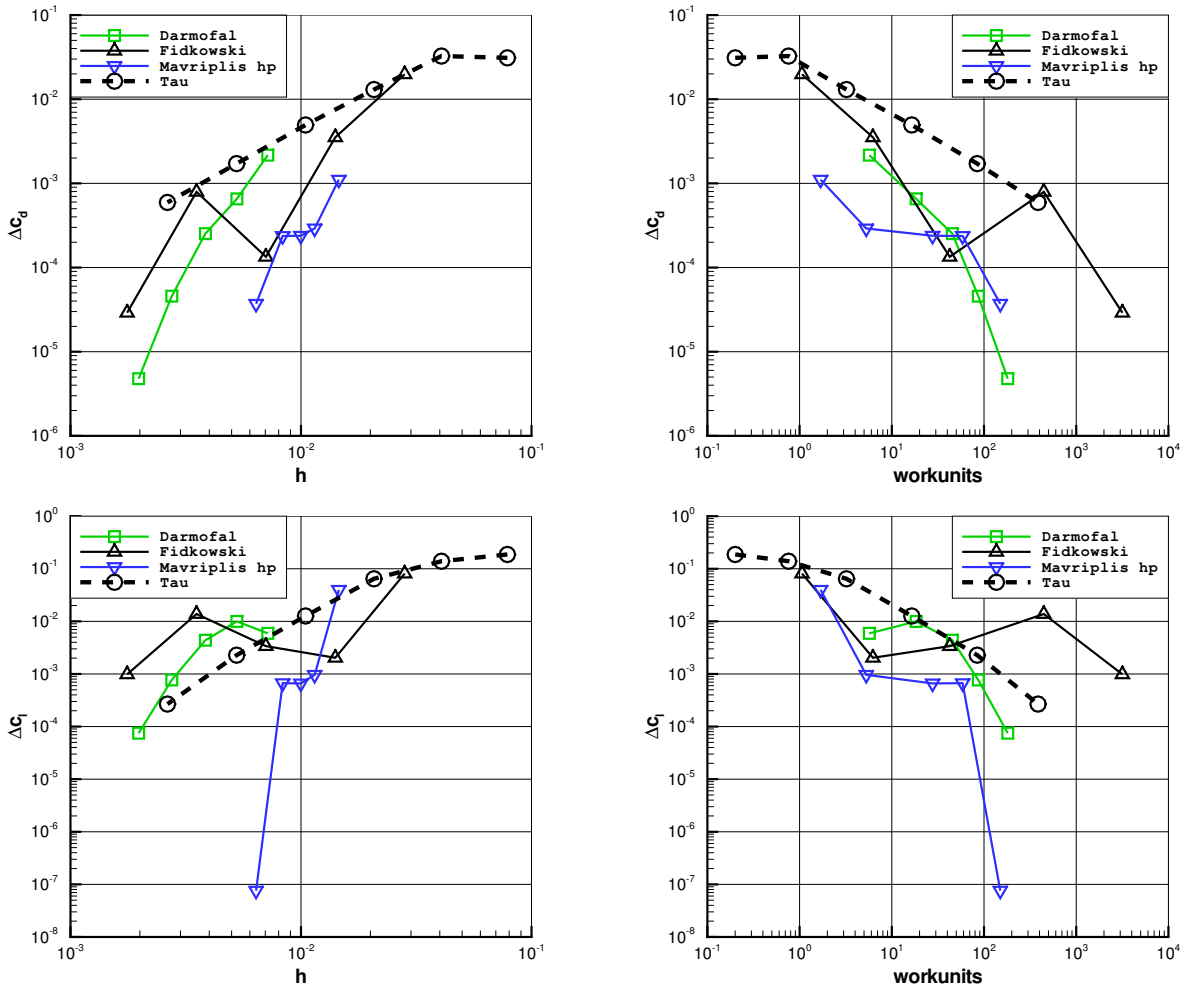
2nd order (p=1)



(Mavriplis hp uses p=1..4. This curve is the same for all values of p)

Convergence – Test Case C1.3b (Transonic Inviscid)

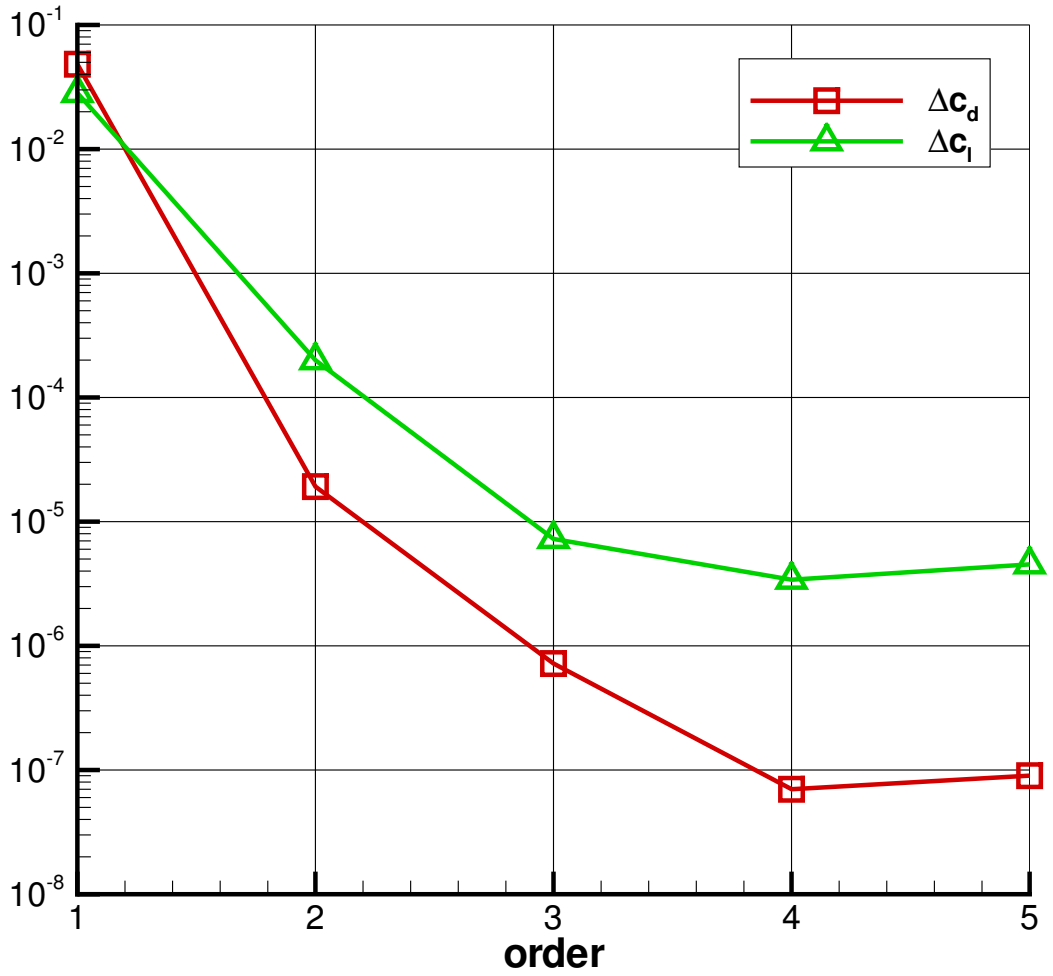
p=2



(Mavriplis hp uses p=1..4. This curve is the same for all values of p)

Convergence Summary
Test Case C1.3c (Subsonic Viscous)

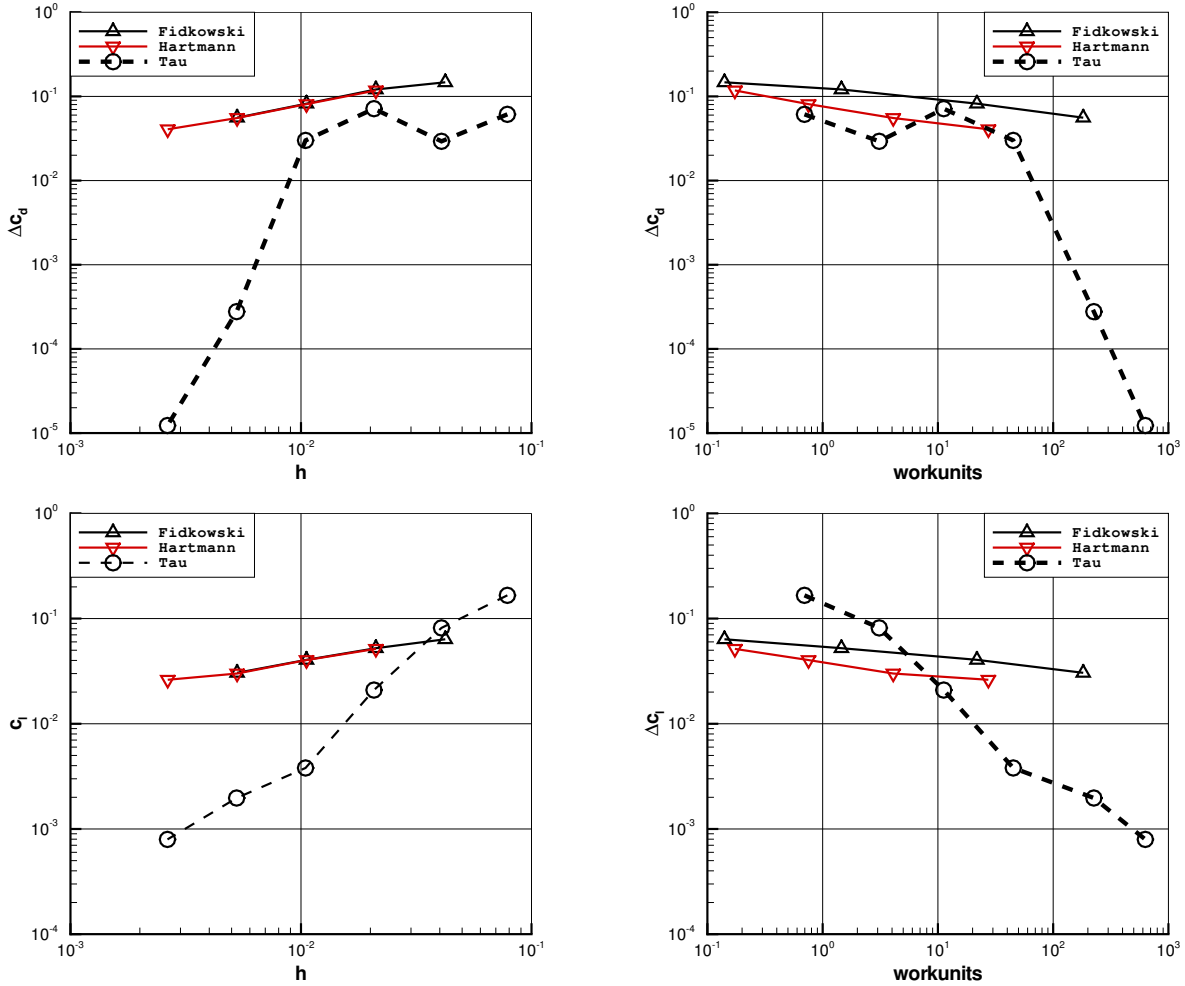
Convergence Towards Truth Solution



Mean lift and drag coefficients for each order on the finest mesh approaching the mean reference values

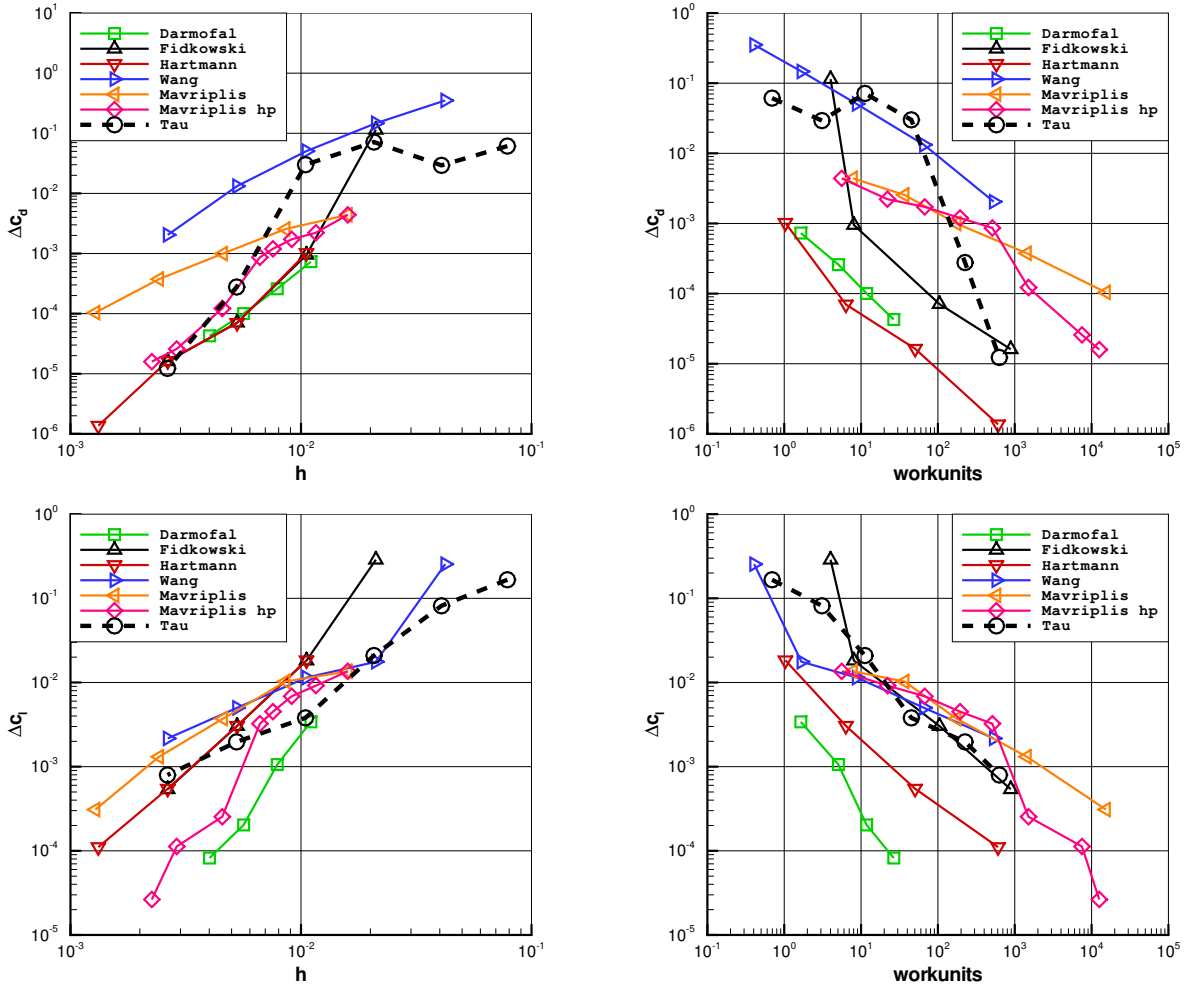
Convergence – Test Case C1.3c (Subsonic Viscous)

1st order (p=0)



Convergence – Test Case C1.3c (Subsonic Viscous)

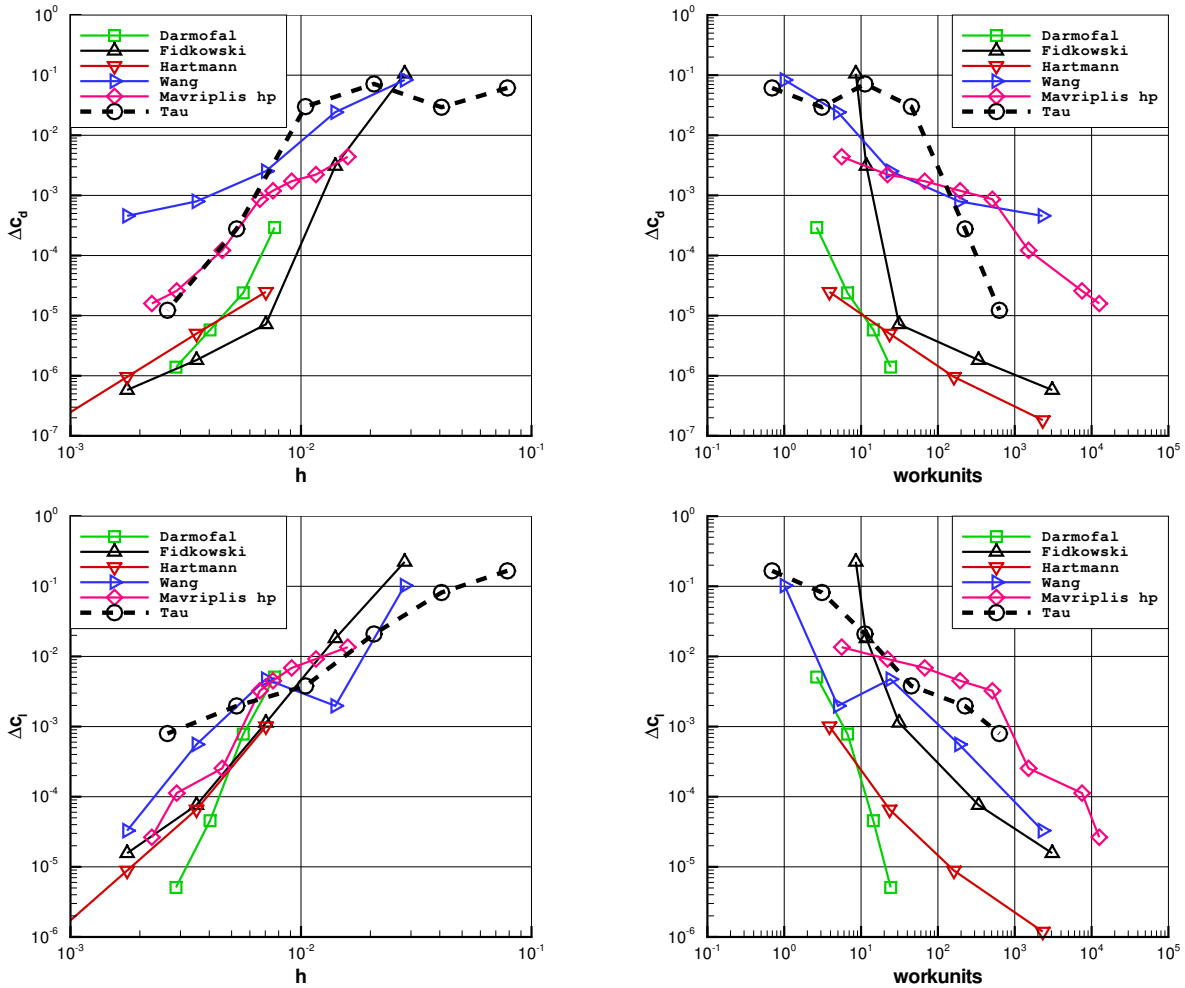
p=1



(Mavriplis hp uses p=1..5. This curve is the same for all values of p)

Convergence – Test Case C1.3c (Subsonic Viscous)

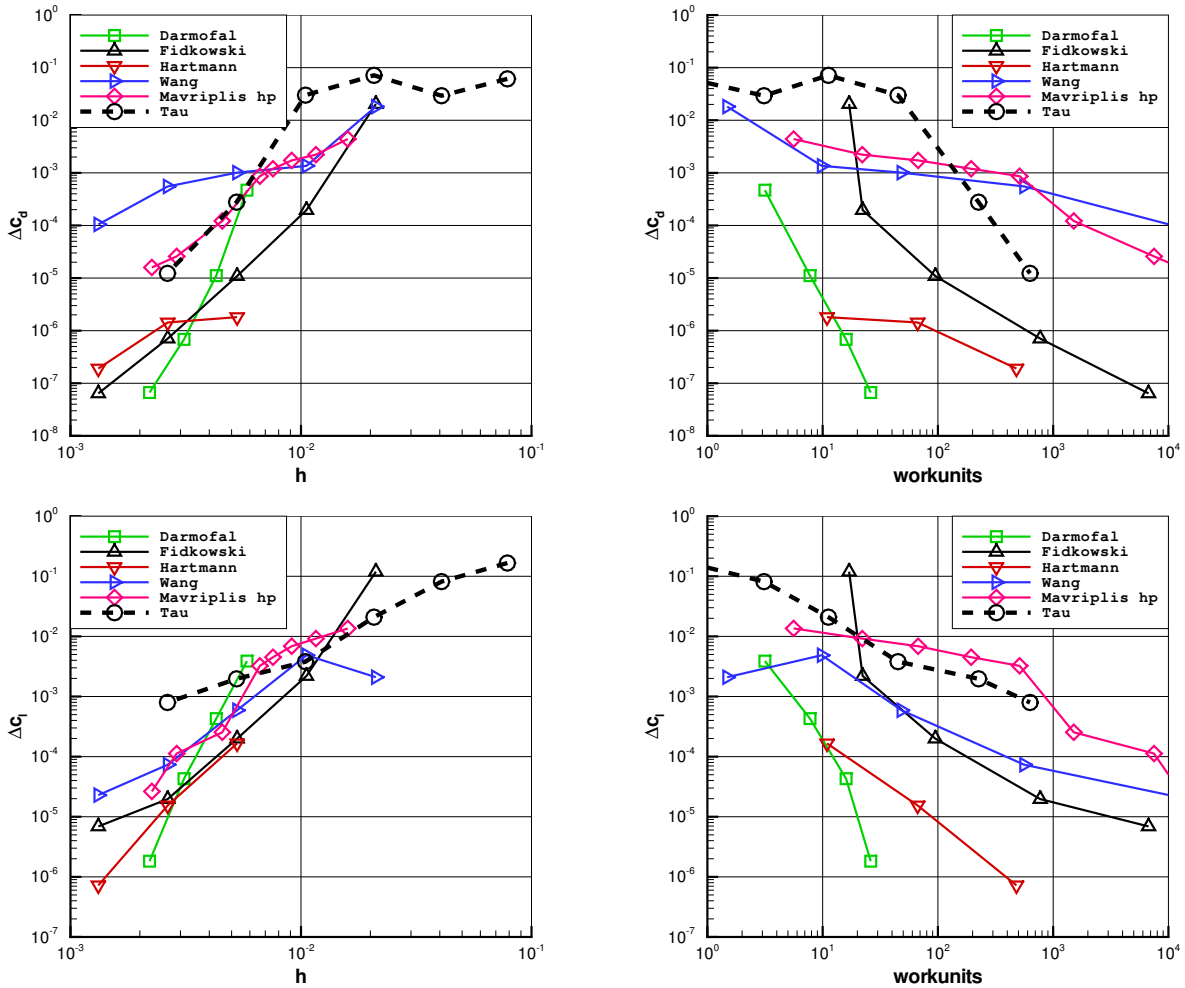
p=2



(Mavriplis hp uses p=1..5. This curve is the same for all values of p)

Convergence – Test Case C1.3c (Subsonic Viscous)

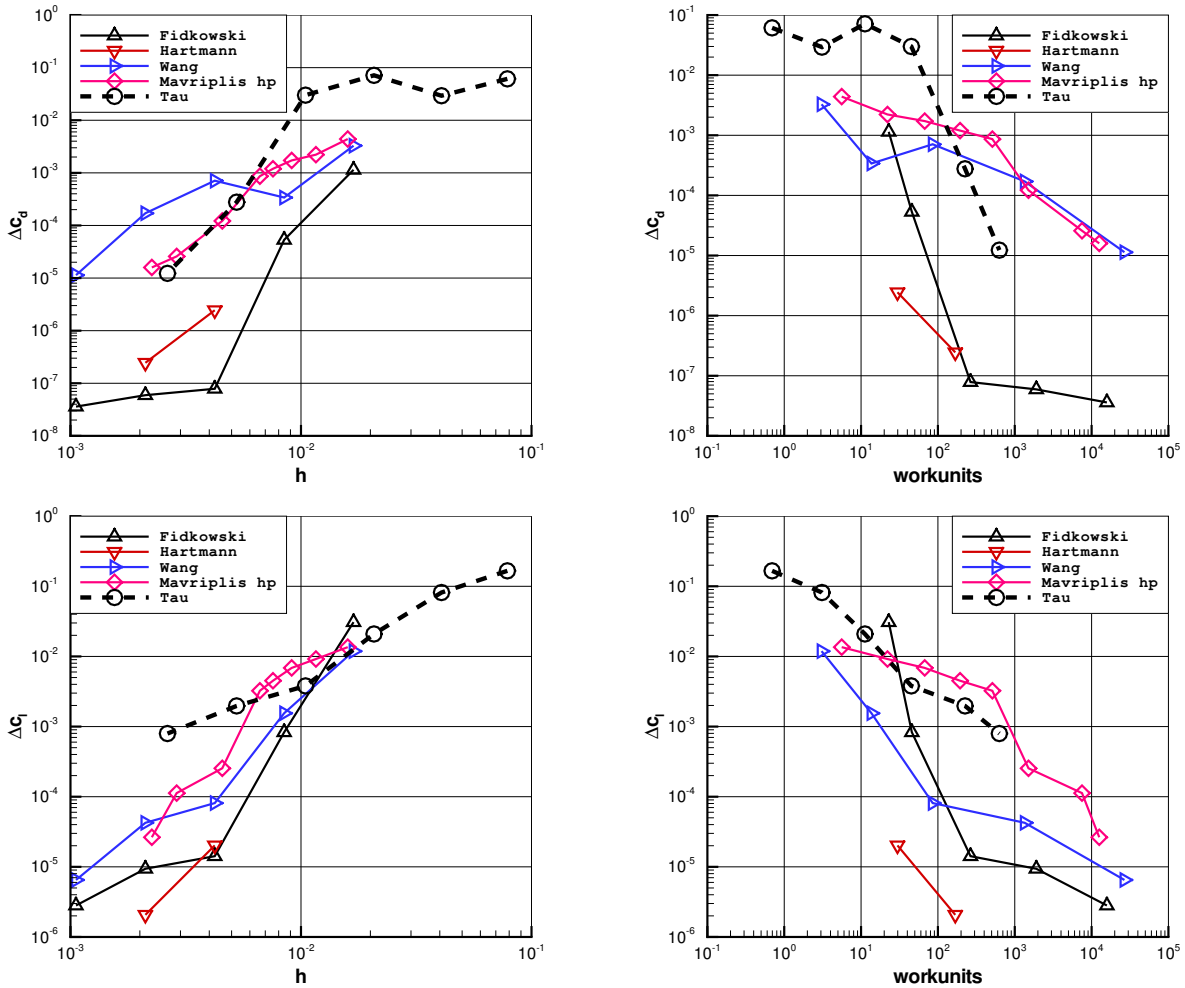
p=3



(Mavriplis hp uses p=1..5. This curve is the same for all values of p)

Convergence – Test Case C1.3c (Subsonic Viscous)

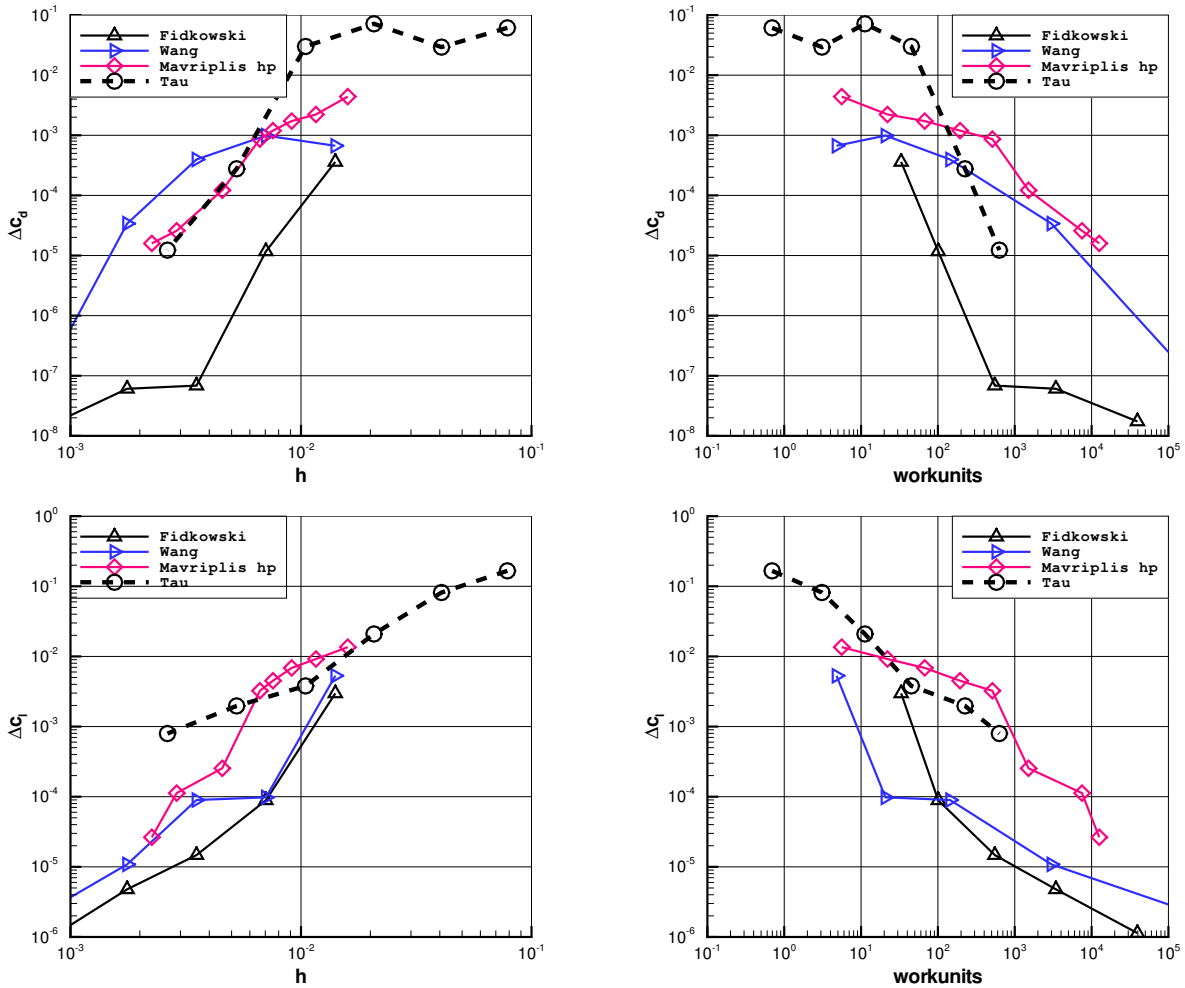
p=4



(Mavriplis hp uses p=1..5. This curve is the same for all values of p)

Convergence – Test Case C1.3c (Subsonic Viscous)

p=5



(Mavriplis hp uses p=1..5. This curve is the same for all values of p)

Summary of Conclusions

- Participants use:
  - Predominantly DG Discretization methods
  - Similar Solution methods for the steady problem
- Higher order pays in terms of work units versus error
  - i.e. for the subsonic cases!
- Convergence in lift and drag shows considerable scatter
- Adaptive mesh refinement demonstrates advantages
- Very difficult to establish clear trends