AR1 Summary: Common Research Model

4th International Workshop on High-Order CFD Methods
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updated after the workshop

Ralf Hartmann, Tobias Leicht

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AR1: 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)

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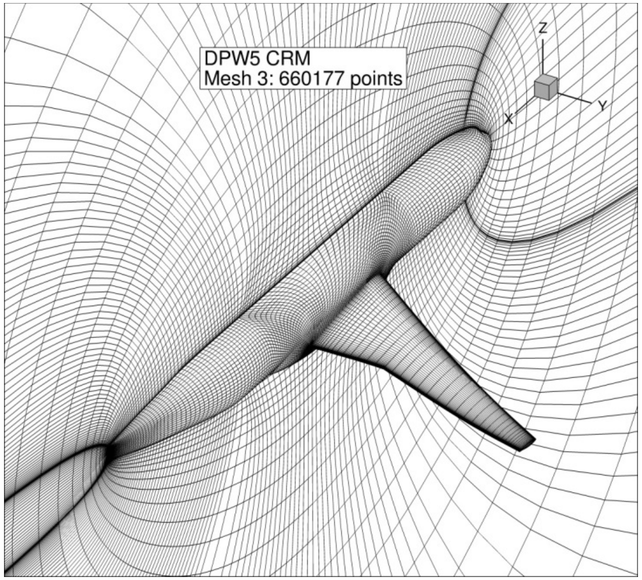
AR1: Common Research Model (CRM)
CFD setting

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

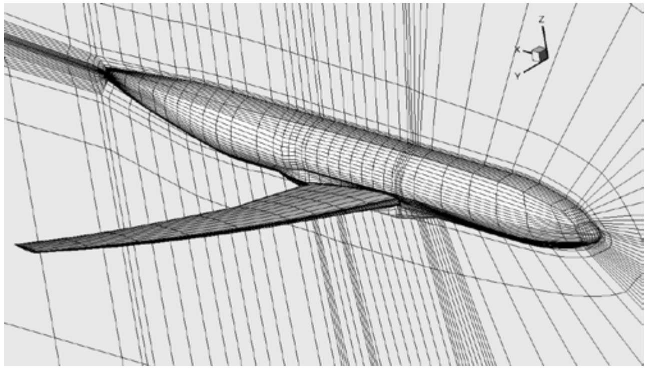
- fully turbulent flow, no transition
- free air, no wind tunnel effects

AR1: 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
  (HioCFD meshes)



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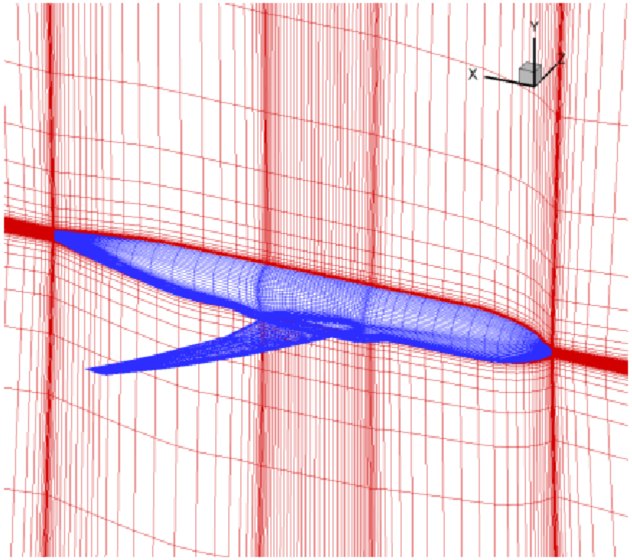
AR1: Common Research Model (CRM)

Meshes

- Grid family of nested multi-block structured meshes by National University of Defense Technology, China

Table 1: Multi-block HO-grid family.

Level	Name	Label	Cells	$\Delta_1 Y^+$
1	Tiny	G1	1140240	2.155
2	Coarse	G2	3848310	1.437
3	Medium	G3	9121920	1.025
4	Fine	G4	30786480	0.683
5	Extra-Fine	G5	72975360	0.500



the tiny grid

Contributions (this workshop)

- Shengye Wang, Yaming Chen, Guangxue Wang, Wei Liu, Xiaogang Deng
  National University of Defense Technology (NUDT), China
  Sun Yat-sen University, China
  FD, 5th-order (WCNS-E5), Menter-SST on
    - grid family of own block-structured meshes

- Ralf Hartmann
  DLR
  DG, p=1 (2^{nd}-order), Wilcox-kω, mesh adaptive results driven by
    - residual indicators (res-adapt)
    - adjoint-based indicators for lift (adj-adapt)
      (3rd-order adjoint solves for error estimation)
    - starting from the HioCFD mesh of University of Michigan

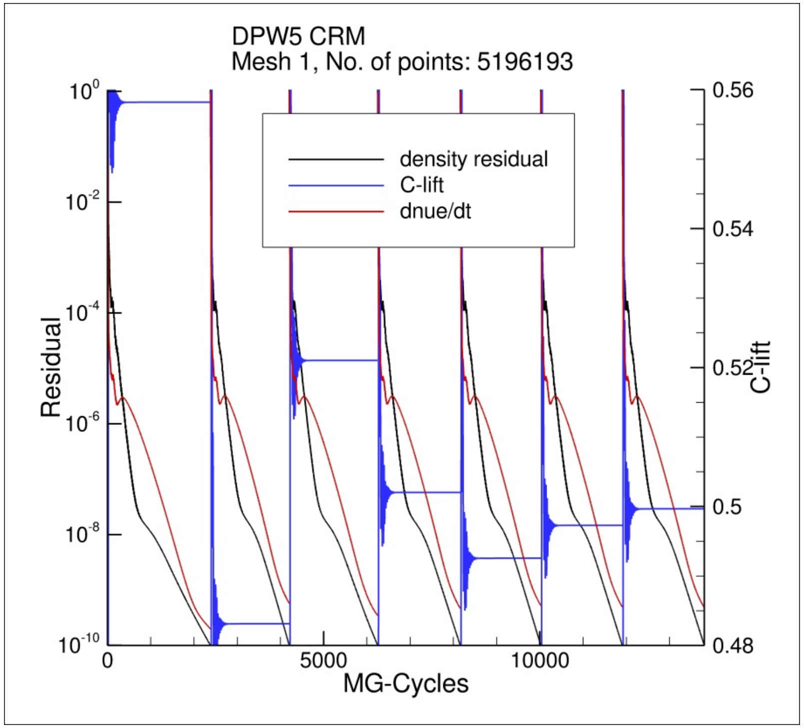
Reference results (already available in HioCFD-3)

- Stefan Langer
  DLR
  FV, 2nd-order central scheme, (negative) SA,
    - mesh sequence from DPW-5
    - mesh sequence based on global refinement of the HioCFD mesh

Individual Presentation(s)

Reference results

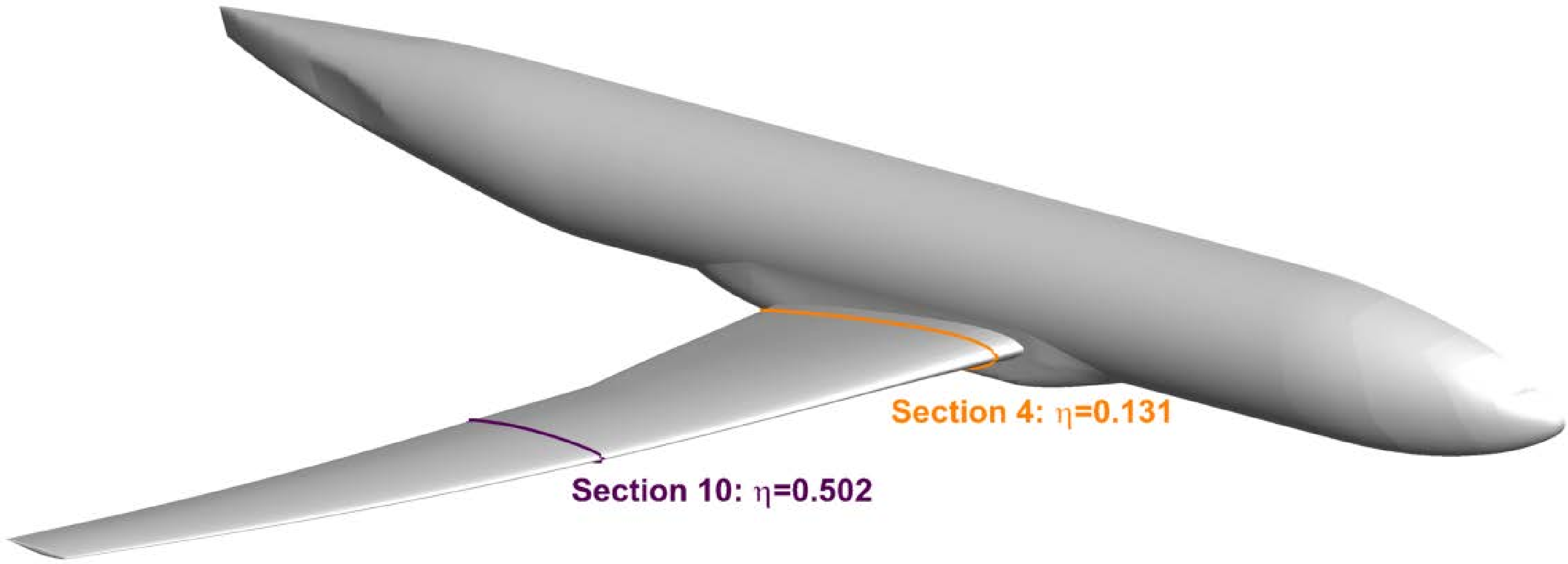
- second order node-centered Finite Volume code (Stefan Langer, DLR)
- central scheme with upwind-based artificial dissipation
- multi-grid based on Galerkin projection
- implicit multi-stage RK smoother
- target lift via AoA-bisection



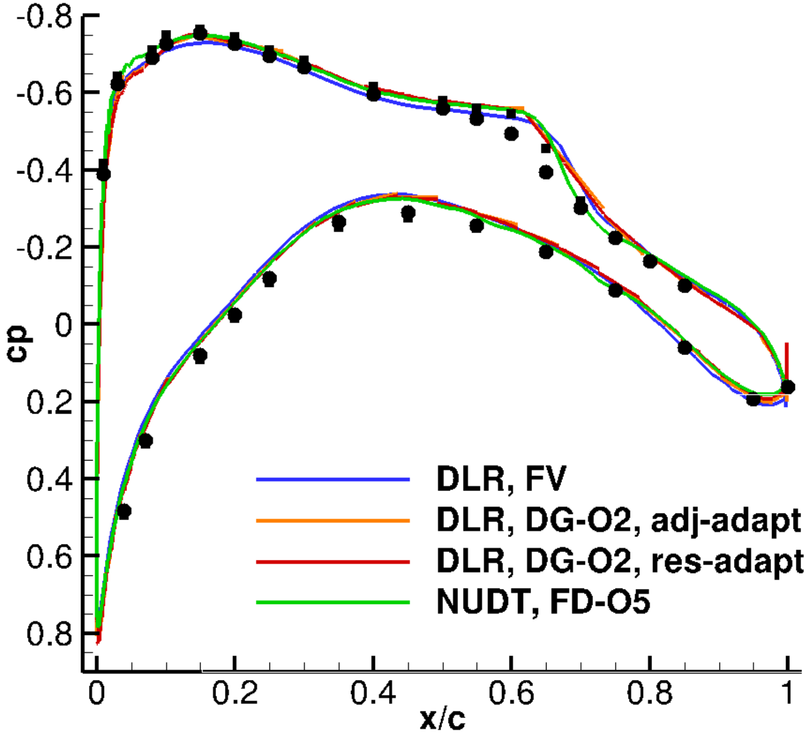
- results on DPW-5 meshes
  - coarse: 660,177 points
  - fine: 41,231,169 points

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

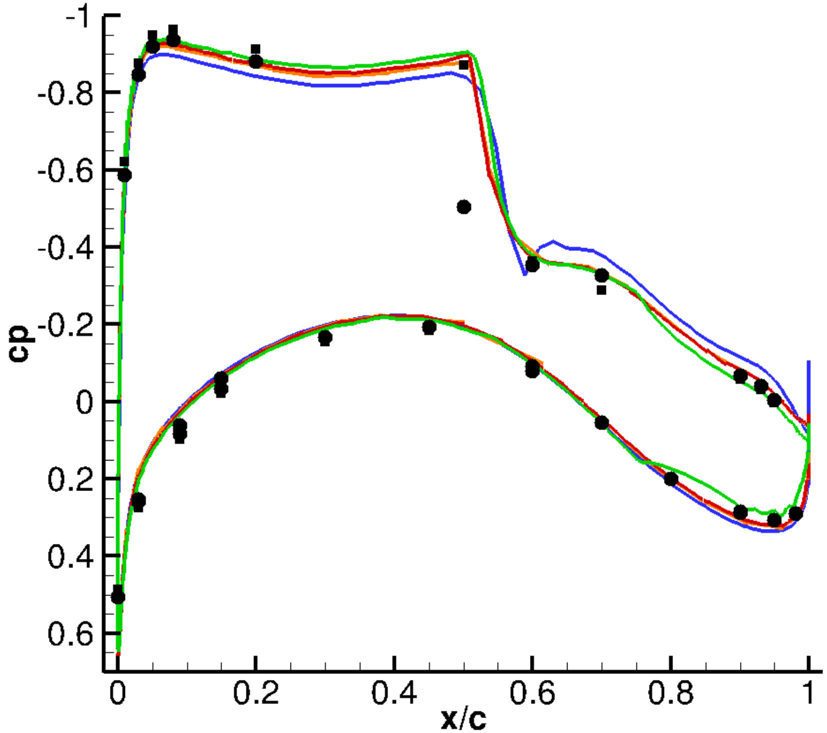
Comparison of results
Sectional cuts



Comparison of results
Sectional cuts



Section 4, η=0.1306



Section 10, η=0.5024

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

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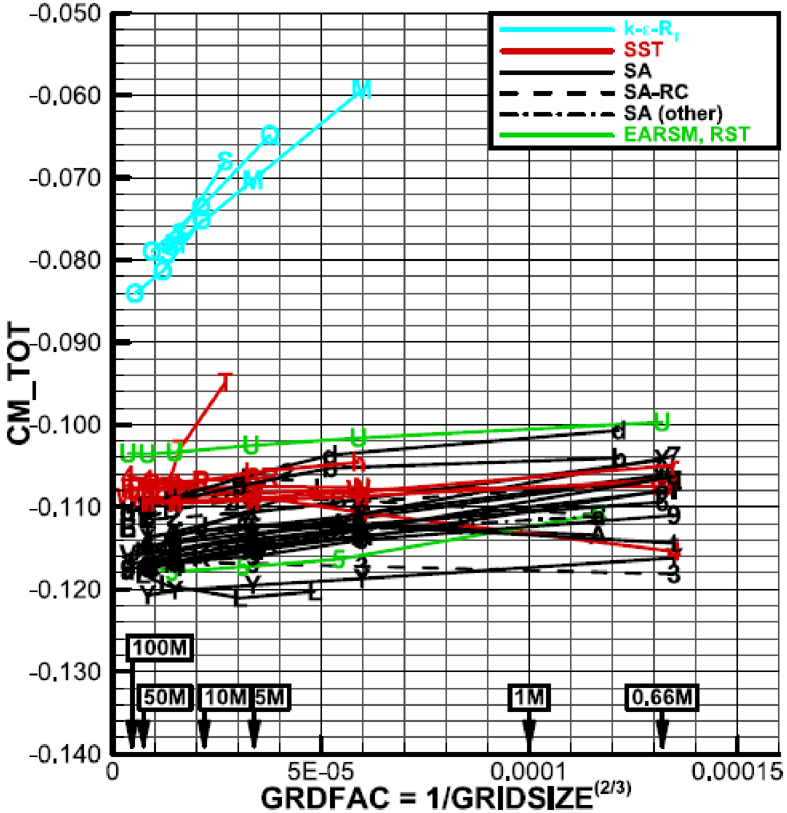
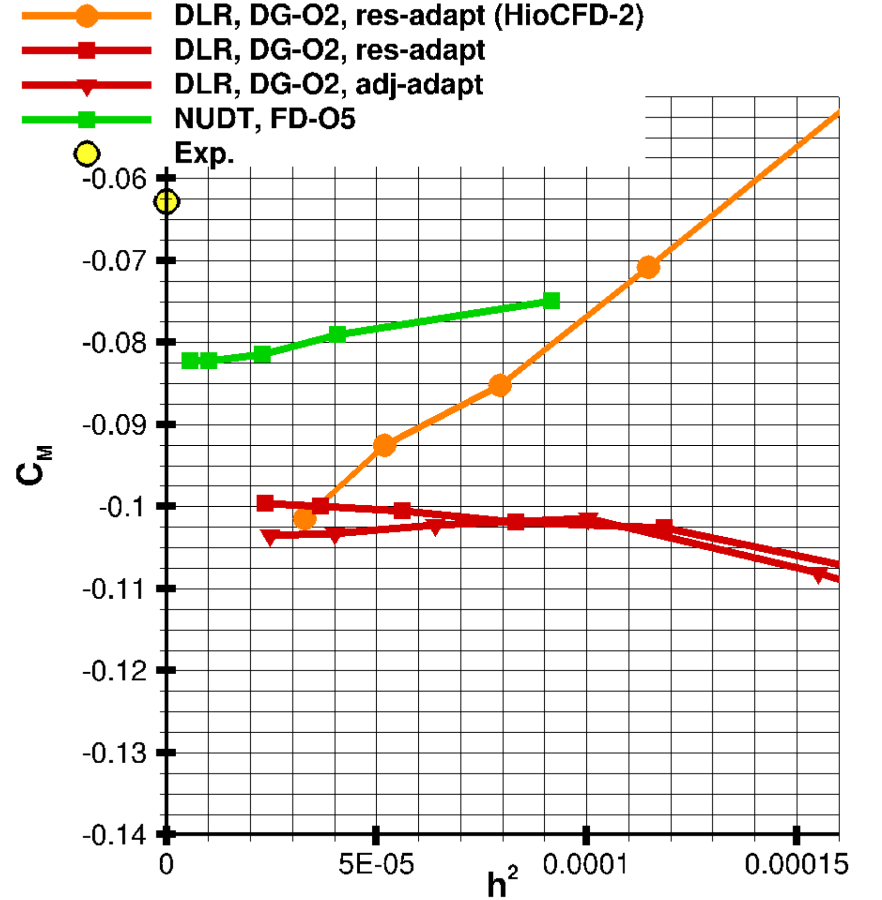
Comparison of results

mesh convergence: pitching moment



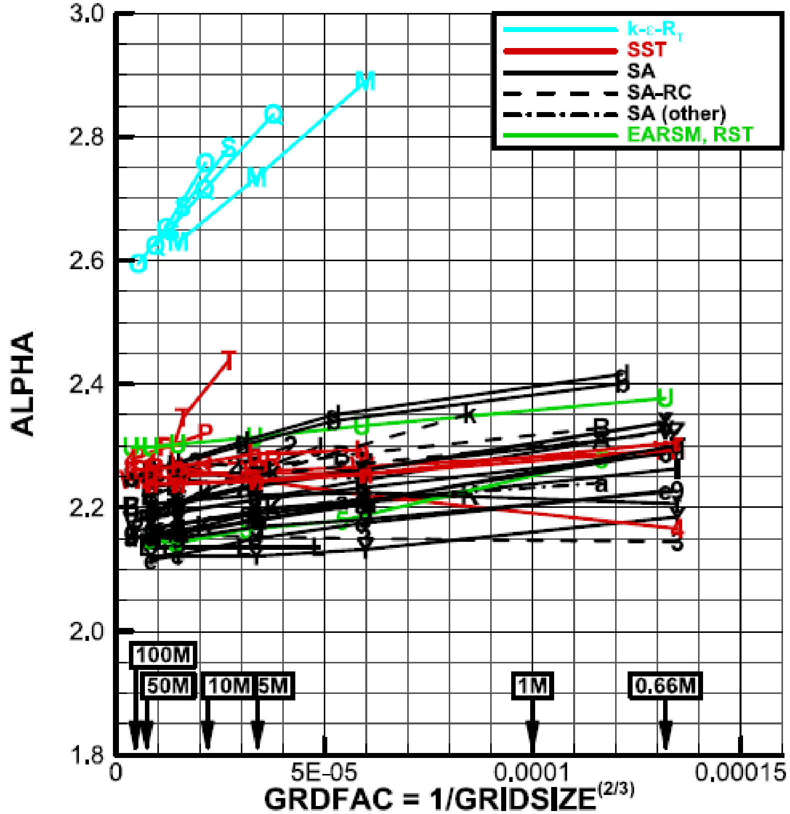
DPW-5



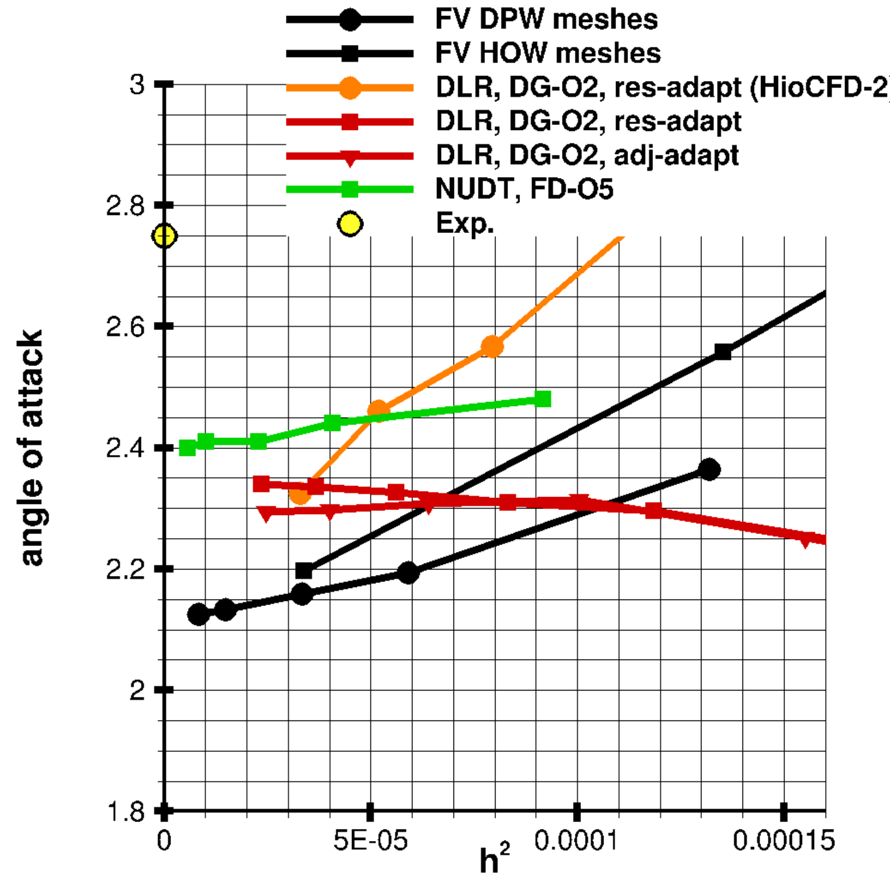
present results

Comparison of results

mesh convergence: angle of attack



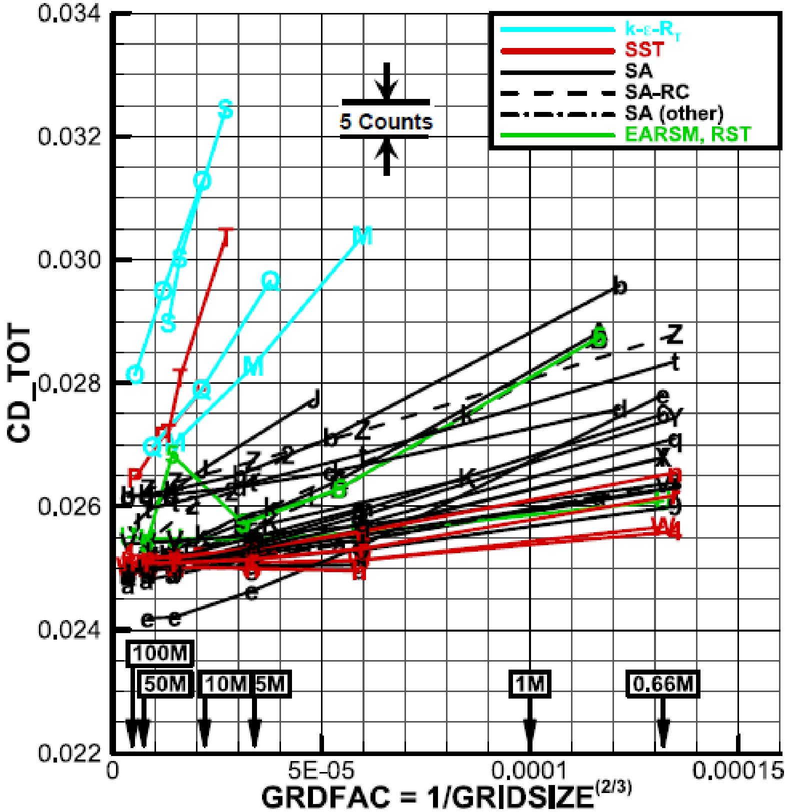
DPW-5



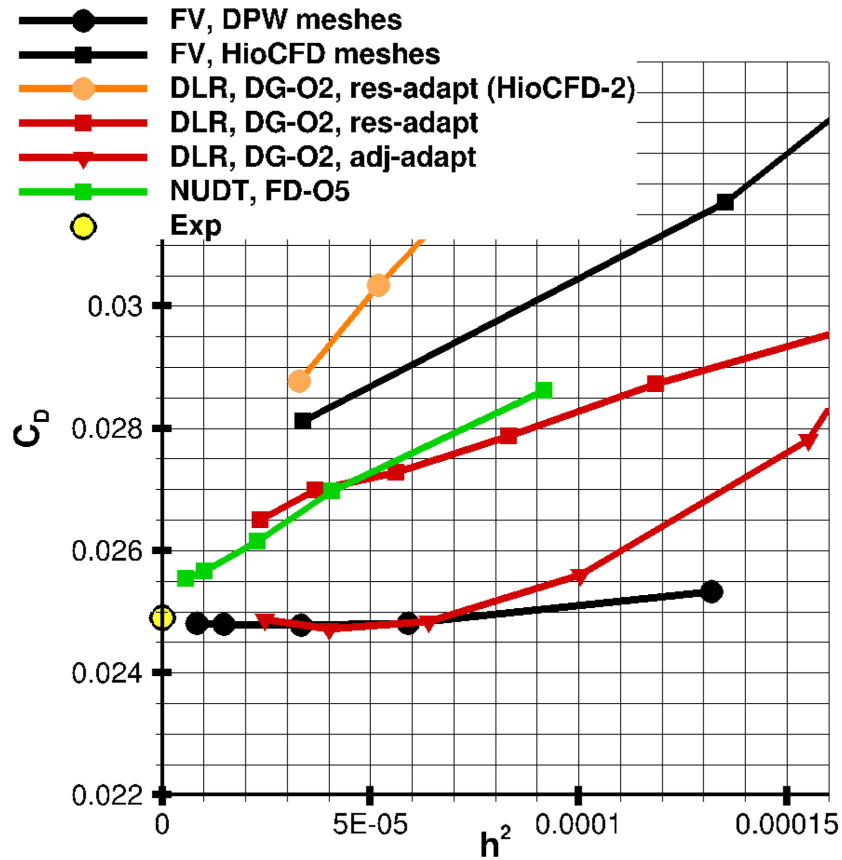
present results

Comparison of results

mesh convergence: drag

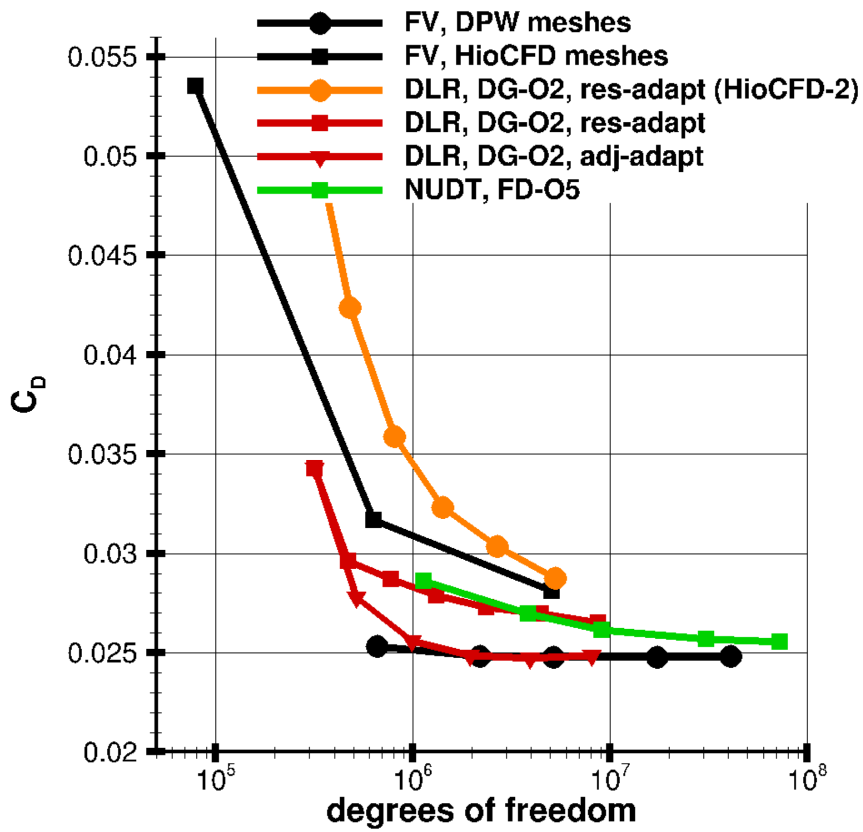


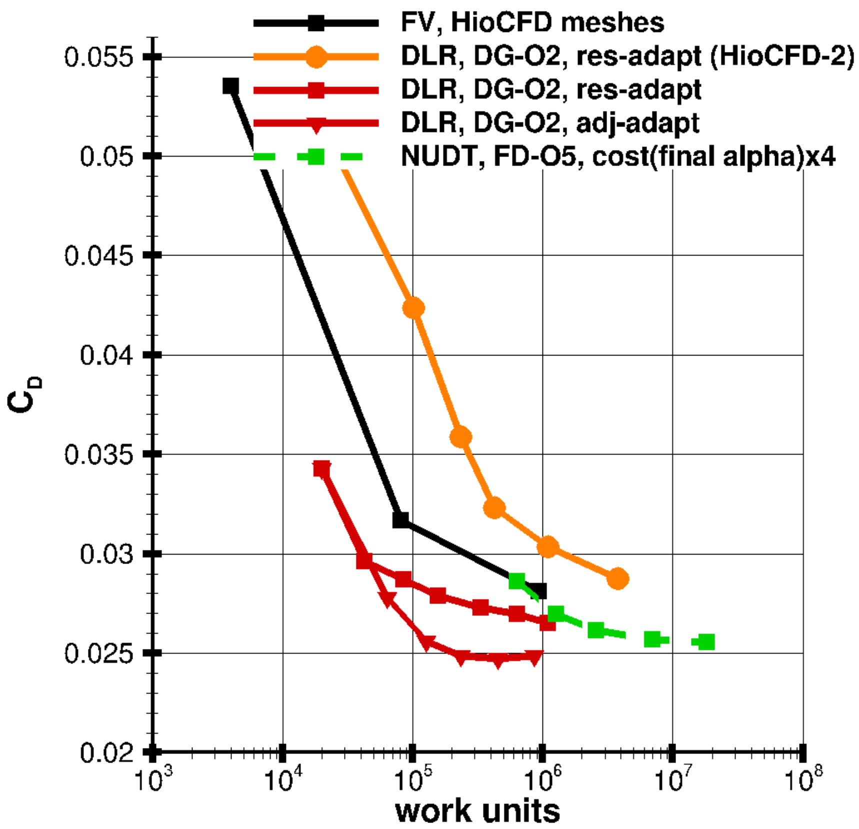
DPW-5



present results

Comparison of results
mesh convergence: drag





Summary

HioCFD mesh:
- DG with res-adapt and adj-adapt outperformes FV on mesh sequence
- DG with adj-adapt more effective than with res-adapt.

DPW meshes:
- FV on DPW meshes shows surprisingly little variation with mesh density.
  - Mainly an effect of underlying mesh sequence.
  - In particular: error cancellation for pressure drag and friction drag (was shown in HioCFD-3).

Meshes by NUDT:
- FD-O5 results in range of expectation with C_M and alpha higher than HiLiftPW-2 results but closer to the experiments.
- Computational cost provided for final alpha only, of e.g. 4 alpha on tiny grid

Conclusions

- Results are reasonable in comparison with DPW-5 results.
  - DG results in the range of FV results.
  - FD results in range with C_M and alpha closer to the experiments
- Shock capturing seems to work reasonably well.

- 3D transonic RANS is still challenging for HO (DG) codes.
- Results indicate some progress…
  - good results with DG-O2, adj-adapt
  - first HO results with FD-O5