Embraer Contribution to DPW-8/AePW-4: Scatter WG Cases

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Embraer

AIAA DPW-8/AePW-4, 6-7 June 2026

Cases Overview

Geometries and grids

Geometry	Case	Type	Grid Families	Grid Levels	Setup
Joukowski	Case 1b	Grid Convergence	Classic Quad	L1-L6	SA
ONERA OAT15A	Case 1a	Grid Convergence	Cadence Unstructured Rev01 Cadence Structured Rev01 HeldenMesh Unstructured Rev01	L1-L6 L1-L6 L1-L6	SA | SA-QCR-RC | SST SA-QCR-RC SA-QCR-RC
	Case 1c	Grid Convergence	Cadence Unstructured Rev02 Cadence Structured Rev02 HeldenMesh Unstructured Rev02	L1-L6 L1-L6 L1-L7	SA SA SA
W1 & W2	Case 1d	Grid Convergence	Cadence TetFF Rev00 Cadence VoxFF Rev00 HeldenMesh Rev00 Cadence TetFF Rev01 Cadence VoxFF Rev01	L1-L6 L1-L6 L1-L7 L1-L6 L1-L6	SA SA SA SA SA
	Case 1e	Polar	HeldenMesh Rev00 Cadence TetFF Rev01 Cadence VoxFF Rev01	L4 L4 L4	SA SA SA
CRM-WB	Case 2a	Grid Convergence	Cadence Rev00 HeldenMesh Rev00	L1-L5 L1-L4	SA SA
	Case 2b	Polar	Cadence Rev00	L3	SA | SA-QCR | SA-QCR-RC

*intermediate results in gray

Cases Overview

Solver general setup

CFD++ 21.1.0

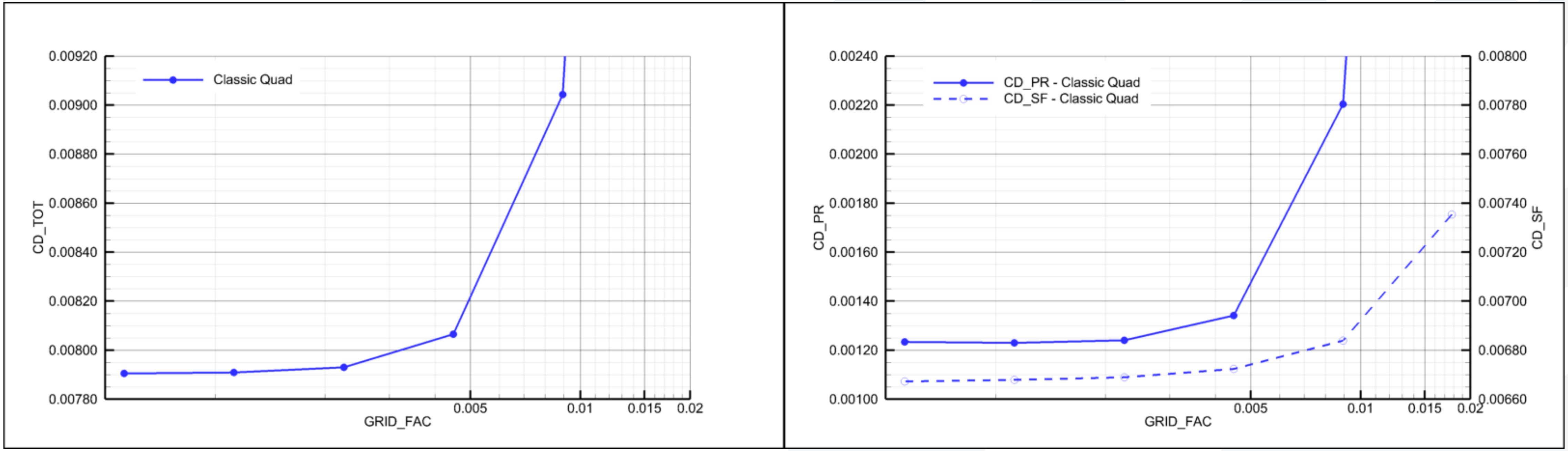
- Formulation: Pre-conditioned compressible RANS, perfect gas (Sutherland's Law)
- Turbulence model details: SA (with ft2 term), QCR is 2013 version
- Time integration: Point-implicit / Multigrid
- Spatial discretization: Finite Volume, 2nd order
- Polynomial type: Nodal-based (Cases 1*), Centroidal-based (Cases 2*)
- TVD limiter: Minmod

Joukowski Airfoil

Case 1b: Grid Convergence (α=0.0° | M=0.15 | RE=6mi)

Global Coefficients

- Drag values lie within the 0.5 drag count band for levels 4-5-6 and within 0.1 drag count for 5-6
- Skin friction converges faster than pressure drag
- Residuals convergence to machine precision (10^{-10})

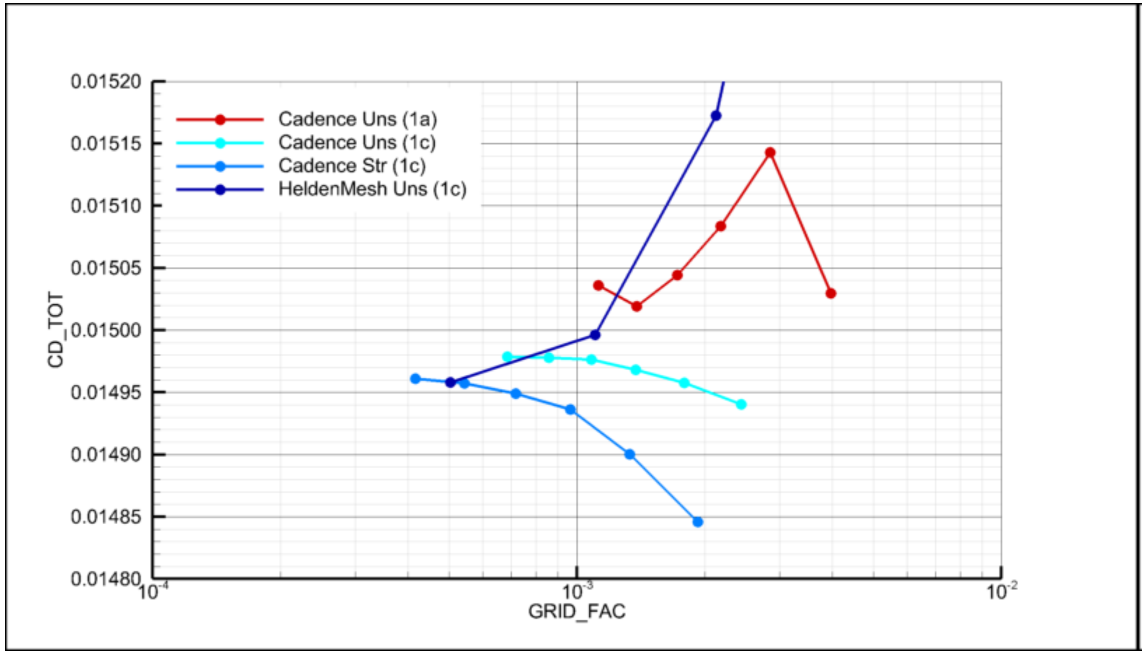


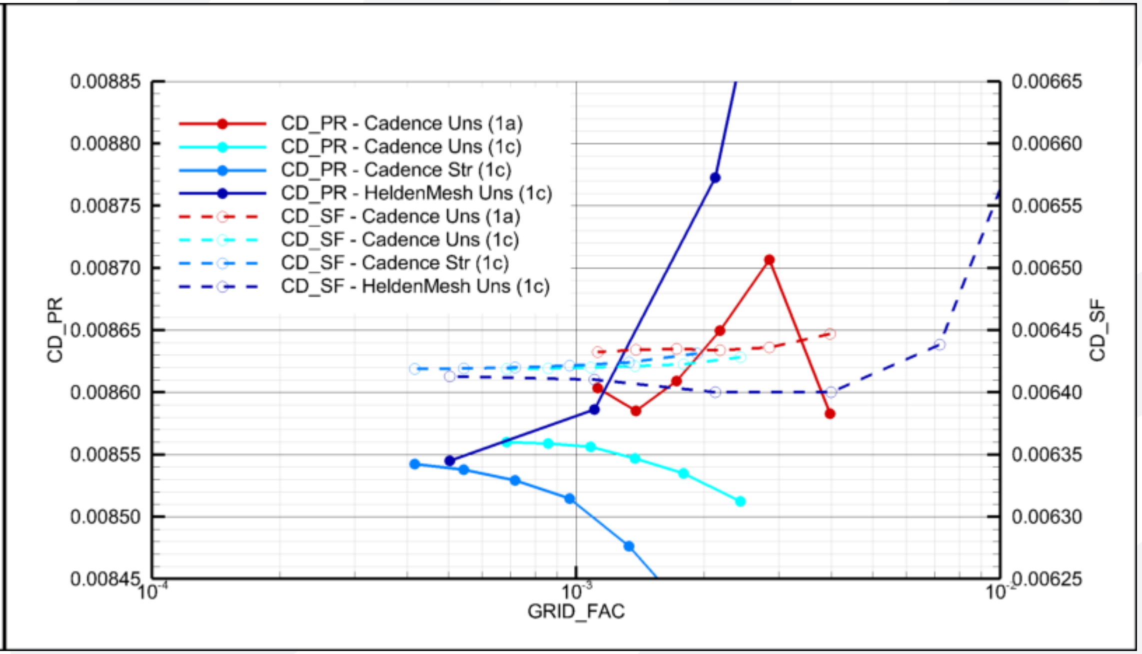
ONERA OAT15A Airfoil

Cases 1a/1c: Grid Convergence (α=1.5° | M=0.73 | RE=3mi)

Global Coefficients

- For Case 1c solutions , total C_D values lie within a 0.2 drag count range for the finest level of each family
- Pressure drag is responsible for most of the scatter, although much smaller is relation to Case 1a



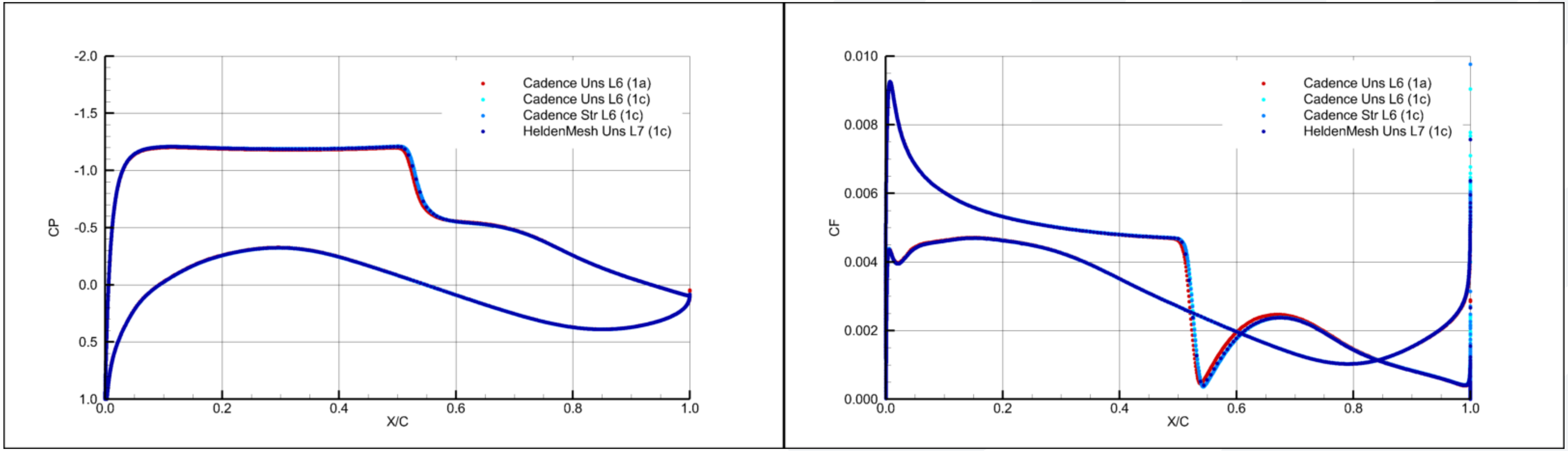


ONERA OAT15A Airfoil

Cases 1a/1c: Grid Convergence (α=1.5° | M=0.73 | RE=3mi)

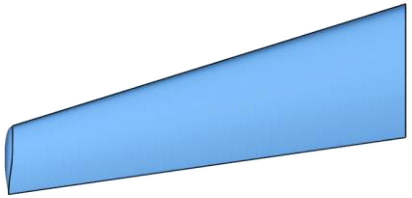
Sectional Cuts

- For Case 1c solutions, excellent agreement in shock position and strength
- Forward shock in Case 1a results in a smaller lift coefficient and less negative pitching moment
- Skin friction distributions also similar



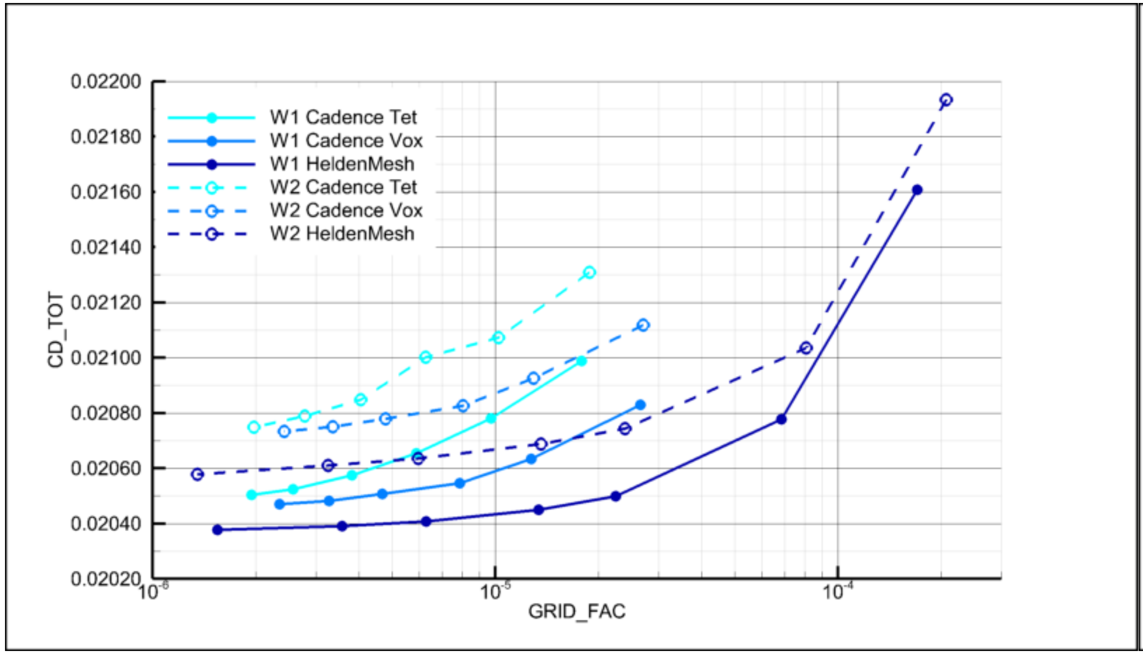
W1 & W2 Wings

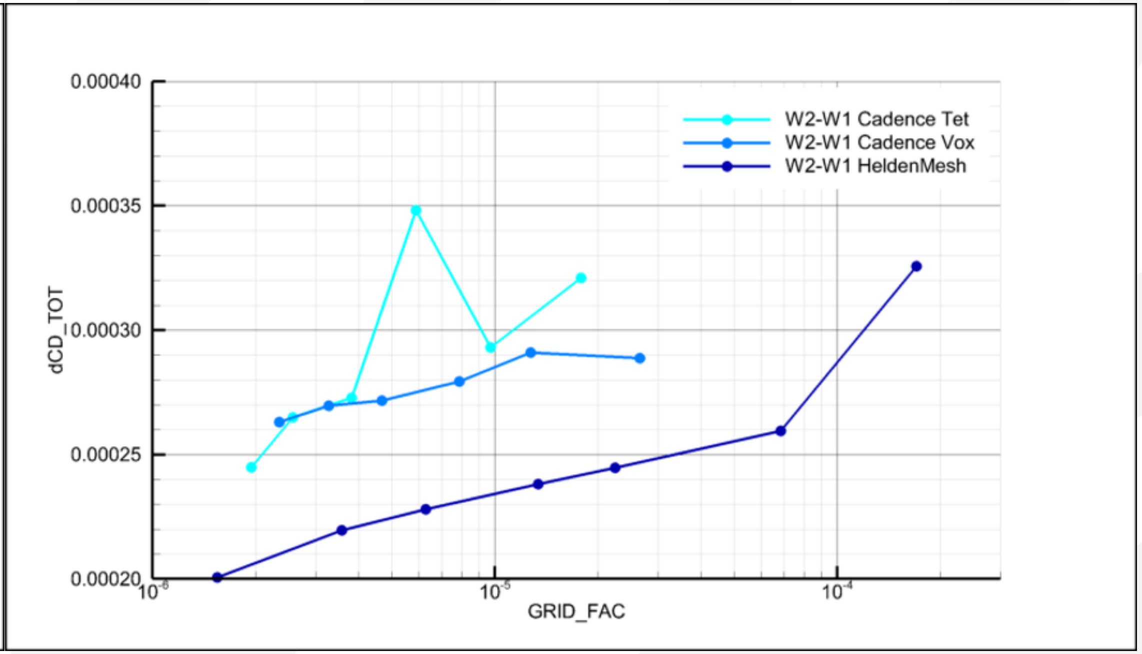
Case 1d: Grid Convergence (α=0.5° | M=0.76 | RE=5mi)



Global Coefficients

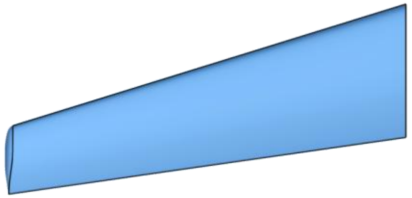
- Cadence and HeldenMesh solutions are closer for wing W1
- Delta drag between wings (W2-W1) tends to reduce with increasing grid refinement





W1 & W2 Wings

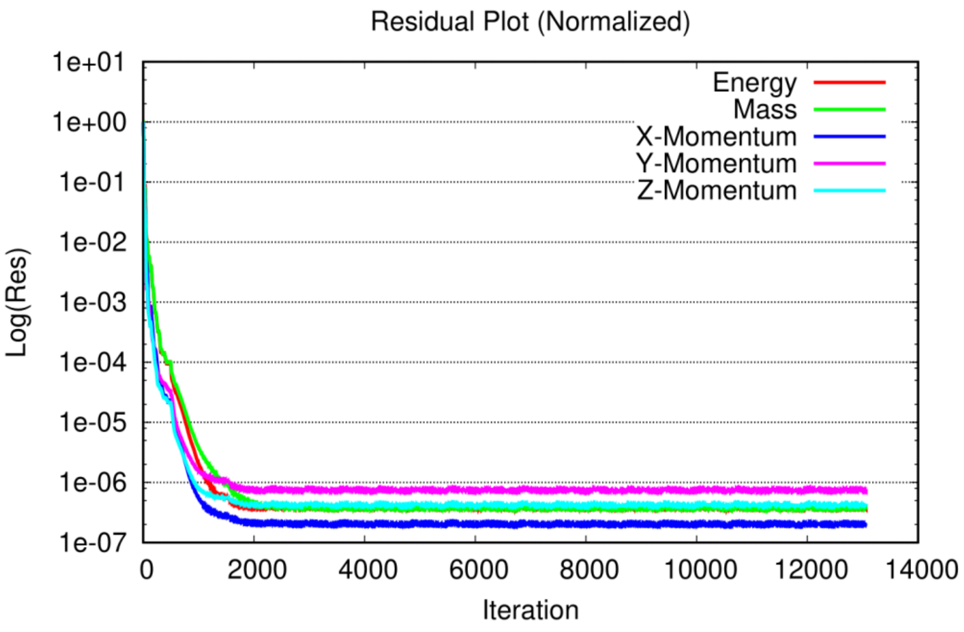
Case 1d: Grid Convergence (α=0.5° | M=0.76 | RE=5mi)



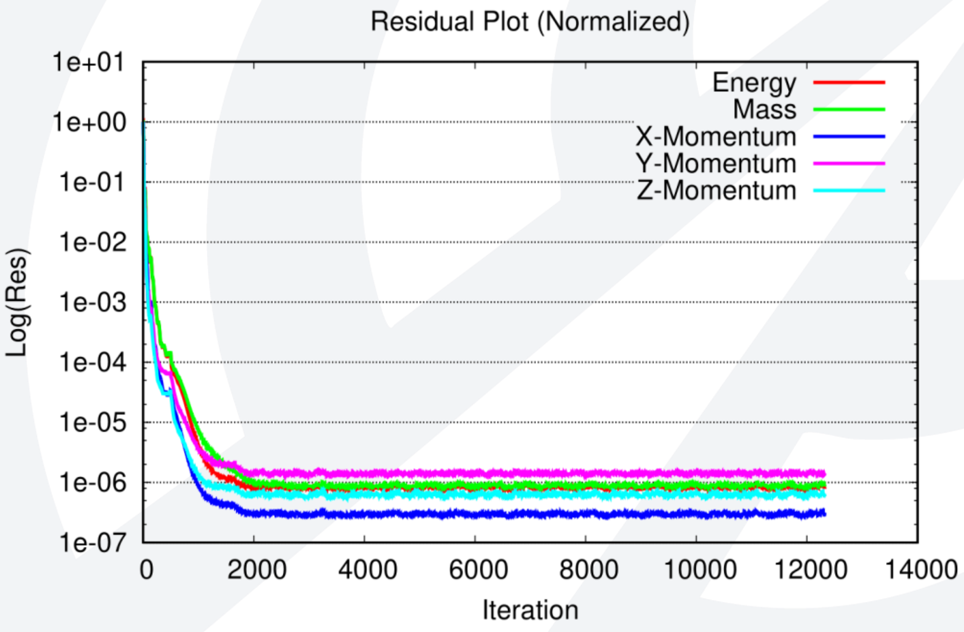
Convergence

- Spike in W2 Cadence Tet L3 solution may be related to poorer residuals convergence
- Coefficients (lift, drag, pitching moment) are well converged in all cases

W1 Cadence Tet L3

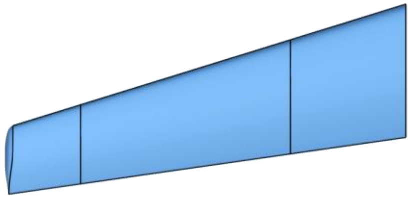


W2 Cadence Tet L3



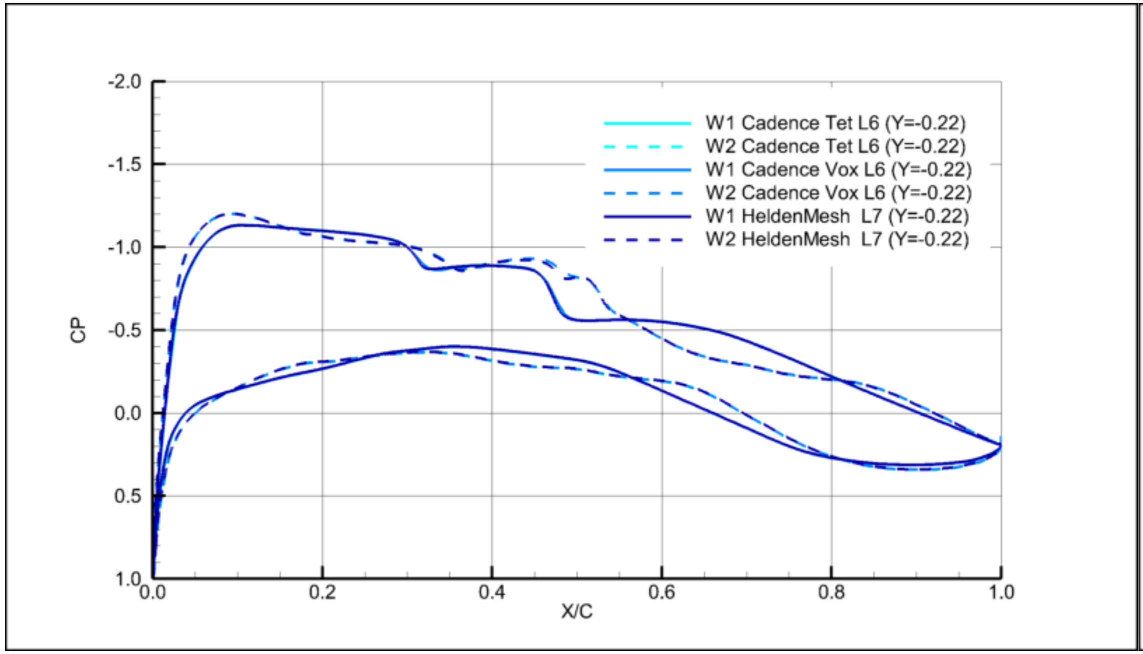
W1 & W2 Wings

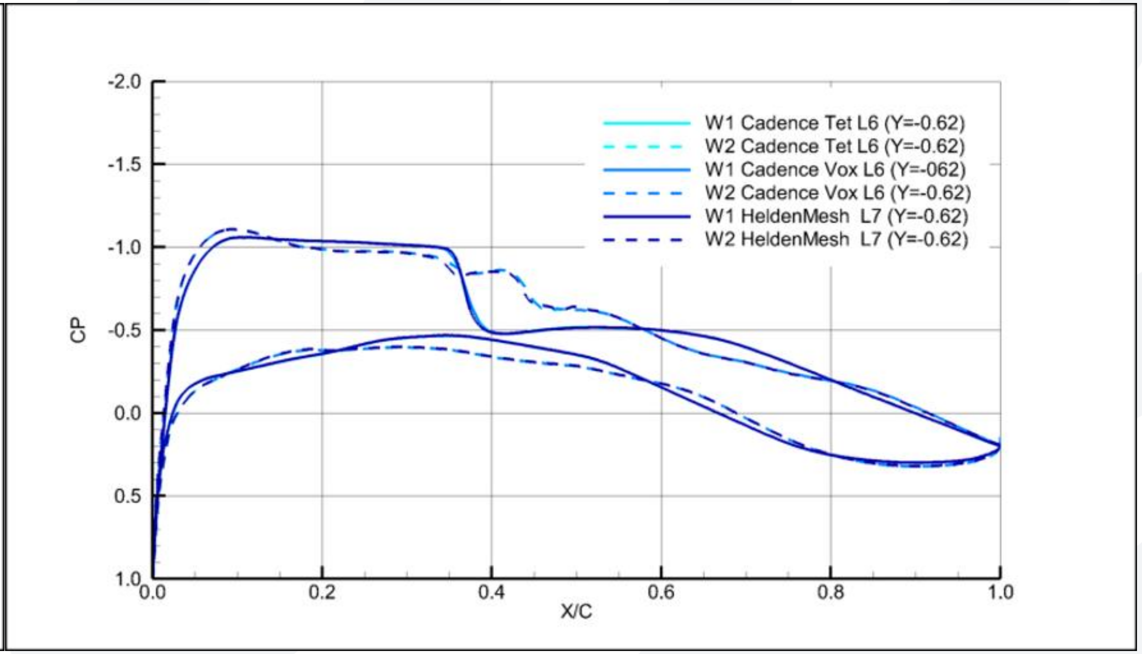
Case 1d: Grid Convergence (α=0.5° | M=0.76 | RE=5mi)



Sectional Cuts

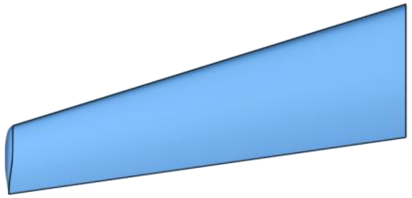
- Good agreement in shock position and strength among grids
- Inboard cut: both wings exhibit successive shocks pattern in this section
- Outboard cut: wing W1 shows a stronger single shock





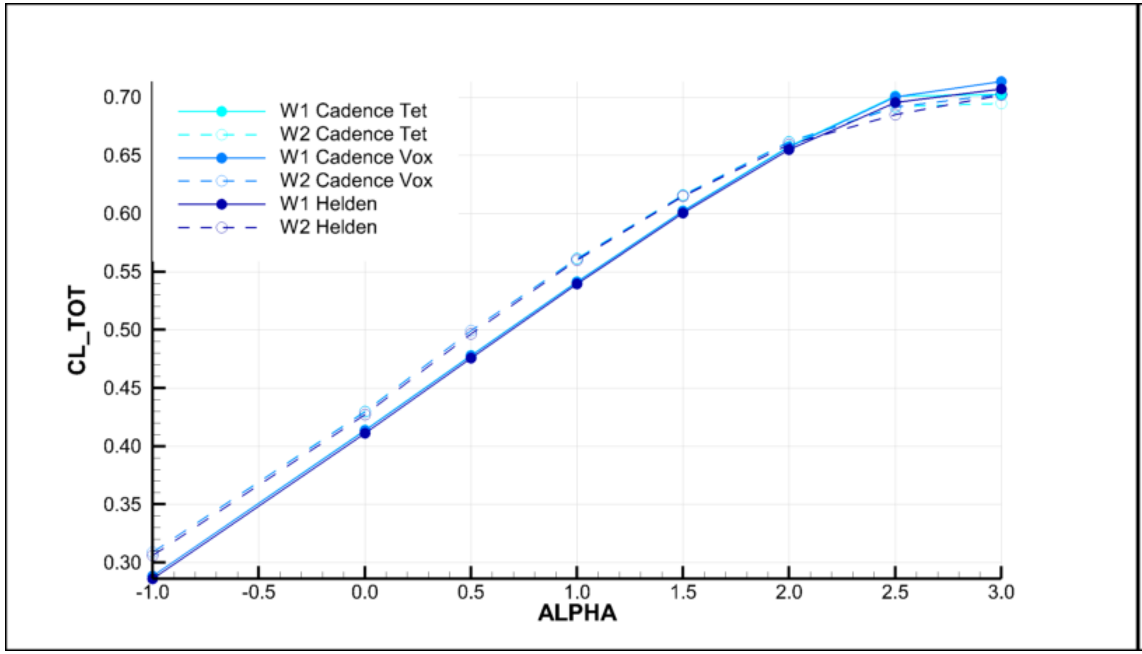
W1 & W2 Wings

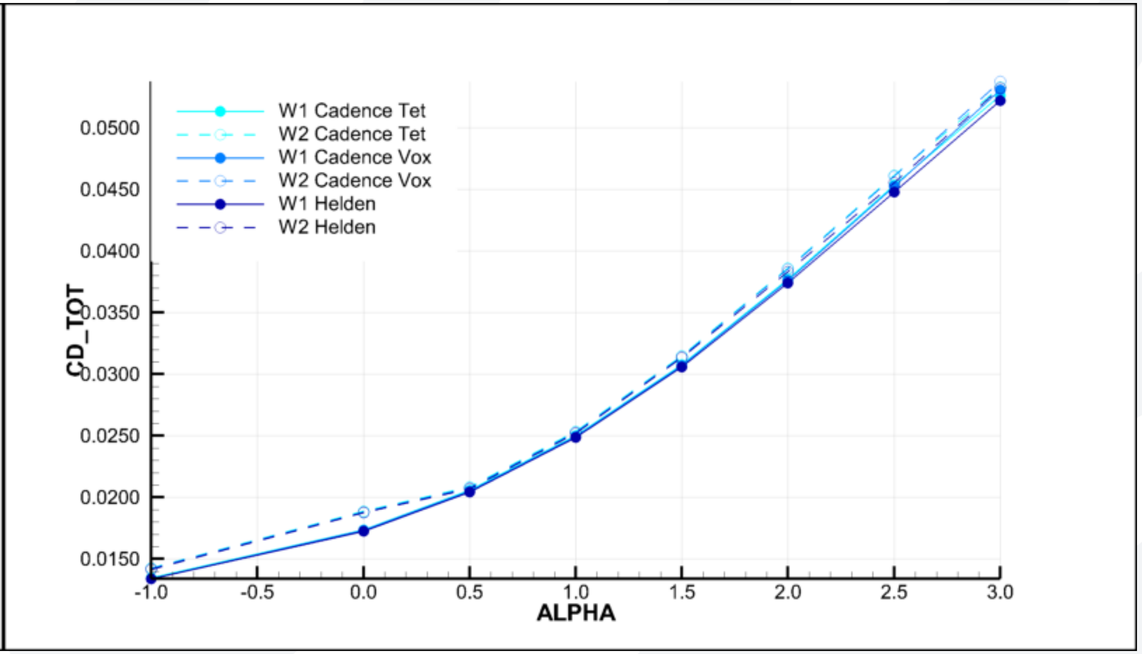
Case 1e: Polar (α sweep| M=0.76 | RE=5mi)



Global Coefficients

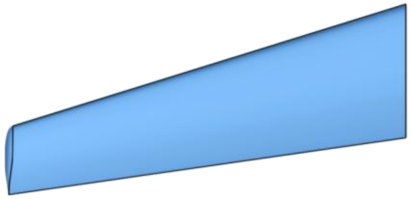
- Warm sweep strategy
- CL x α and CD x α curves are consistent among wings and grids
- CD of W2 is always higher for a given α





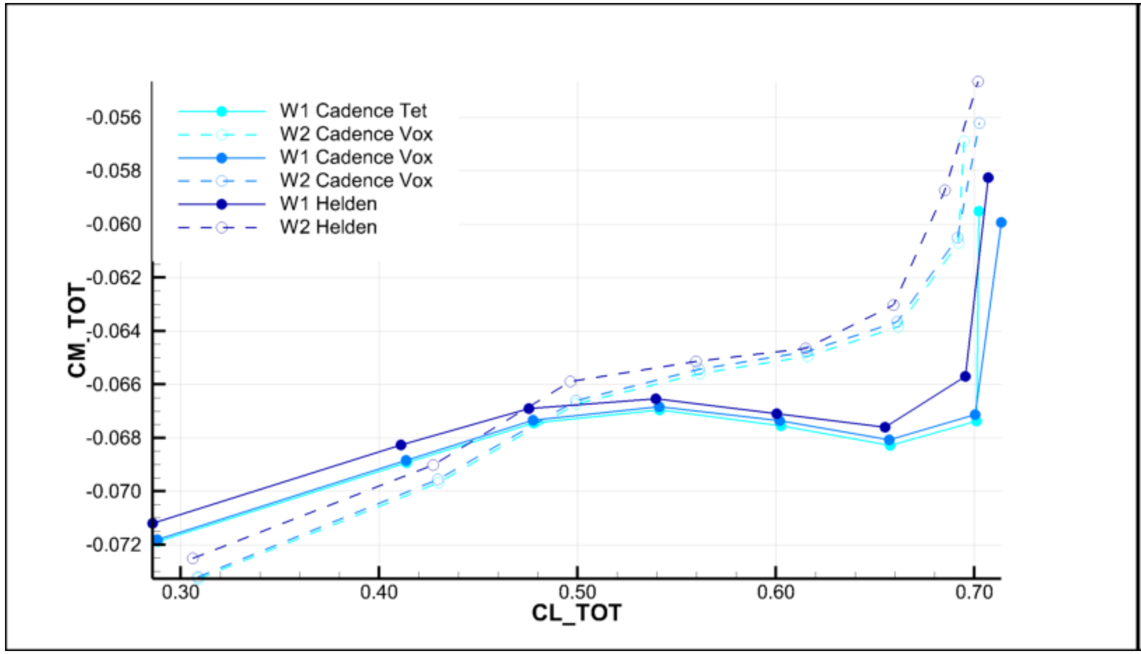
W1 & W2 Wings

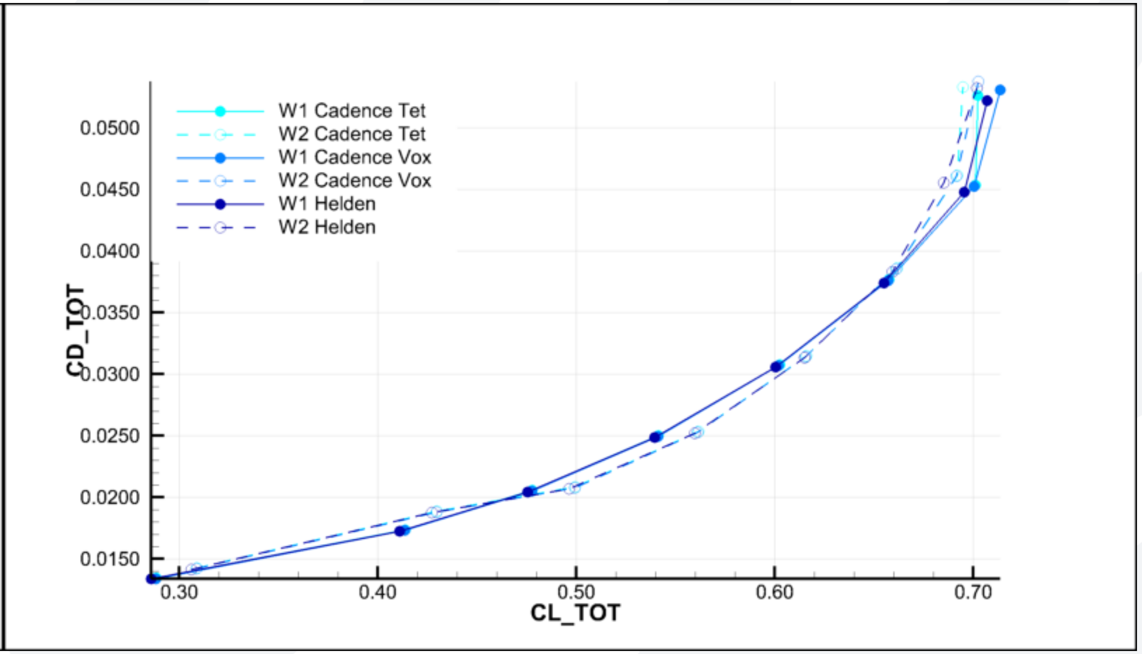
Case 1e: Polar (α sweep| M=0.76 | RE=5mi)



Global Coefficients

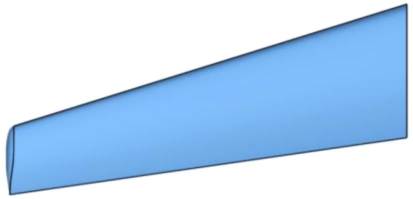
- Crossing of CM x CL W1/W2 curves is consistent among grids
- Drag polar comparison highlights wing W2 optimization point





W1 & W2 Wings

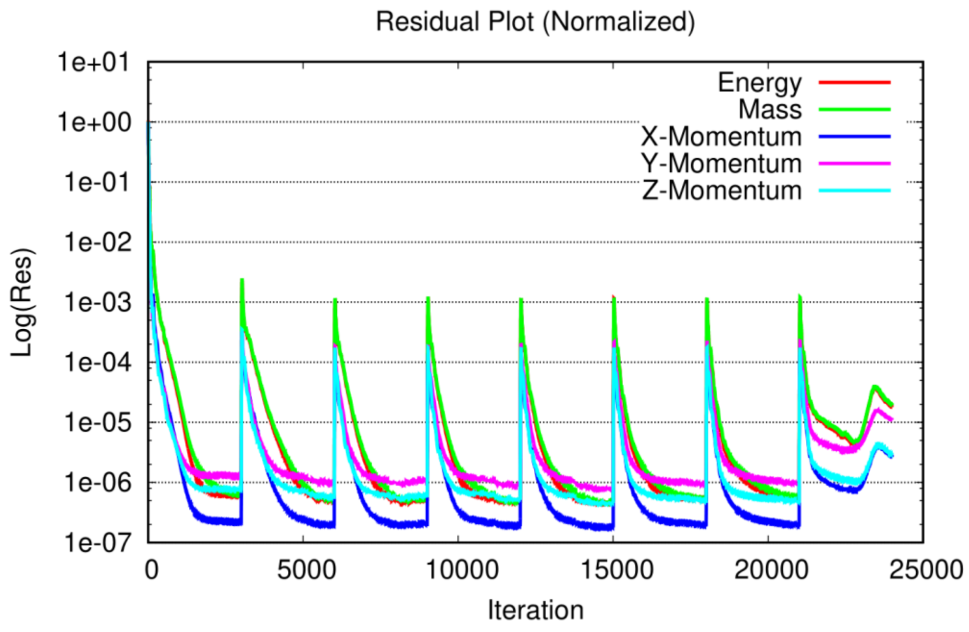
Case 1e: Polar (α sweep| M=0.76 | RE=5mi)



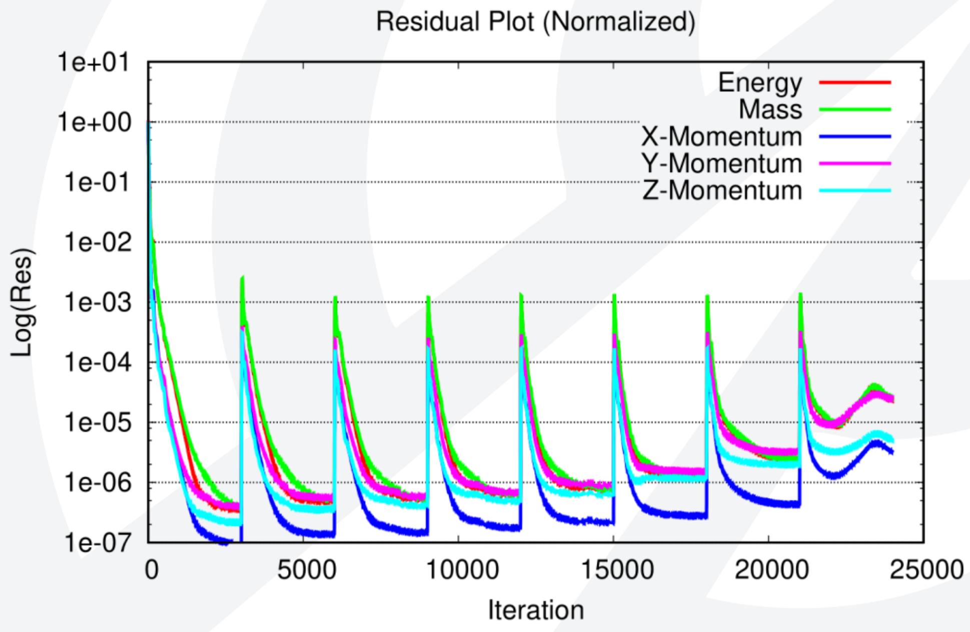
Convergence

- W1 is a more robust aerodynamic design in higher α's/ CL's
- W1 keeps good residual convergence levels up to α=2.5°, W2 holds on until α=2.0°

W1 Cadence Tet L4



W2 Cadence Tet L4

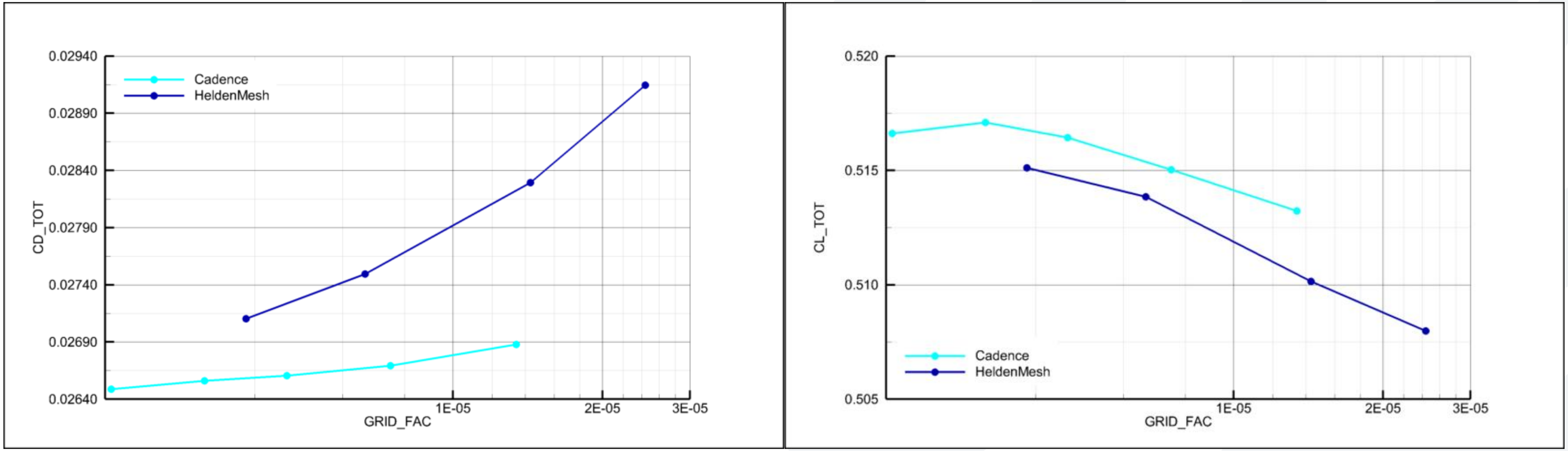


CRM Wing Body

Case 2a: Grid Convergence (α=2.5° | M=0.85 | RE=5mi)

Global Coefficients

- Finest grids simulations (Cadence L6, HeldenMesh L5/L6) were not ready in time for the workshop
- HeldenMesh family exhibits steeper slopes in CD and CL grid convergence curves

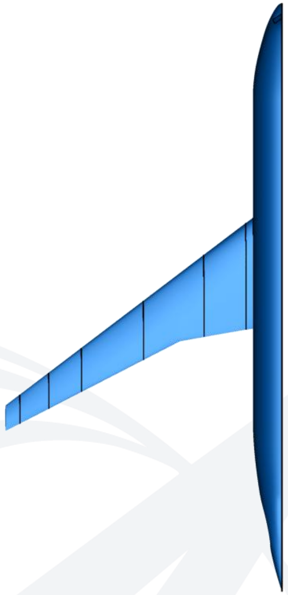


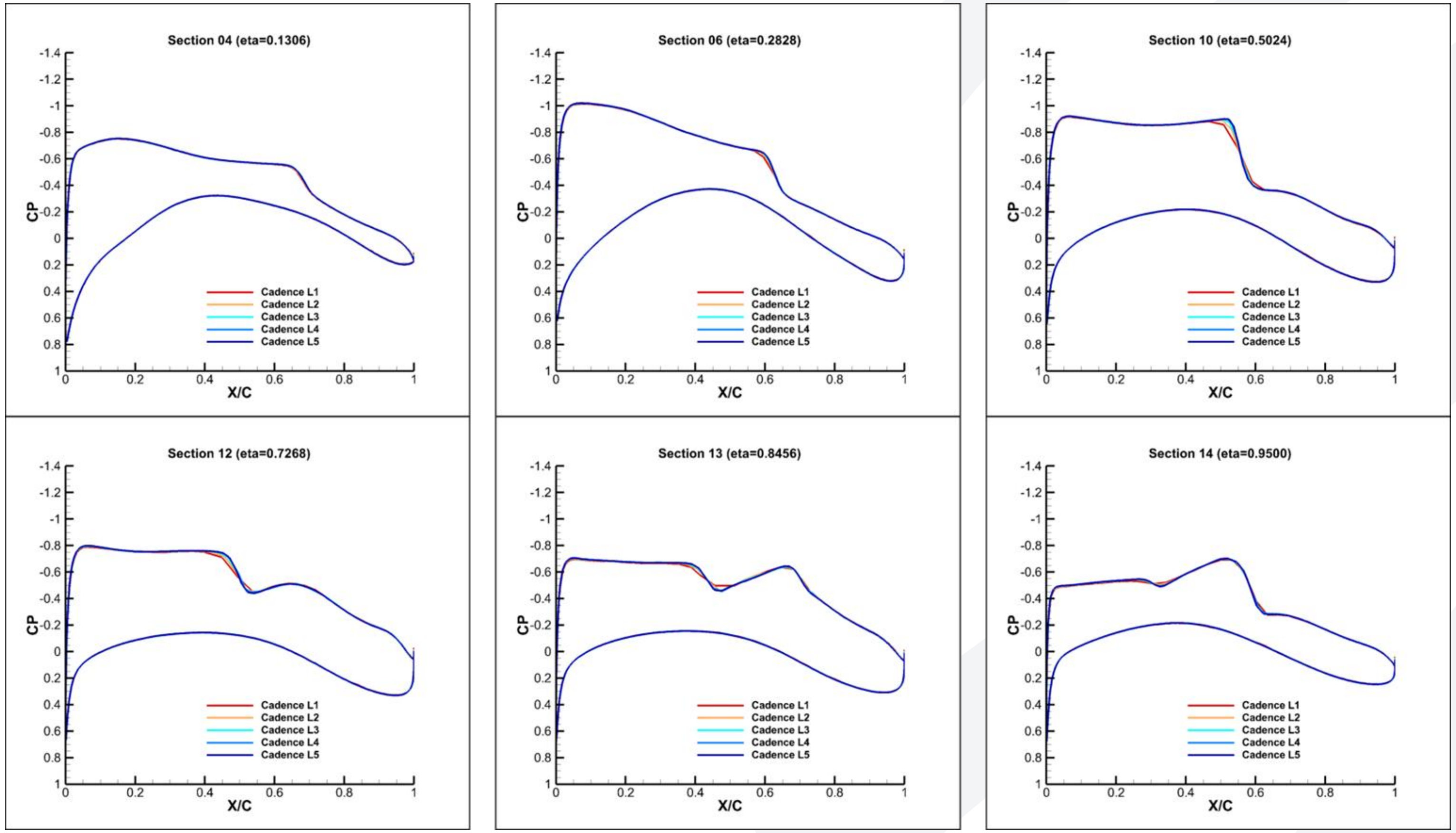
CRM Wing Body

Case 2a: Grid Convergence (α=2.5° | M=0.85 | RE=5mi)

Sectional Cuts

- Cadence family: better shock definition in refined grids





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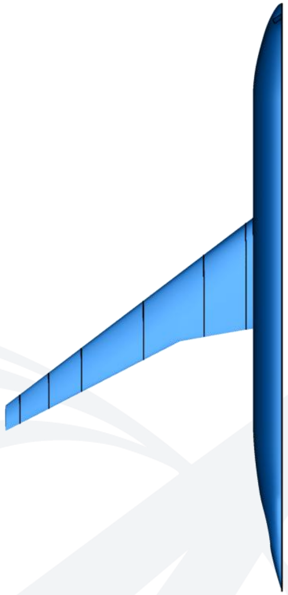
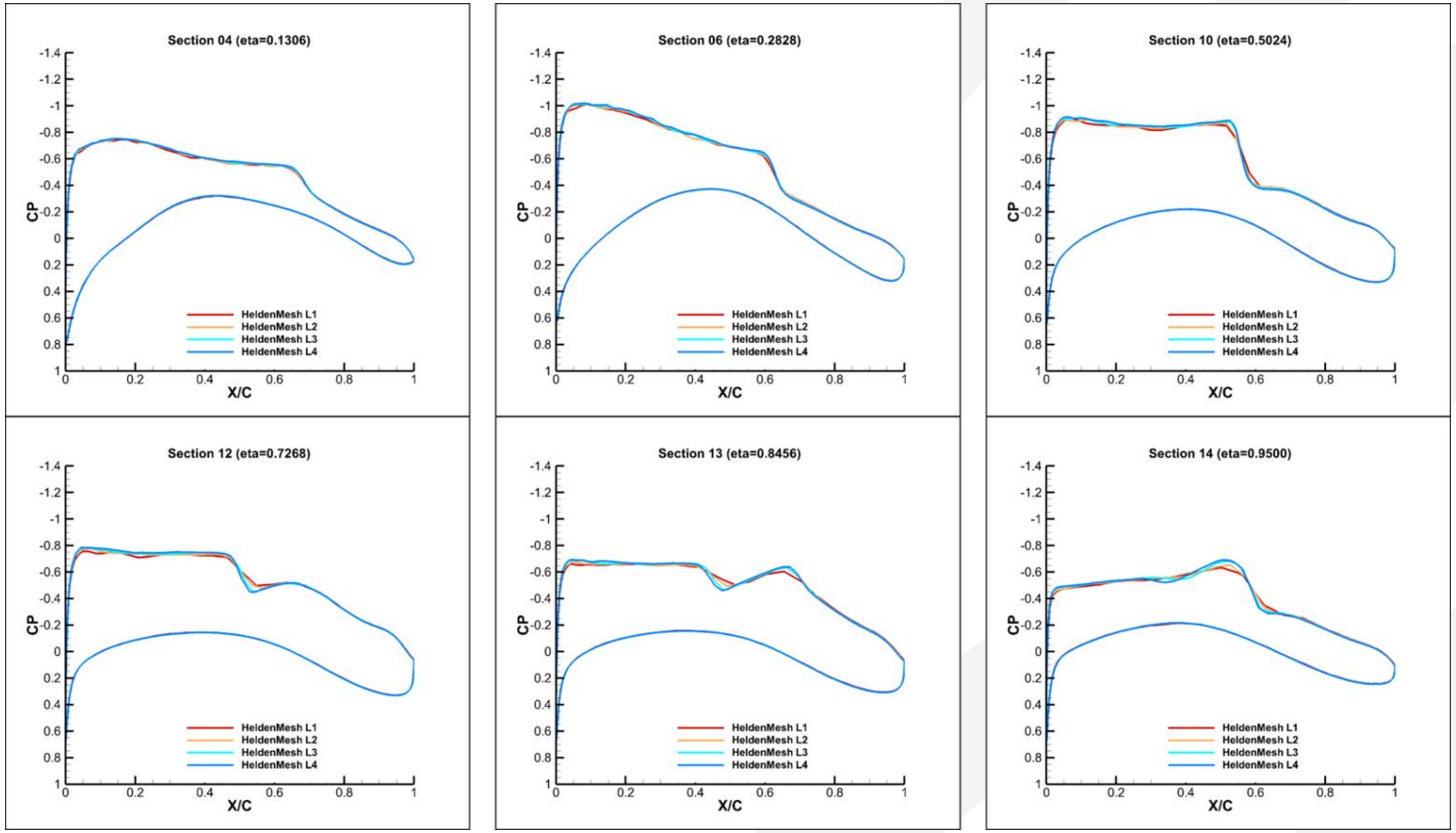
CRM Wing Body

Case 2a: Grid Convergence (α=2.5° | M=0.85 | RE=5mi)

Sectional Cuts

- HeldenMesh family: oscillations in upper surface Cp's even in L4 grid (further investigation needed)
- Differences in trailing edge Cp's between families





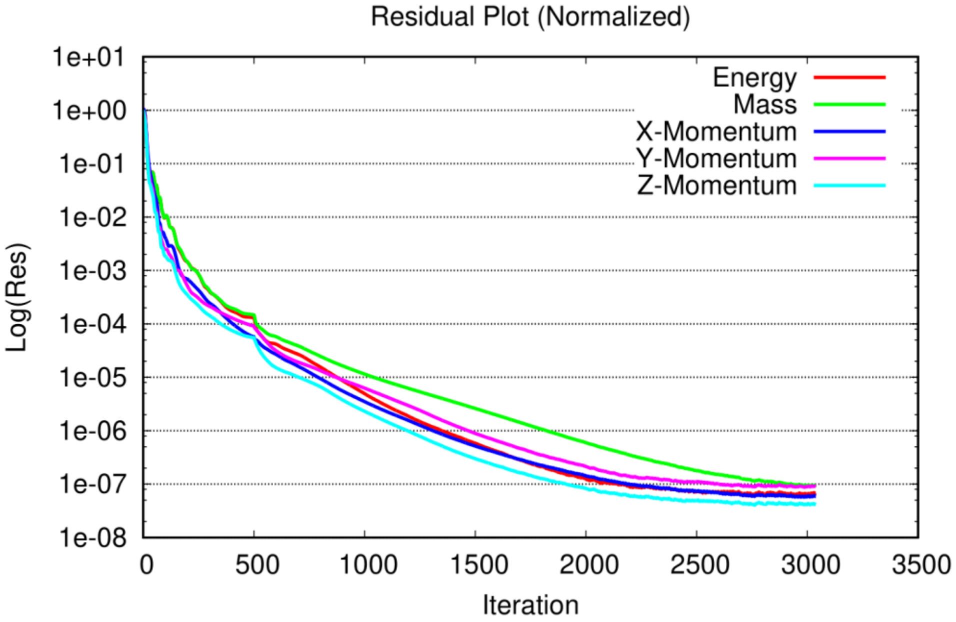
CRM Wing Body

Case 2a: Grid Convergence (α=2.5° | M=0.85 | RE=5mi)

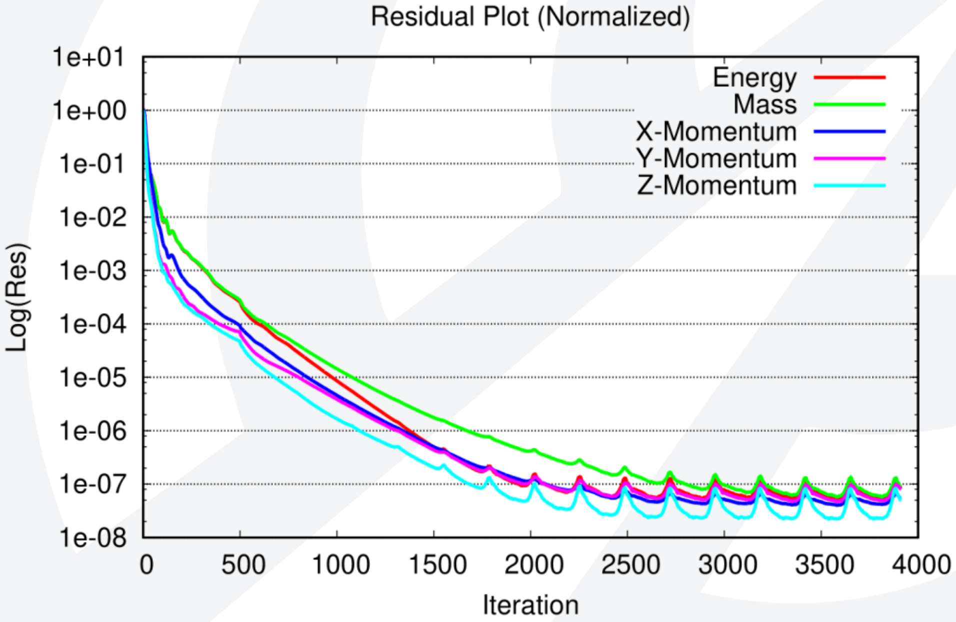
Convergence

- Similar levels in residuals drop for all grid levels (≈10^{-7})
- Cadence family solutions results in smoother residuals curves

Cadence L4



HeldenMesh L4

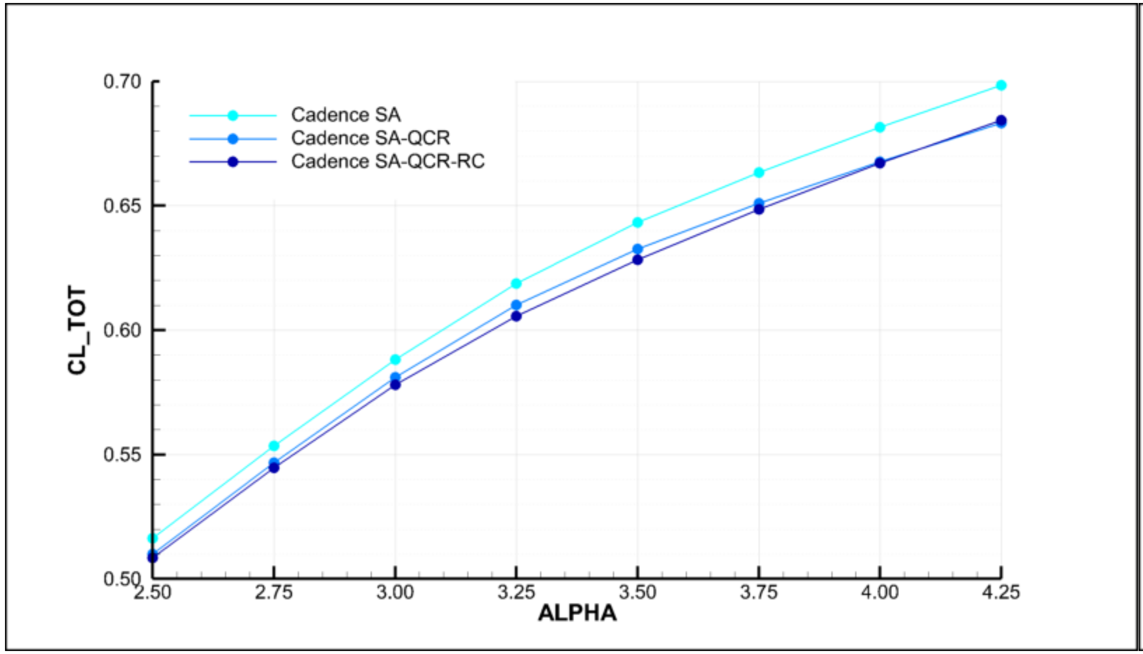


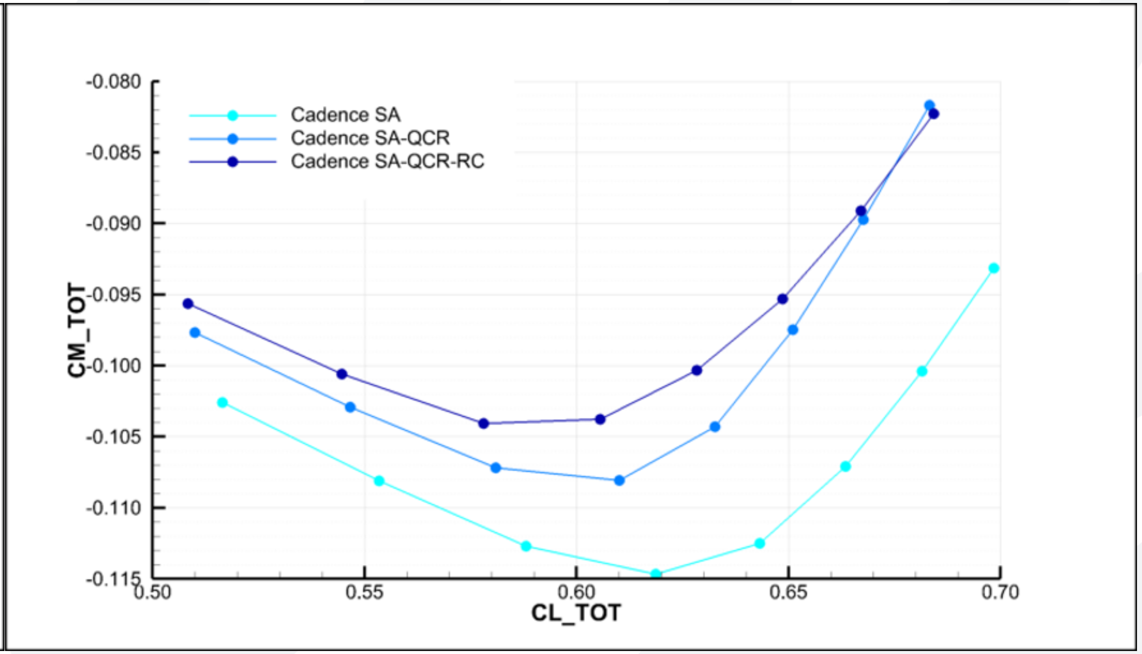
CRM Wing Body

Case 2b: Polar (α sweep| M=0.85 | RE=5mi)

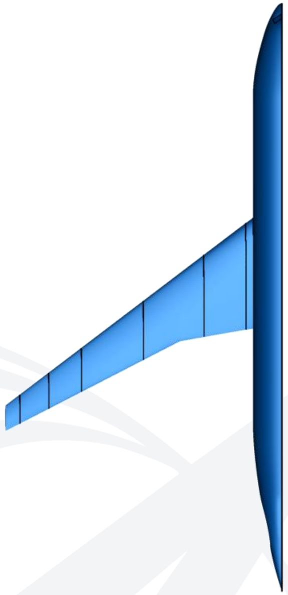
Global Coefficients

- Same warm sweep strategy of Case 1e
- QCR has more influence in changing solution than RC correction
- CL and CM differences among setups suggests more aft loading in SA solution





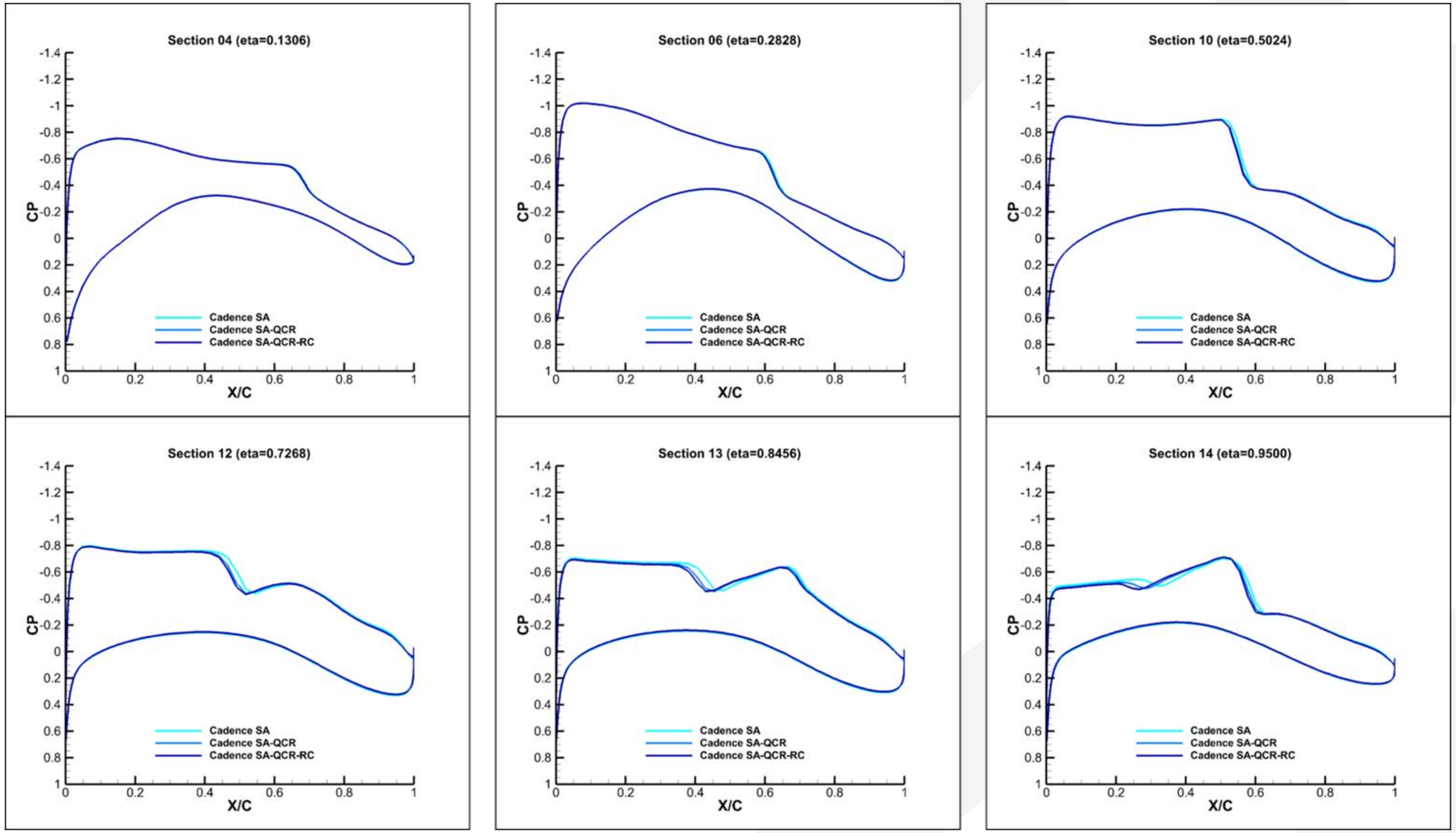
CRM Wing Body



Case 2b: Polar (α sweep| M=0.85 | RE=5mi)

Sectional Cuts (α=2.5°)

- Differences in shock position are more relevant in the outboard panel



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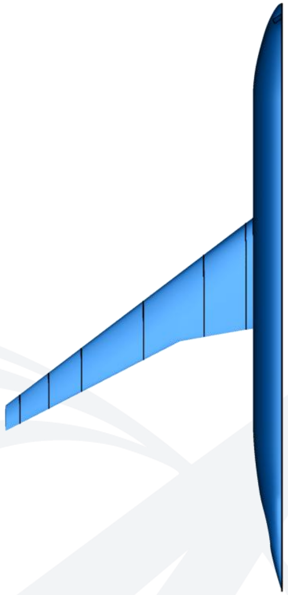
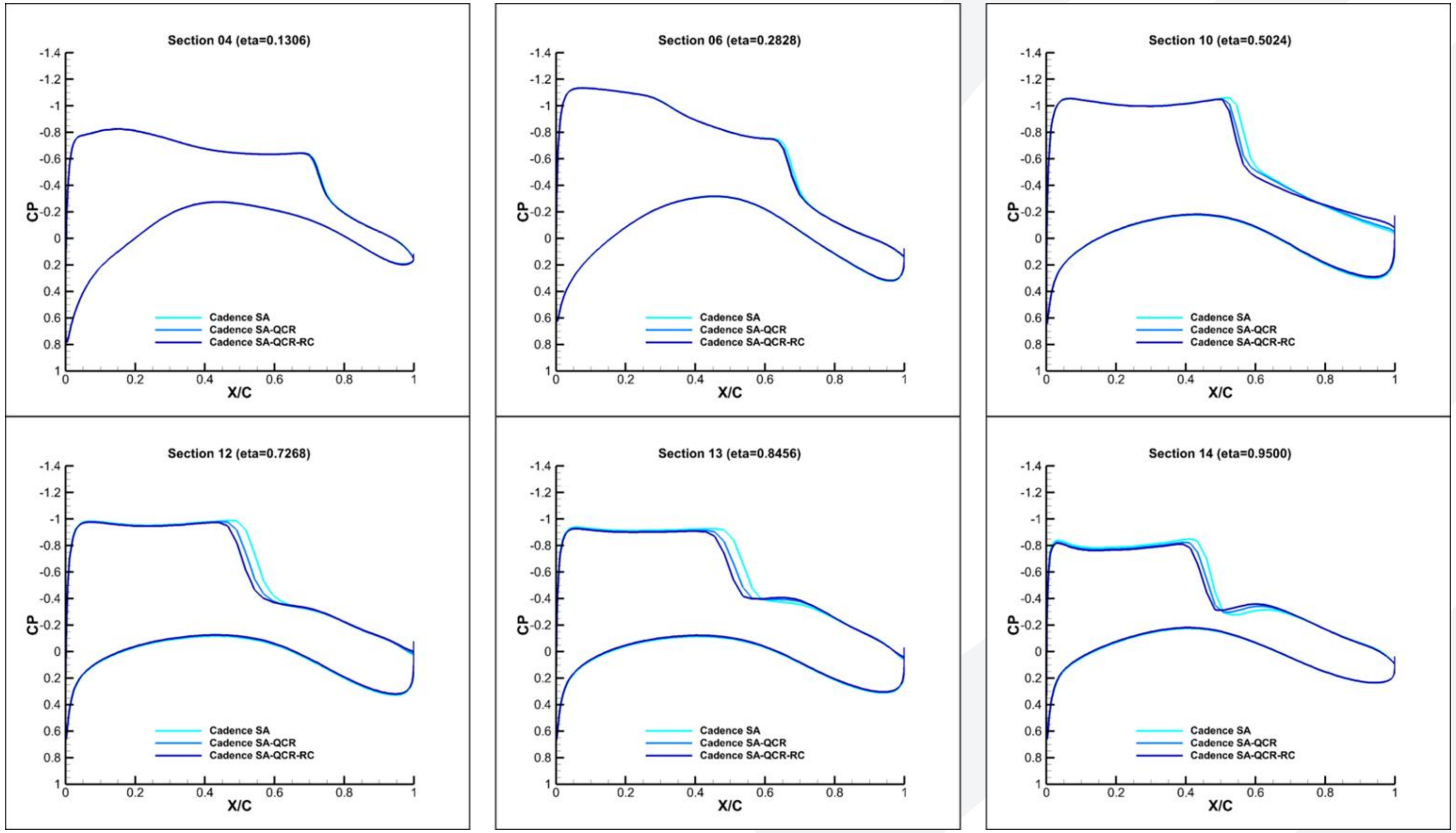
CRM Wing Body

Case 2b: Polar (α sweep| M=0.85 | RE=5mi)

Sectional Cuts (α=3.5°)

- Trailing edge separation first appears in SA-QCR-RC solution (Section 10)
- No sign of spurious side-of-body separation in SA solution (Section 04)





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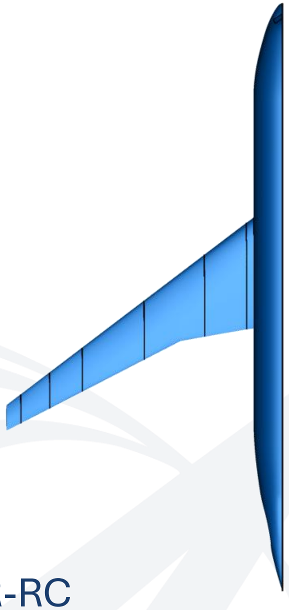
CRM Wing Body

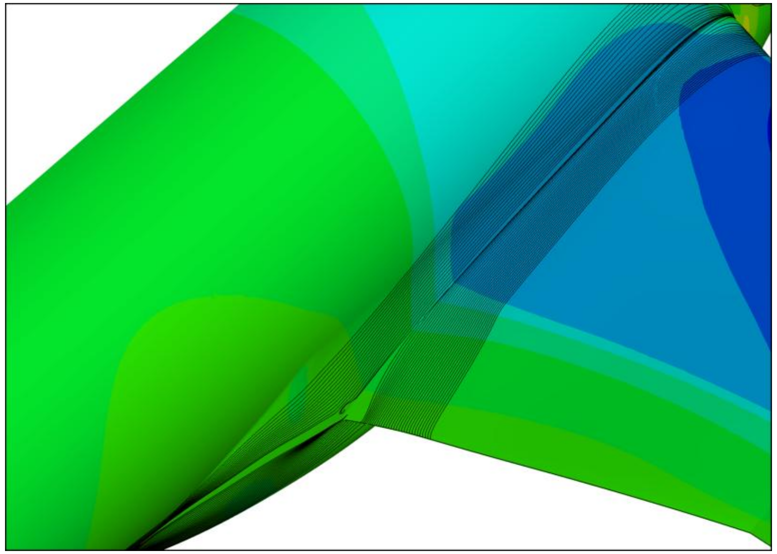
Case 2b: Polar (α sweep| M=0.85 | RE=5mi)

Topology (α=3.5°)

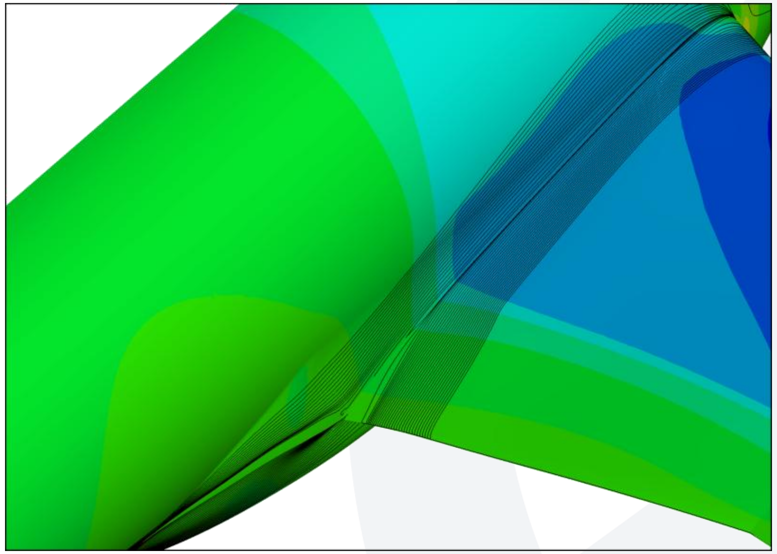
- Resemblant side-of-body separation region among setups



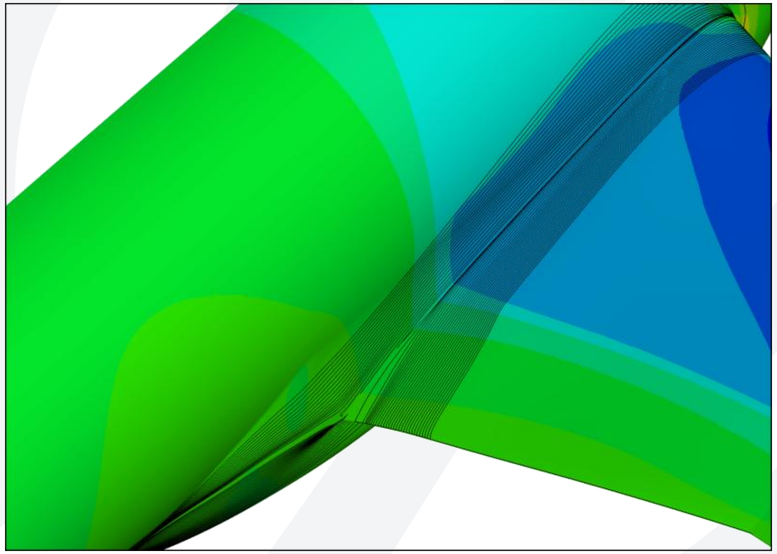
Cadence SA



Cadence SA-QCR

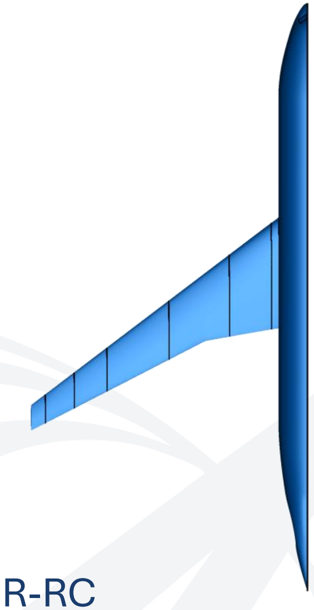


Cadence SA-QCR-RC



CRM Wing Body

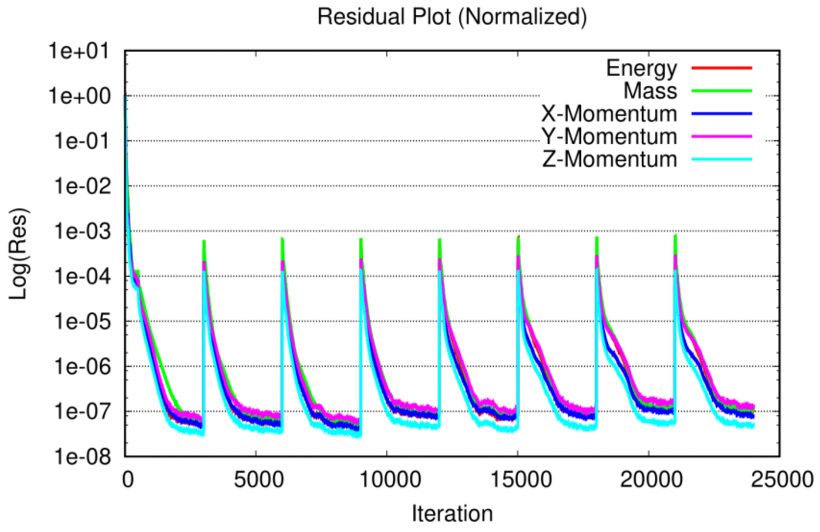
Case 2b: Polar (α sweep| M=0.85 | RE=5mi)



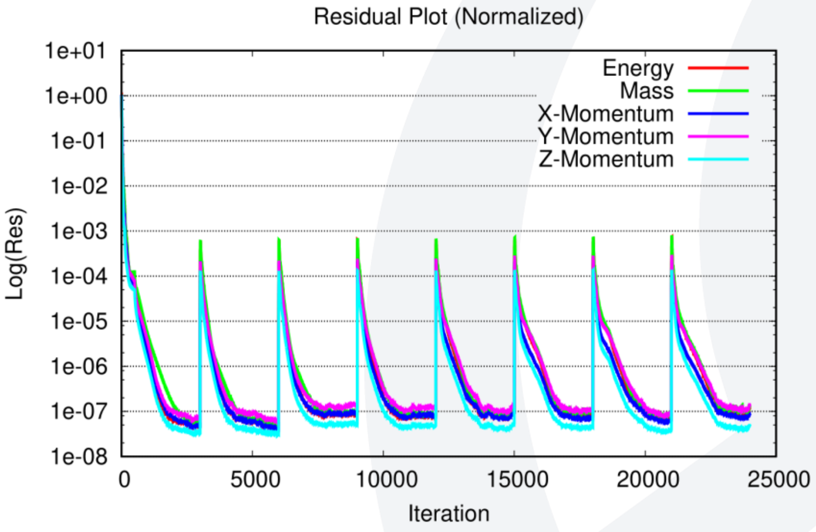
Convergence

- Similar levels in residuals drop for all setups (≈10^{-7})
- Higher α's were less challenging to converge in comparison to W1/W2 polars

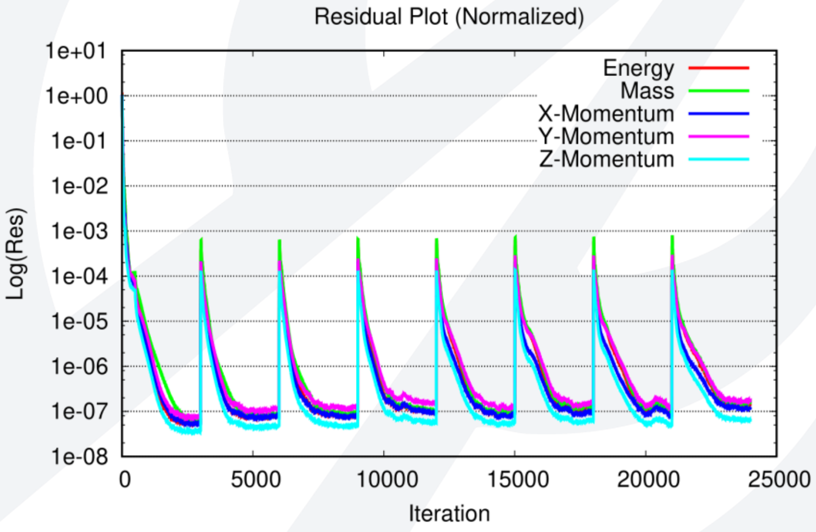
Cadence SA



Cadence SA-QCR



Cadence SA-QCR-RC



Cases Overview

Conclusions and next steps

Conclusions

- Grid topology and quality play an important role in residuals convergence trends
- SA corrections (QCR,RC) may shift solutions in several drag counts even in a simple case
- A comprehensive problem definition tends to reduce sources of scatter

Next Steps

- Simulation of Case 2a finest grids (Cadence L6, HeldenMesh L5/L6)
- Investigation of Case 2a HeldenMesh grid family results
- Investigation of Case 2a nodal-based solutions

More details in future publications/special sessions!

Thank You