C3.5 Summary: Common Research Model

3rd International Workshop on High-Order CFD Methods
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updated/corrected after the workshop

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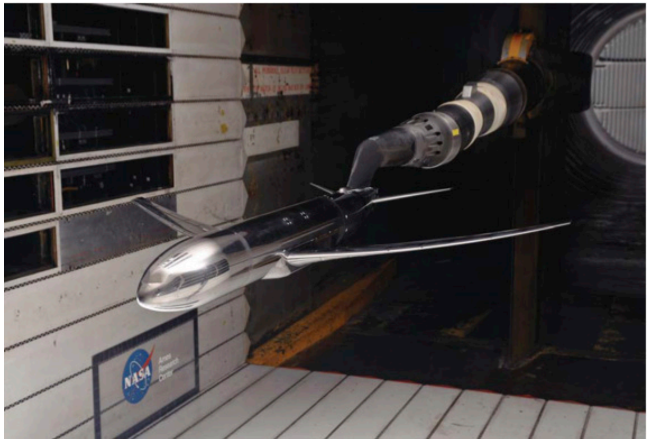
DLR

C3.5: Common Research Model (CRM)

Overview



- steady-state RANS case
- cruise conditions – transonic flow
- wing-body configuration
  similar to modern airliner

- experimental data
- extensively studied in AIAA Drag Prediction Workshops 4 and 5
  numerical data (Finite Volume) from many groups
  (55 contributions from 22 groups in DPW-5)

- References:
  - http://commonresearchmodel.larc.nasa.gov
  - http://aaac.larc.nasa.gov/tsab/cfdlarc/aiaa-dpw
    for comparison figures are taken from DPW-5 summary presentation
    (http://aaac.larc.nasa.gov/tsab/cfdlarc/aiaa-dpw/Workshop5/presentations/DPW5_Presentation_Files/14_DPW5%20Summary-Draft_V7.pdf)

C3.5: Common Research Model (CRM)
CFD setting

Ma=0.85
Re=5×10^6
target C_L=0.5 ± 0.001

- fully turbulent flow, no transition
- free air, no wind tunnel effects

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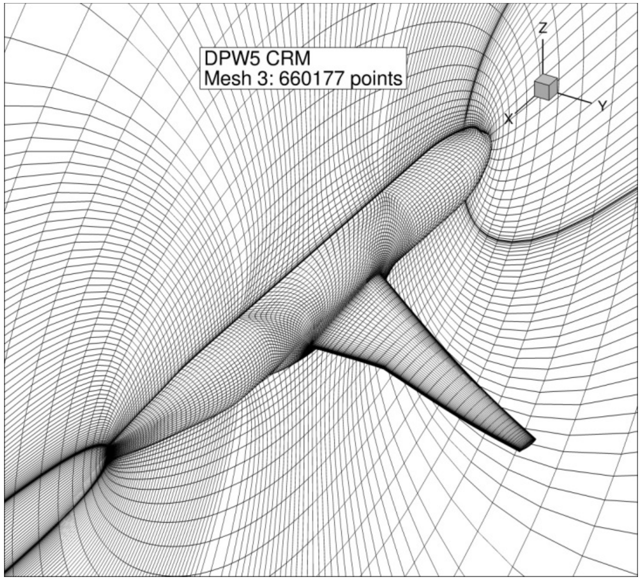
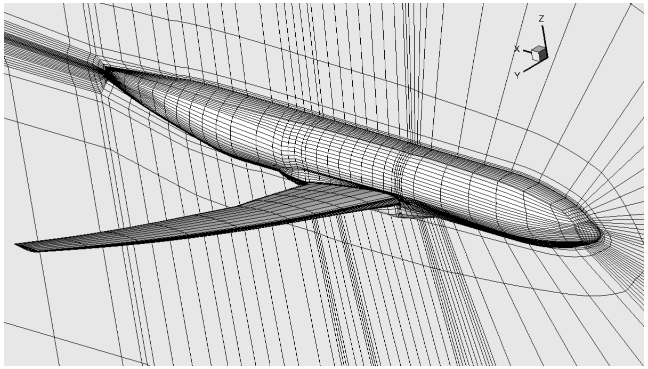
C3.5: Common Research Model (CRM)
Meshes

- multi-block structured meshes
  from DPW-5
  not high-order,
  not suited for agglomeration
  to HO-macro-elements



- coarse cubic hexahedral HO-meshes
  by University of Michigan
  obtained via agglomeration of
  linear structured meshes
  (45 k and) 80 k element meshes,
  provided on workshop website



Results (second workshop)

- only two groups with high order codes
- only second order solutions (third order adjoint solves for error estimation)

- Marco Ceze, Krzysztof Fidkowski
  University of Michigan
  DG, p=1, SA, mesh adaptive results driven by drag adjoint

- Ralf Hartmann
  DLR
  DG, p=1, kω, mesh adaptive results driven by (unweighted) residual ind.

- Stefan Langer
  DLR
  FV, second order central scheme, (negative) SA,
  mesh sequence from DPW-5

Additional results (third workshop)

- Marco Ceze, Krzysztof Fidkowski
  University of Michigan
  DG, p=1, SA,
  mesh adaptive results driven by drag adjoint (respecting the lift constraint)

- Ralf Hartmann
  DLR
  DG, p=1, kω, mesh adaptive results driven by
    a) (unweighted) residual indicators
    b) lift adjoint

- Stefan Langer
  DLR
  FV, second order central scheme, (negative) SA,
  mesh sequence based on global refinement of HOW mesh

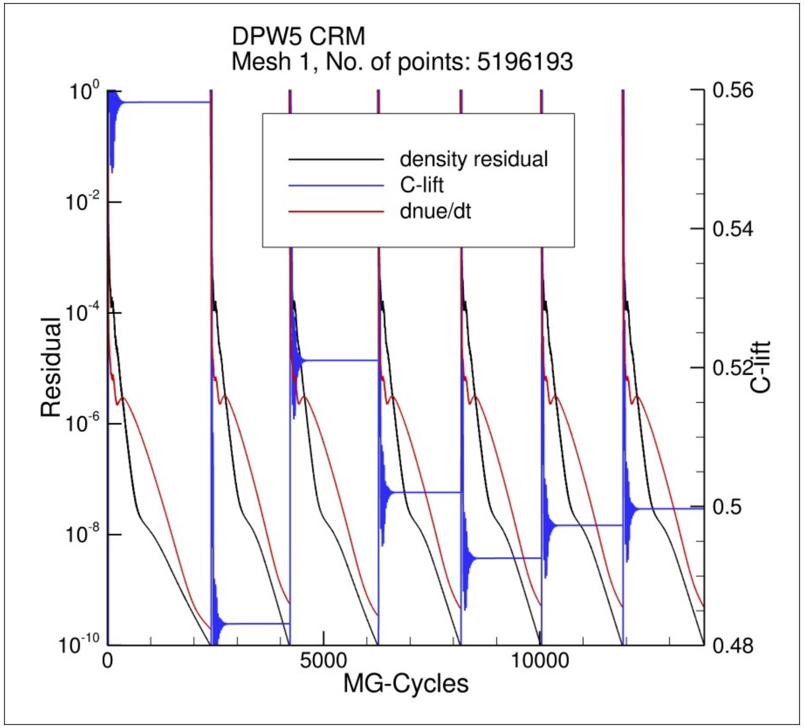
Individual Presentation(s)

Reference results

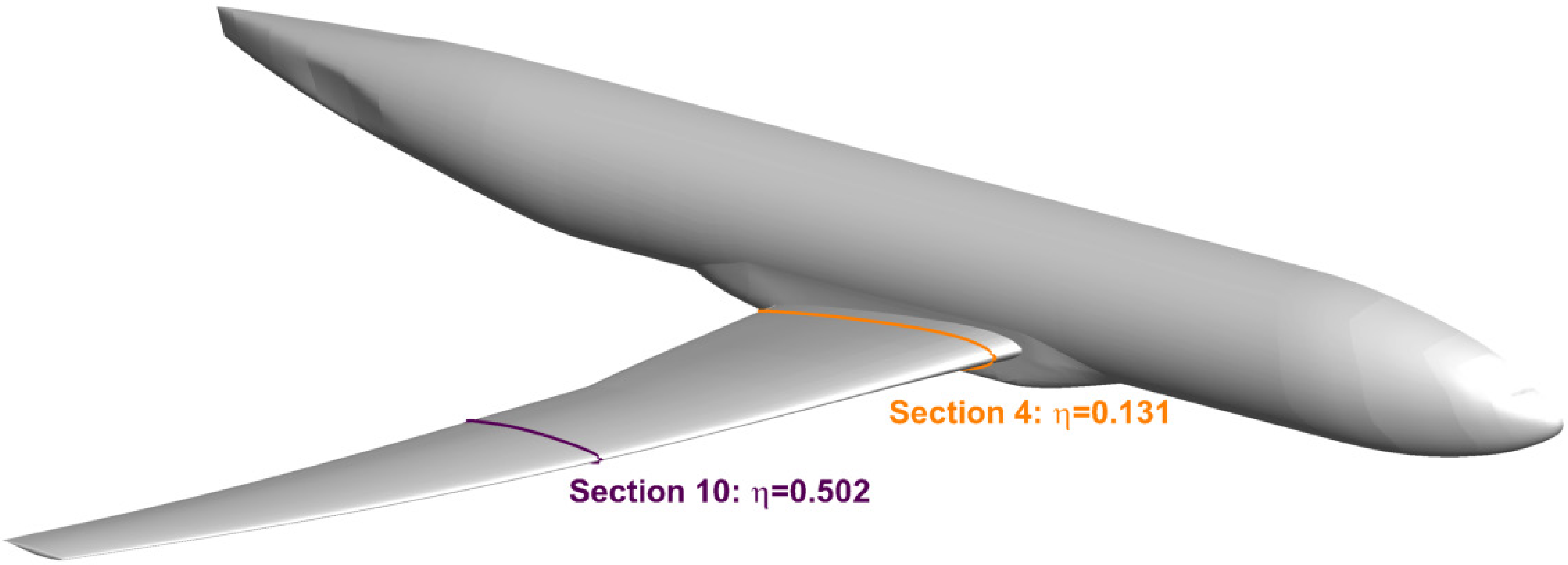
- second order node-centered Finite Volume code (Stefan Langer, DLR)
- central scheme with upwind-based artificial dissipation
- multi-grid based on Galerkin projection
- implicit multi-stage RK smoother
- target lift via AoA-bisection

- results on DPW-5 meshes
  - coarse: 660,177 points
  - fine: 41,231,169 points

- results on HOW-based meshes
  - coarse: 79,505 cells
  - fine: 5,088,320 cells

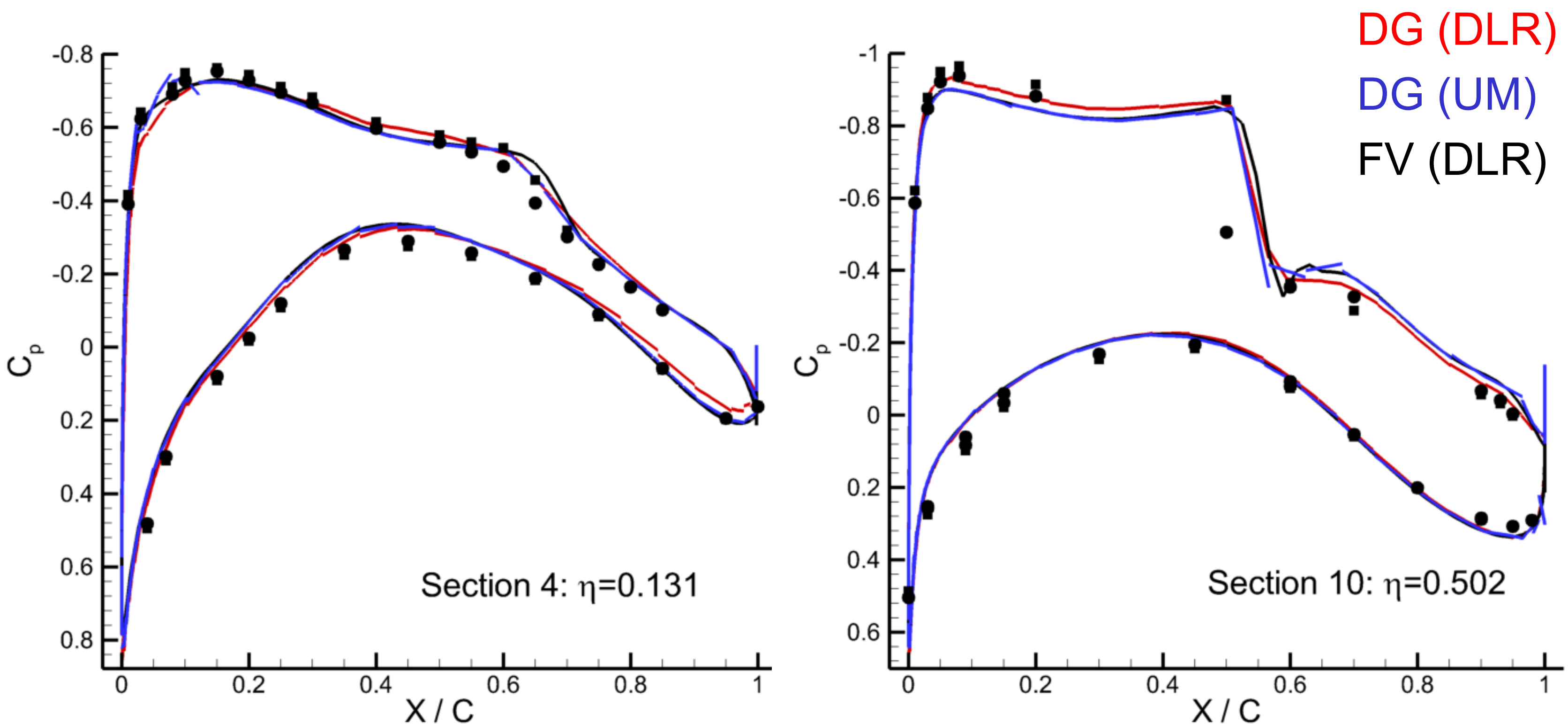


Comparison of results
Sectional cuts



Comparison of results

Sectional cuts



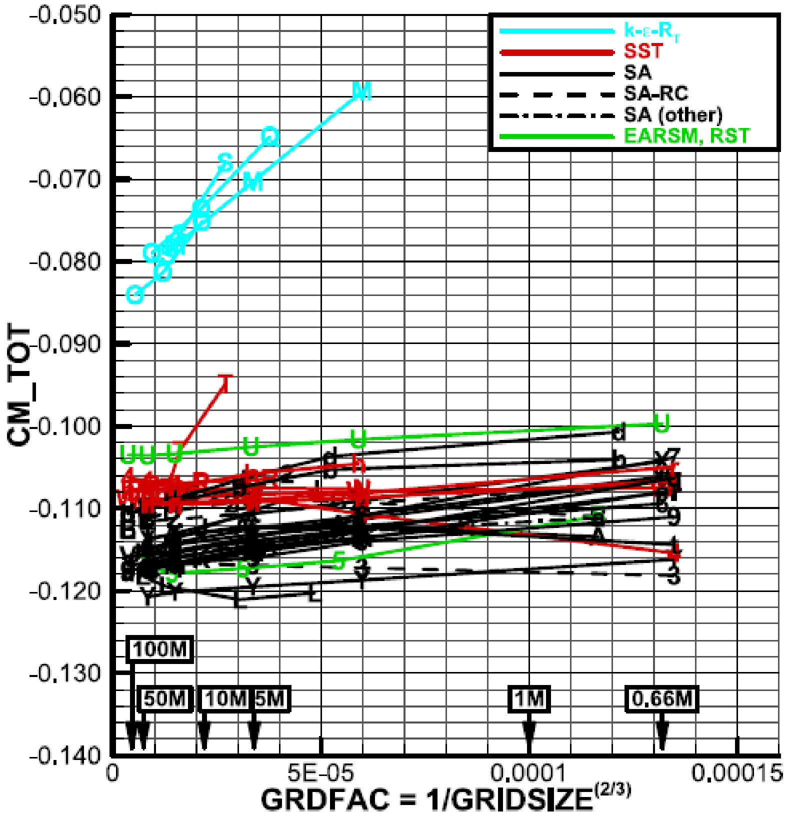
Comparison of results
Integral and scalar values

- drag coefficient
- pitching moment coefficient
- angle of attack

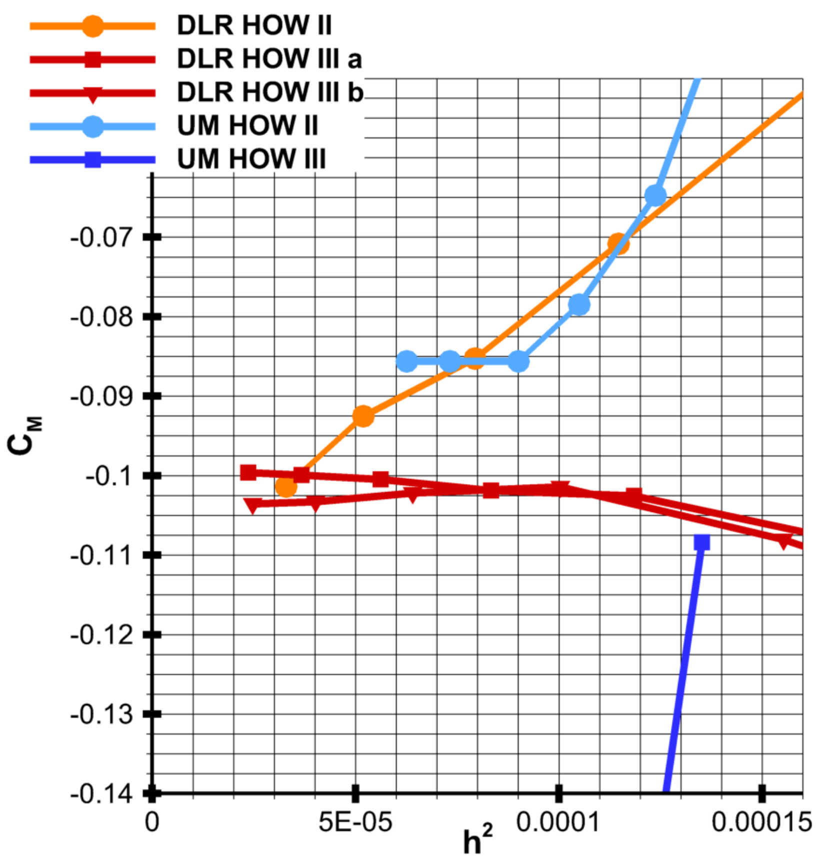
close similarity of plots to DPW-5 summary

- same axis ranges
- plotted against $h^2 = \left(\frac{1}{\sqrt[3]{DoF}}\right)^2$
- for second order convergence this yields straight lines

Comparison of results
mesh convergence: pitching moment



DPW-5



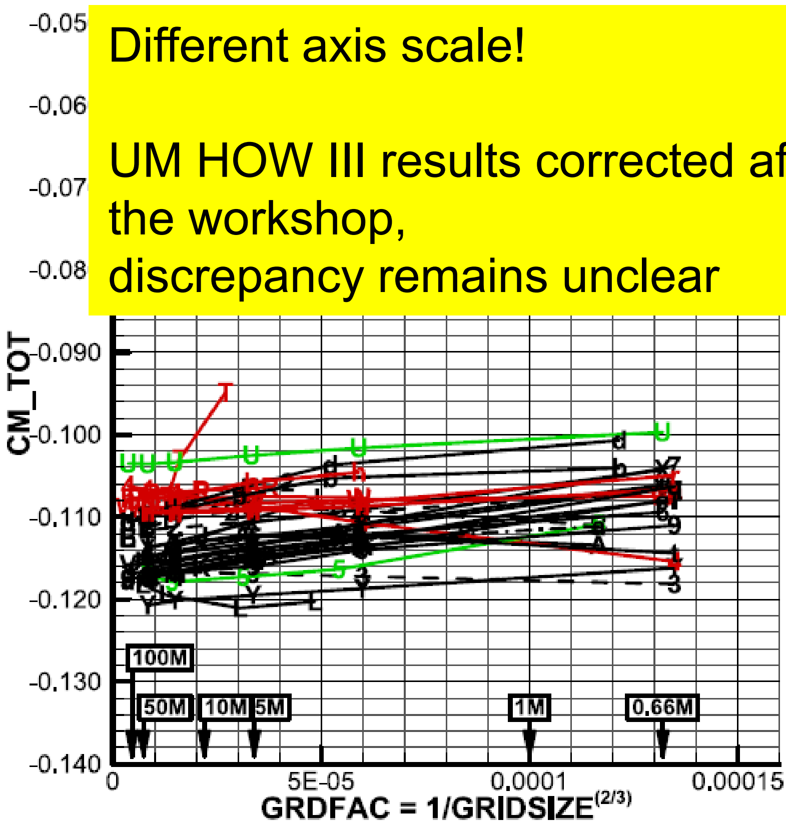
present results

Comparison of results

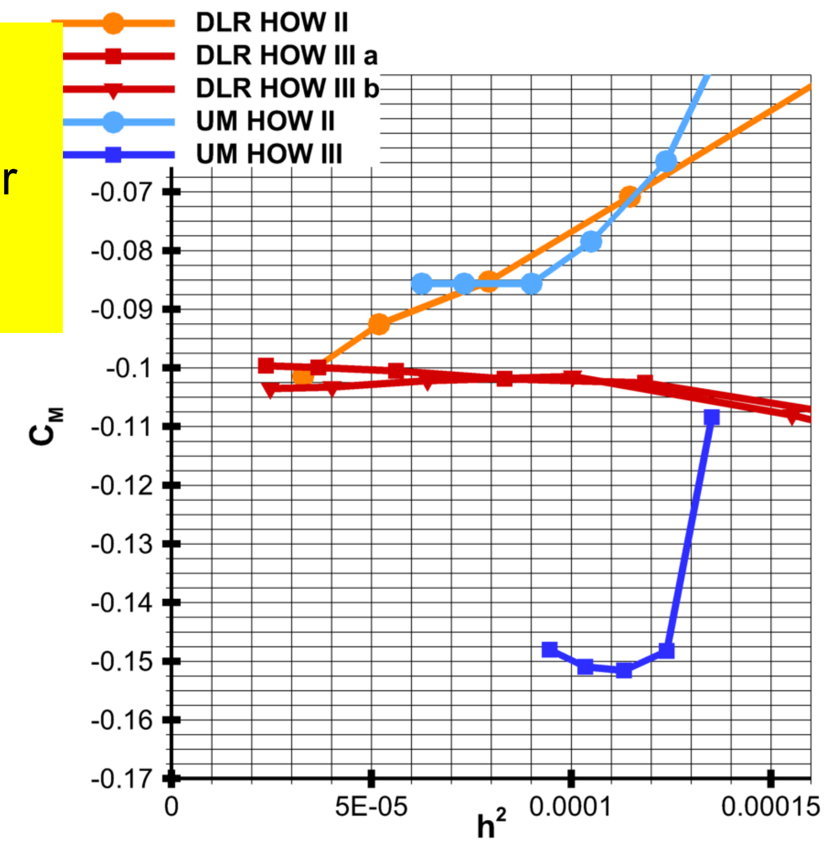
mesh convergence: pitching moment

Different axis scale!

UM HOW III results corrected after the workshop,
discrepancy remains unclear

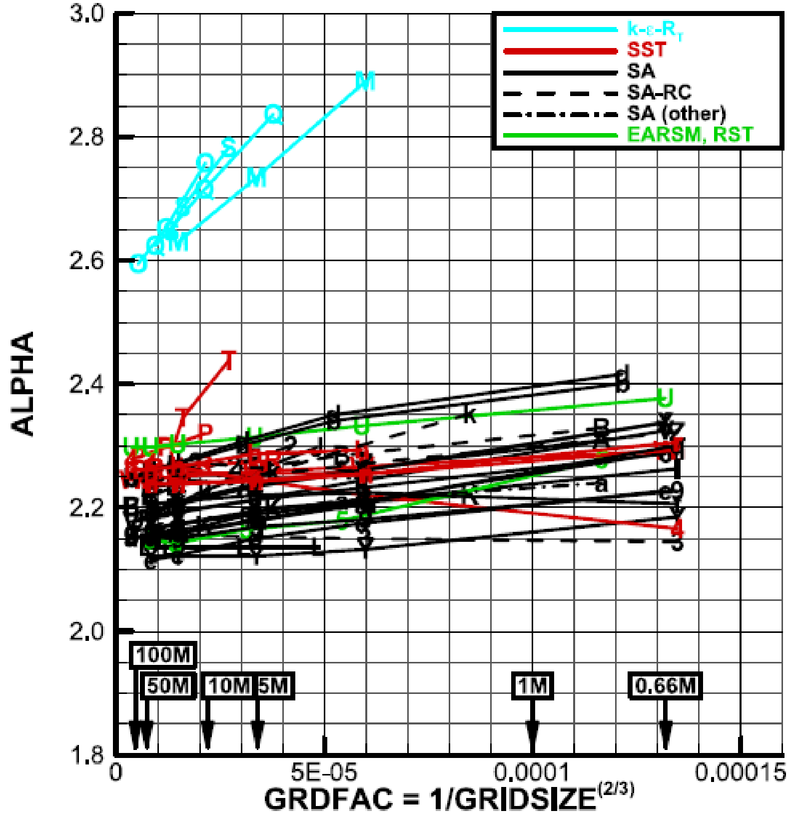


DPW-5

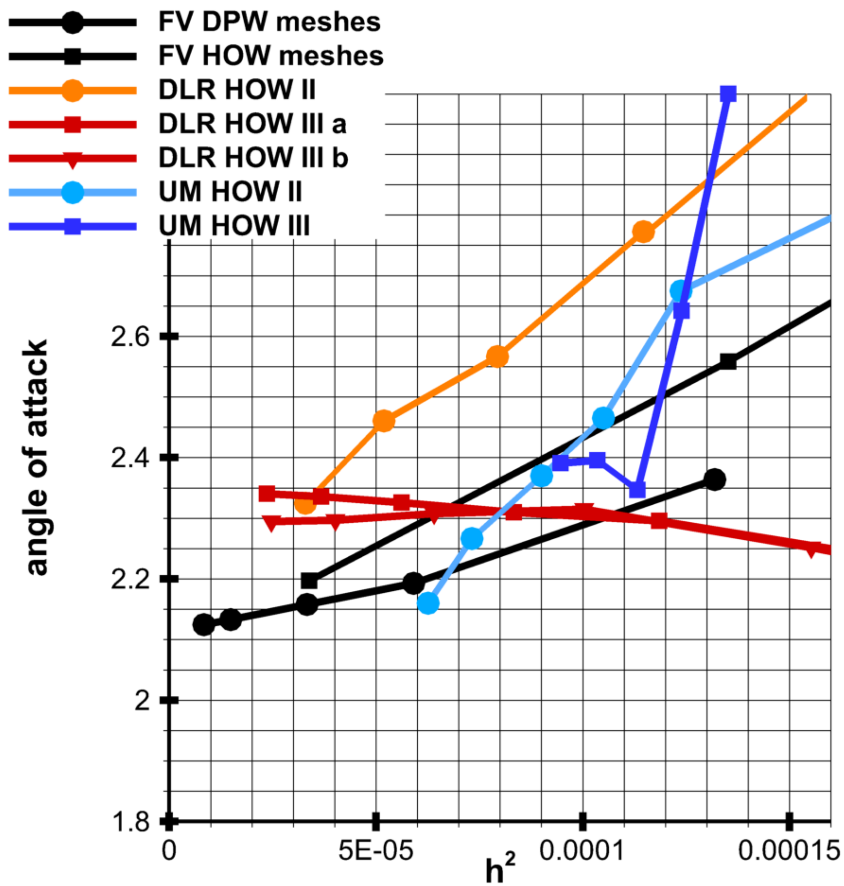


present results

Comparison of results
mesh convergence: angle of attack

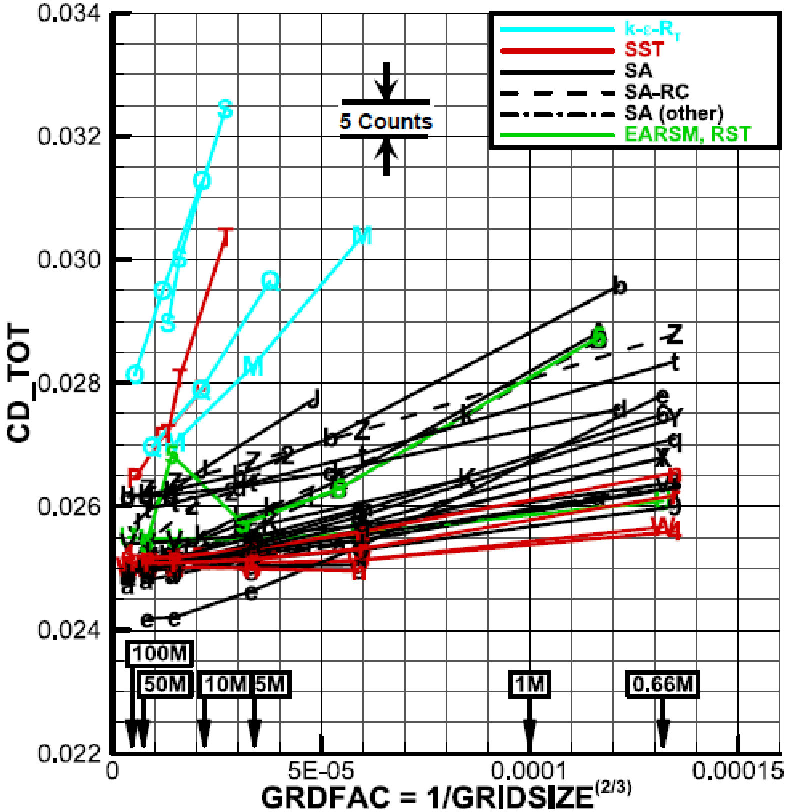


DPW-5

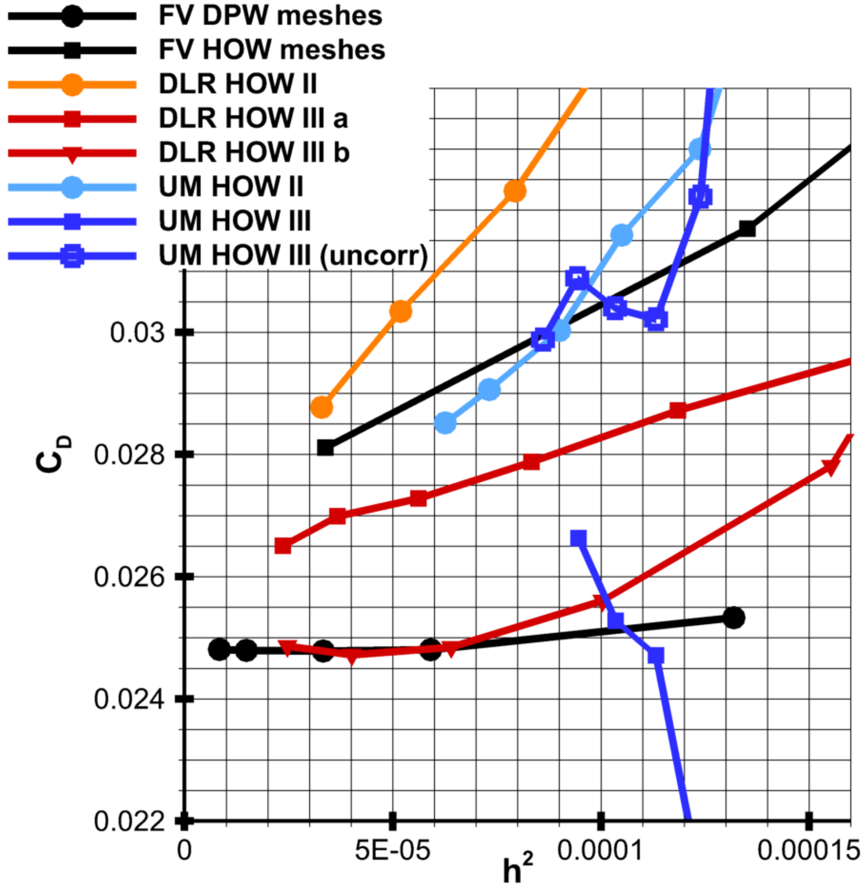


present results

Comparison of results
mesh convergence: drag

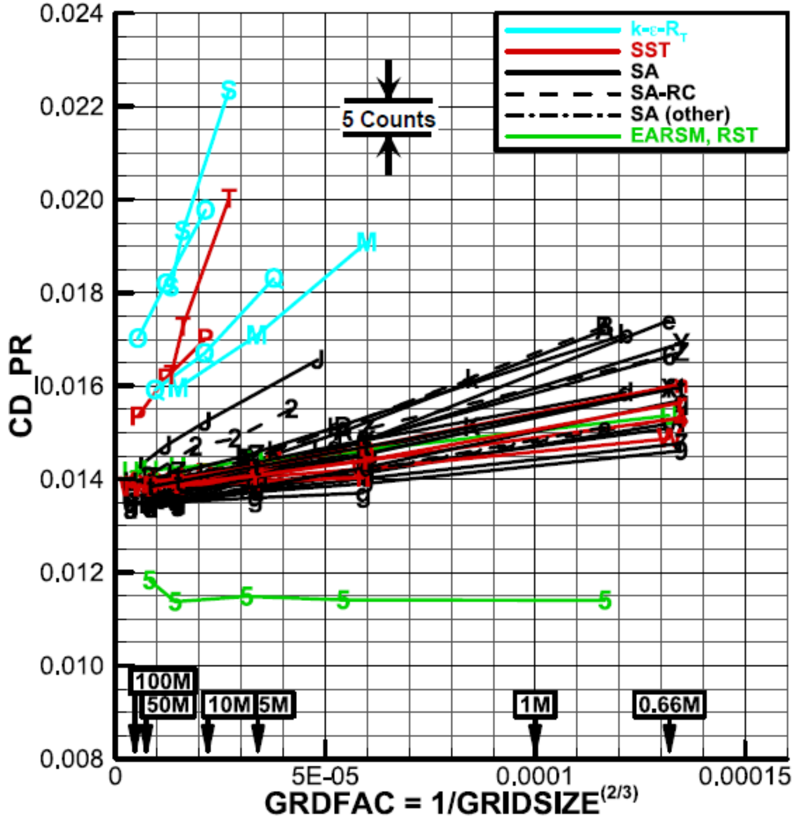


DPW-5

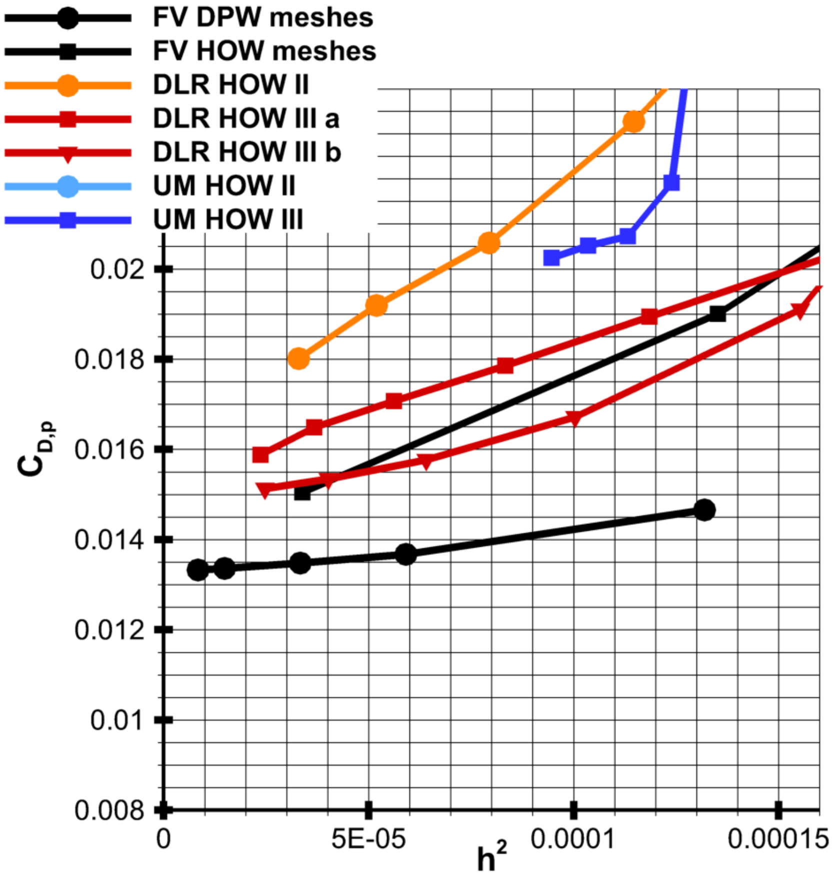


present results

Comparison of results
mesh convergence: pressure drag

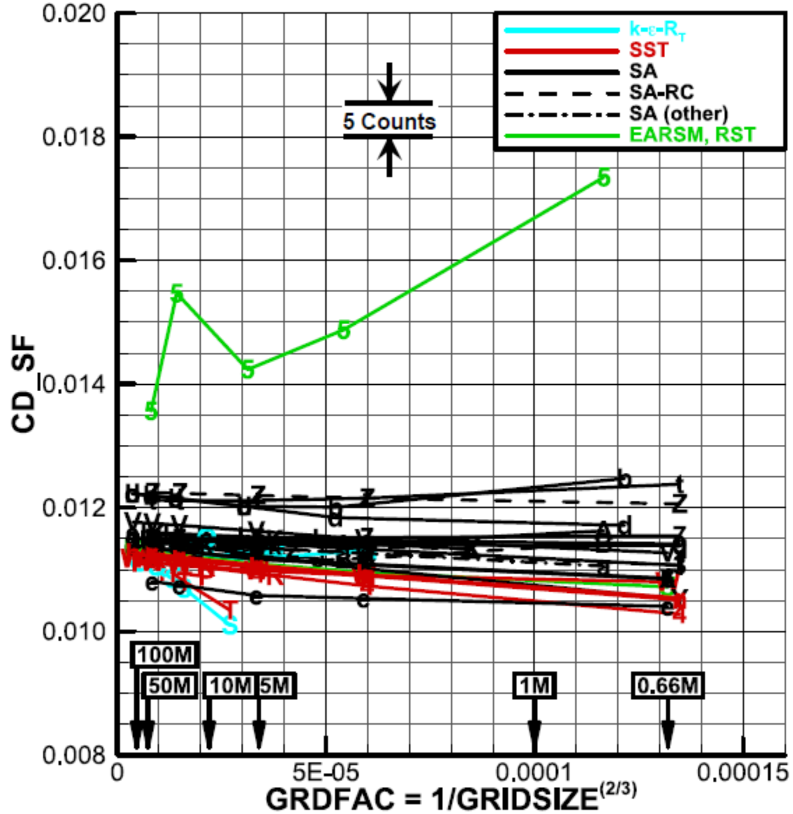


DPW-5

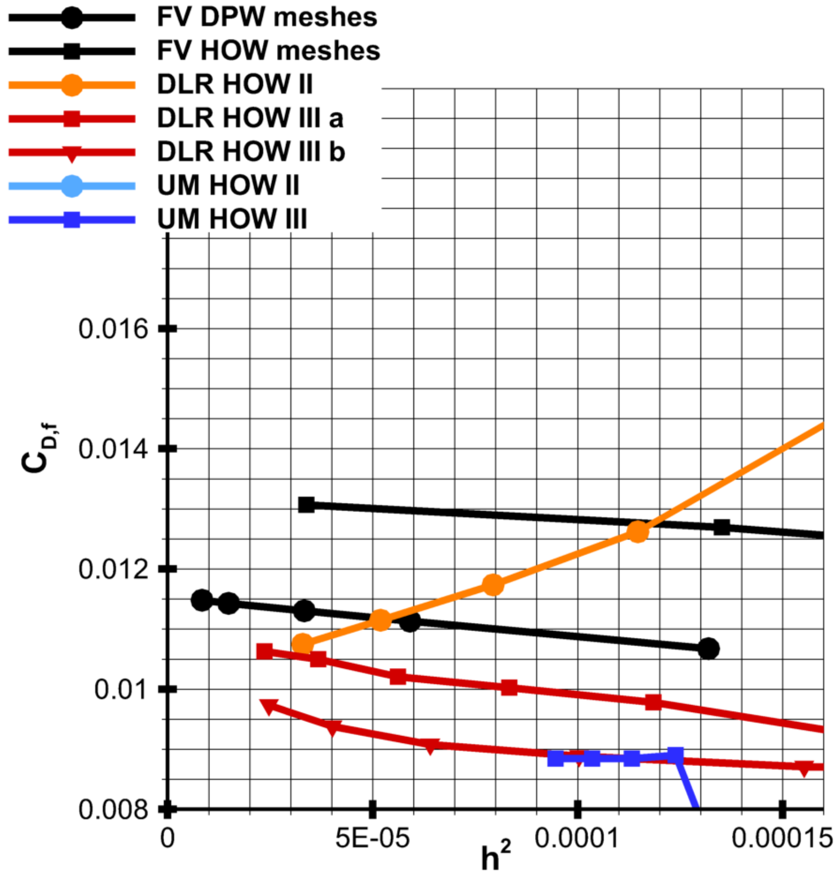


present results

Comparison of results
mesh convergence: friction drag



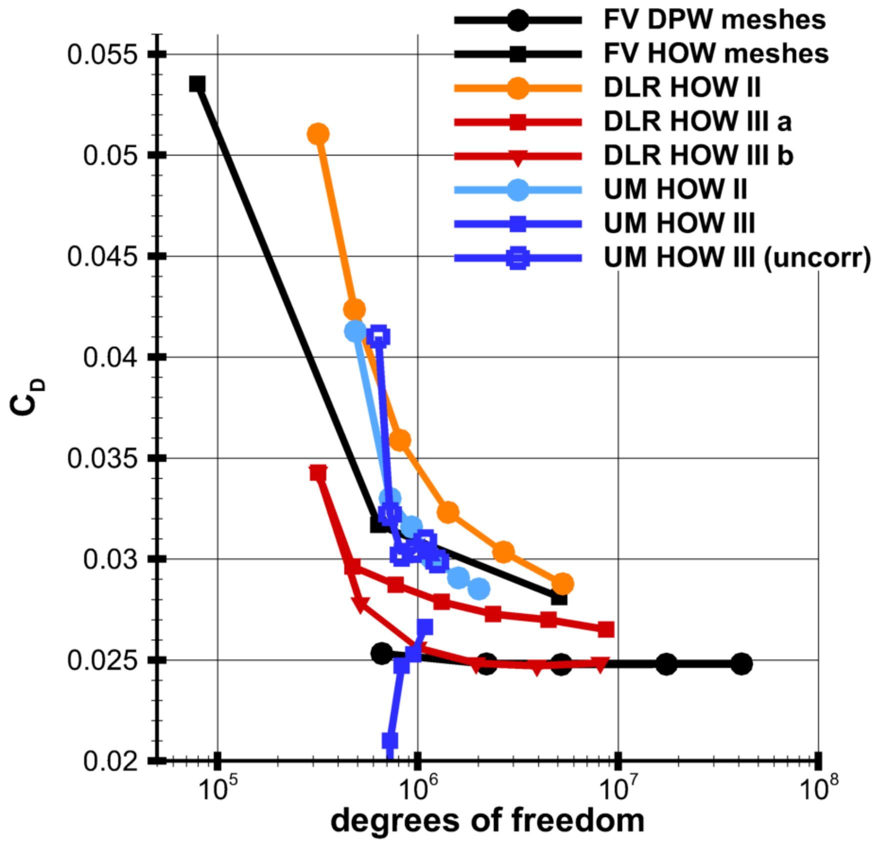
DPW-5

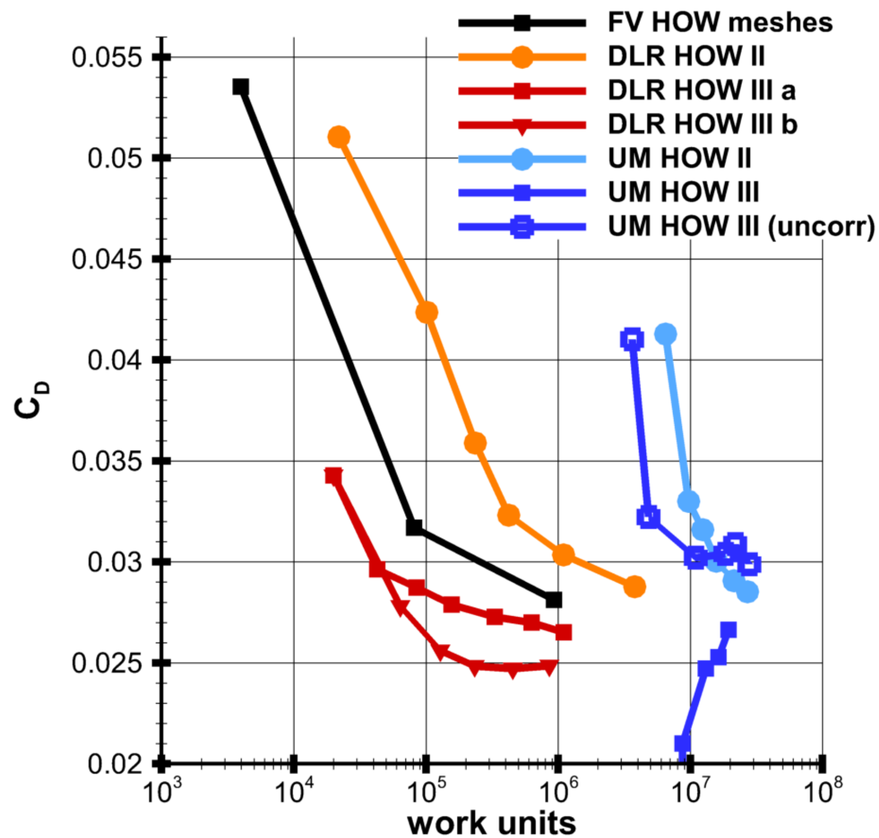


present results

Comparison of results

mesh convergence: drag





Observations

- (some) DG results are not mesh converged.
  → Large variation between last two adaptation steps.
  → FV on DPW meshes shows surprisingly little variation with mesh density.
    - Mainly an effect of underlying mesh sequence.
      - FV results on HOW mesh equally bad.
    - Also: error cancellation for pressure drag and friction drag.

- Confirmation of expectations (UM vs. DLR)
    - Adaptation seems to improve convergence of drag results, adjoints more effective than unweighted residuals.
    - Higher computational cost (work units) for UM than DLR at same degrees of freedom, consistent to results for other cases.

Conclusions

- Results are reasonable in comparison with DPW-5 results.
    - DG results (mostly) heading towards the range of FV results.
- Some differences are not clear.
- Shock capturing seems to work reasonably well.

- 3D transonic RANS is still challenging for HO (DG) codes.
- Results indicate some progress…
- … but currently not at higher order.

The present results demonstrate the applicability of DG for this scenario, but they do not show a clear advantage of DG over FV methods.