CR1 - DPW6 Common Research Model

Marshall C. Galbraith

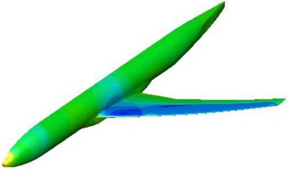
Aerospace Computational Design Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

Common Research Model (CRM) Overview

- Steady-state RANS
- Cruise condition – transonic
- Wing-body representative of modern airliner

- Extensively studied in AIAA Drag Prediction Workshops 4, 5, and 6 with numerical data (mostly Finite Volume) from many groups
  - 55 contributions from 22 groups in DPW-5
  - 48 contributions from 25 groups in DPW-6
- References:
  - `http://commonresearchmodel.larc.nasa.gov`
  - `https://aiaa-dpw.larc.nasa.gov`
  - Figures are taken from DPW-5 and DPW-6 summary presentations

Previous High-Order Workshops



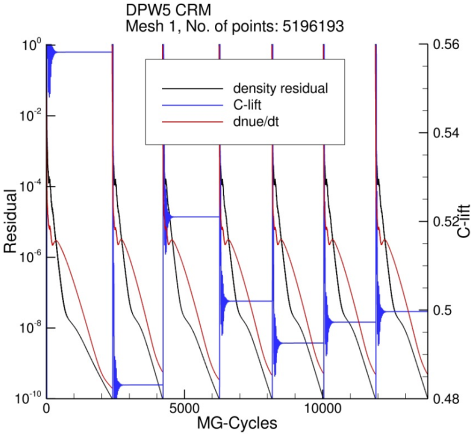
Fully turbulent transonic, no wind tunnel effects
Mach = 0.85, Re = 5×10^6, $C_L = 0.5 \pm 0.001$

- 2^{nd} High-Order Workshop (3 Contributions)
  - Two: DG, P=1, mesh adaptive (SA or $k\omega$)
  - One: FV, 2^{nd}-order central (SA)
- 3^{rd} High-Order Workshop (Same 3 Contributors)
  - Two: DG, P=1, improved mesh adaptive (SA or $k\omega$)
  - One: FV, 2^{nd}-order central (SA)
- 4^{th} High-Order Workshop (1 Contributor)
  - One: FD, 5^{th}-order WCNS-E5 (Menter-SST)

Fixed C_L Calculations

- Fixed C_L important for design
  - All DPW mesh refinement studies with fixed C_L
- Increases computational requirements (find α)
- Many contributors to are students

2^{nd}-order FV
Stefan Langer, DLR



Fixed α Calculations

6th CFD Drag Prediction Workshop
Washington D.C. – June 2016

Applied Aerodynamics Technical Committee

Case 3: CRM WB Static Aero-Elastic Effect:

- NASA Common Research Model, Wing-Body
- Mach=0.85: **Mach=0.3**
  - α=2.50°, $\boxed{2.75°}$, 3.00 °, 3.25 °, 3.50 °, 3.75 °, 4.00 °
- Grid Resolution Level:
  - 3) Medium,
- Chord Reynolds Number: 5×10^6
- Measured Static Aero-Elastic Wing Deformation at each angle of attack

5^{th} High-Order Workshop Participants

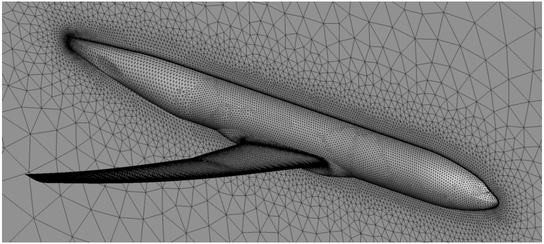
- Ryan Glasby and Taylor Erwin, U. of Tennessee
  SUPG P=1, P=2, negative-SA
- Behzad Ahrabi, U. of Wyoming
  SUPG P=1, P=2, negative-SA
- Michael Brazell, U. of Wyoming
  DG-SIP P=1, P=2, negative-SA
- Kyle Anderson, NASA Langley
  SUPG P=1, negative-SA
- Marshall Galbraith, MIT
  DG-BR2 P=1, P=2, negative-SA (Mach 0.3)

High-Order Workshop Meshes

New all tetrahedral grids. Not a family (no order of accuracy).

	Q1 Nodes	Q2 Nodes	Cells	DG P1	DG P2
ExtraTiny	0.18	1.5	1.0	4.3	10.7
Tiny	0.33	2.6	1.9	7.7	19.2
Coarse	0.43	3.4	2.5	10.0	25.0
Medium	0.82	6.5	4.8	19.1	47.8
Fine	1.8	14.5	10.7	42.8	107.0

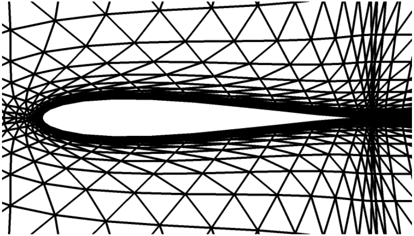
Counts in millions



Coarse Grid Q2 by Steve Karman (Pointwise)

Joukowski Airfoil Verification for High-Order Methods

- Misnomer: “High-order methods are less sensitive to the mesh”
  - Compact schemes less sensitive to poor shape (e.g. misaligned anisotropy) and mesh irregularity
  - Solution/Output accuracy sensitive to global distribution

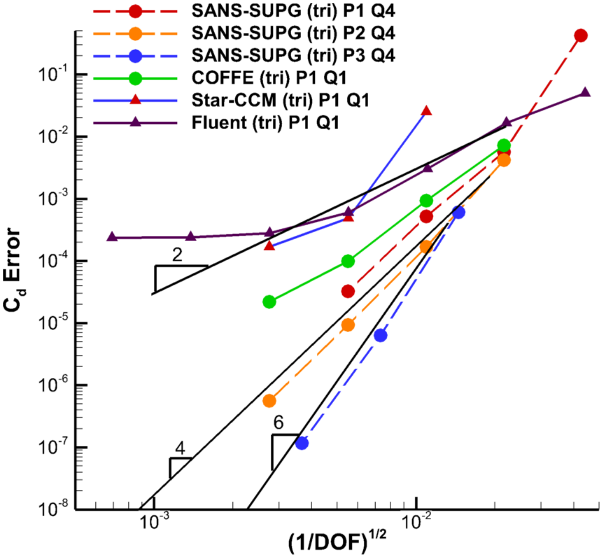


- L^2 Solution Error: $O\left(h^{P+1}\right)$
  - Solution smoothness
- Output functional error: $O\left(h^{2P}\right)$
  - Solution and adjoint smoothness
- Joukowski cusped trailing edge
  - Reduce inviscid singularity
- Mach 0.5, $\alpha = 0^\circ$, $Re = 1000$
- Symmetric: $C_l \equiv 0$
- C-grid: Clustering at stagnation point and trailing edge

Optimal mesh distributions will observe $O\left(h^{2P}\right)$ with fewer DOF

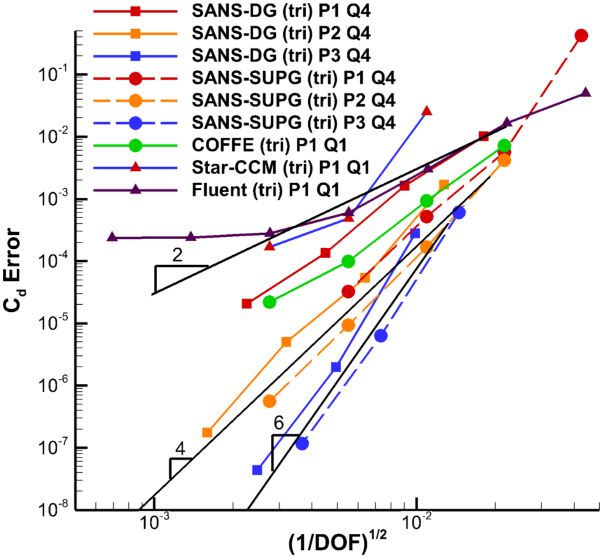
Participant Presentations

Summary for Joukowski Airfoil Verification



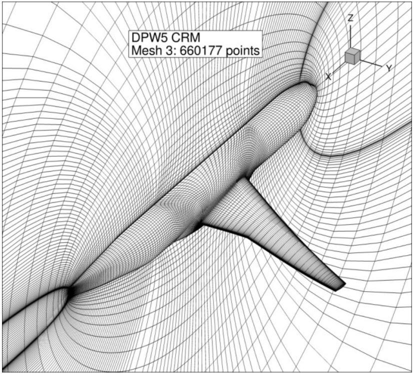
Fluent, Star-CCM, COFFE: 4^{th} workshop. SANS vs. COFFE: Q=4?

Summary for Joukowski Airfoil Verification

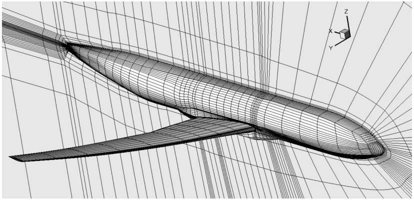


High-Order Workshop Meshes

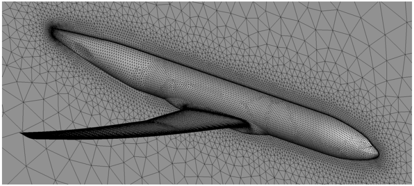
FV: multi-block structured meshes from DPW-5
not high-order



High-Order Workshops 2, 3, 4
Intentionally poor quality
Intended hanging-node adaptation



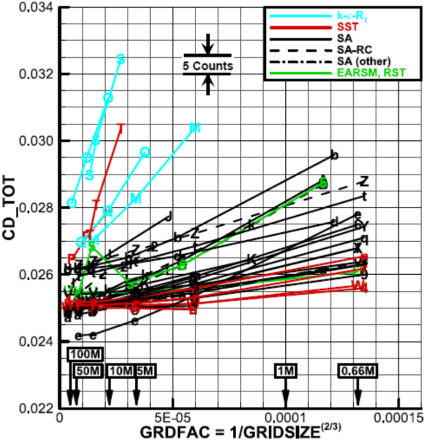
Current workshop meshes
Intended to give good results



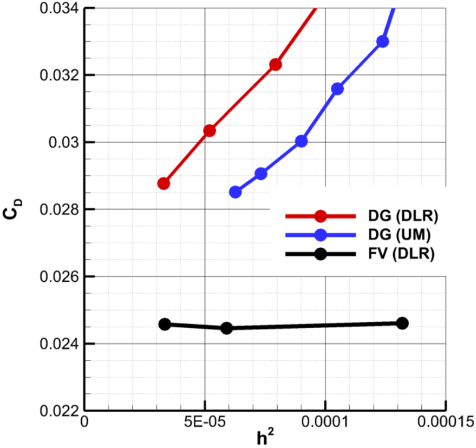
Comparison of Results

- Previous Workshops: Fixed C_L
- Current Workshop: Fixed α
- Drag Coefficient
- Same axis range to DPW-5 plots
  - GRDFAC: $h^2 = \left(\frac{1}{\sqrt[3]{DOF}}\right)^2$
  - 2^{nd}-order convergence yields straight lines
- Current workshop C_L and Idealized Profile Drag Coefficient (*CDpi*)

$C_L = 0.5 \pm 0.001$

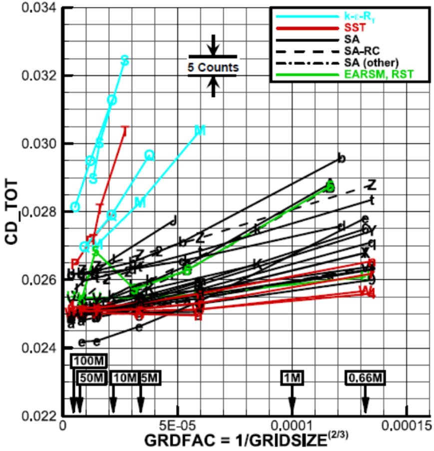


DPW-5

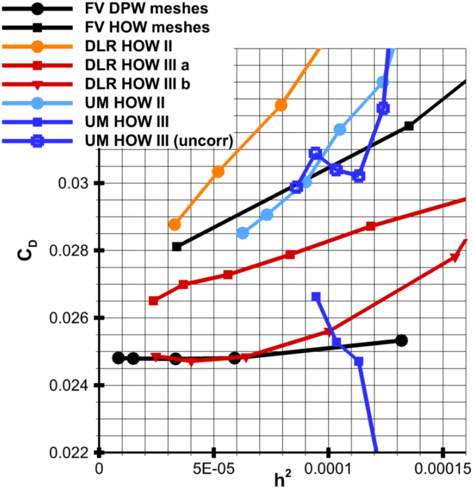


DLR P1 – residual hanging node
UM P1 – drag adjoint hanging node

$C_L = 0.5 \pm 0.001$



DPW-5



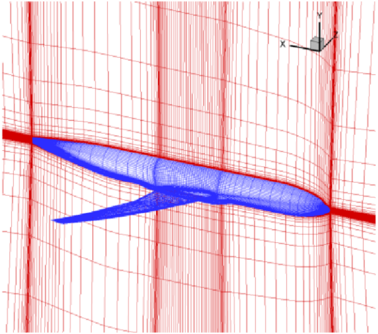
DLR P1 – a) residual b) lift adjoint
UM P1 – drag adjoint hanging node

4^{th} High-Order Workshop, FD Meshes

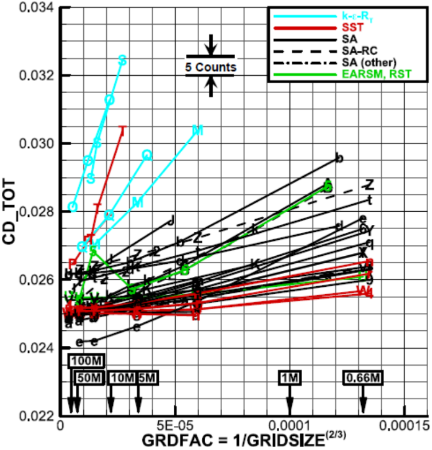
National University of Defense Technology, China
Menter-SST
First submission with high-order finite difference

Table 1: Multi-block HO-grid family.

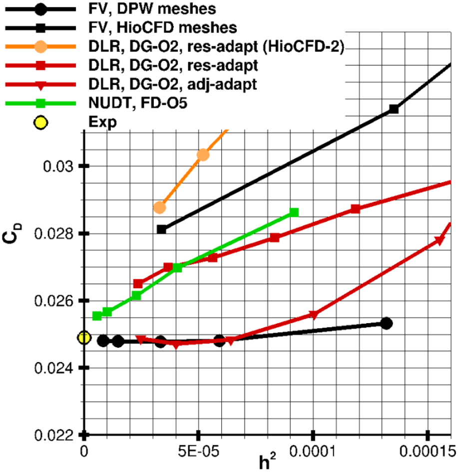
Level	Name	Label	Cells	$\Delta_1 Y^+$
1	Tiny	G1	1140240	2.155
2	Coarse	G2	3848310	1.437
3	Medium	G3	9121920	1.025
4	Fine	G4	30786480	0.683
5	Extra-Fine	G5	72975360	0.500



$C_L = 0.5 \pm 0.001$

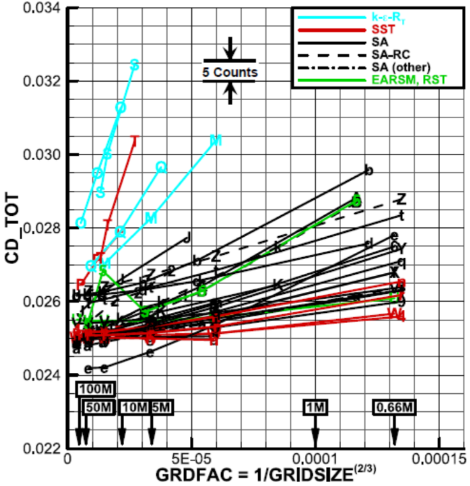


DPW-5



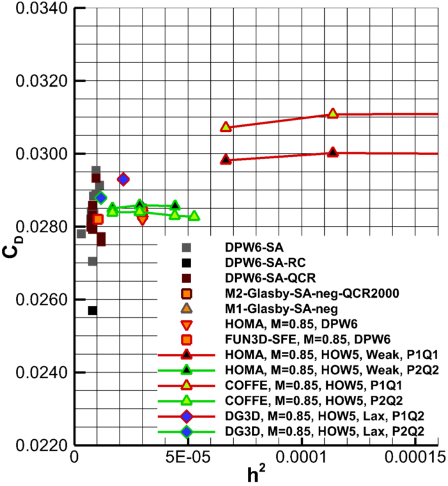
5^{th} High-Order Workshop, C_D

$C_L = 0.5 \pm 0.001$



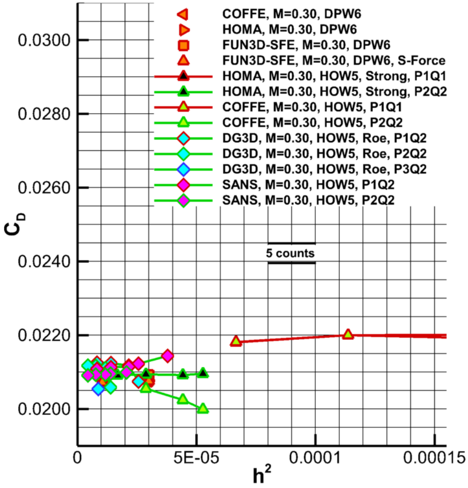
DPW-5

$\alpha = 2.75°$

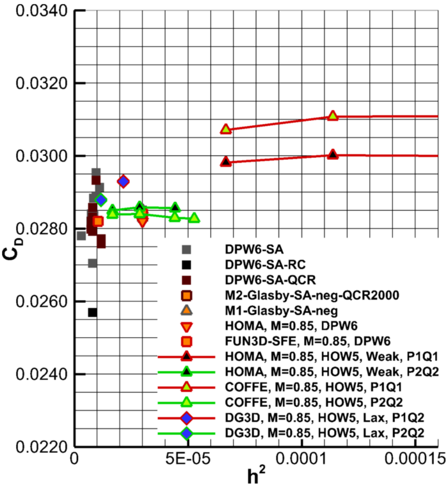


First P2 results!

5^{th} High-Order Workshop, C_D

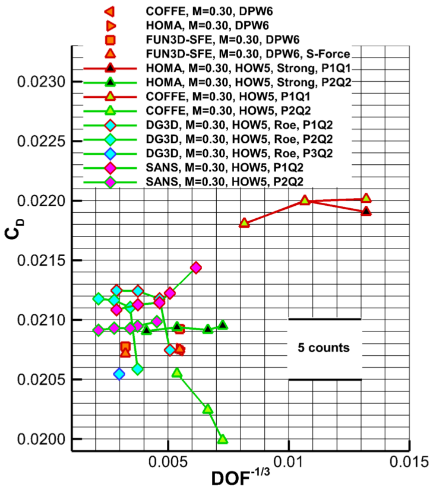


M=0.3

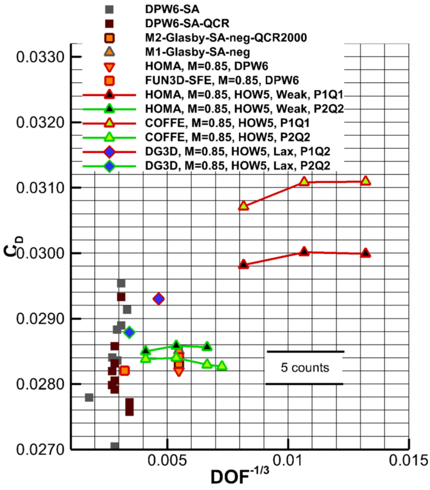


M=0.85

5^{th} High-Order Workshop, C_D

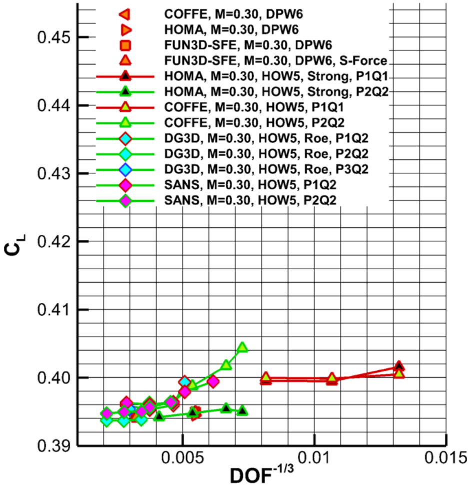


M=0.3

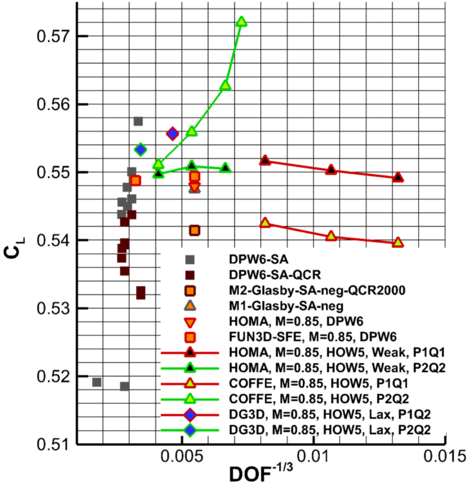


M=0.85

5^{th} High-Order Workshop, C_L

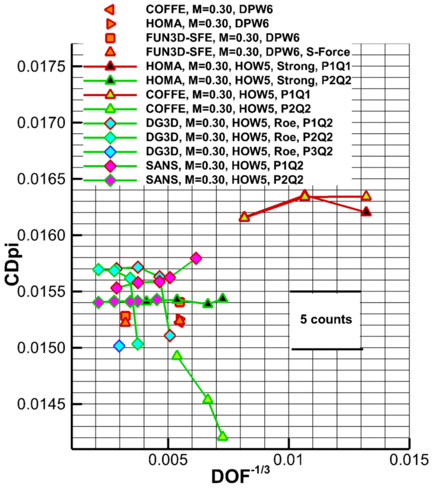


M=0.3

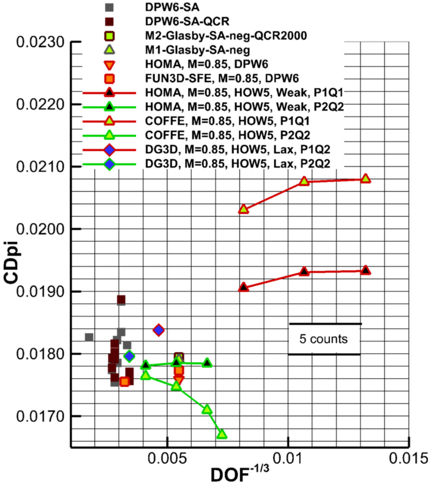


M=0.85

Idealized Profile Drag Coefficient: $CDpi = C_D - C_L^2/(\pi AR)$



M=0.3



M=0.85

Summary

2^{nd} and 3^{rd} Workshops:
"The present results demonstrate the applicability of DG for this scenario, but they do not show a clear advantage of DG over FV methods."

Summary

2^{nd} and 3^{rd} Workshops:
"The present results demonstrate the applicability of DG for this scenario, but they do not show a clear advantage of DG P=1 over FV methods."

Summary

2^{nd} and 3^{rd} Workshops:
"The present results demonstrate the applicability of DG for this scenario, but they do not show a clear advantage of DG P=1 over FV methods."

- Transonic RANS is still challenging (non-linear solver)
- Meshes matter
  - Previous Workshops: Intentionally poor hex meshes intended for hanging-node adaptation
  - Current Workshop: Intended to give good results
- First DG and SUPG P=2 results
  - Within the spread of DPW-6 results
- Discrepancies between FEM solutions unresolved
- Meshing is not well understood for high-order scheme

Open Discussion

Backup Slides

Uniformly Refined Families of Meshes