USM3D-ME Buffet Simulations of the ONERA OAT15A Airfoil for DPW-8/AePW-4

Tausif Jamal, Brent Pomeroy, and Seth Kelly

Configuration Aerodynamics Branch
NASA Langley Research Center, Hampton, VA 23681

Introduction

- **Supports DPW-8/AePW-4 Buffet Working Group**
- **ONERA OAT15A transonic airfoil**
  - Well-studied geometry and results are compared to Jacquin, et al.
  - Buffet Working Group Test Case 1a
  - RANS, range of angles of attack (alphas) from 1.36 through 3.90 deg
  - Mach 0.73
  - Re = 3 million
- **Additional statistics-based time-filtering technology is in development**

Grids

- **Grid partners encouraged to employ best/desired practices**
- **Committee-supplied mixed-element Cadence and Helden unstructured grids**

Cadence Rev01

Grid Level	Approx Cell Count	Target y^+
L1	47,000	1.000
L2	89,000	0.670
L3	150,000	0.500
L4	235,000	0.400
L5	353,000	0.330
L6	517,000	0.290

Helden Rev01

Grid Level	Approx Cell Count	Target y^+
L1	10,000	4.000
L2	35,000	2.000
L3	134,000	1.000
L4	528,000	0.500
L5	2,076,000	0.250
L6	8,208,000	0.125

Grids

- **Grid partners encouraged to employ best/desired practices**
- **Committee-supplied mixed-element Cadence and Helden unstructured grids**
  - Cadence Rev01, Helden Rev01, and Helden Rev02
  - Feedback from participants led to updated Helden grids
  - Simulated L1, L2, and L3 for Cadence Rev01 and Helden Rev01; only L3 for Helden Rev02

Cadence Rev01

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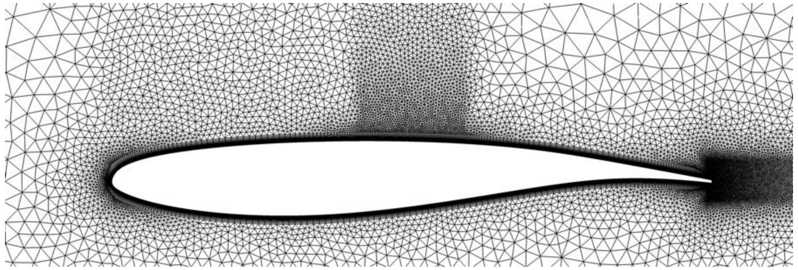
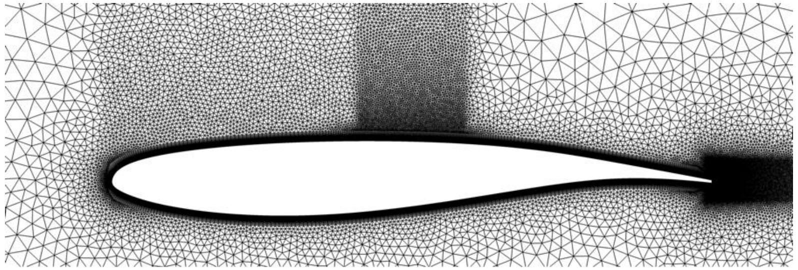
L1-L3 Grid Images

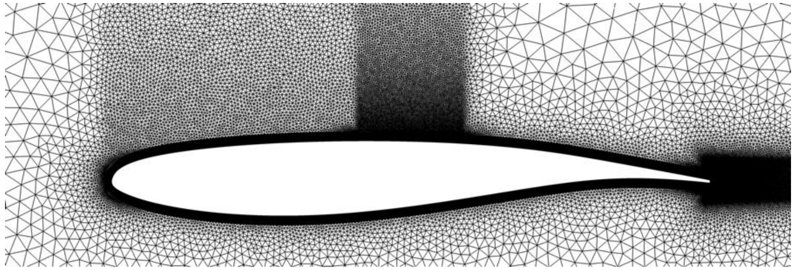
Cadence L1



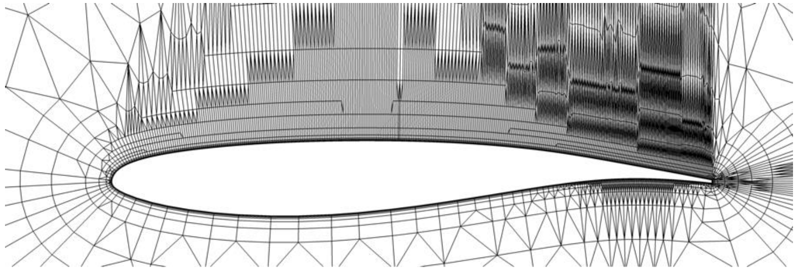
Cadence L2



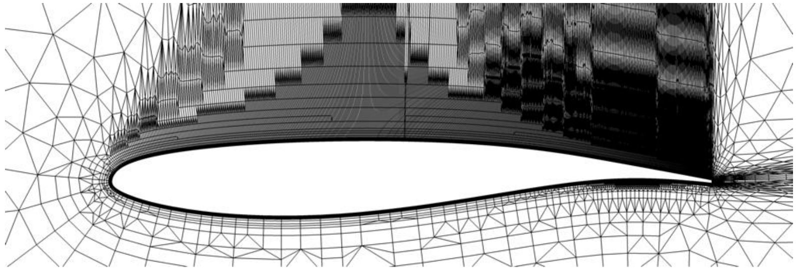
Cadence L3



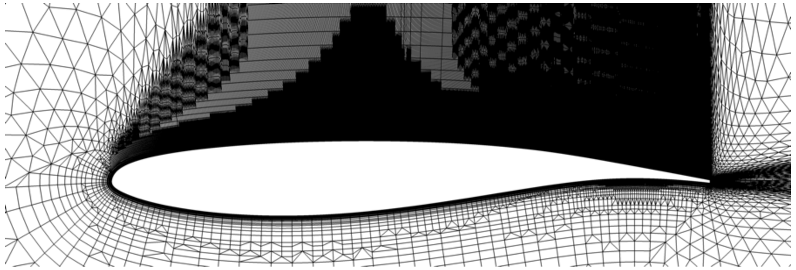
Helden Rev01 L1



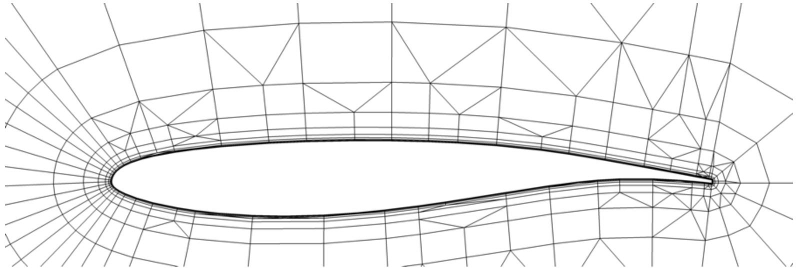
Helden Rev01 L2



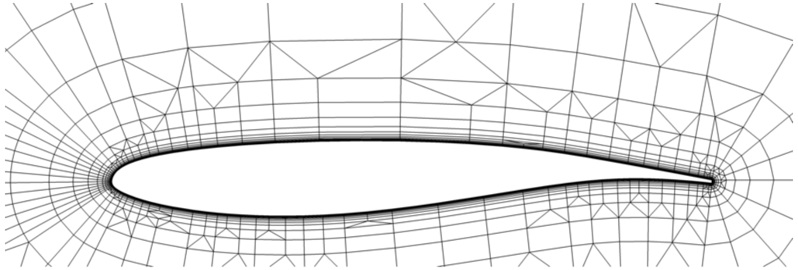
Helden Rev01 L3



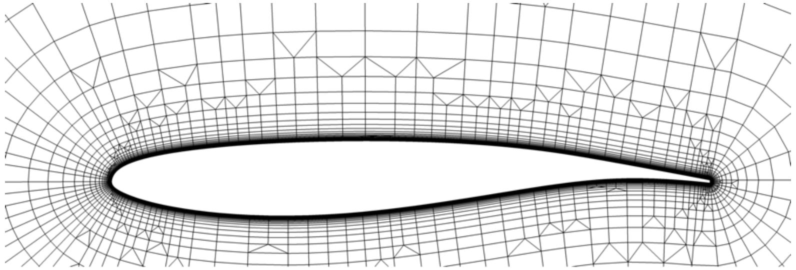
Helden Rev02 L1



Helden Rev02 L2

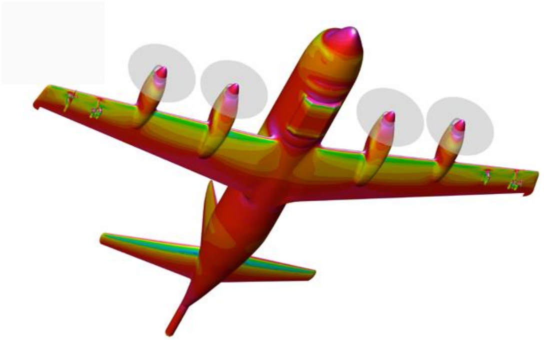


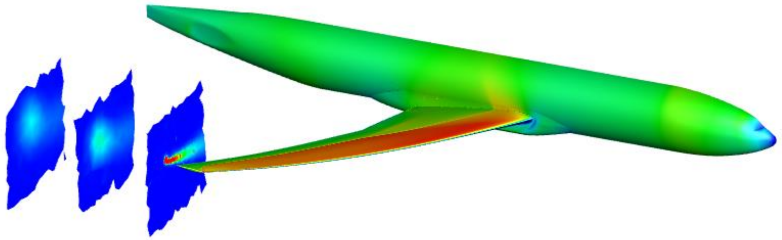
Helden Rev02 L3



Numerical Method

- **USM3D-ME (mixed element)**
  - Developed at NASA Langley Research Center, successor to USM3D solver
  - Strong linear solver increases robustness and efficiency
  - Second order in space coupled with Roe's flux-difference-splitting FDS scheme
- **Setup**
  - RANS, local time-stepping
  - First order to start simulation, then second order
- **Turbulence model**
  - SA-neg
  - SA-neg-R (rotation correction)
  - SA-neg-QCR2000
- **Cadence: SA-neg, SA-neg-R, and SA-neg-QCR**
- **Helden: SA-neg**

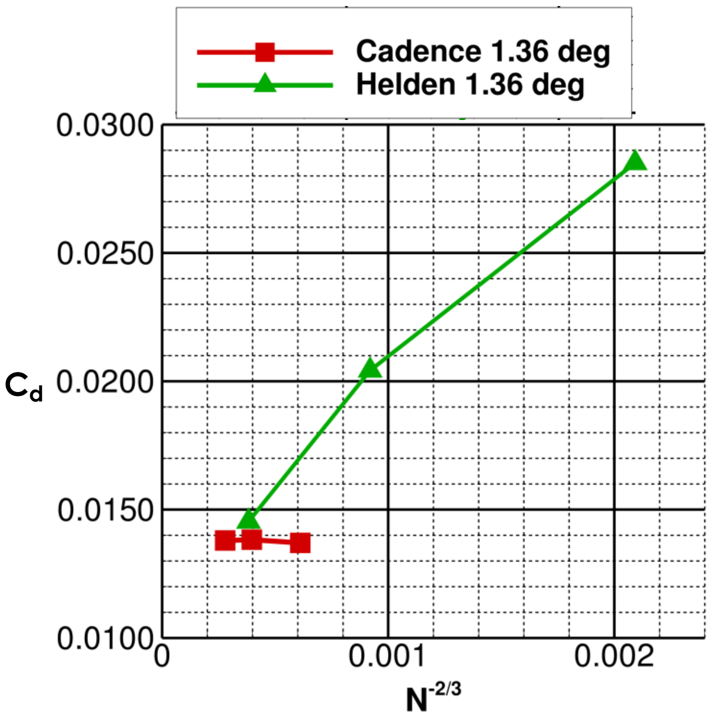


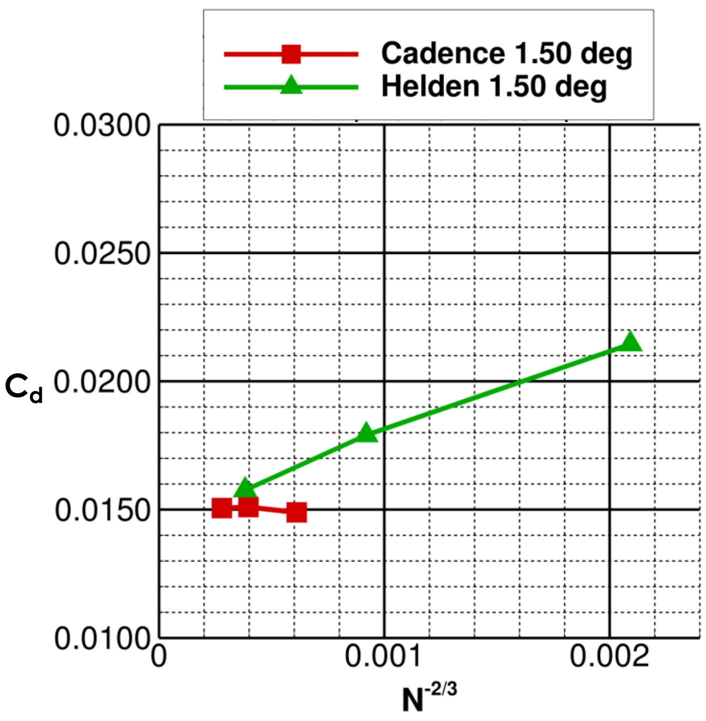


Simulations carried out using USM3D-ME

Grid Convergence (SA-neg)

- **Cadence**
  - Good grid convergence for L1-L3 at low alpha
  - Moderate grid convergence for alpha above 3.10 deg
- **Helden Rev01**
  - Solution not yet grid converged
  - May need additional analysis using L4-L6
  - Recall the Helden L1 and L2 are much coarser than the Cadence L1 and L2





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- **Helden Rev01**
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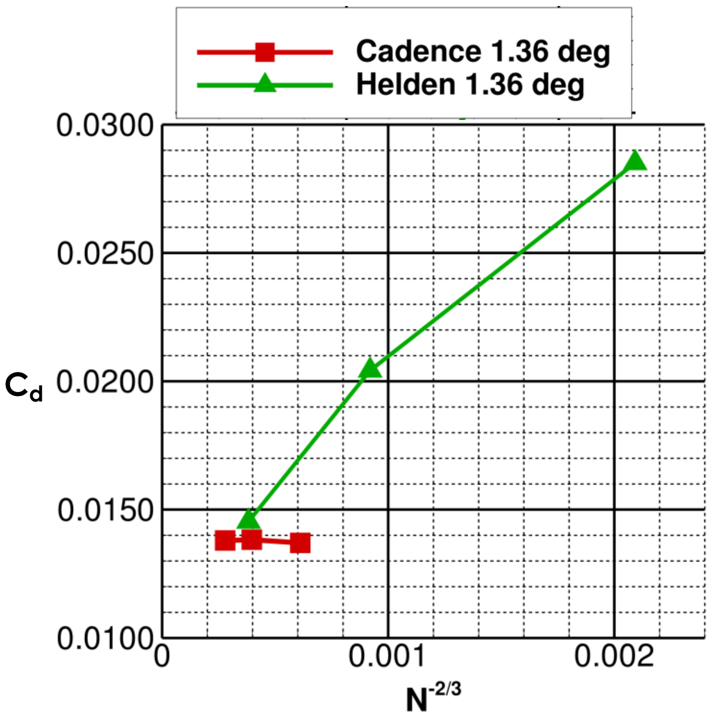
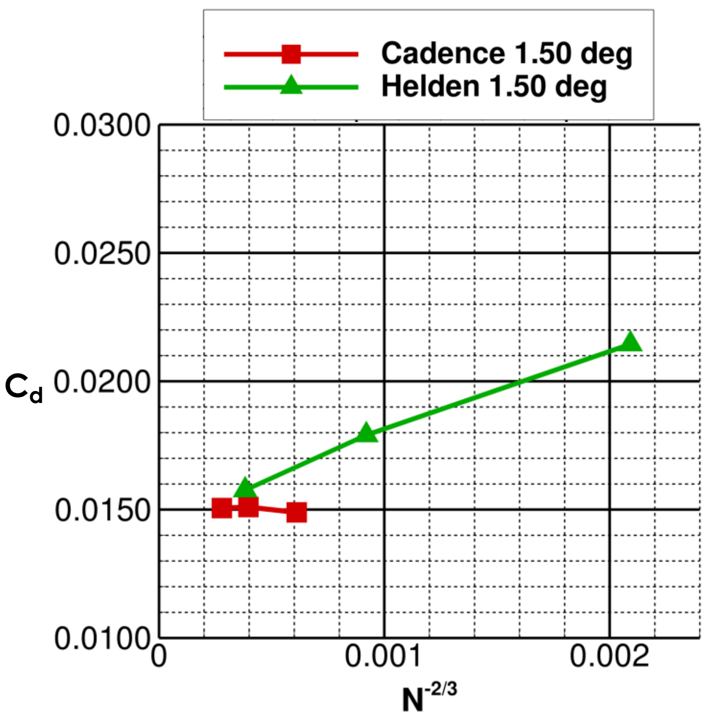
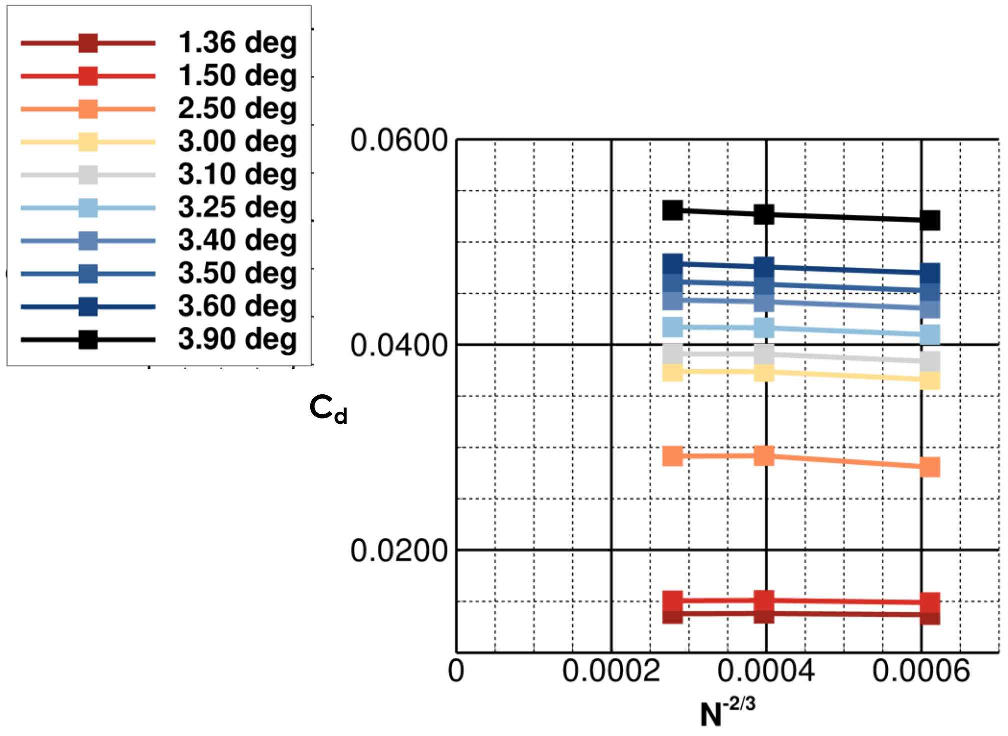
  - May need additional analysis using L4-L6
  - Helden L1 and L2 are much coarser than the Cadence L1 and L2; L3 are similar

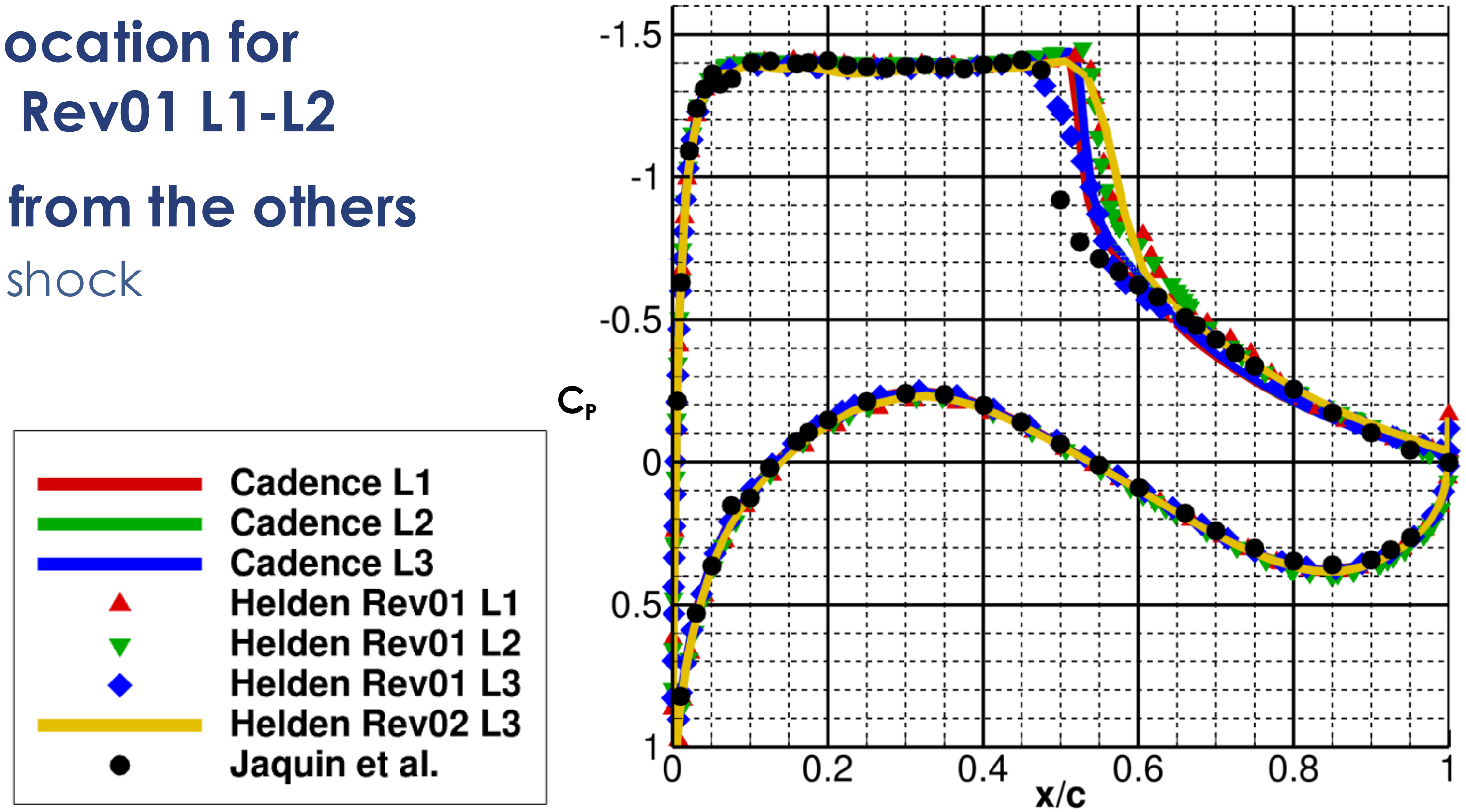






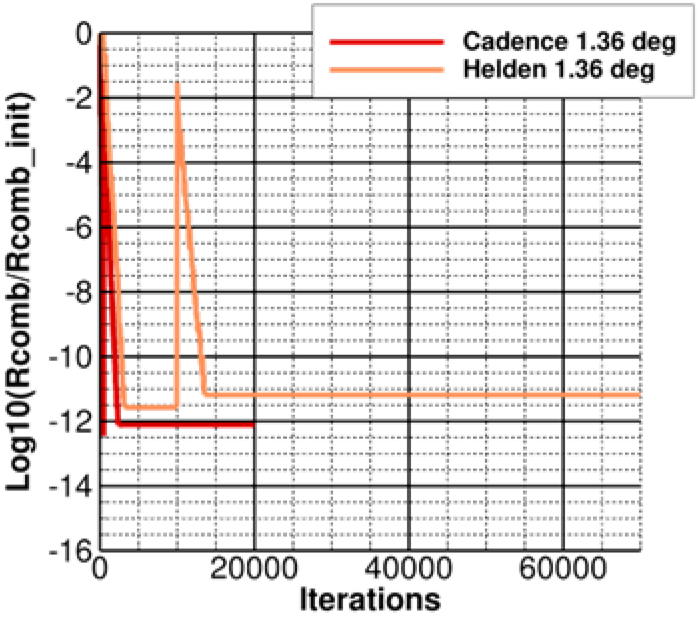
Grid Convergence (SA-neg)

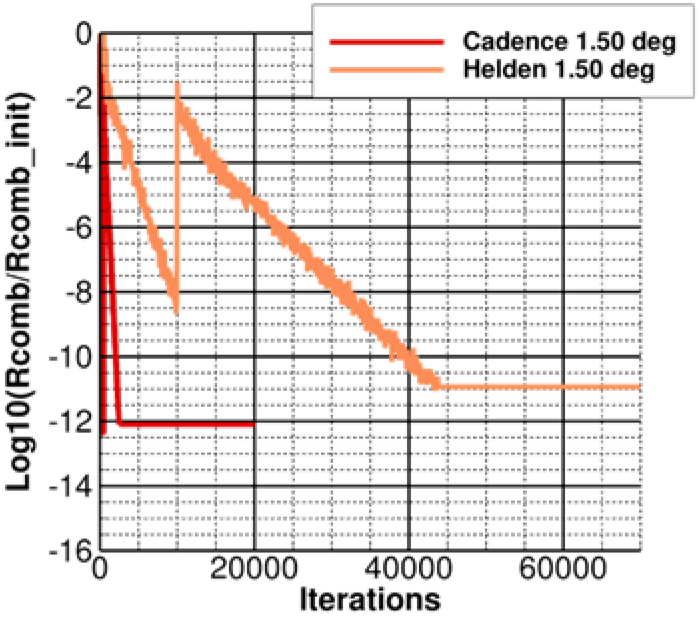
- Pressure comparison shown at alpha of 3.00 deg
- Helden Rev01 averaged over one C_L cycle
- Minimal difference in Cadence L1-L3
- Good agreement in shock location for Cadence L1-L3 and Helden Rev01 L1-L2
- Helden Rev01 L3 is different from the others
  - Weaker pressure recovery at shock
  - Upstream location of shock
- Helden Rev02 L3 shock location is furthest downstream



Simulation Convergence – Both Grid Partners

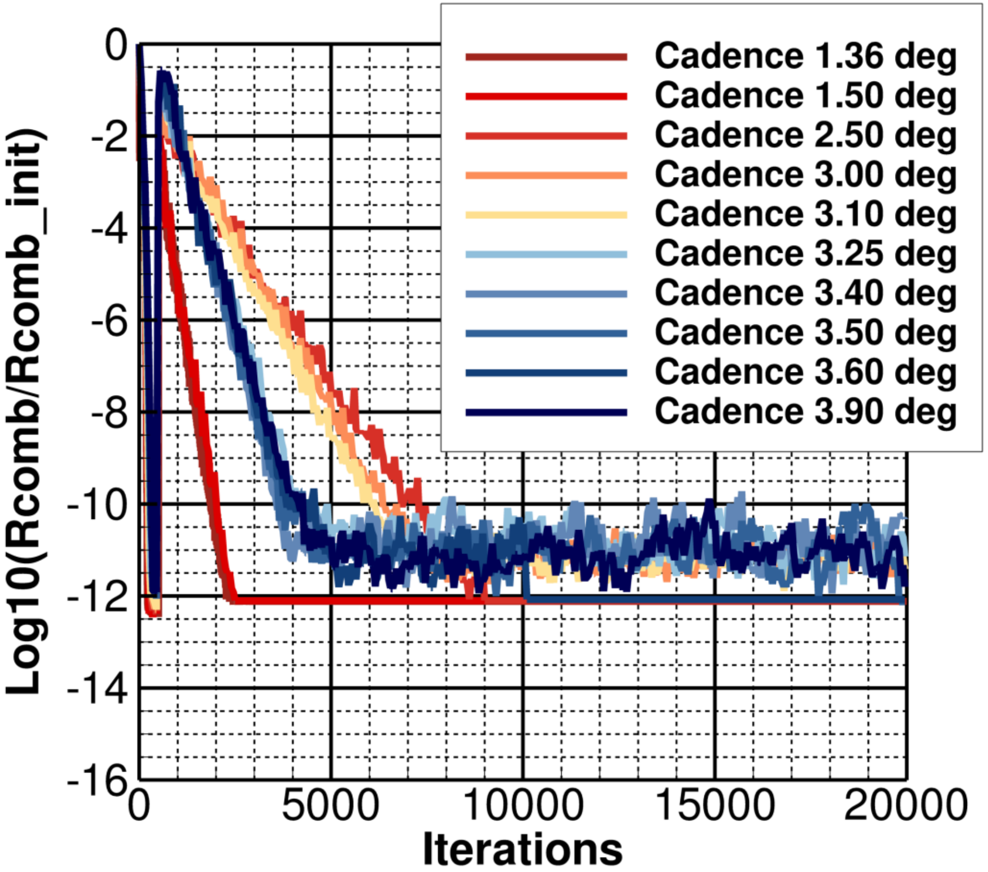
- **HANIM scheme yields converged solutions for low alphas**
- **Plotted L3 solutions are representative of L1-L3 results**
- **Rapid convergence for Cadence grids**
  - Approach machine zero within ~2000 iterations
  - Similar convergence at alphas of 1.36 and 1.50 deg
- **Helden Rev01**
  - Good convergence for low alpha
  - Unable to achieve adequate convergence at higher alphas





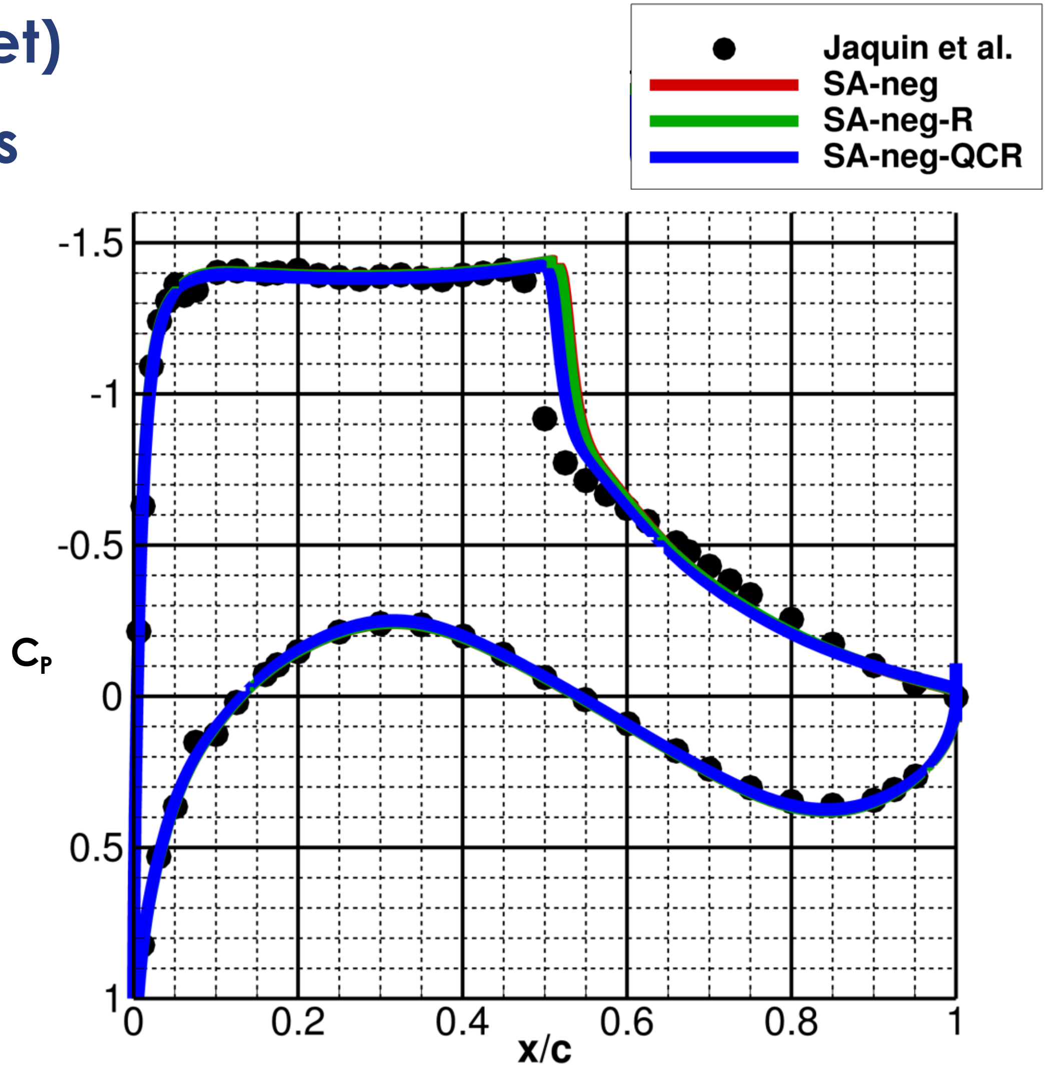
Simulation Convergence – Cadence Grids

- **Rapid convergence for Cadence grids (SA-neg shown)**
  - Approach machine zero within ~2000 iterations
  - HANIM scheme yields rapid, robust convergence at wide range of alpha
- **Differing rates of convergence**
  - Rapid: alpha of 1.36 to 1.50 deg (fully attached flow)
  - Slow: alpha of 2.50 to 3.10 deg (approaching and reaching buffet onset)
  - Moderate: alpha of 3.25 deg and above (significant flow separation)
- **Similar convergence rates for other two turbulence models**



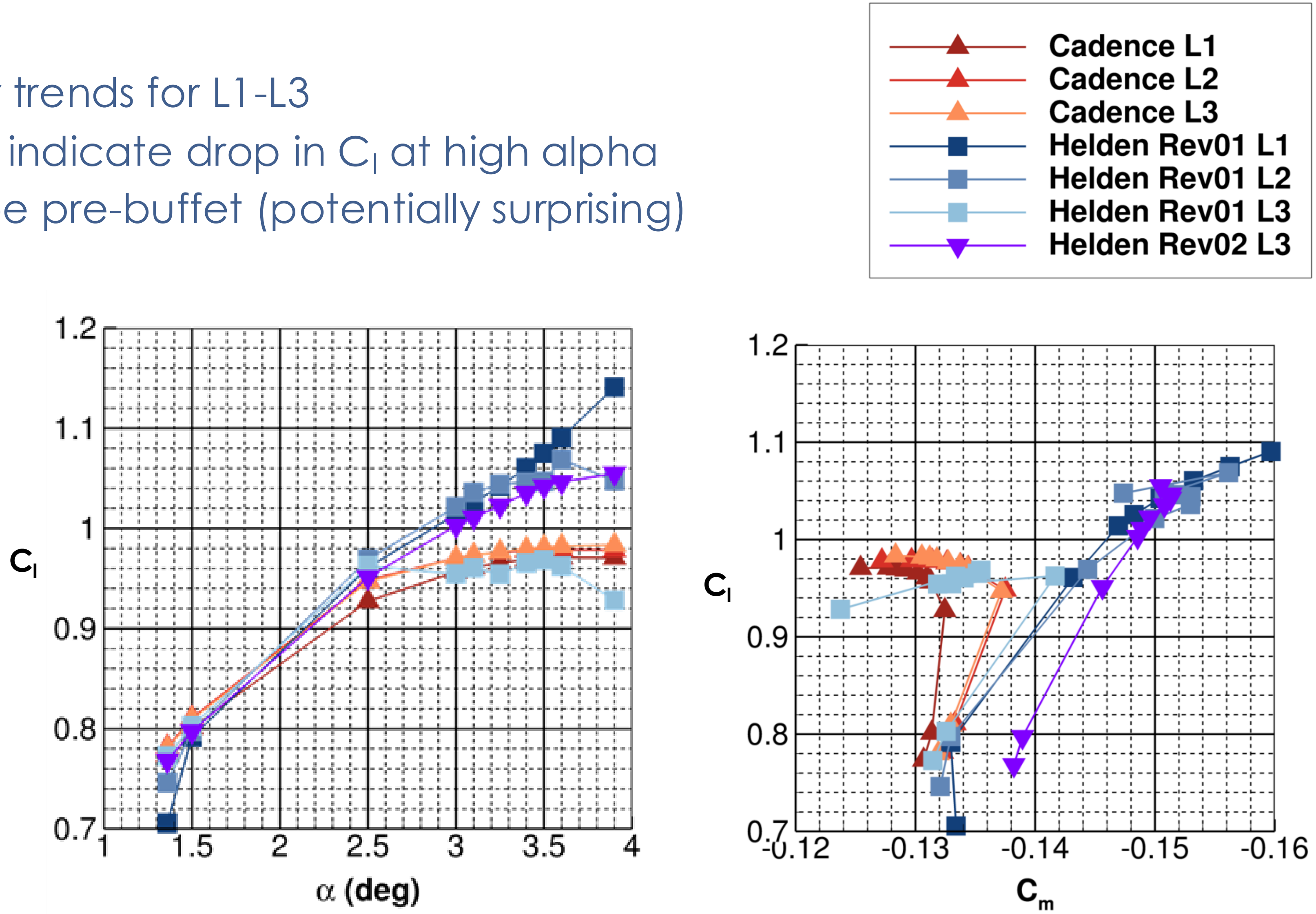
Turbulence Model Sensitivity

- **L3 Cadence grid at 3.00 deg alpha (pre-buffet)**
- **Minimal variations in three turbulence models**
  - Similar shock location and recovery
  - Inconsequential pressure recovery differences
- **Similar trends at higher alpha, including post-buffet angles**
- **No variations in shock-induced separation**



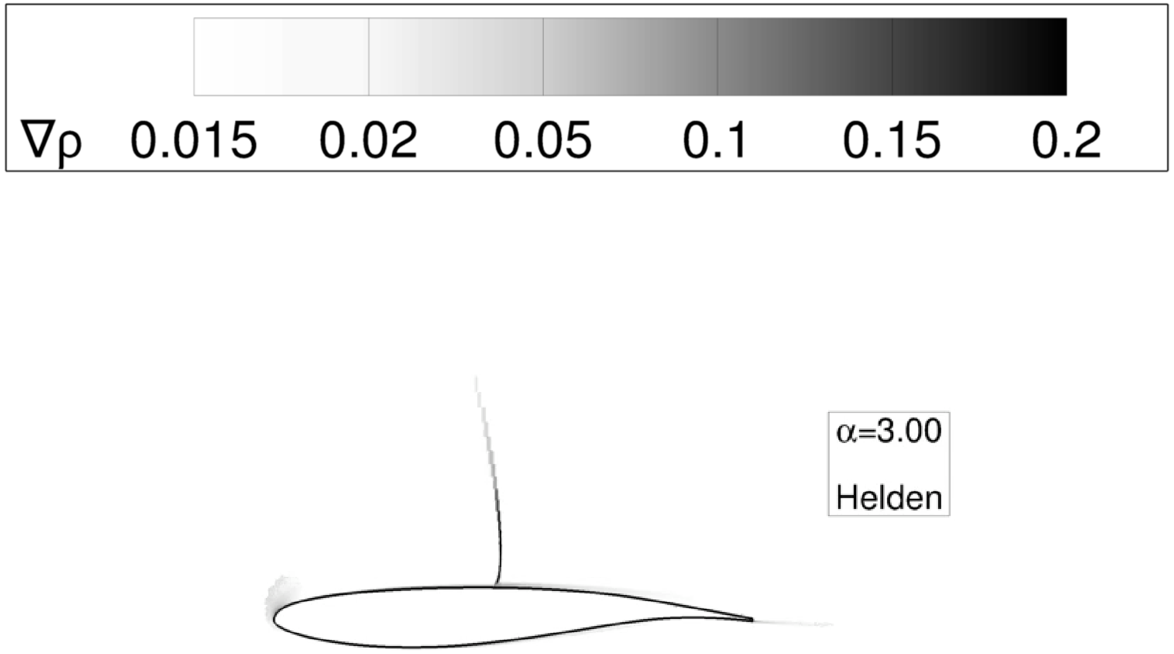
Force and Moment Comparison

- **Lift curve**
  - Cadence grids show similar trends for L1-L3
  - Helden grids do not always indicate drop in C_l at high alpha
  - Non-constant C_l-alpha slope pre-buffet (potentially surprising)
- **Pitching moment**
  - Helden Rev01 L1 and L2 show increased C_m at high alpha (consistent with high C_l)
  - Cadence grids show the classic C_m breaks
- **Increased Helden grid density studies may be insightful**



Shock Location and Structure

- **Alpha 3.00 deg**
  - Shock oscillations observed for L1-L3 Helden grids (seen above 2.50 deg)
  - Stationary shock for all Cadence grids
  - Moderate shock-induced separation



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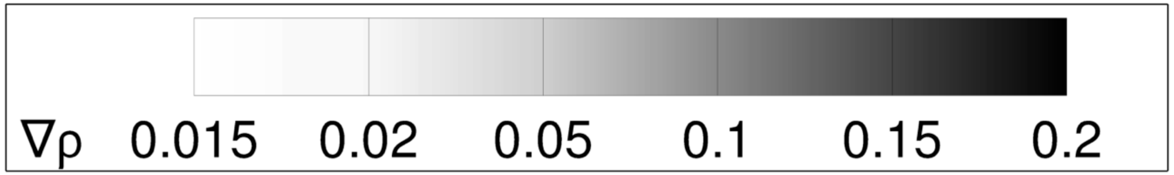
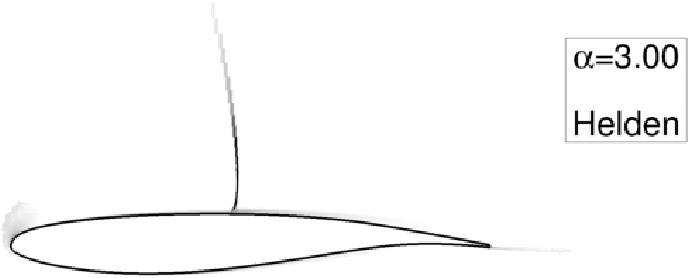
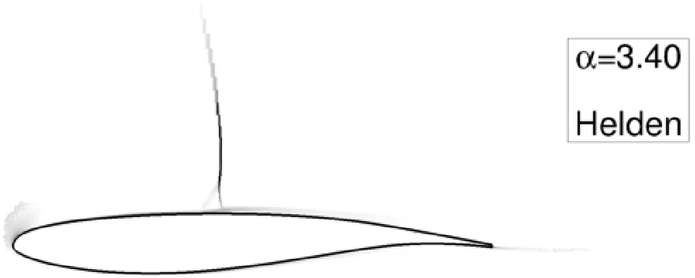
- **Alpha 3.40 deg**
  - Significant shock-induced separation
  - Similar, yet larger, shock movement
  - Stationary shock for all Cadence grids



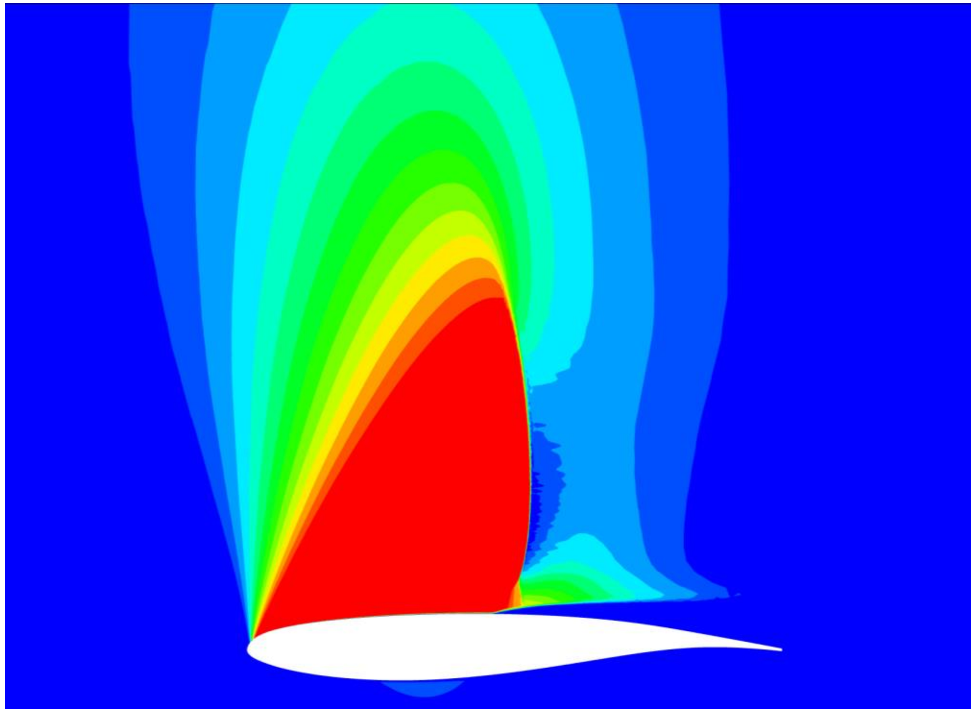




Summary and Conclusions

- **USM3D-ME simulations performed on ONERA OAT15A airfoil**
- **Minimal differences seen in SA-neg, SA-neg-R, and SA-neg-QCR**
- **Differing grid approaches yielded varying results**
  - Cadence: characteristic F&M behavior; stationary shock
  - Helden: unconverged solution and shock movement may indicate unsteadiness (time-accurate solutions are needed)
- **Grid resolution and growth schedule can dramatically affect results, especially between grid families**

Questions?



Tausif Jamal
tausif.jamal@nasa.gov

Brent Pomeroy
brent.w.pomeroy@nasa.gov