Buffet Working Group
Summary Presentation

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Outline

- Background and Participants
- Test Case 1
- Test Case 2
- Test Case 3
- Desired Future Work

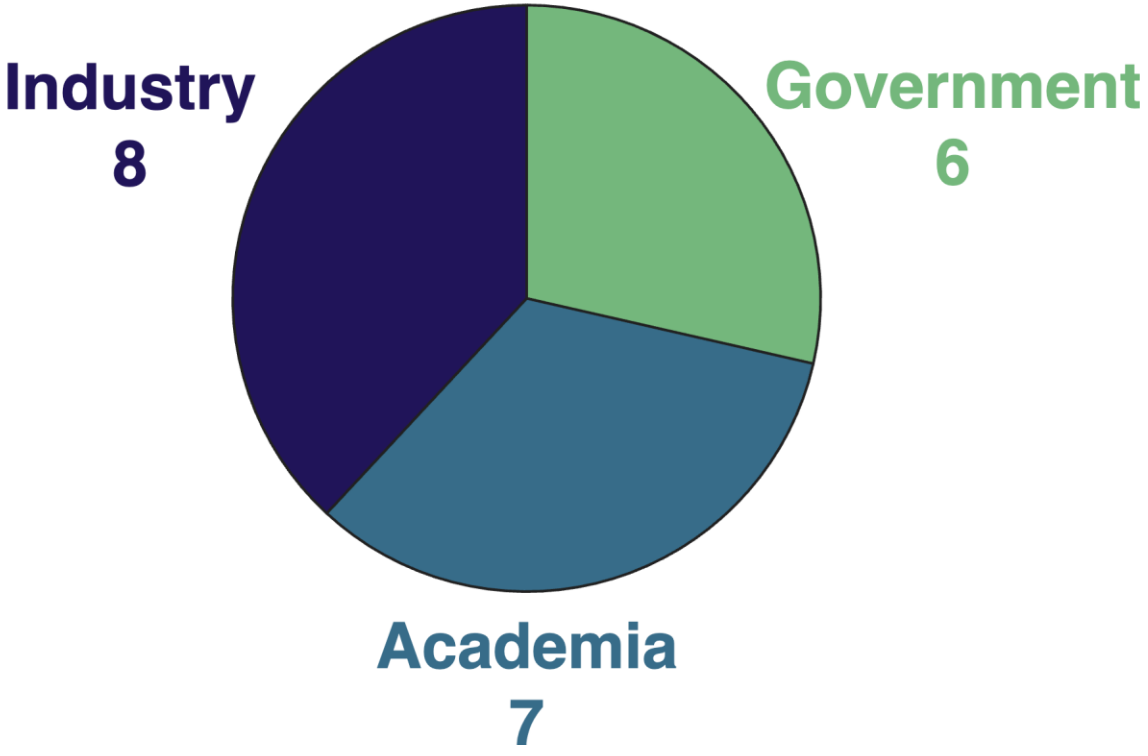
Background and Participants

History and Background

- **Organizing Committee**
  - Hadar Ben-Gida, Technion-Israel Institute of Technology
  - Brent Pomeroy, NASA Langley Research Center (Emeritus)
  - Daniela Raveh, Technion-Israel Institute of Technology
  - Andrea Sansica, JAXA
  - Bret Stanford, NASA Langley Research Center
- **Test Case 3 was one of the motivations for joint workshop**
  - Test Cases 2 and 3 matured quickly
  - Goals largely crafted before DPW-8/AePW-4 launch (SciTech 2024)

Participant Summary

- **21 teams from varied agency types**
  - Industry: 8
  - Government: 6
  - Academia: 7
- **Large group**
  - 104 on email distribution list
  - 15-30 participants per call
- **Monthly tagups**
- **Strong presence at mini workshops**



DPW Turbulence Model Learnings: An Attempt

- **A retrospective of DPW learnings is appropriate**
- **The following summary indicates general trends and opinions for applied transonic wing/airfoil aerodynamics**
  - These are general, debatable, statements from DPW learnings
  - The chart is not intended to be comprehensive
- **Corrections and tuning can be applied to each of these turbulence models**
- **Characteristics are subject to spirited discussion**

DPW Turbulence Model Learnings: An Attempt

Model	Type	Characteristics
SA		
k-ω		
k-ε		
SST		
RSM		

DPW Turbulence Model Learnings: An Attempt

Model	Type	Characteristics
SA	• Solves for modified kinematic eddy viscosity	• Established dependability with well-behaved flows including adverse pressure gradients and mild/moderate boundary layer separation • Separation may be delayed
k-ω	• Solves for kinetic energy and specific dissipation rate, indirectly capturing eddy viscosity	• Sensitive to freestream conditions and outer flow contamination
k-ε	• Solves for kinetic energy and dissipation rate, indirectly capturing eddy viscosity	• Can delay or miss separation, especially due to strong adverse pressure gradients
SST	• Includes considerations of k-ω and k-ε • Modifies eddy viscosity to transport turbulent shear stress	• Established dependability with well-behaved flows including adverse pressure gradients and mild/moderate boundary layer separation • May yield early separation
RSM	• Solves 7 equations, including full turbulent stress tensor • Accounts for anisotropic turbulence	• High-curvature flowfields can be captured well • Slower convergence and greater numerical stiffness

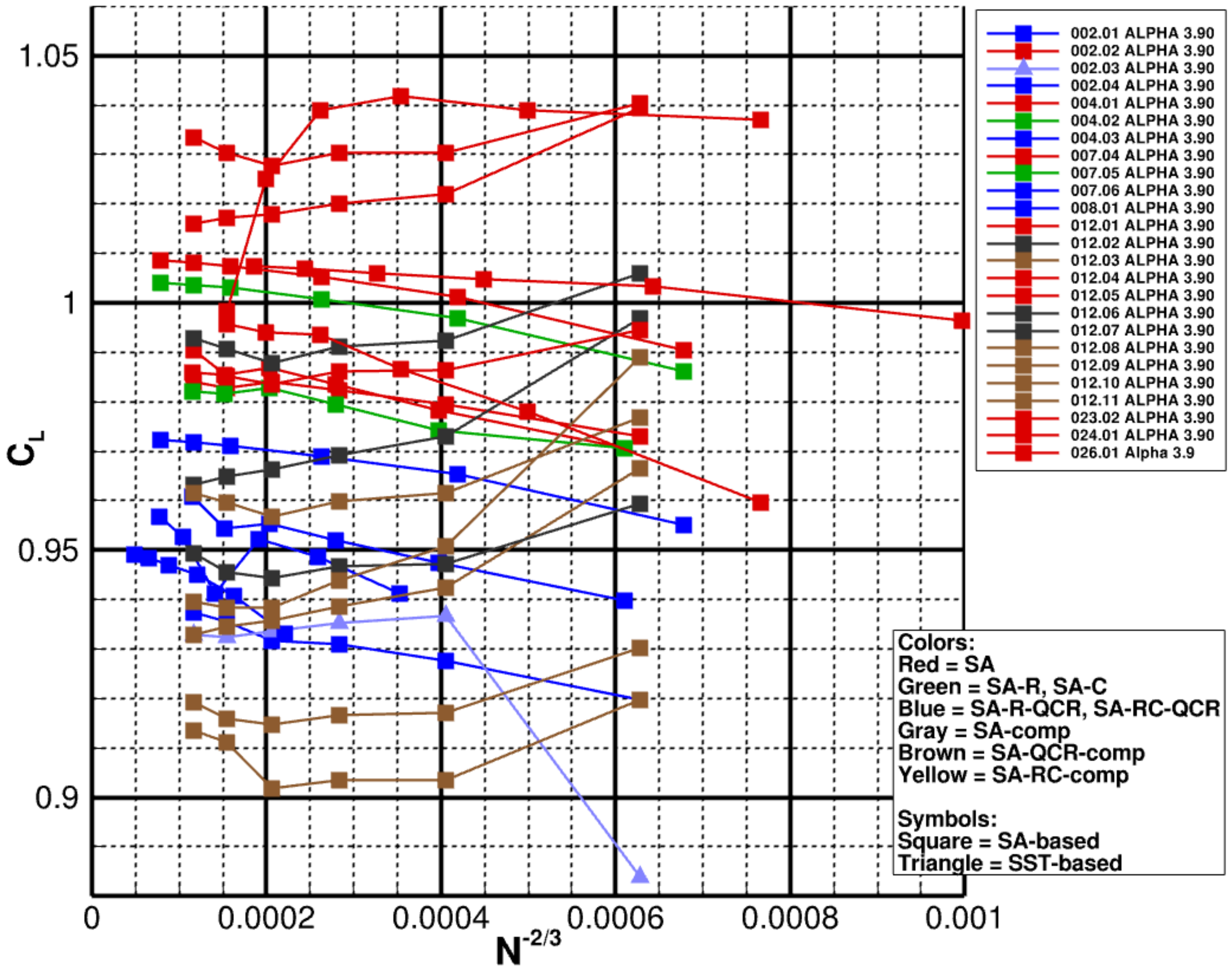
Test Case 1

Overview

- **Many custom grids were generated**
  - Few passed export control and thus grid comparisons were not possible
  - Wide variety of gridding practices and approaches
- **Significant student participation**
- **Experimental reference:**
  Jaquin, et al. "Experimental Study of Shock Oscillation over a Transonic Supercritical Profiles." AIAA Journal, Vol. 47, No. 9, 2009. Pages 1985-1994.

Test Case 1a: Grid Level Effect at 3.90 deg

- **Results shown at 3.9 deg, but representative of high-alpha cases**
- **SA, SA-R, SA-C ("SA," red and green)**
  - Elevated C_L
  - Elevated C_D
  - Decreased C_M
- **SA-QCR, SA-comp, SA-QCR-comp, SA-RC-comp ("QCR/comp," blue, black, brown)**
  - Decreased C_L
  - Decreased C_D
  - Elevated C_M
- **Few contributions with SST; no RSM (used in Test Case 2)**

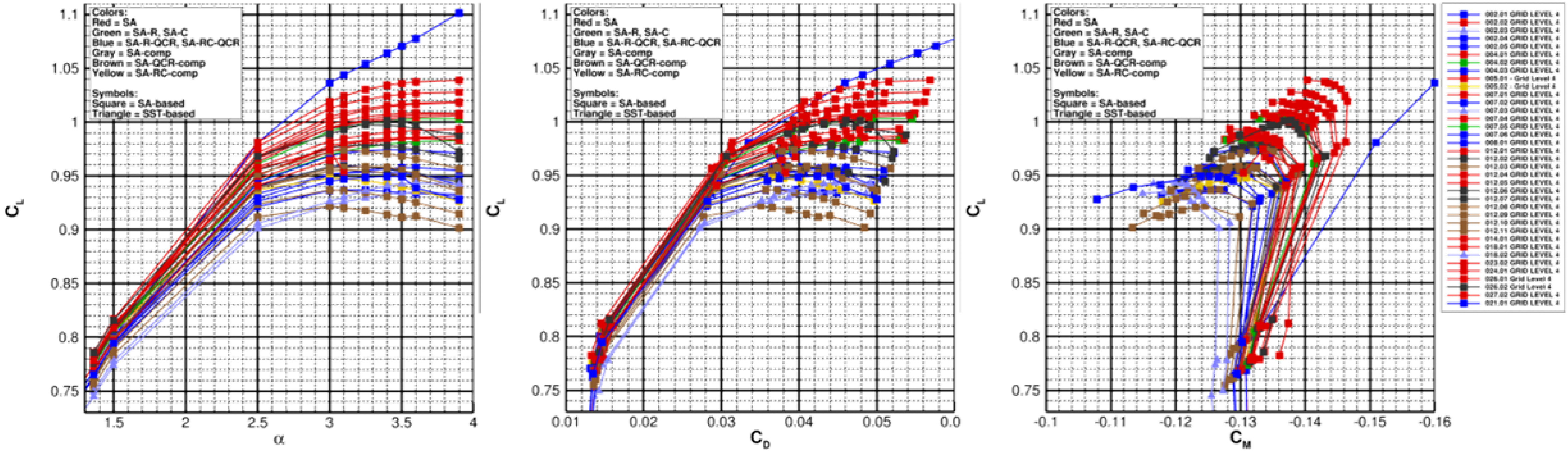


Test Case 1a: Integrated F&M

- **Increased scatter relative to DPW-VII**
- **SA group: red and green**
  - Elevated C_L, elevated C_D, decreased C_M
- **QCR-comp group: blue, gray, and brown**
  - Decreased C_L, decreased C_D, increased C_M

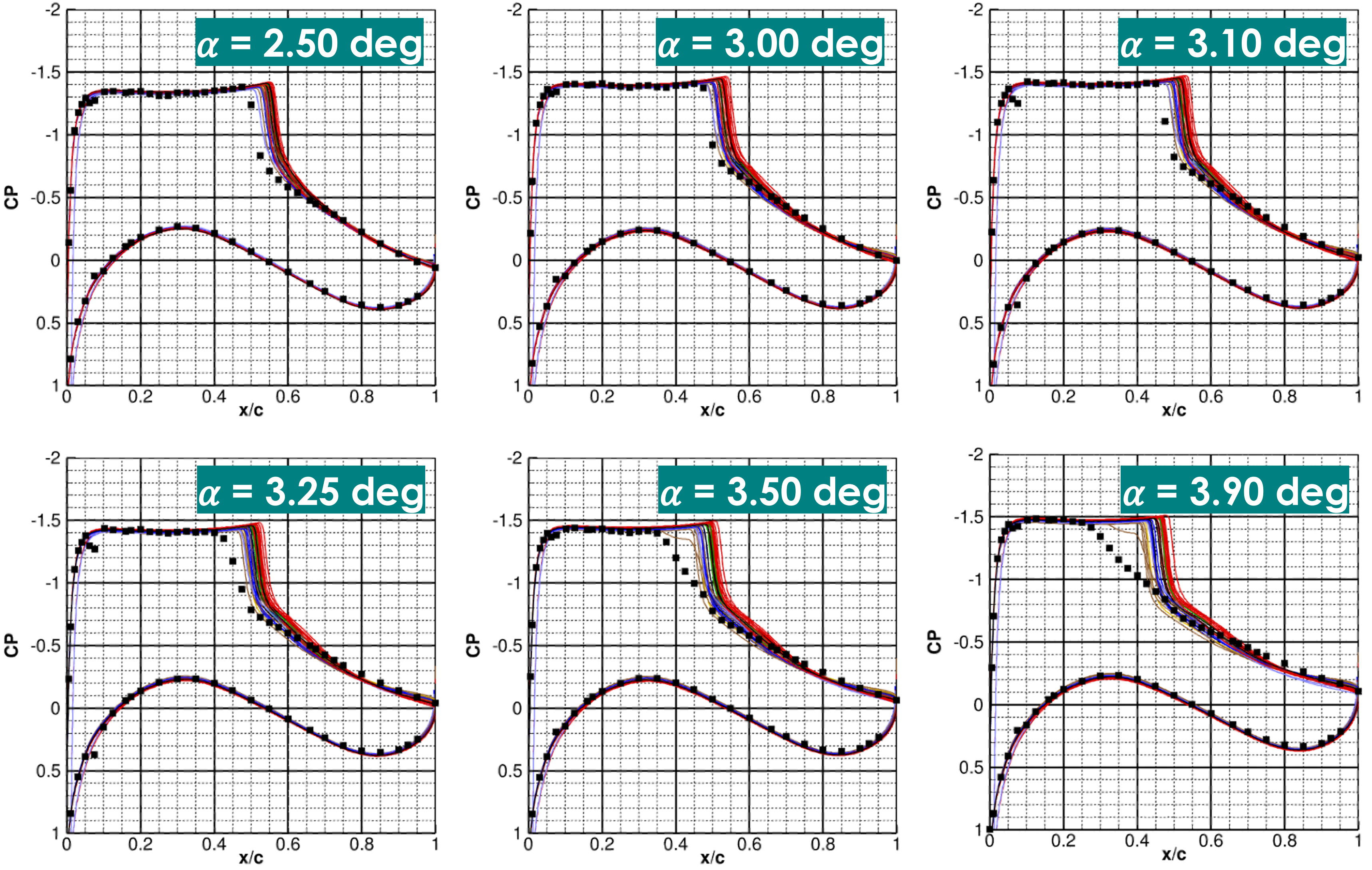
SA
SA-R, SA-C
SA-R-QCR, SA-RC-QCR
SA-comp
SA-QCR-comp
SA-RC-comp

Squares: SA
Triangles: SST



Test Case 1a: Sectional Cuts

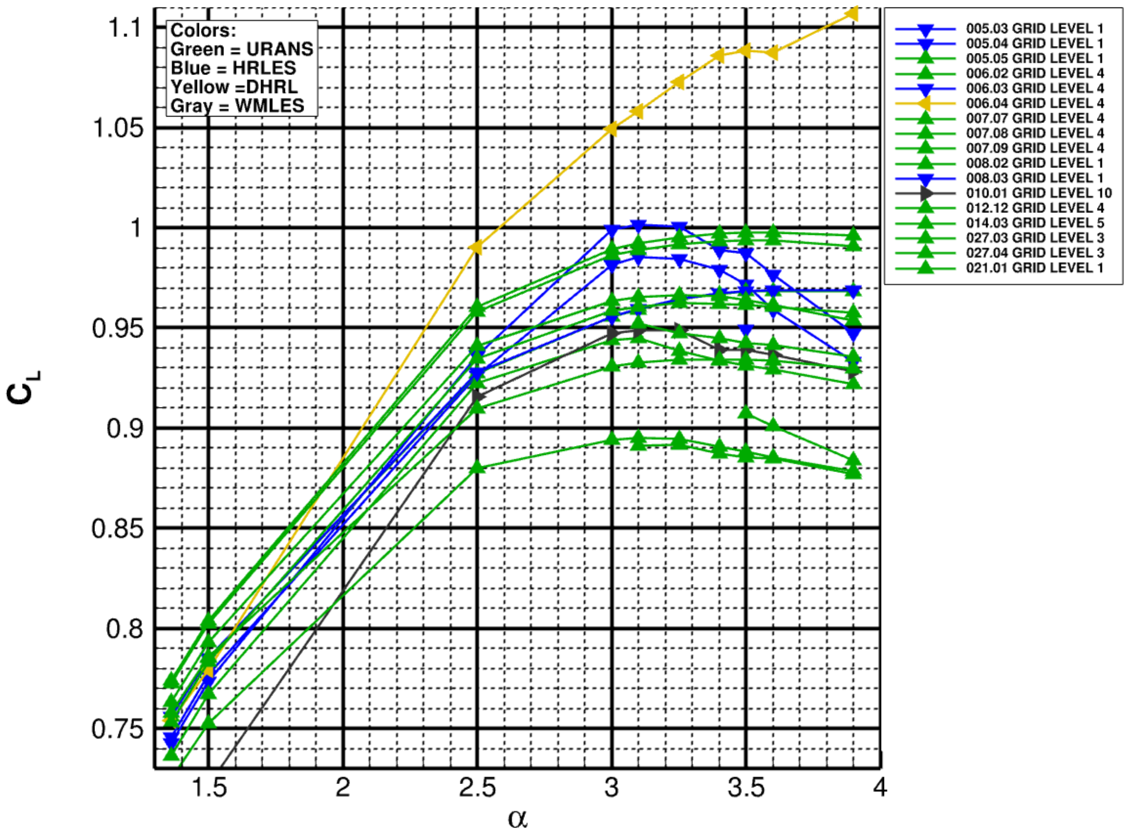
- **Most solutions predict the shock too far downstream**
  - "-comp" correction gives improvements
- **Steady calculations**
  - Shock does not move
  - Simulations do not capture the smooth (time-averaged) gradient across the shock for post-onset cases



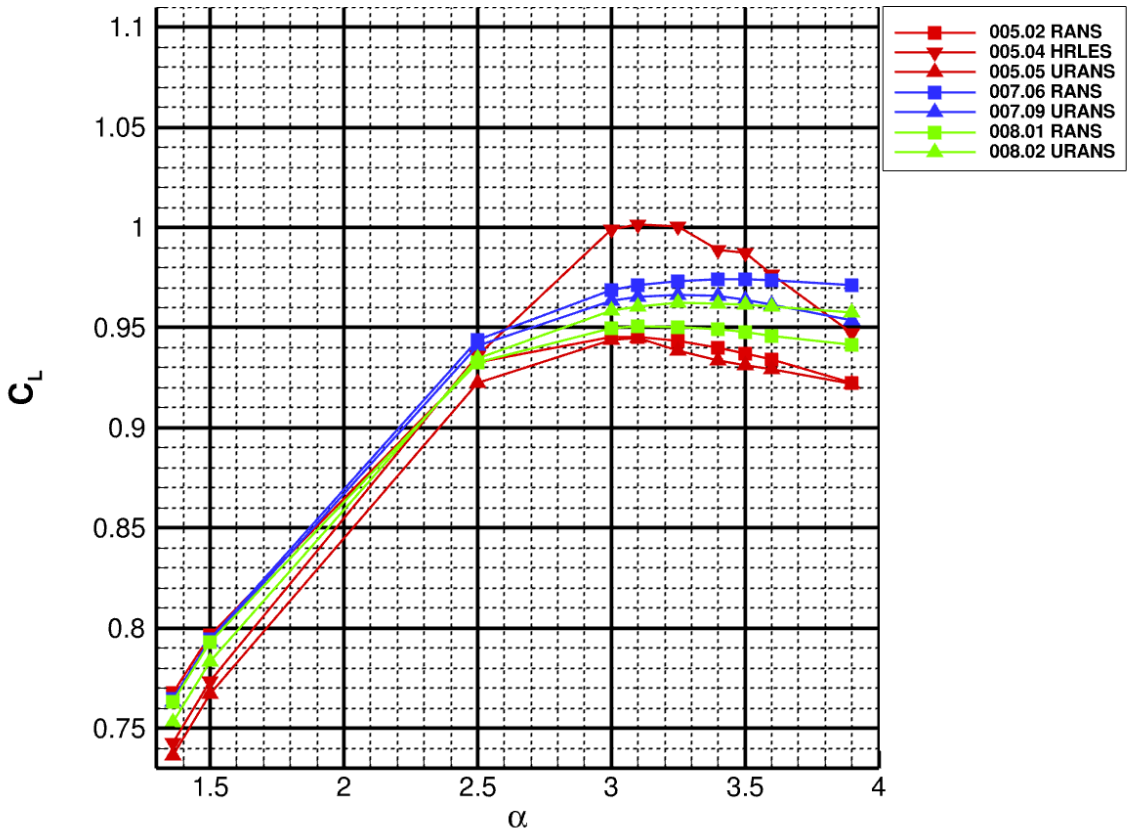
Test Case 1b: Integrated F&M

- For the same setup, steady & unsteady values do not match pre-buffet
- Early RANS separation anticipated but not necessarily observed

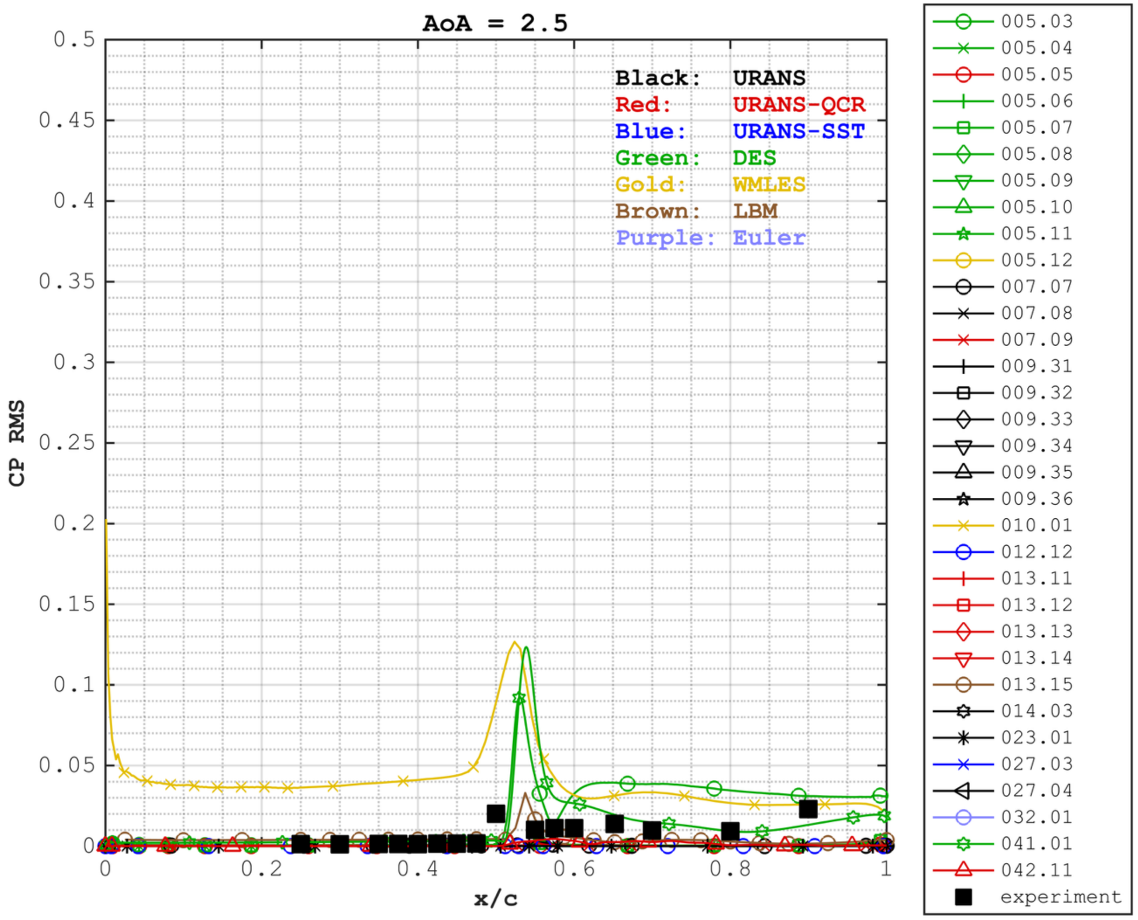
Colored by method

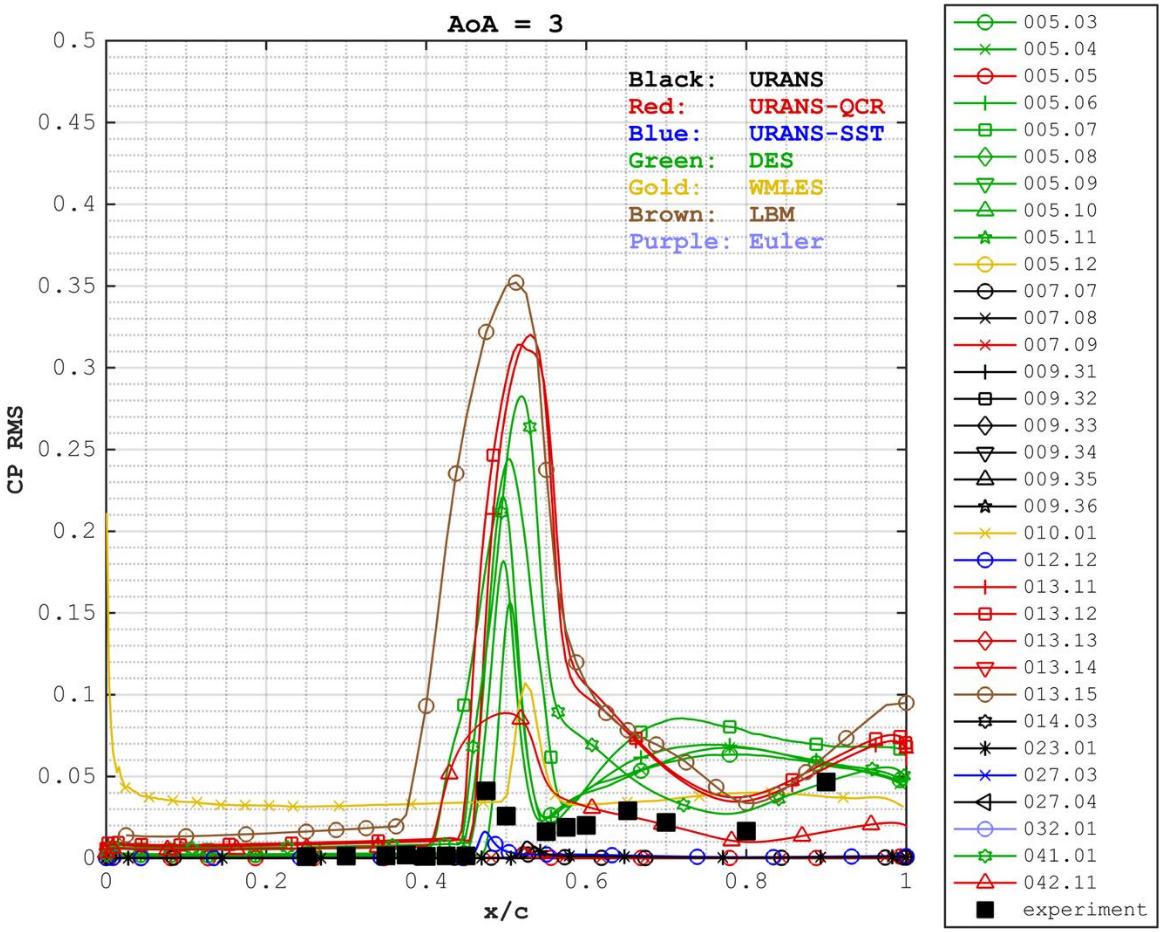


Colored by ID (selected) contributions

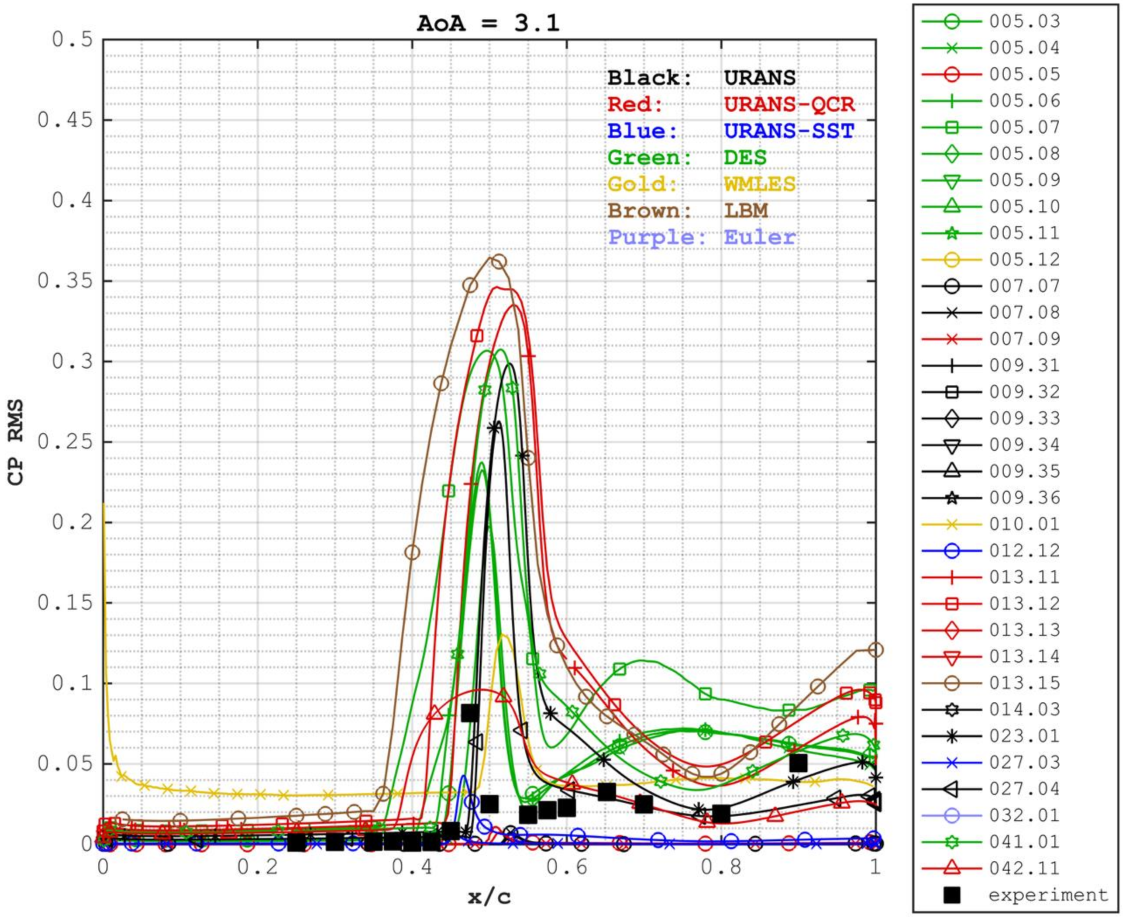


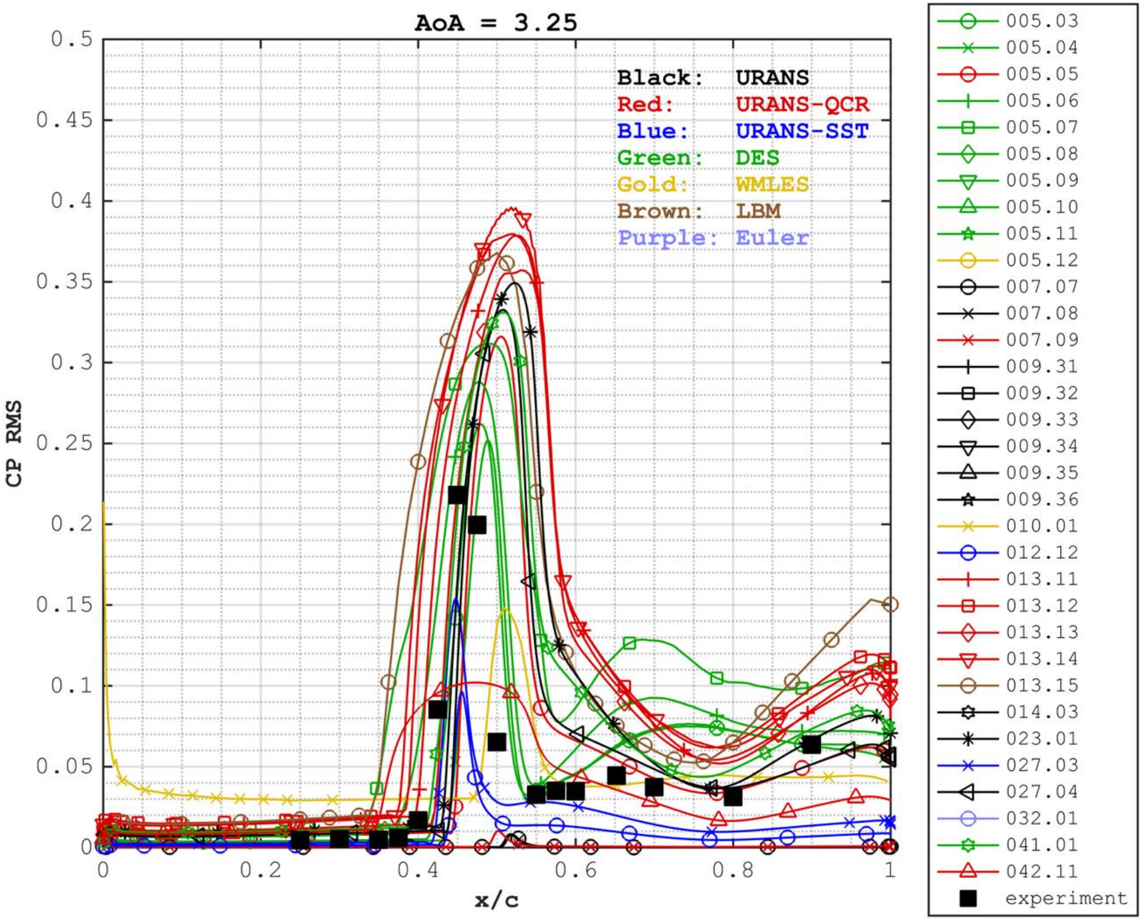
Unsteady Sectional Cuts: Pre-Buffet Onset





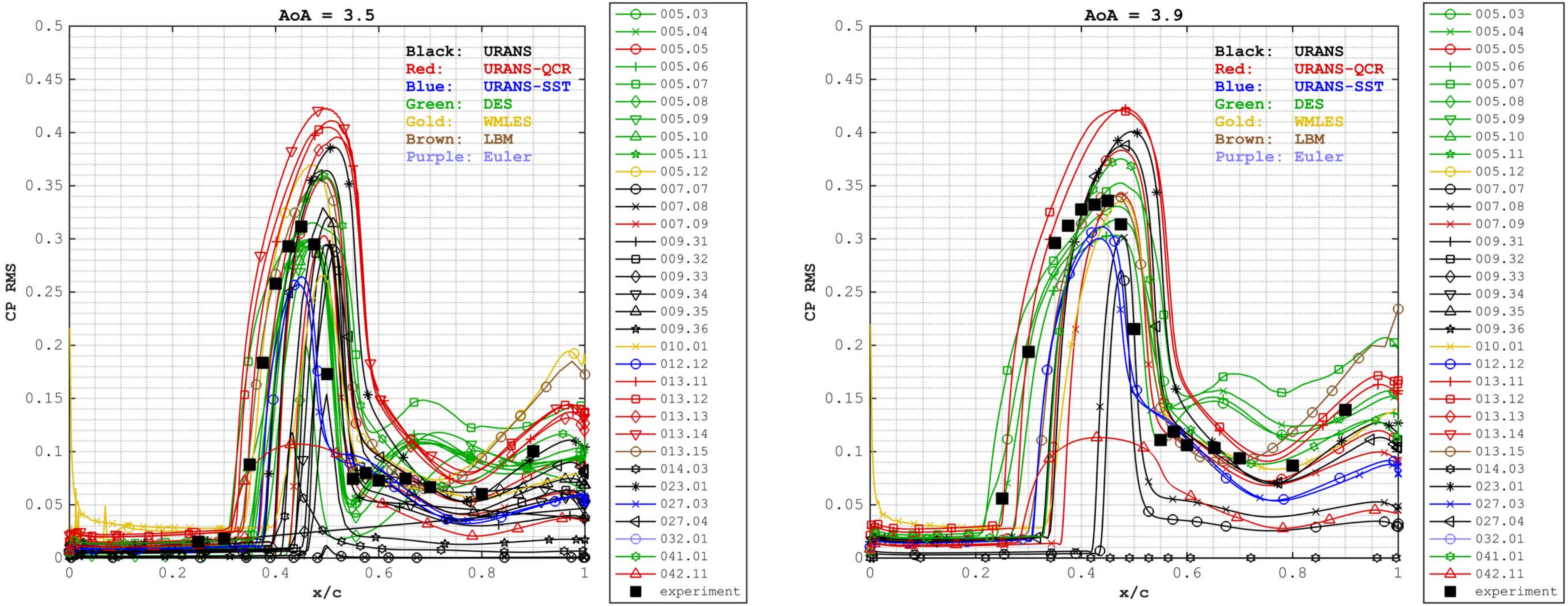
Unsteady Sectional Cuts: Post-Buffet Onset



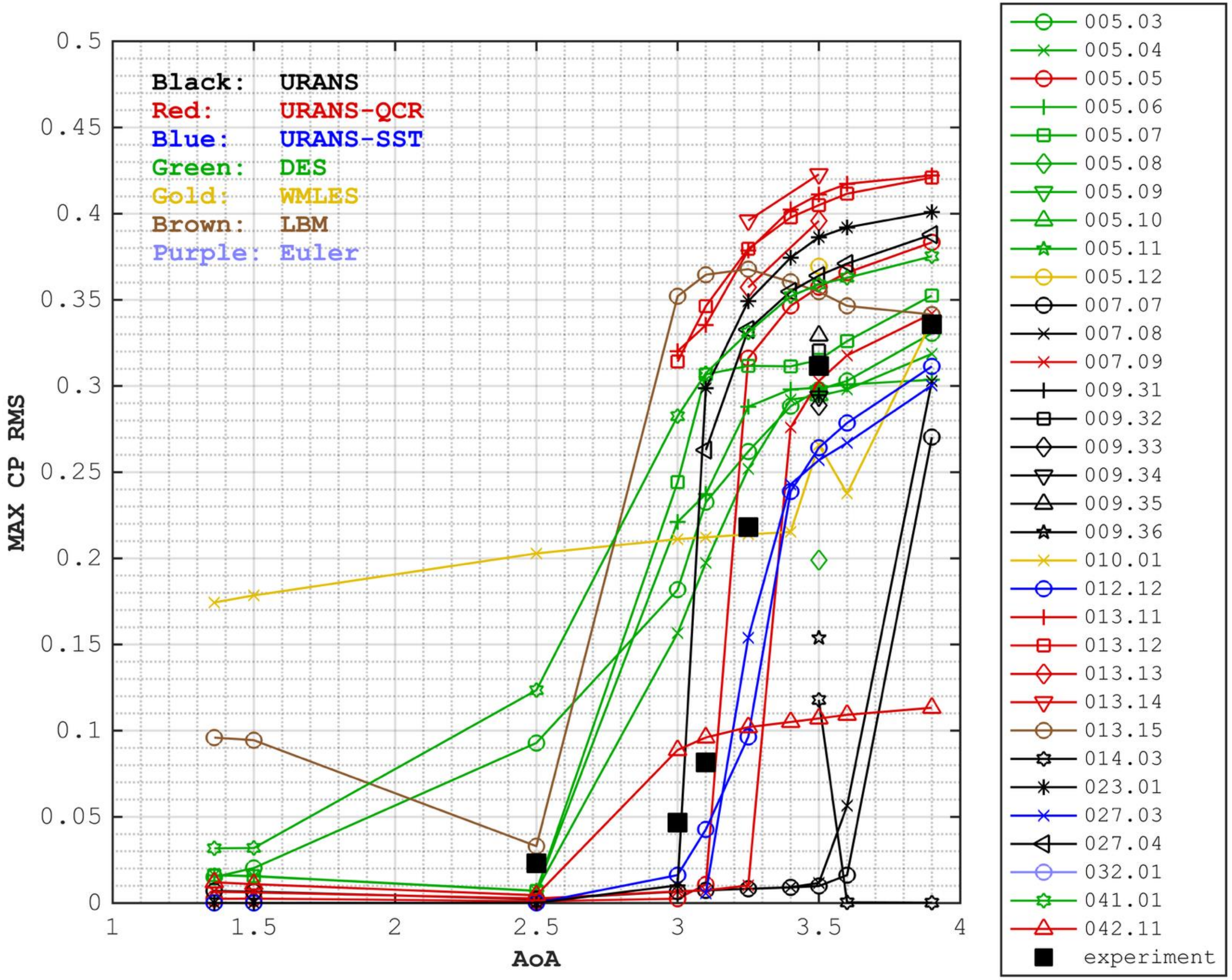


Note: Buffet onset measured at 3.1 deg in Jaquin, et al.

Unsteady Sectional Cuts: Post-Buffet Onset



Unsteady Sectional Cuts: AoA Sweep



- **The SST-based solvers are closest to the experimental data, in terms of both buffet onset and post-buffet RMS levels**
  - Only two SST submissions, however
- **Most other results (QCR-based, DES) predict early buffet onset by 0.5-1 deg and overpredict RMS levels**
- **No RSM**

Test Case 2

Orientation

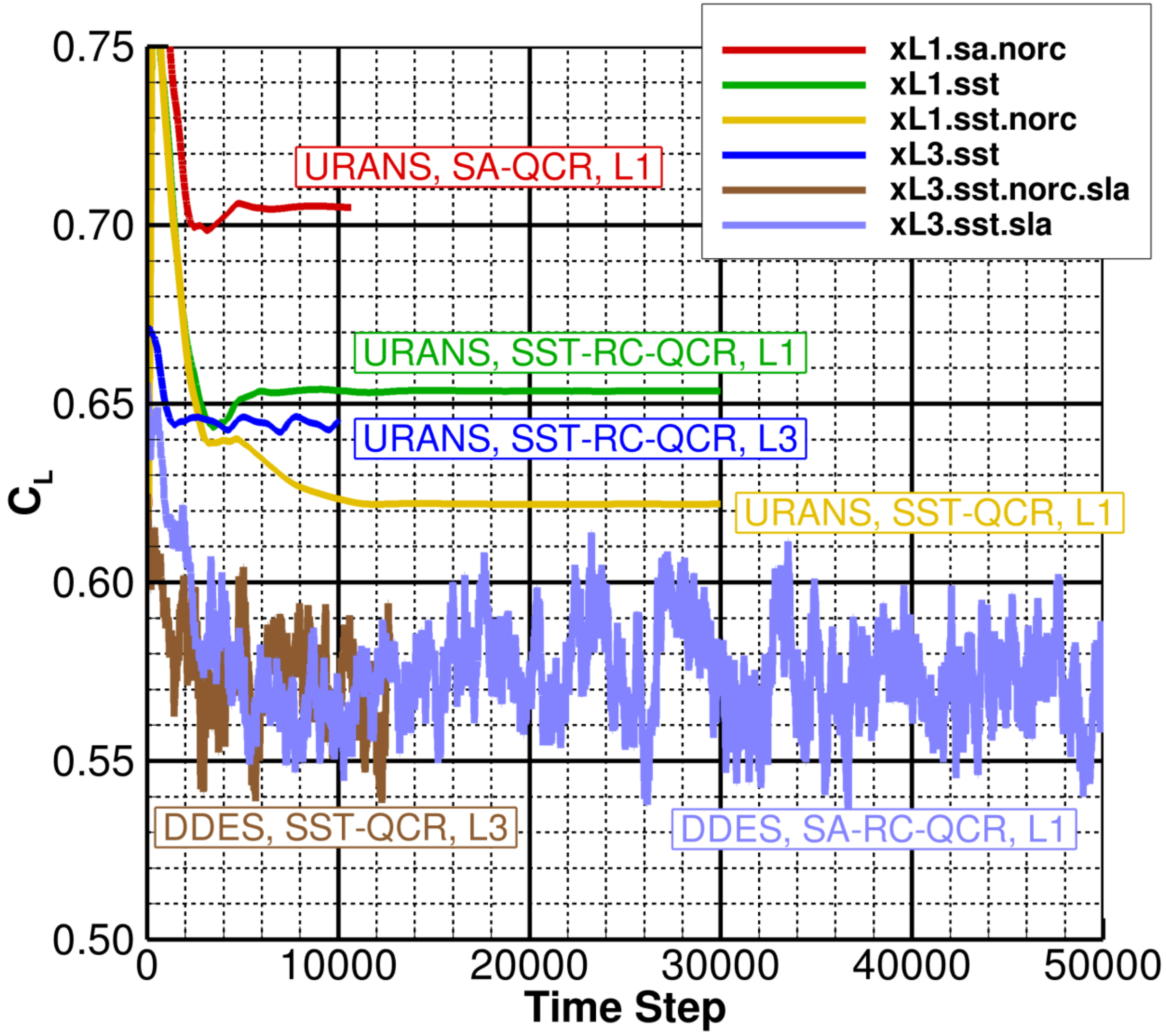
- **Parametric sweeps presented showing F&M and sectional cuts**
  - Temporal scheme
  - Turbulence model
  - Grid type
  - Grid level
- **Surface contour plots are shown at the end of the section**
- **No zeroing of data to a consistent point (e.g., 2.29 deg)**
  - Need universal simulations at 2.29 deg
  - Sometimes called the "Tinoco correction" or the "Tinoco slide"
- **Experimental reference:**
  Shunsuke Koike, Makoto Ueno, Kazuyuki Nakakita and Atsushi Hashimoto, "Unsteady Pressure Measurement of Transonic Buffet on NASA Common Research Model", AIAA 2016-4044, June 2016.

Submissions

Temporal Formulation	Turbulence Model	Grid	Submission ID
URANS	SA-RC-QCR	Helden	007.10
	SA-RC-QCR	Helden	007.11
	SA-RC-QCR	Cadence	007.12
	SA-RC-QCR	Cadence	007.13
	SST	Cadence	021.02
	RSM	Cadence	027.05
HRLES	SA-neg	Ames Multiblock	005.01
	SST	Cadence	021.03
	SA-neg	Cadence	041.02
Lattice Boltzman	k-ε	Custom Cartesian	013.01
	k-ε	Custom Cartesian	013.02
WMLES	Dynamic Smagorinsky	Custom Hex	002.01
	Dynamic Smagorinsky	Custom Voroni	010.02
Adaptive Euler	N/A	Custom Mixed Element	032.01

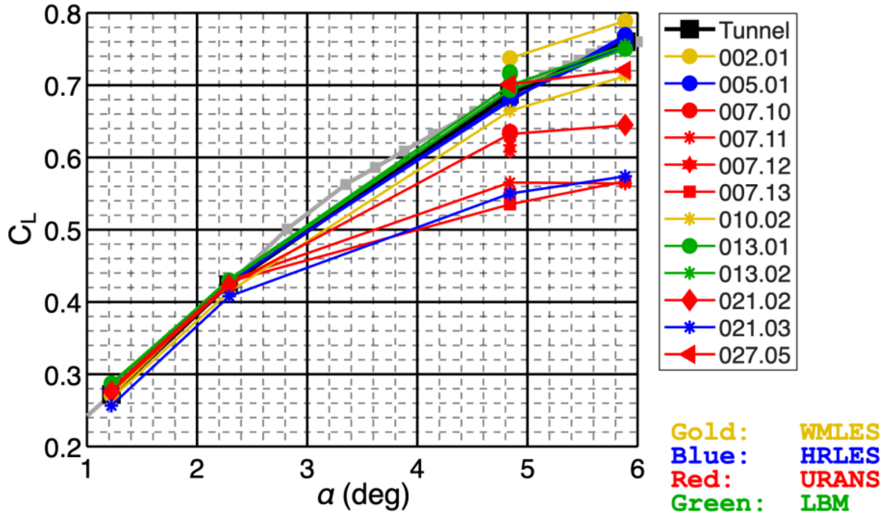
Buffet: A Difficult Aerodynamic Problem

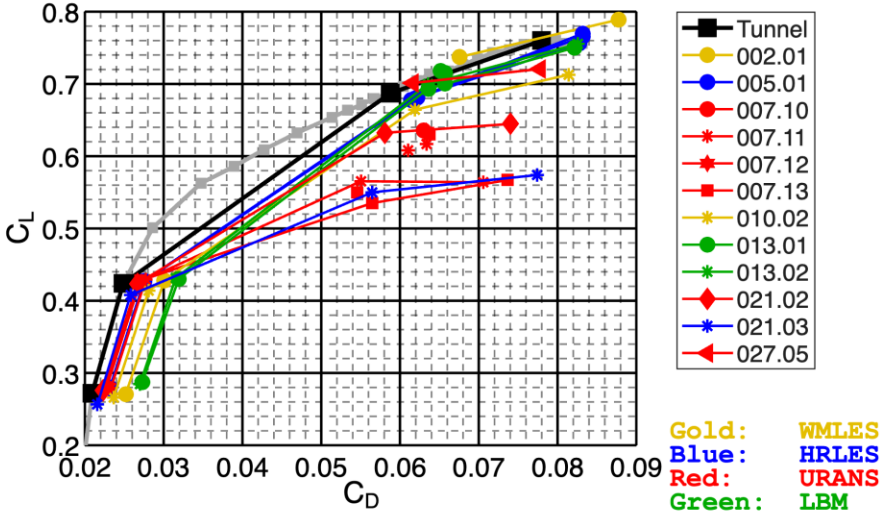
- Time histories shown from one participant's initial investigation at 5.89 deg
- URANS may not yield unsteady flow for L1-L3
- Some participants had isolated success at L4+
- Determining truth can be difficult
- Additional work needed to understand time integration parameters

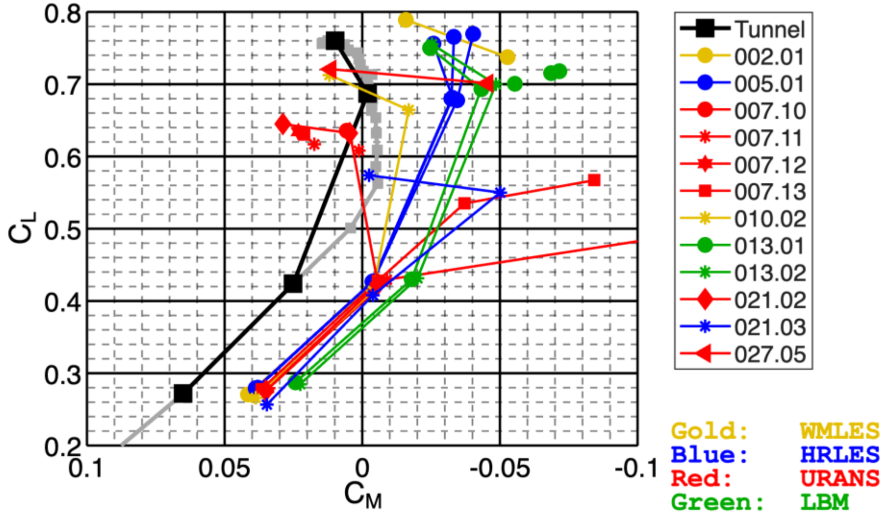


Temporal Formulation Effect – All F&M

- Encouraging clustering in lift and drag depending upon scheme and turbulence model
- Elevated pitching moment scatter
- Multiple lines of same color/symbol are submissions at multiple grid levels

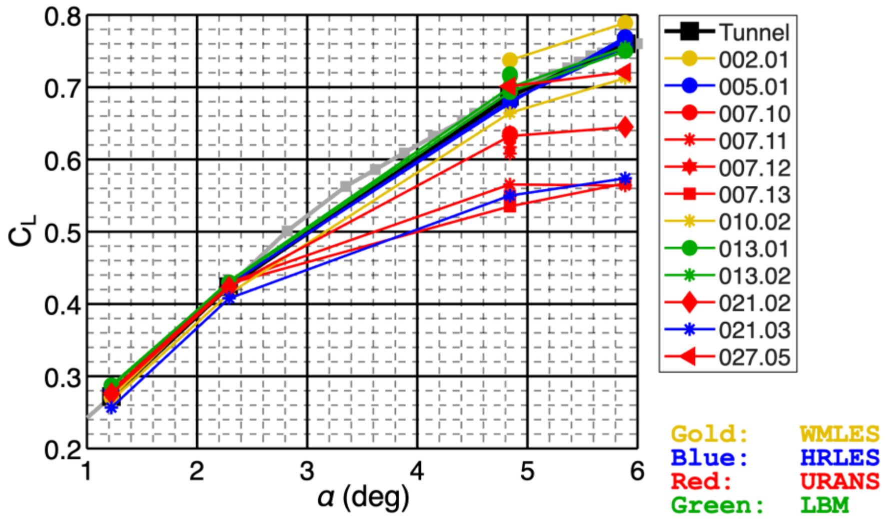


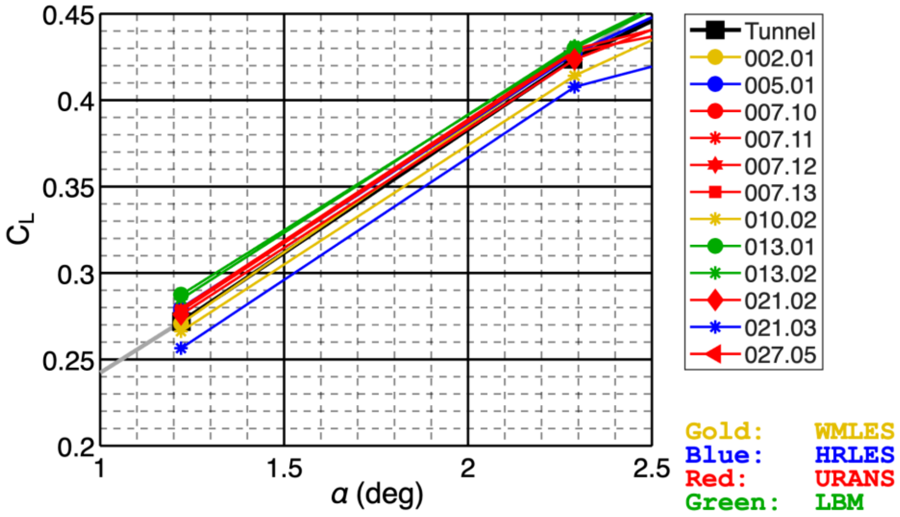


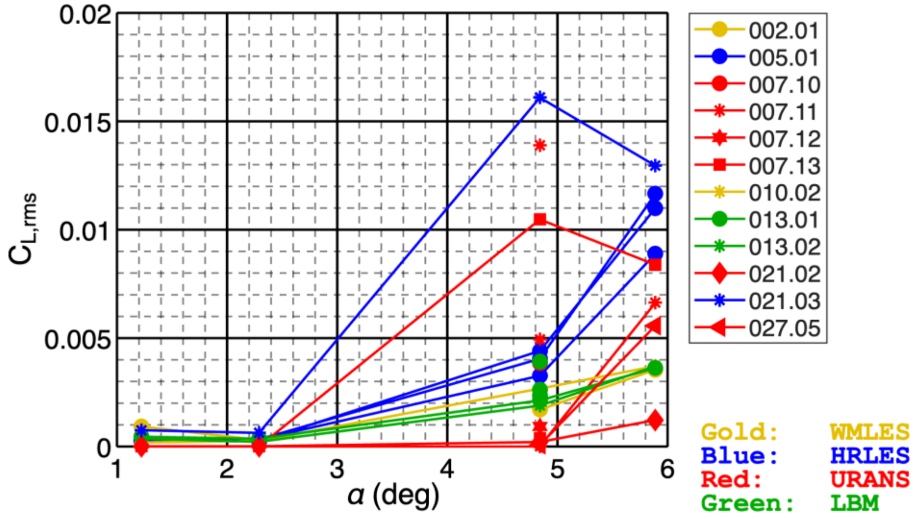


Temporal Formulation Effect – Lift

- **Low-alpha**
  - C_L spread ±0.02
  - Minimal $C_{L,rms}$ (no spurious unsteadiness), but some spread observed; URANS shows least
- **High-alpha**
  - URANS gives rapid drop in lift
  - Other schemes have some success
  - HRLES may yield fastest increase in $C_{L,rms}$

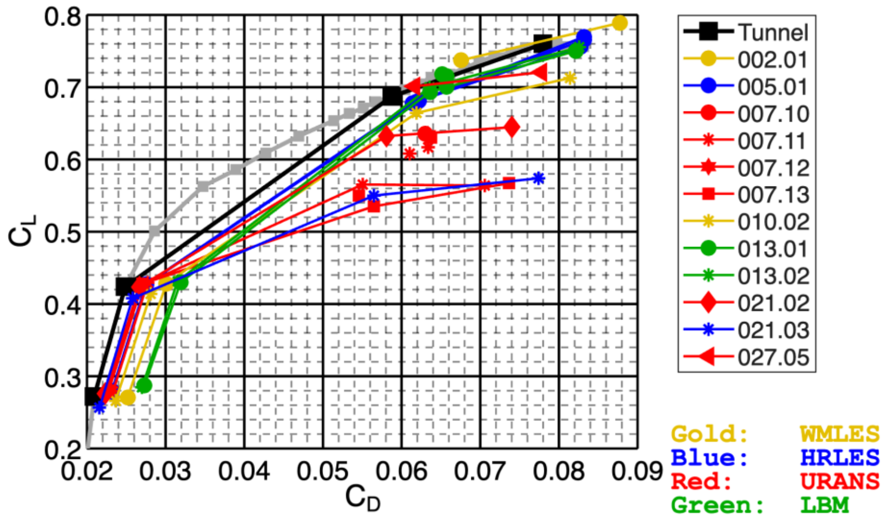


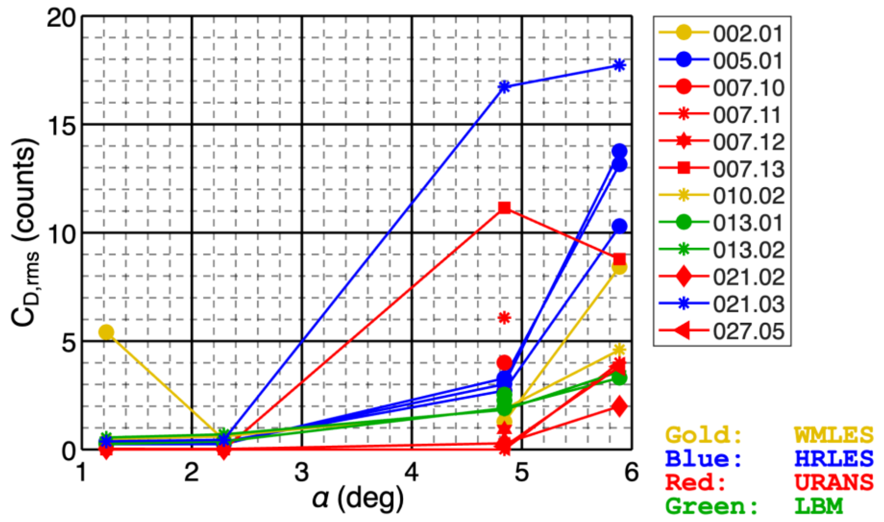




Temporal Formulation Effect – Drag

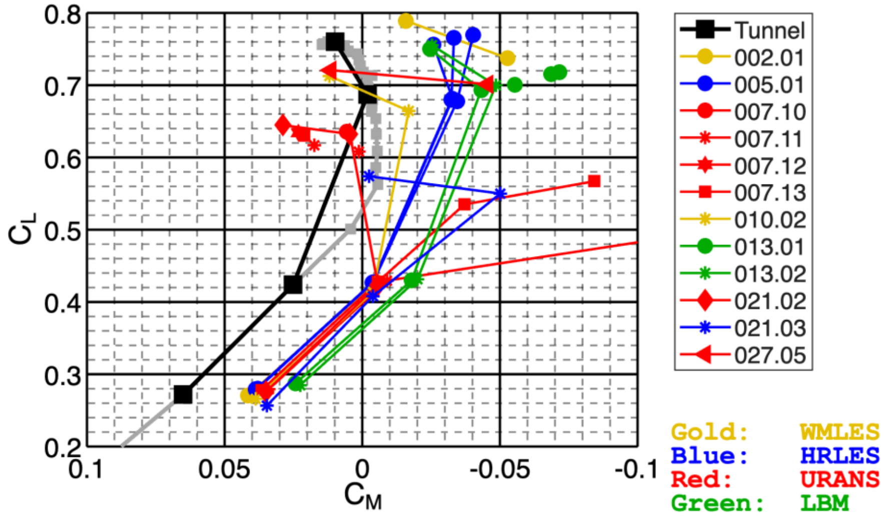
- **Low-alpha**
  - Surprising scatter across all schemes (56.9 counts or 27.2%) at 2.29 deg
  - Similar scatter for 1.24 and 2.29 deg
  - WMLES/SD and LBM/k-ε yield highest drag
  - Opportunity for an Unsteady Source of Scatter Working Group?
  - WMLES may give spurious unsteadiness
- **High-alpha**
  - URANS drop in C_L does not necessarily correspond to elevated C_D
  - LBM yields least unsteadiness with HRLES indicating the most

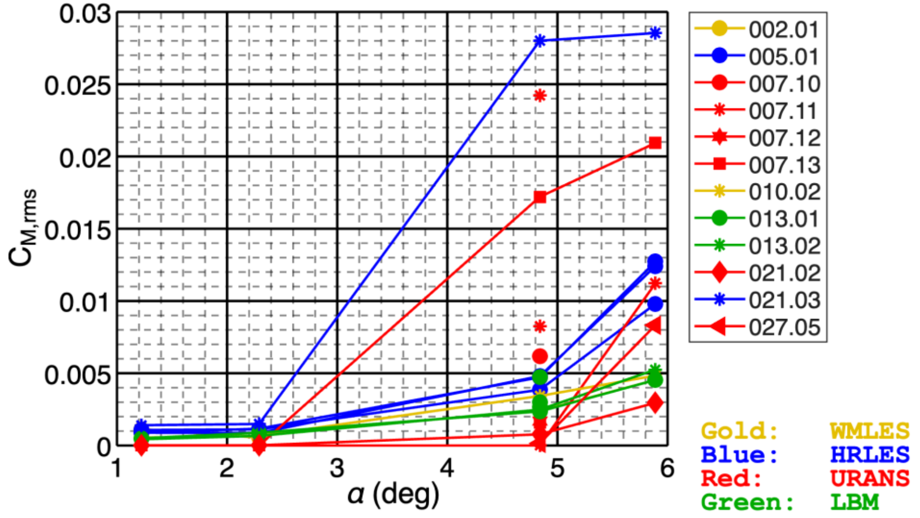




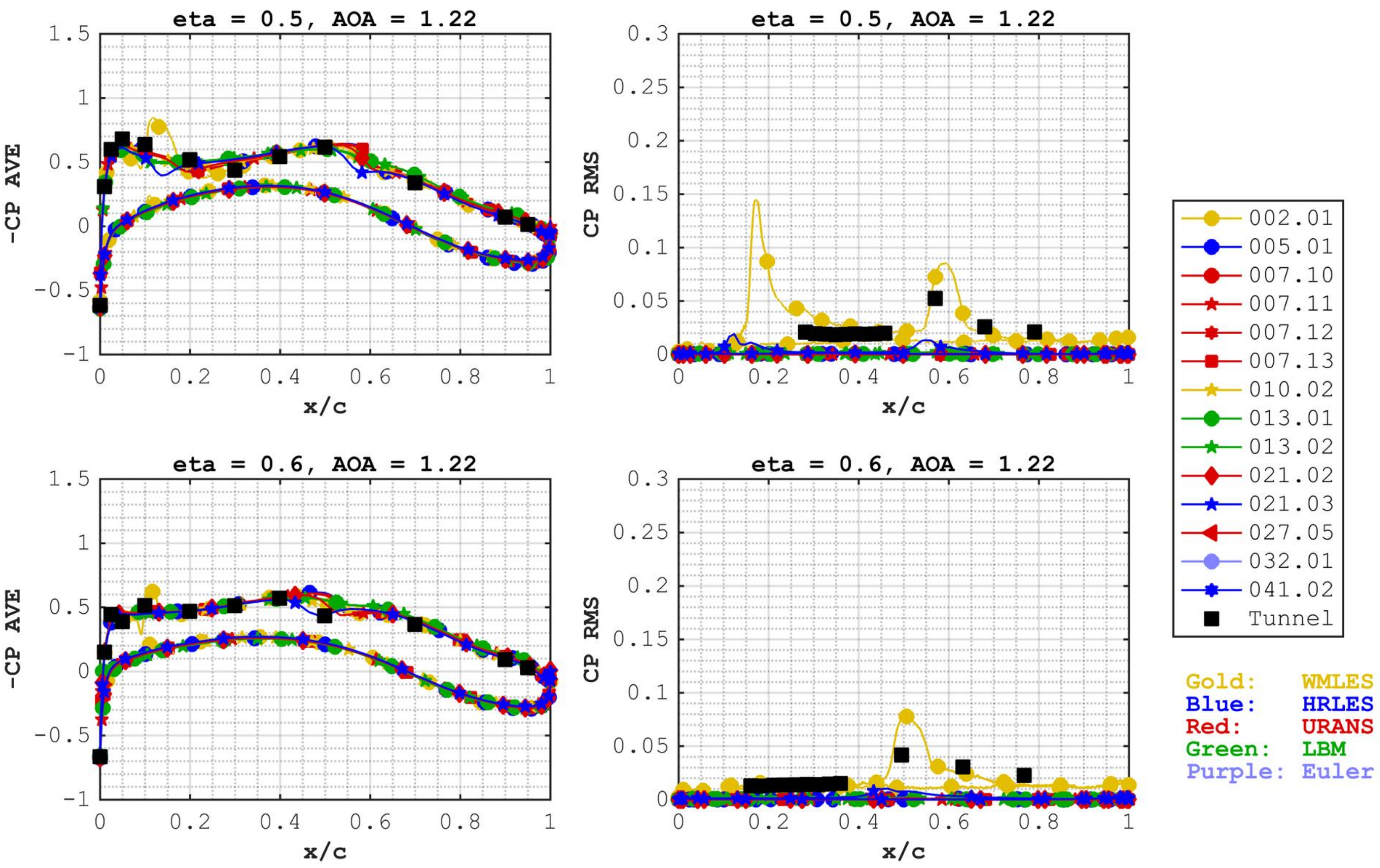
Temporal Formulation Effect – Pitching Moment

- **Low-alpha**
  - Minimal $C_{M,rms}$ (consistent with $C_{L,rms}$)
  - Consistent "rightward" shift of data relative to experimental data (not necessarily incorrect)
- **High-alpha**
  - URANS can predict large-magnitude nose-up pitching moment
  - C_L-C_M shows similar scatter as DPW-VII, which was RANS-heavy (surprising)
  - $C_{M,rms}$ trends mimic trends in both $C_{L,rms}$ and $C_{D,rms}$

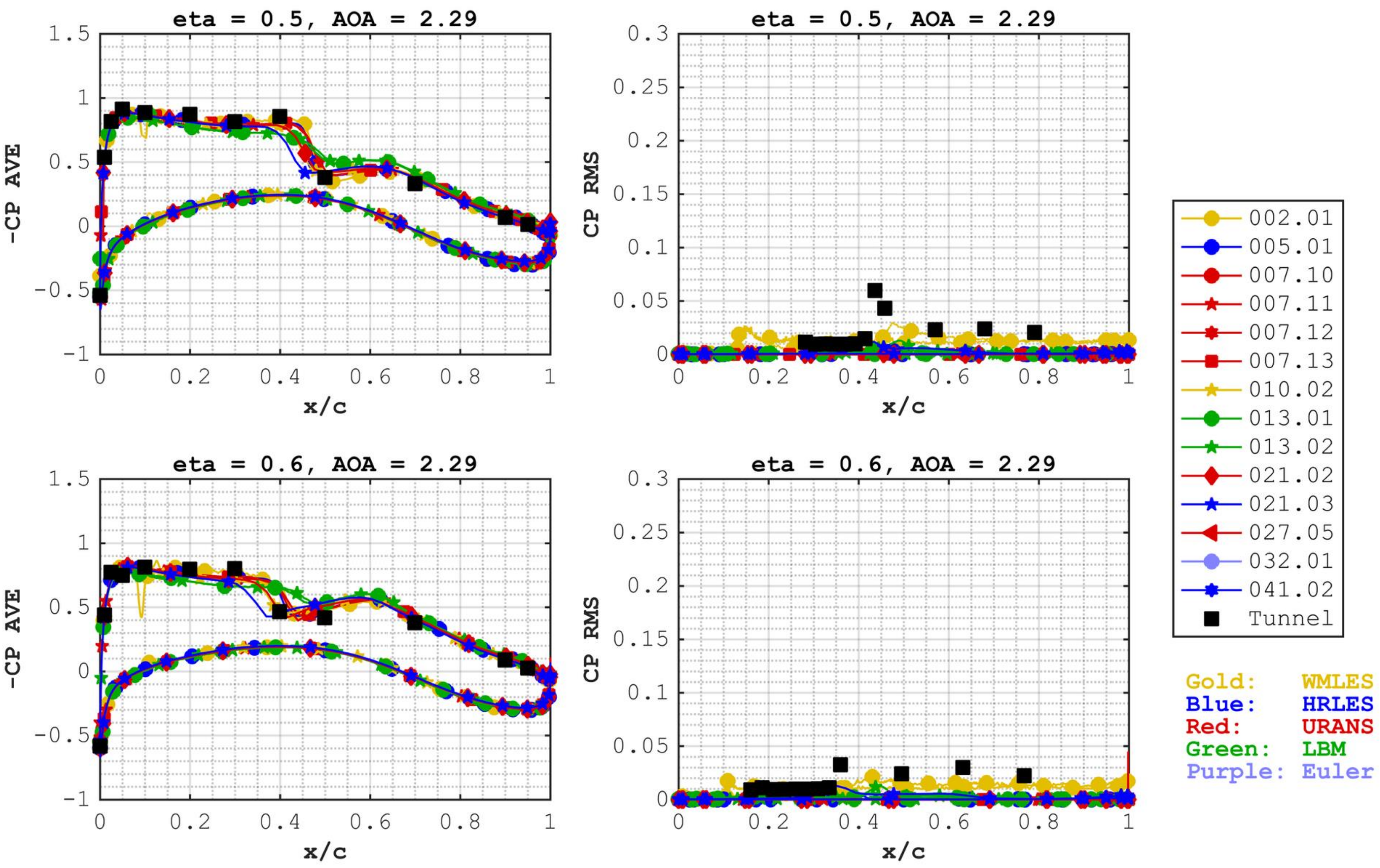




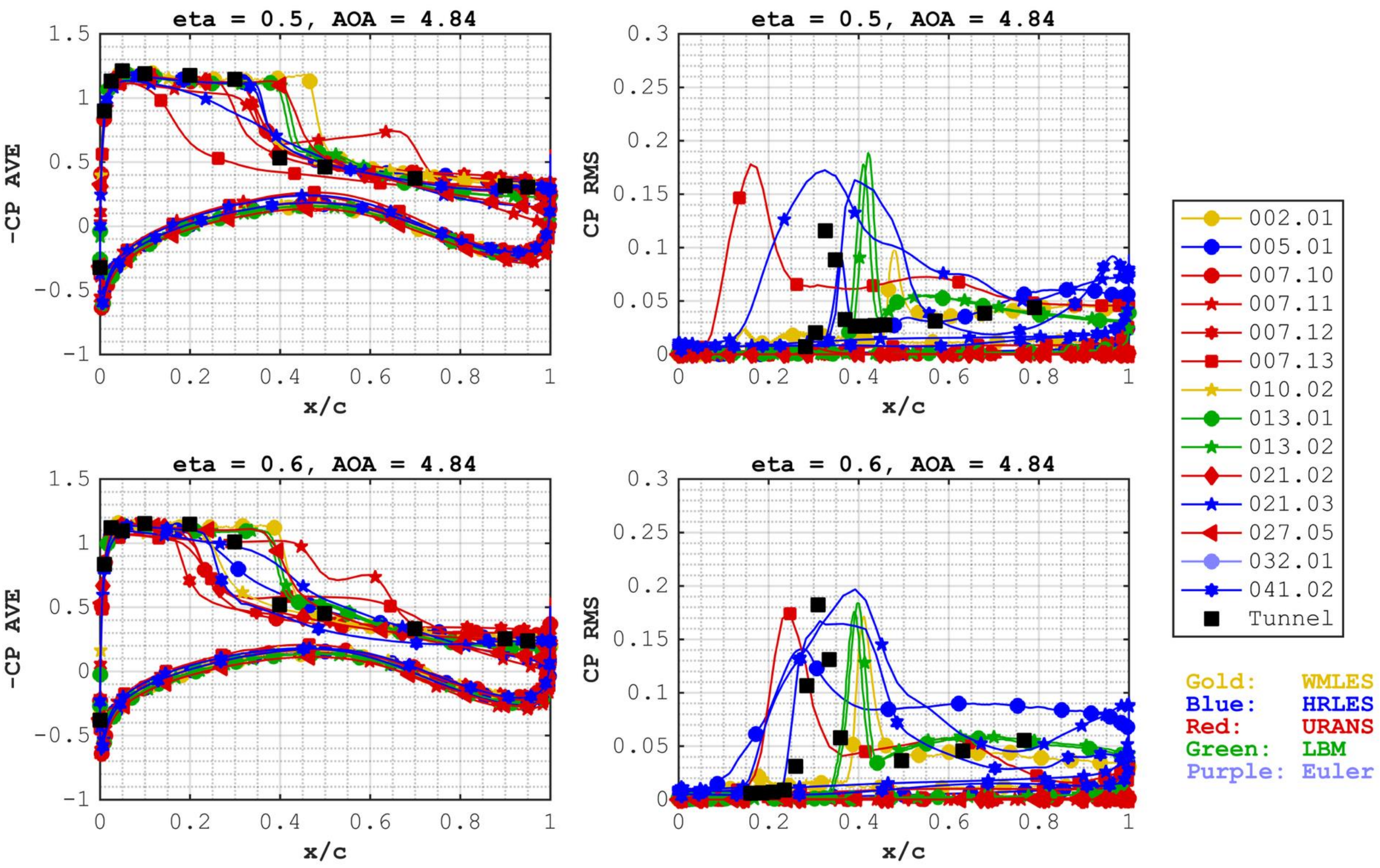
Temporal Formulation Effect – 1.22 deg



Temporal Formulation Effect – 2.29 deg

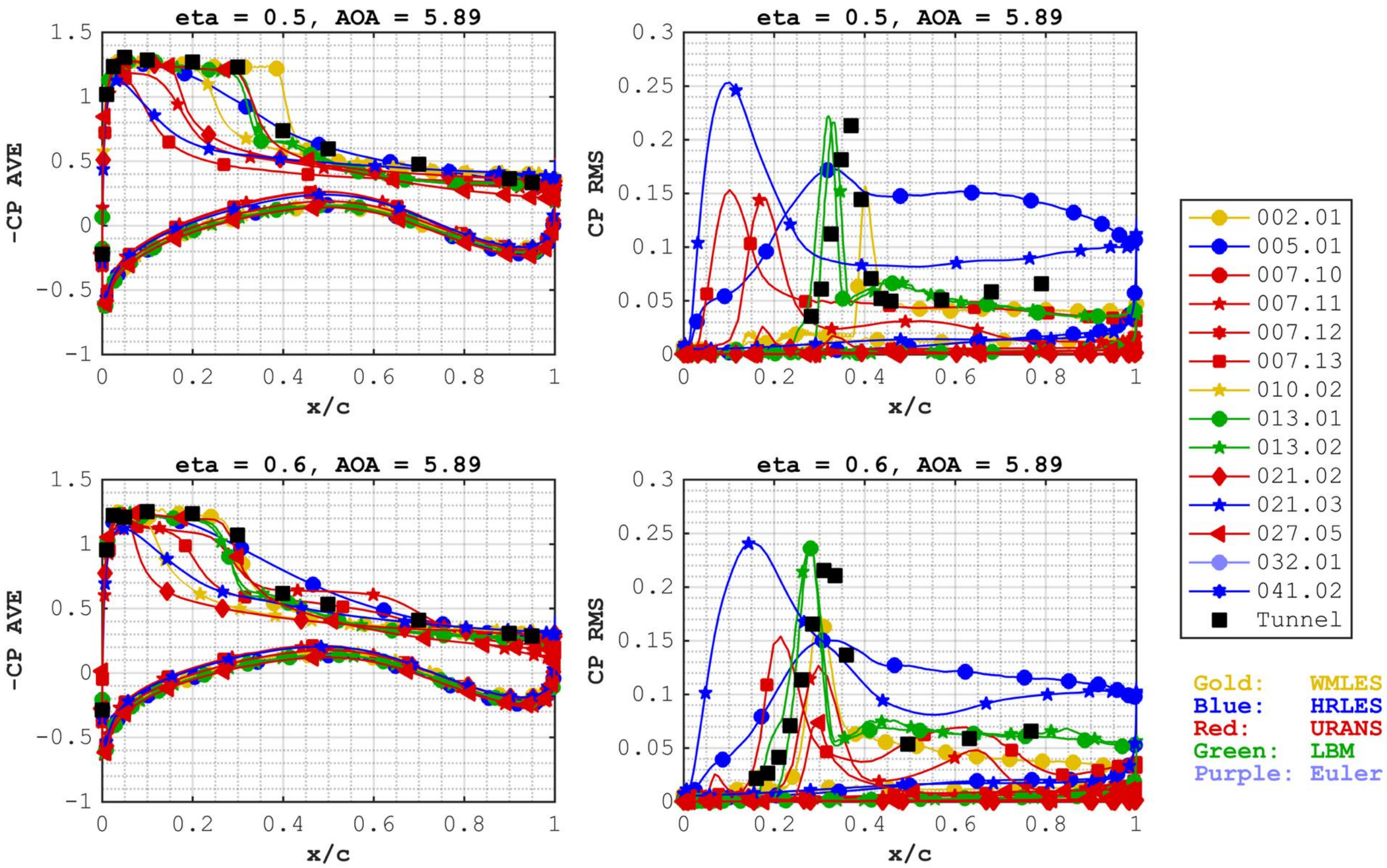


Temporal Formulation Effect – 4.84 deg



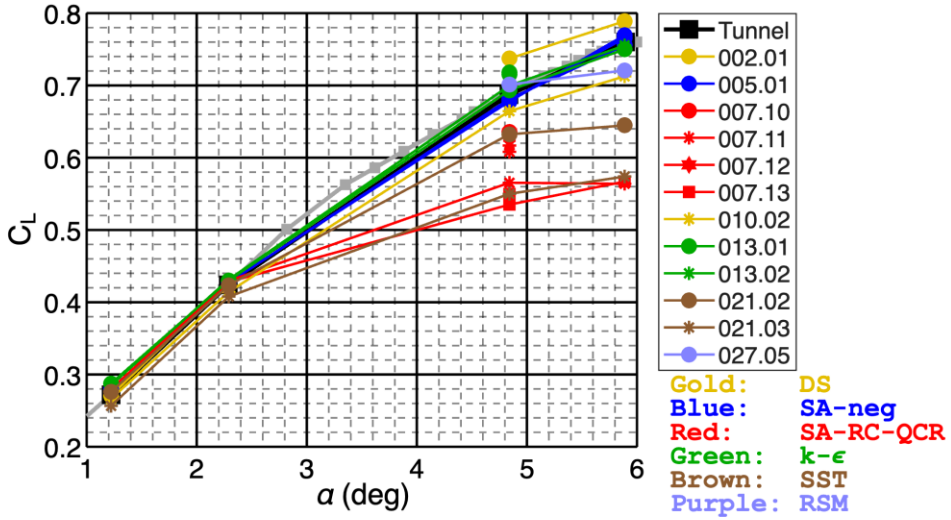
Temporal Formulation Effect – 5.89 deg

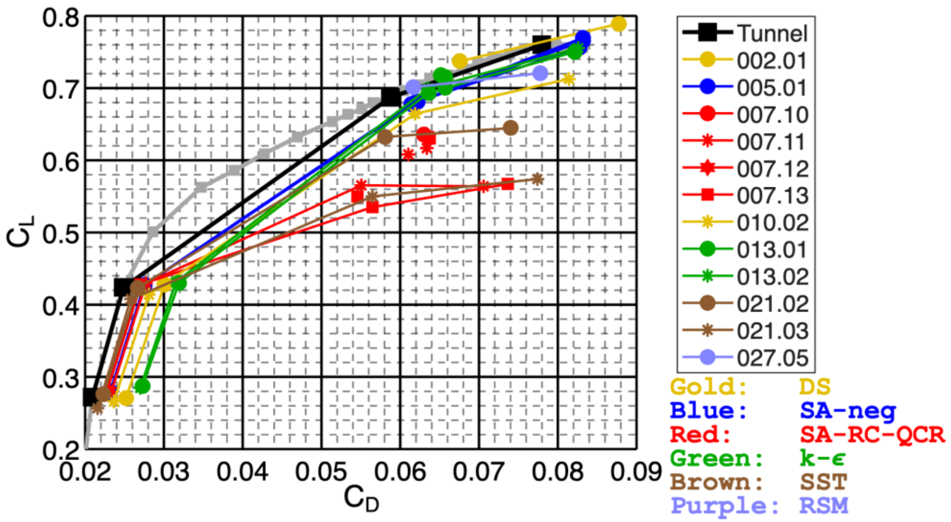
- Large code-to-code variations in the average shock locations and RMS spread, at 4.84 and 5.89 deg
- The sole LBM results are closest to the experimental data, particularly at 5.89 deg

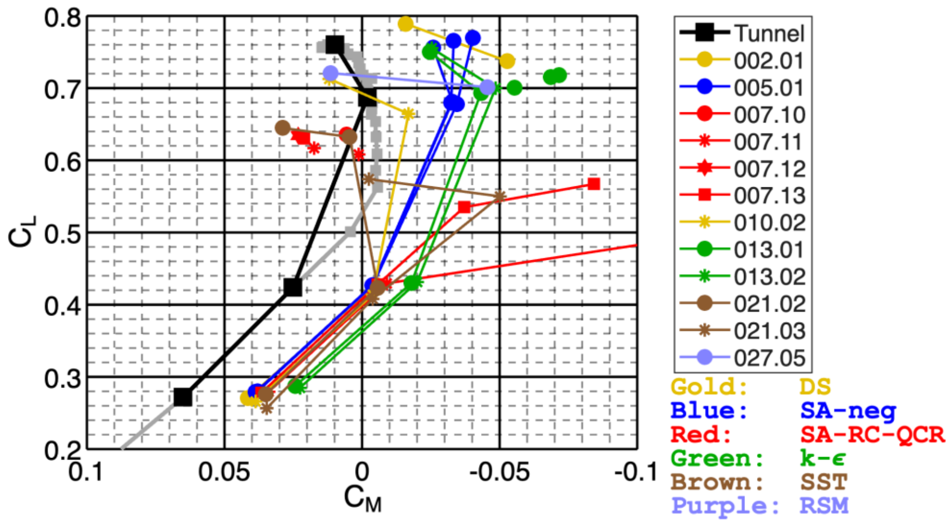


Turbulence Model Effect – All F&M

- **Submissions contain few scheme/turbulence model overlaps**
  - Hinders determining source of spread (is it scheme or model?)
  - More overlap is desired
- **The new SA-neg (stress) shows good promise**

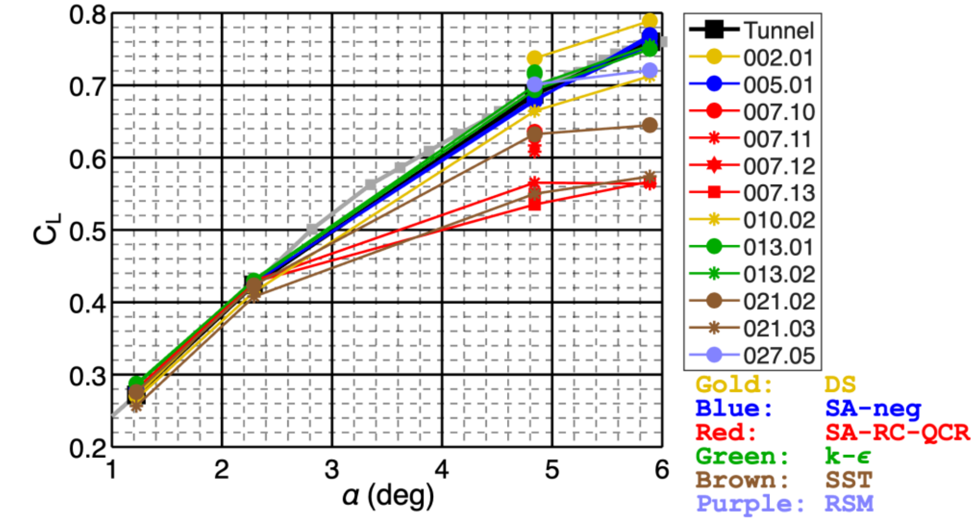


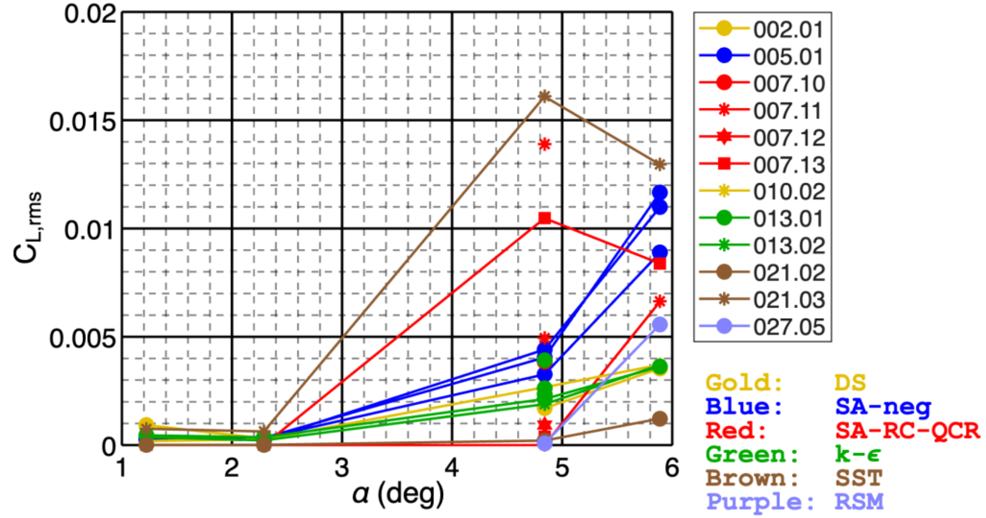




Turbulence Model Effect – Lift

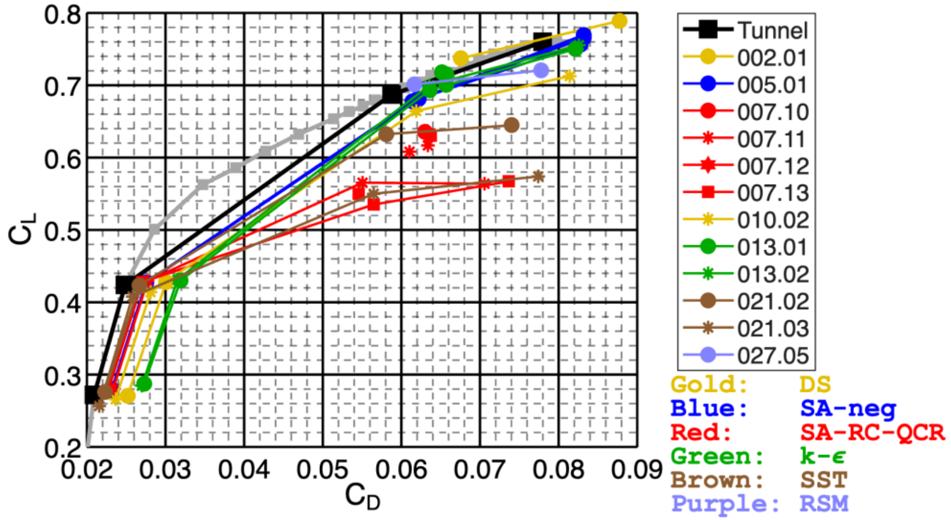
- **Low-alpha**
  - Minimal conclusive trends
- **High-alpha**
  - Drop in lift seen with URANS also observed with SA-RC-QCR (which of these is the cause?)
  - SST, URANS and HRLES, also shows reduced lift
  - SA-neg with Shear-Constrained LES yields good results

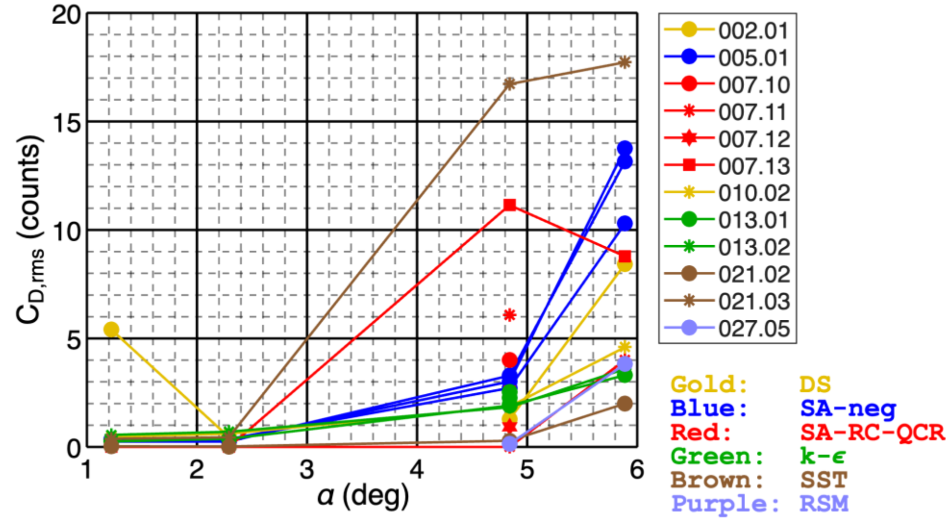




Turbulence Model Effect – Drag

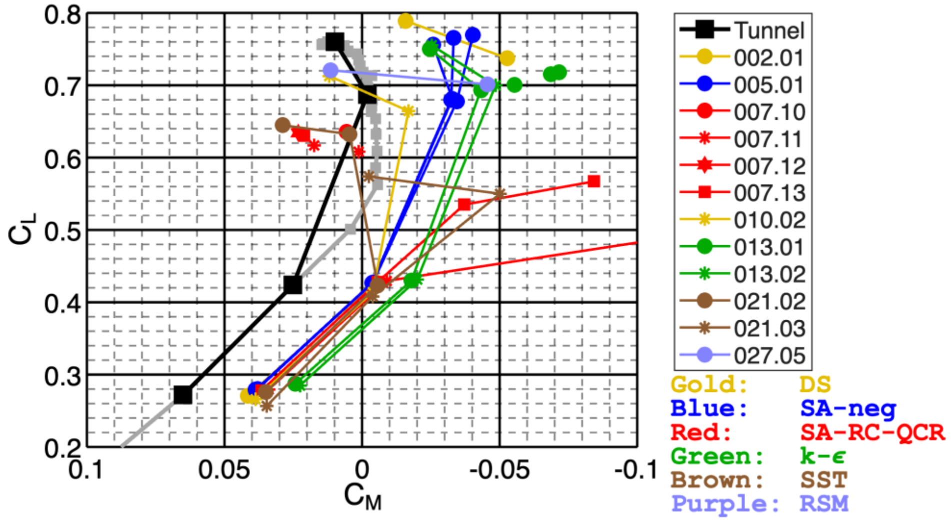
- **Low-alpha**
  - WMLES/DS and LBM/k-ε are elevated; is it scheme or turbulence model?
- **High-alpha**
  - SA-neg shows minimal spread with different grid levels
  - SST indicates reduced lift and increased $C_{D,rms}$

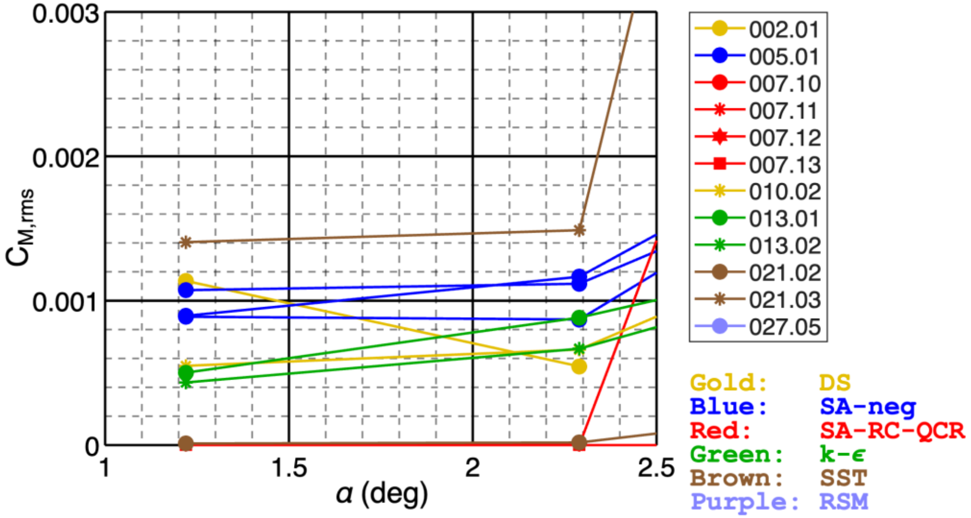


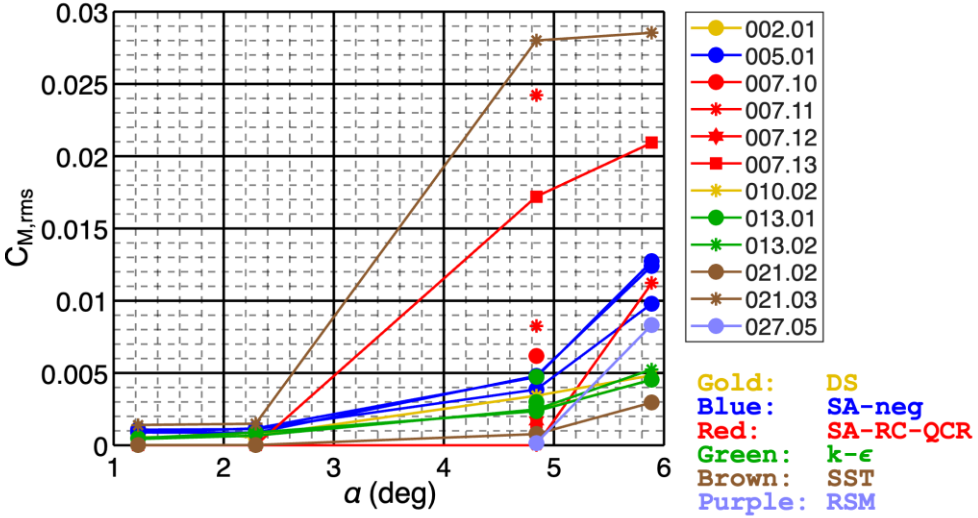


Turbulence Model Effect – Pitching Moment

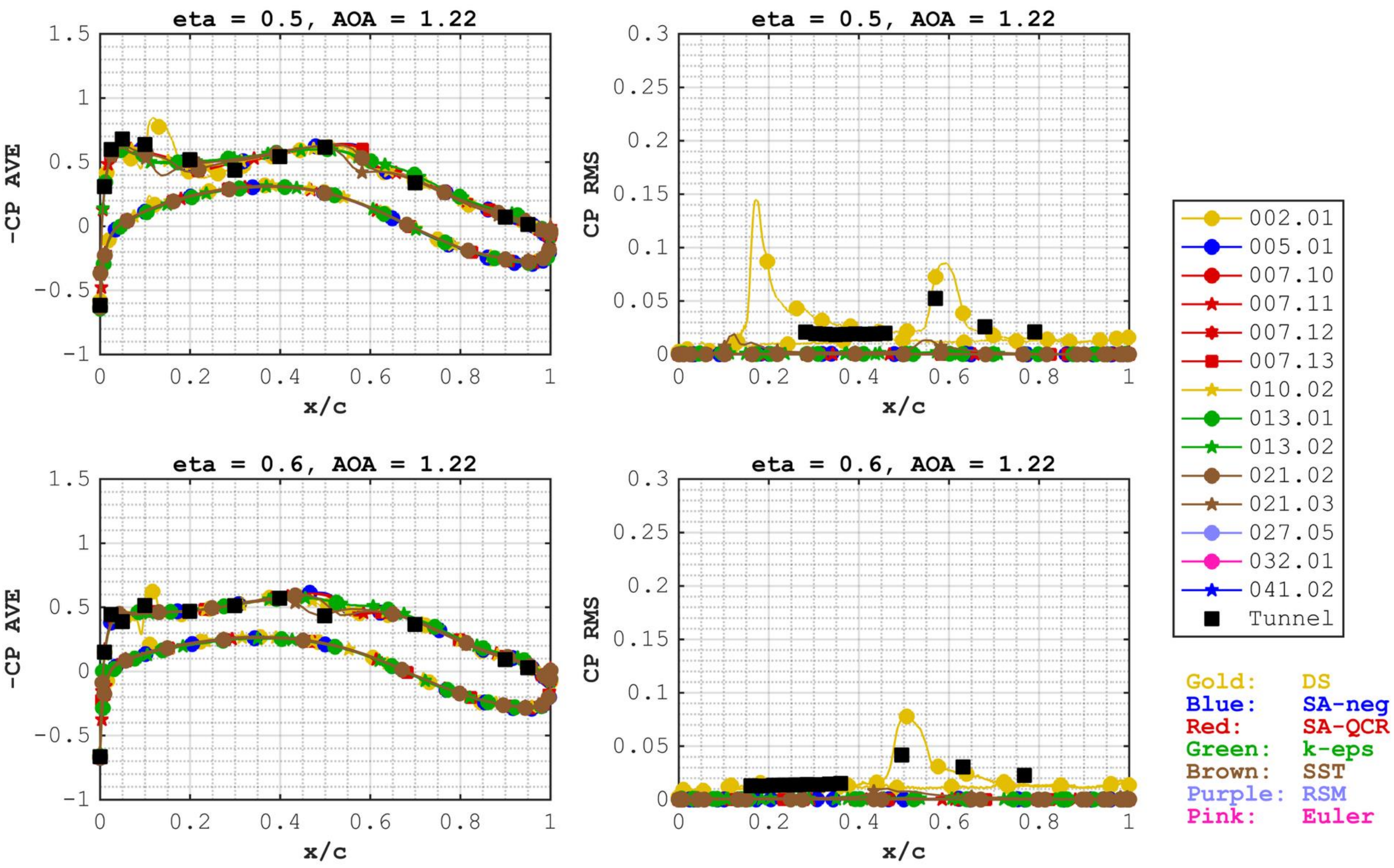
- **Low-alpha**
  - – SST may yield excess $C_{M,rms}$ (truth unknown)
- **High-alpha**
  - – SA-RC-QCR is sensitive to grid/time step
  - – SST is sensitive to scheme
  - – Questions remain regarding URANS and grid sensitivity



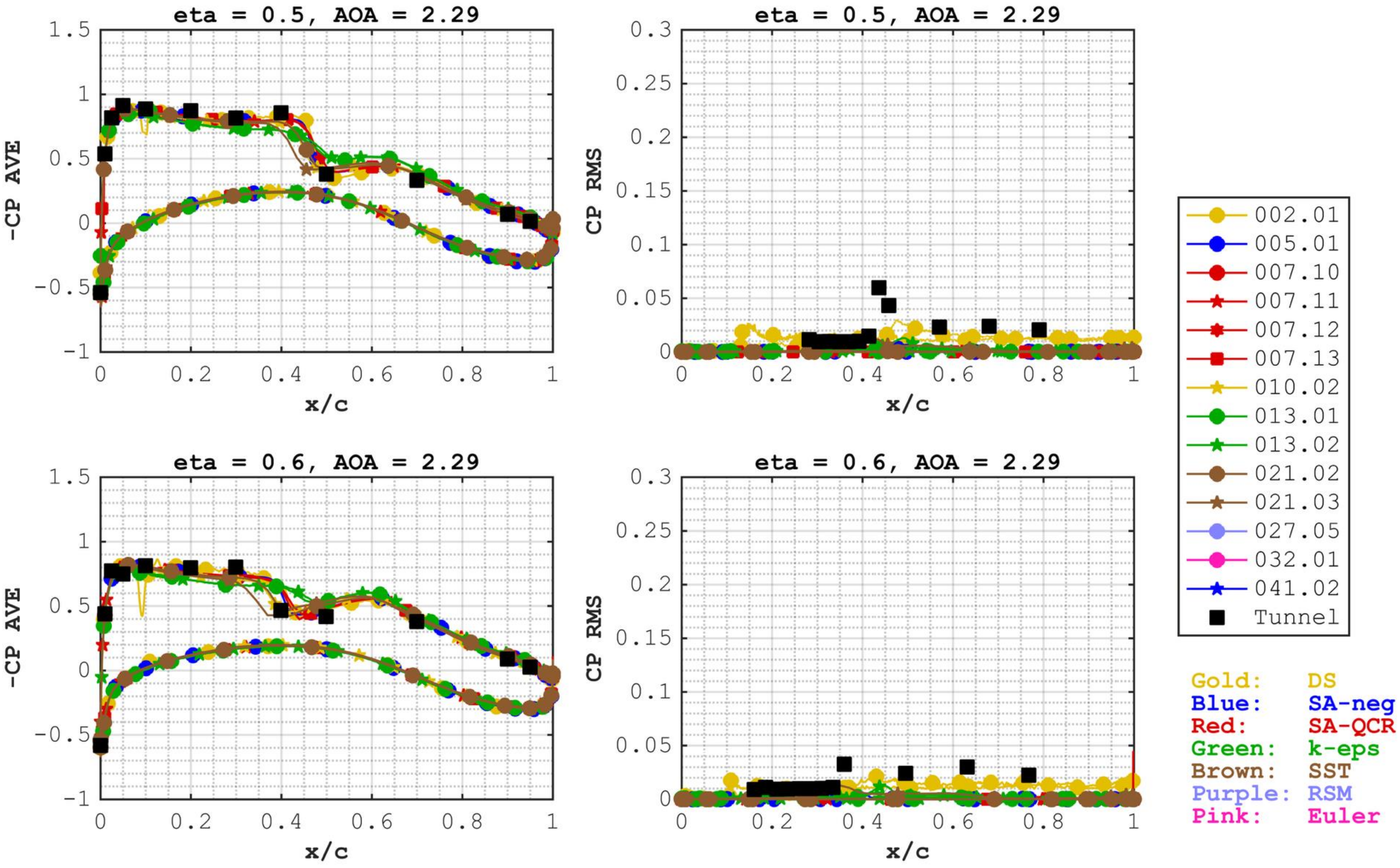




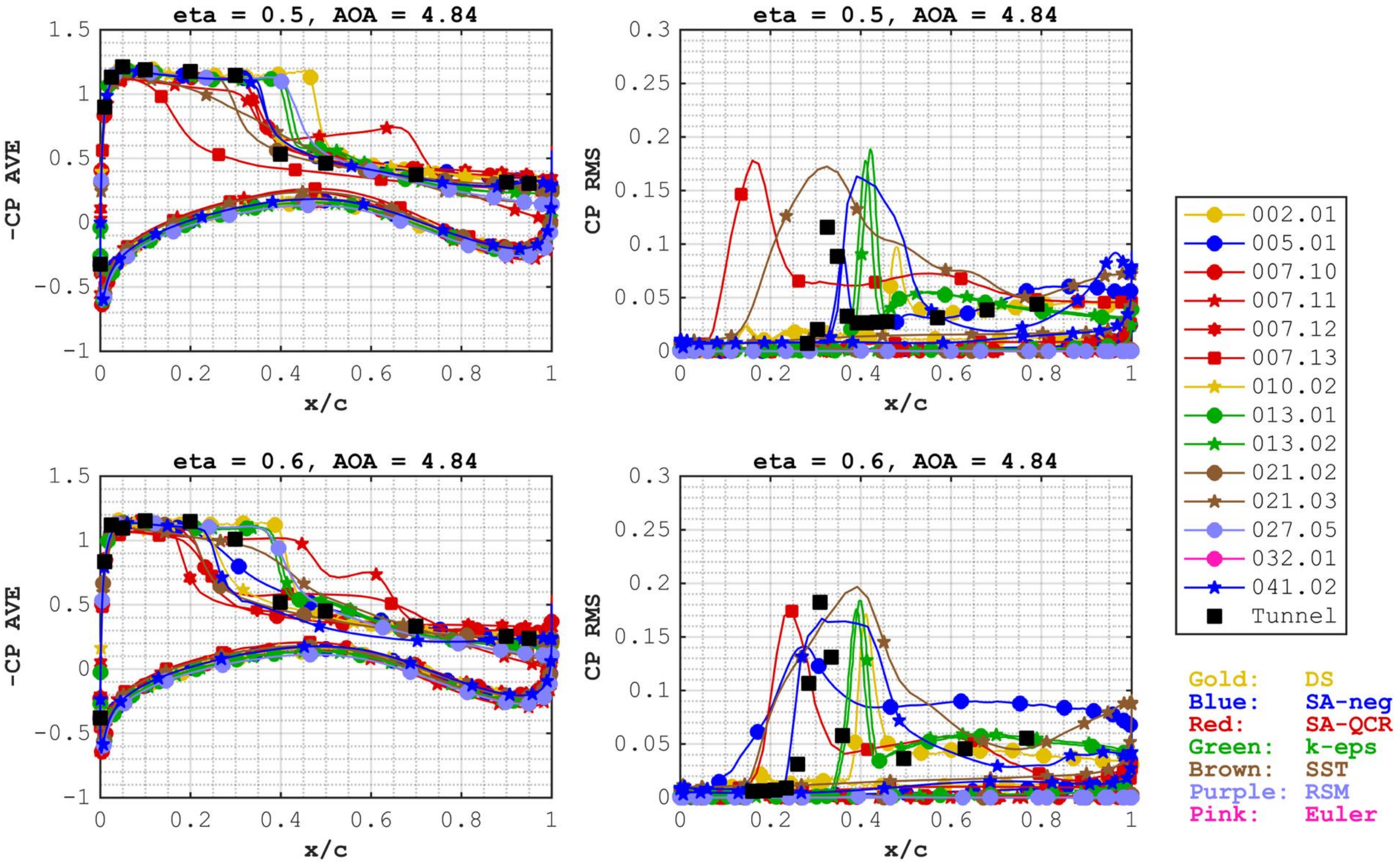
Turbulence Model Effect – 1.22 deg



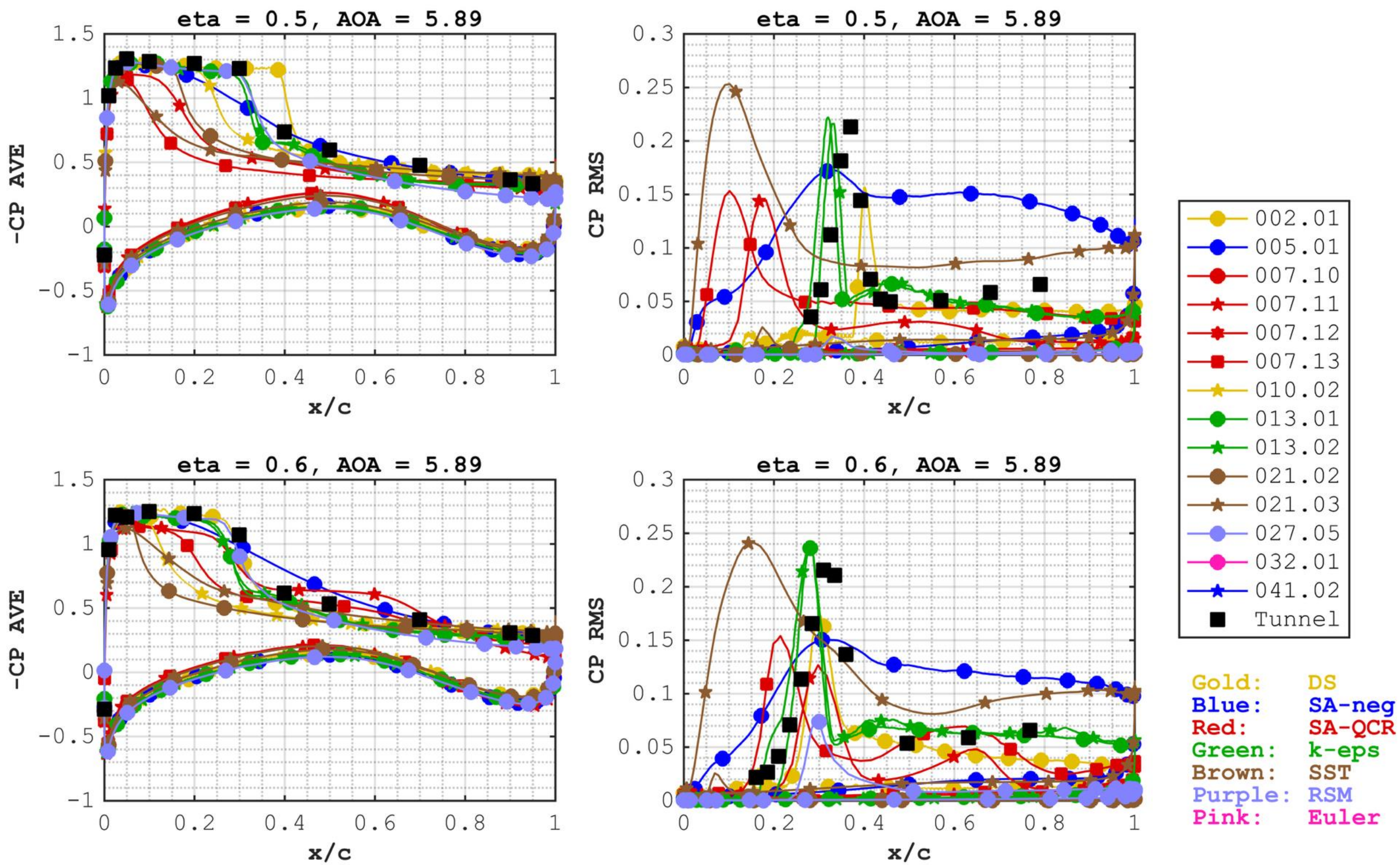
Turbulence Model Effect – 2.29 deg



Turbulence Model Effect – 4.84 deg

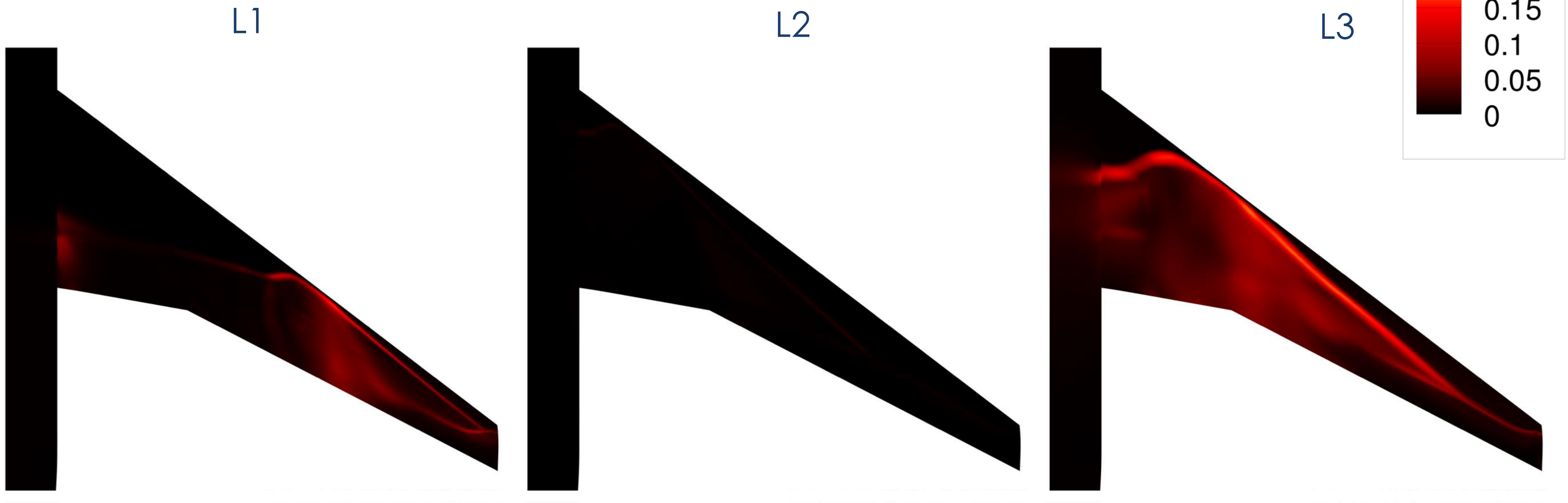


Turbulence Model Effect – 5.89 deg



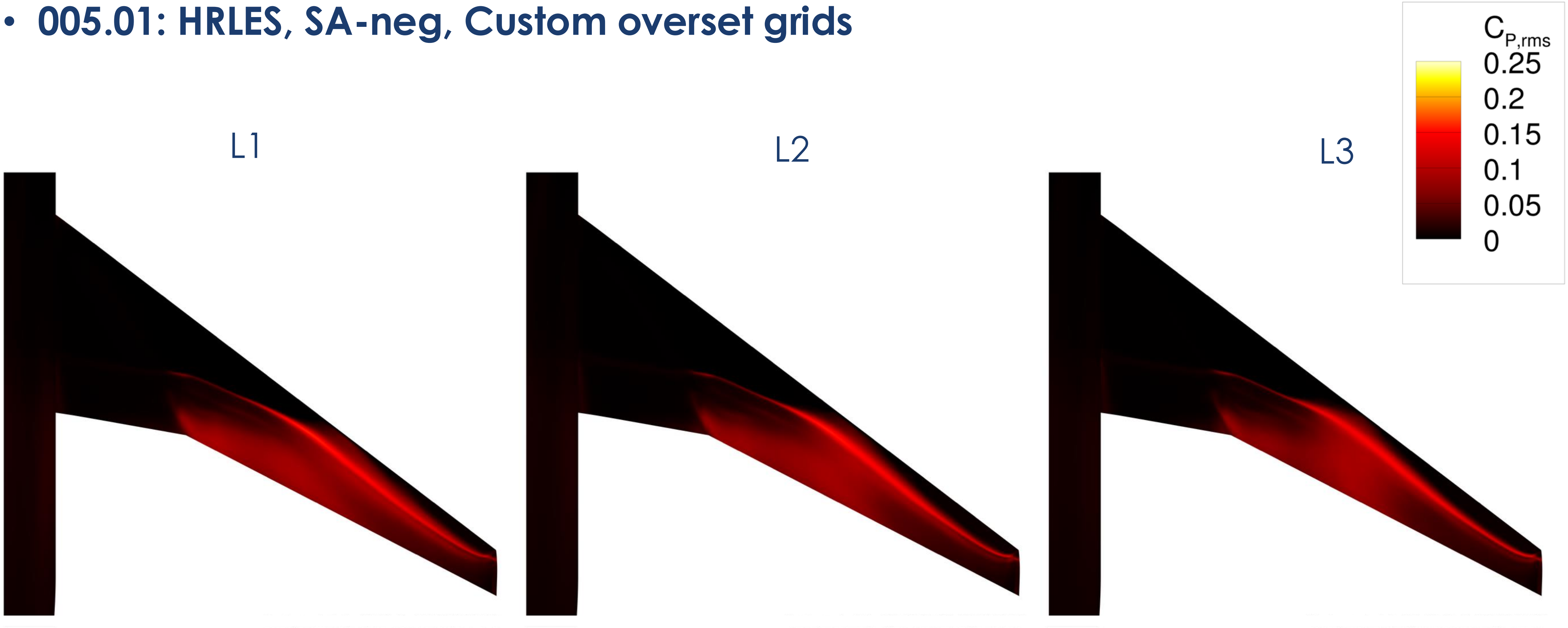
$C_{P,rms}$ Effect of Grid Density at 4.84 Deg (URANS)

- **007.13: URANS, SA-RC-QCR, Cadence grids**



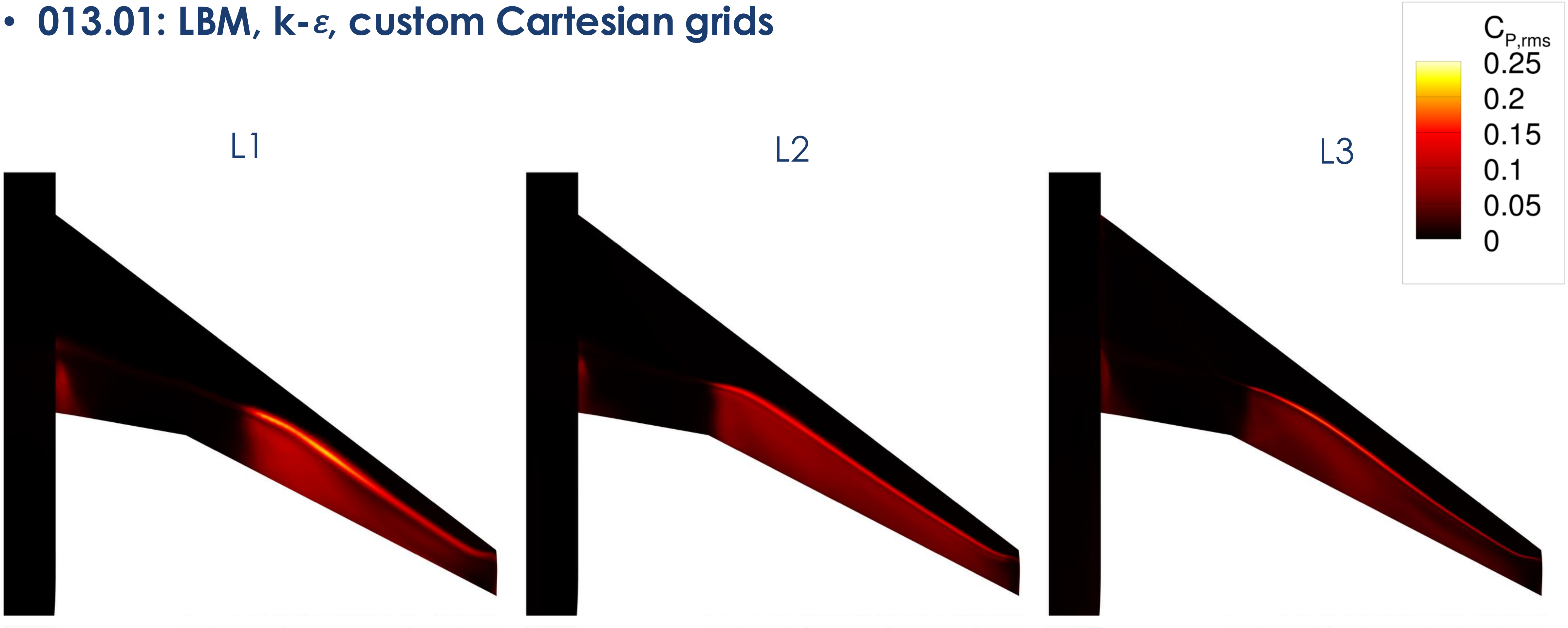
$C_{P,rms}$ Effect of Grid Density at 4.84 Deg (HRLES)

- **005.01: HRLES, SA-neg, Custom overset grids**

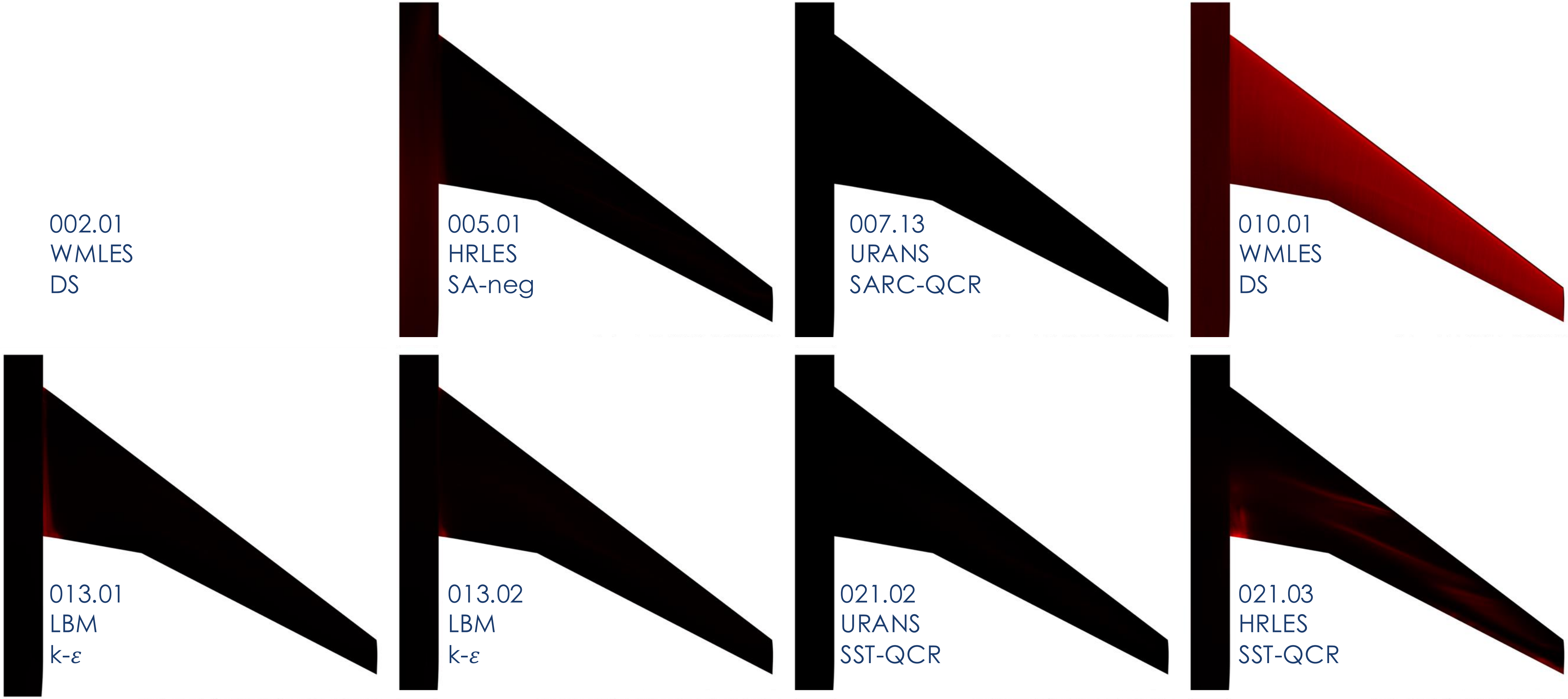


$C_{P,rms}$ Effect of Grid Density at 4.84 Deg (LBM)

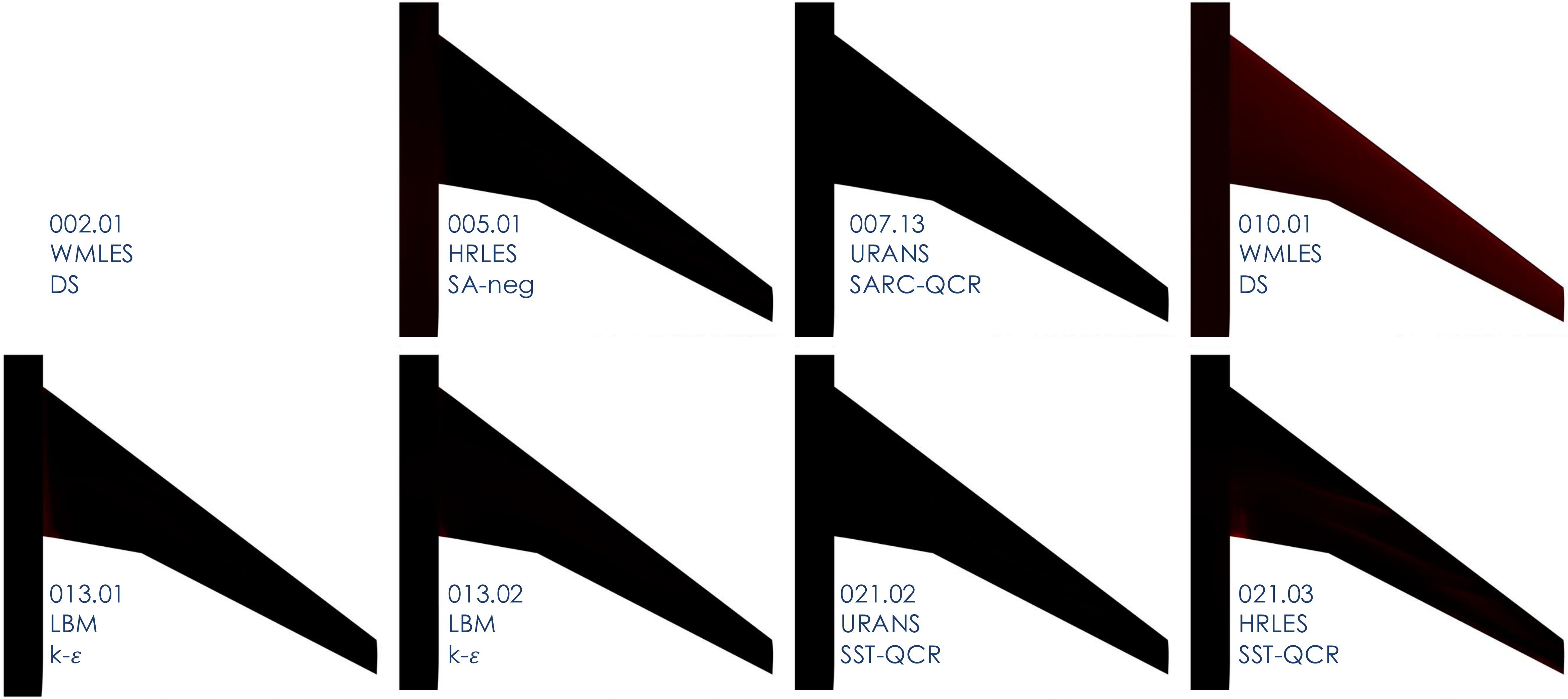
- **013.01: LBM, k-ε, custom Cartesian grids**



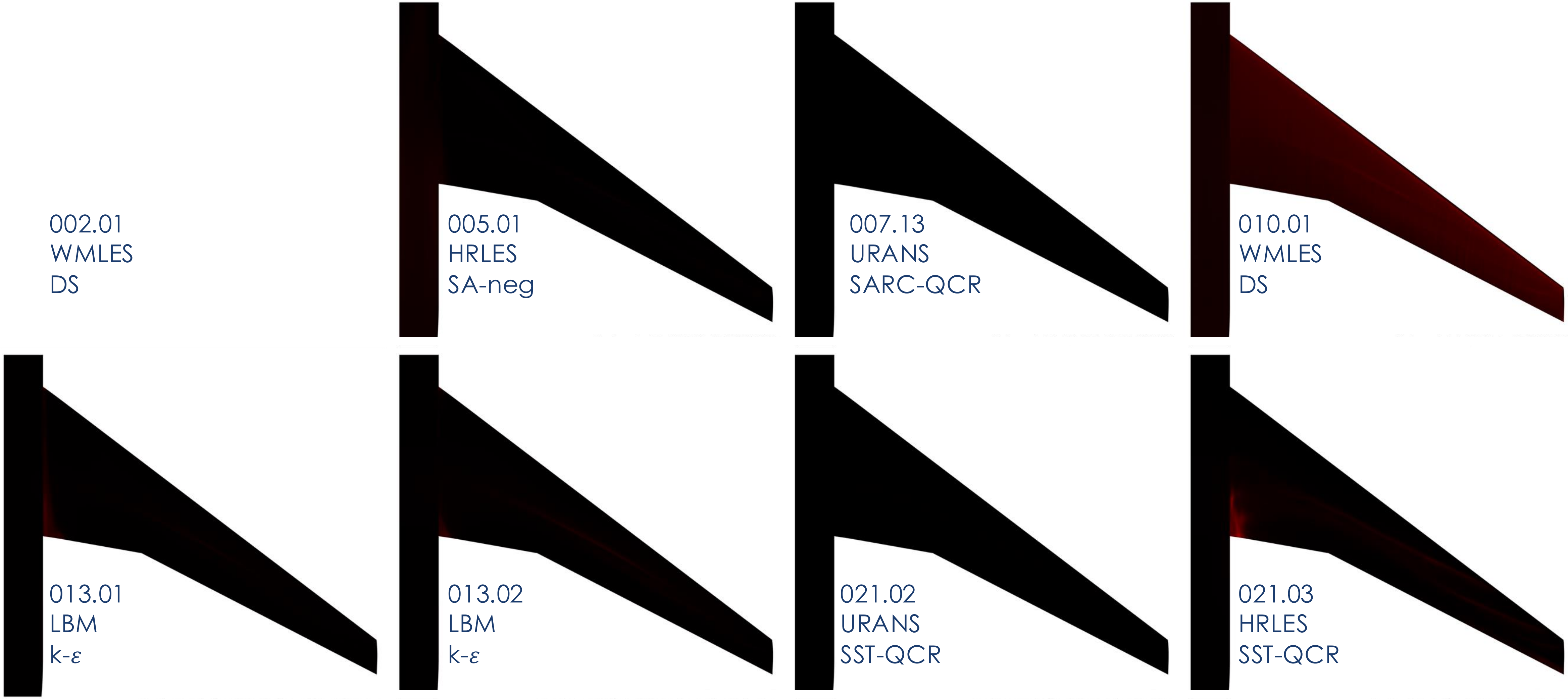
$C_{P,rms}$ (1.22 deg; Grid L3) – Expanded Contours



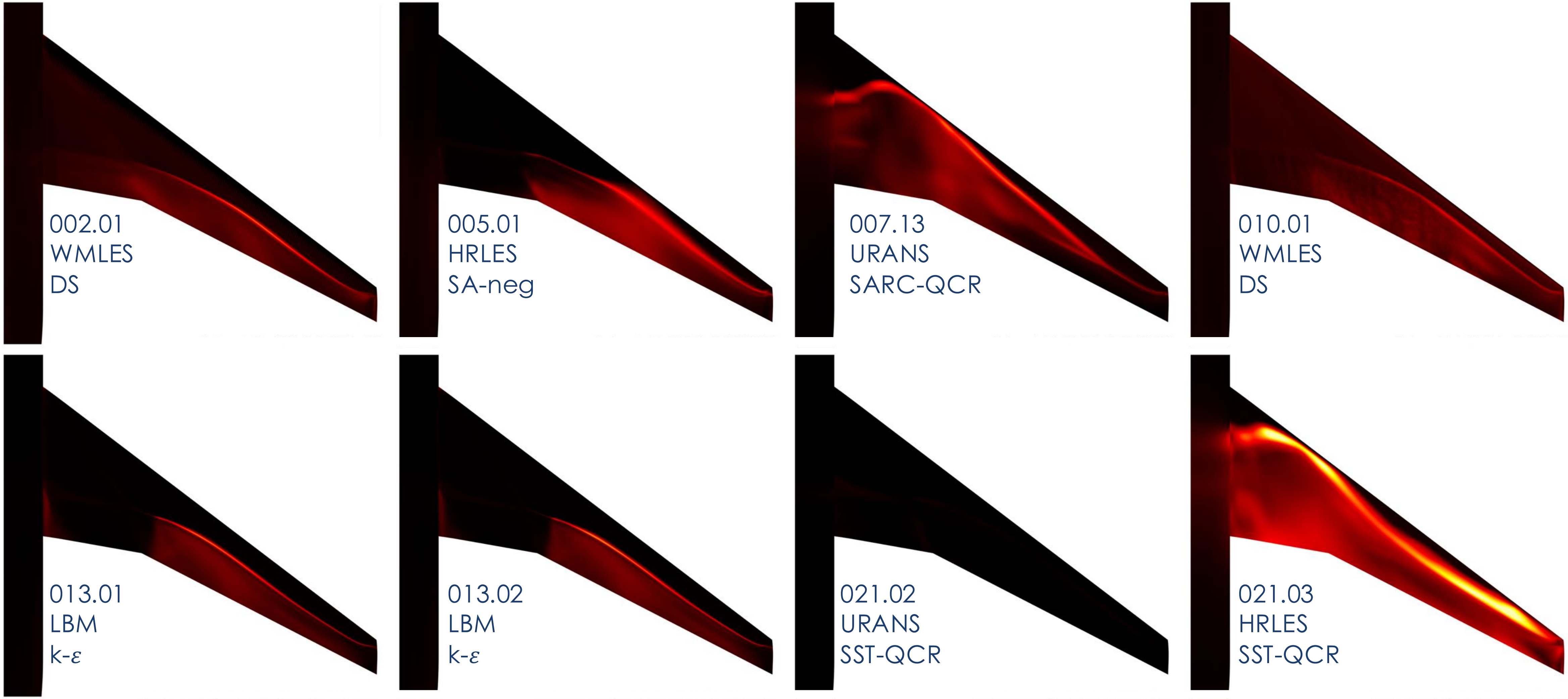
$C_{P,rms}$ (1.22 deg; Grid L3)



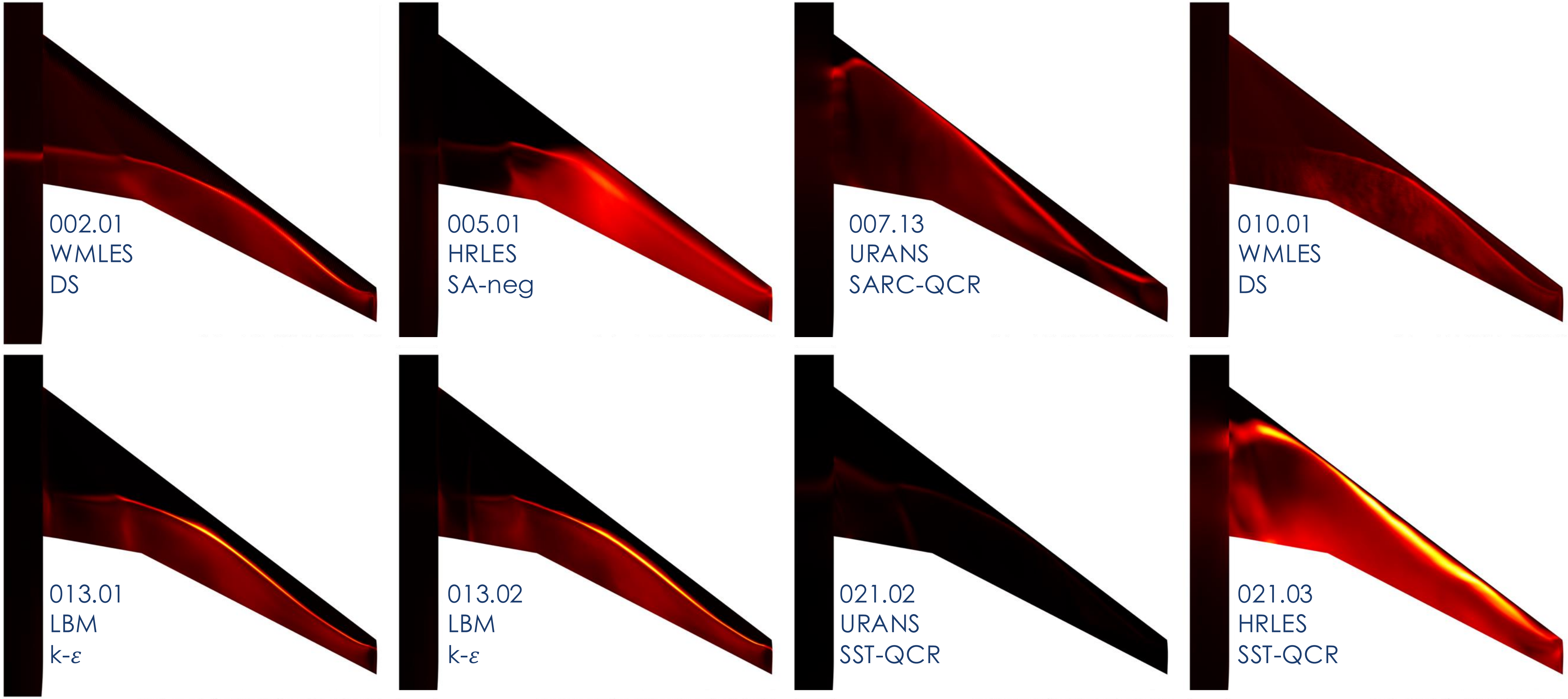
$C_{P,rms}$ (2.29 deg; Grid L3)



$C_{P,rms}$ (4.84 deg; Grid L3)



$C_{P,rms}$ (5.89 deg; Grid L3)



Test Case 3

Summary

- Difficult and expensive computational problem
- Some progress from four participants
- More to be discussed at SciTech

Open Questions and Desired Future Work

Overview

- Community is quite close to resolving some key questions
- Opportunities exist to round out the data set for SciTech and final paper
- You are encouraged to execute additional analysis as outlined
- Final data are due November 15, 2026 (hard stop)

Test Case 1

- **Ensemble results are understood quite well**
- **Surprising amount of scatter for an airfoil**
  - Large number of custom grids
  - Solver settings
  - Are turbulence models implemented correctly?
- **Grid convergence is difficult to achieve for unsteady schemes, even with attached flow**
- **Consider submitting solutions that didn't go unsteady as this is a big learning**
- **Diminishing (or diminished) returns for additional simulations**
  - Always more to learn, but we largely understand the data
  - Focus upon Test Cases 2 and 3 would be more beneficial
  - Computationally limited participants can still provide one or two valuable Test Case 2 simulations (see next slide)

Test Case 2: Open Questions

1.) Is WMLES necessary? What can be solved with URANS and HRLES?
- *Execute additional HRLES simulations*
- *Constant turbulence model and scheme-appropriate grid, different schemes*

2.) Do any non-SA turbulence models predict the flowfield with sufficient accuracy?
- *Perform turbulence model sensitivities for a given scheme/approach at L3+*

3.) Is URANS a dead end? Can HRLES be sufficient?
- *Execute URANS and HRLES with finer grids (L4+) for Cadence and Helden grids*
- *Evaluate and increase subiterative convergence*

4.) What grid convergence metrics can we discern?
- *Execute simulations on L2 and L4*

5.) Can point-matched data shed light on the high-alpha conditions?
- *Execute simulations at alpha = 2.29 deg*

Test Case 3: Open Questions

1.) Do we have any quantitative data of reasonable confidence?

- *Work-in-progress data are encouraged*
- *For this test case only, data can be published without your Participant ID if desired to encourage work-in-progress submissions*

2.) What lessons have been learned so far?

- *Significant information can be captured without quantitative results*
- *Have code or method struggles been identified?*
- *What improvements must be made to grid-movement schemes? Can simulations start from a jig shape?*

3.) Can you provide any key images depicting your results, grid, troubleshooting process, etc.?

Work Beyond DPW-8/AePW-4

- **Desired high Reynolds number experimental data set**
  - Physics at 20M or 30M are very different than 1.5M or 2M
  - uPSP, F&M time histories, and dynamic deformation metrics
- **Robust grid sensitivity studies**
  - Grid convergence for scale-resolving techniques for very fine grids
  - Grid movement improvements, especially adaptation
- **Effect of nacelle/pylon (and strake?)**
- **Dynamic vehicle considerations**
- **Side-of-body physics**

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  - Craig Hunter, NASA Langley Research Center (Emeritus)
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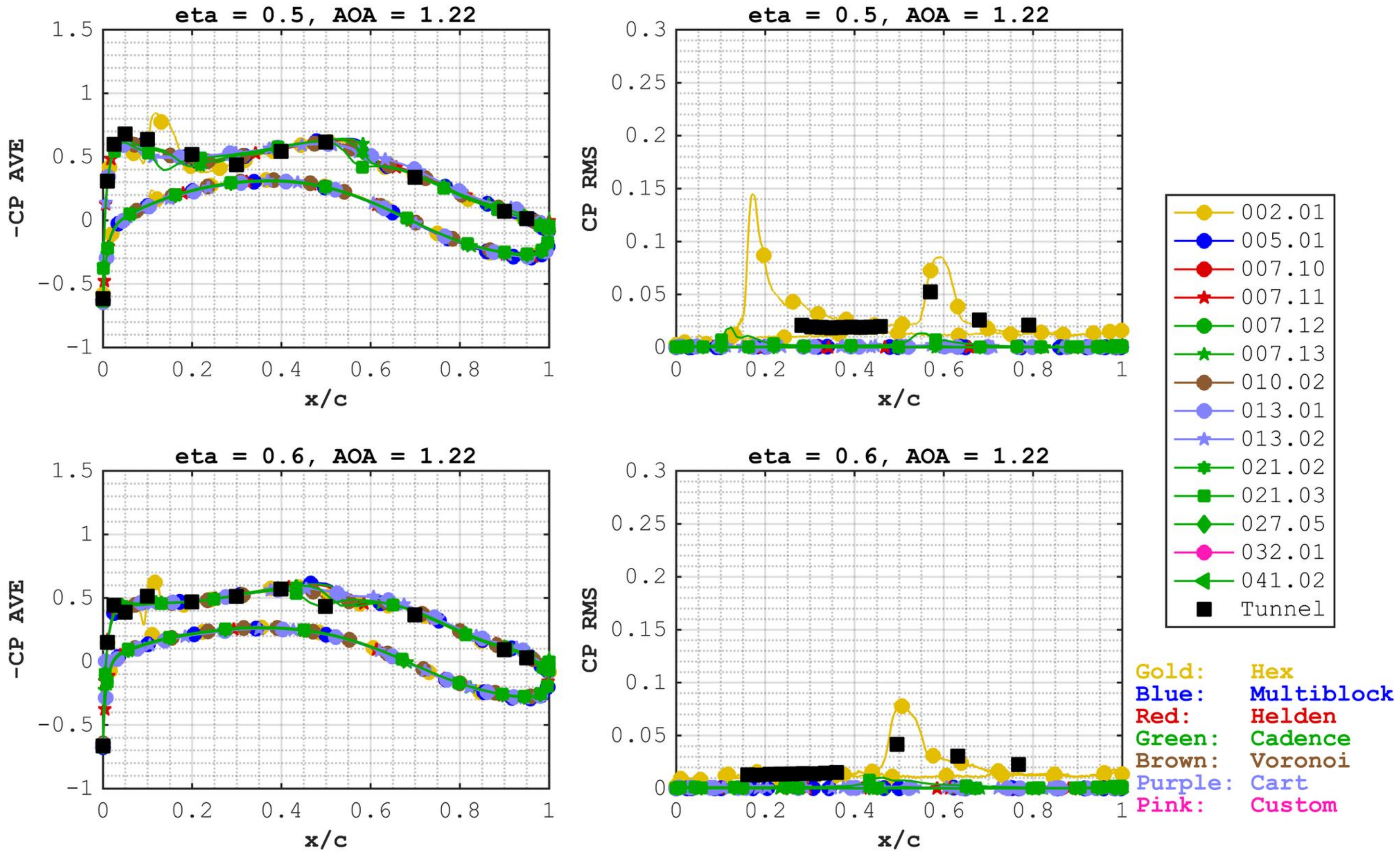
  - Chris Rumsey, NASA Langley Research Center (Emeritus)
  - Ethan Vogel, NASA Langley Research Center

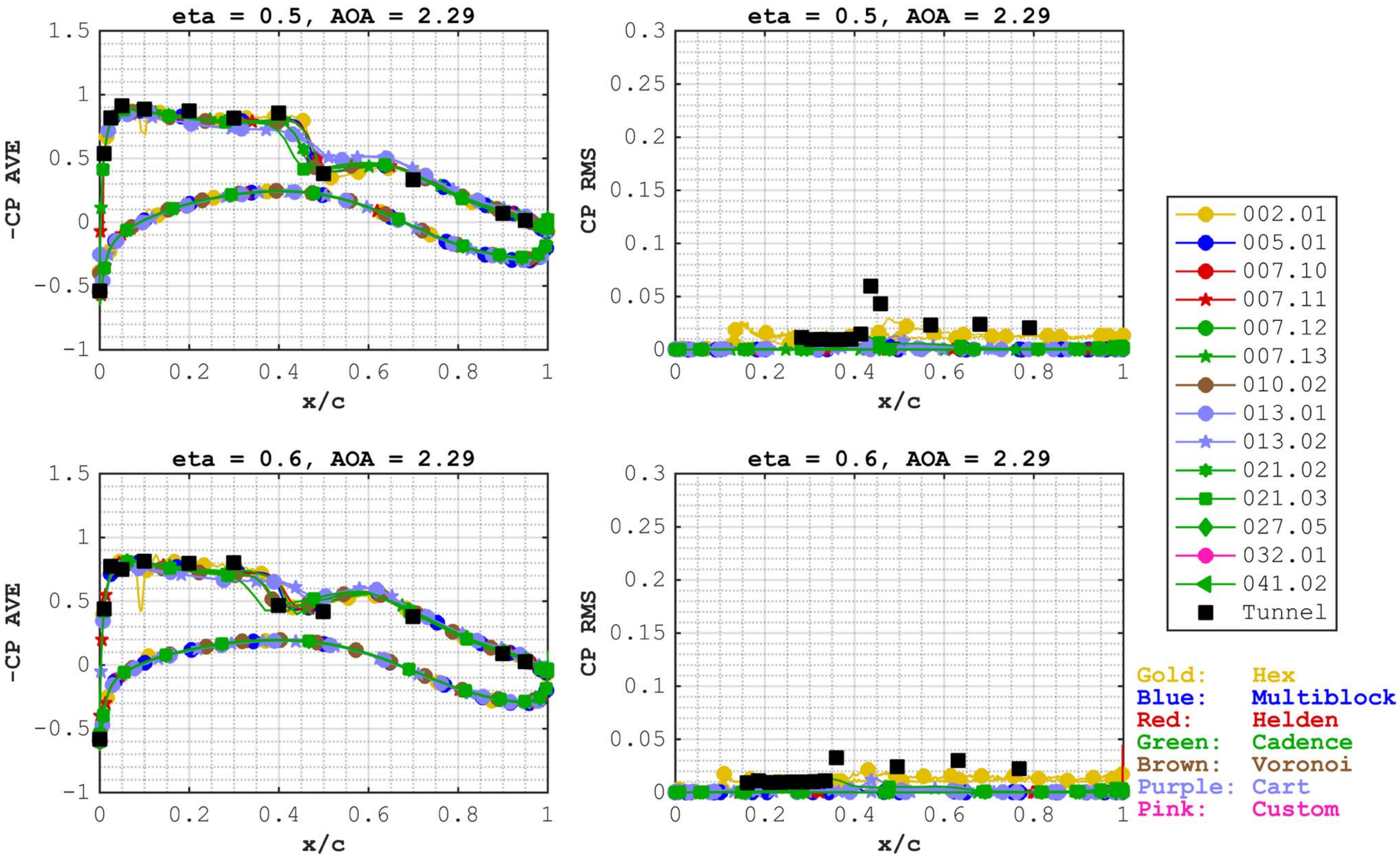
Questions?

Backup

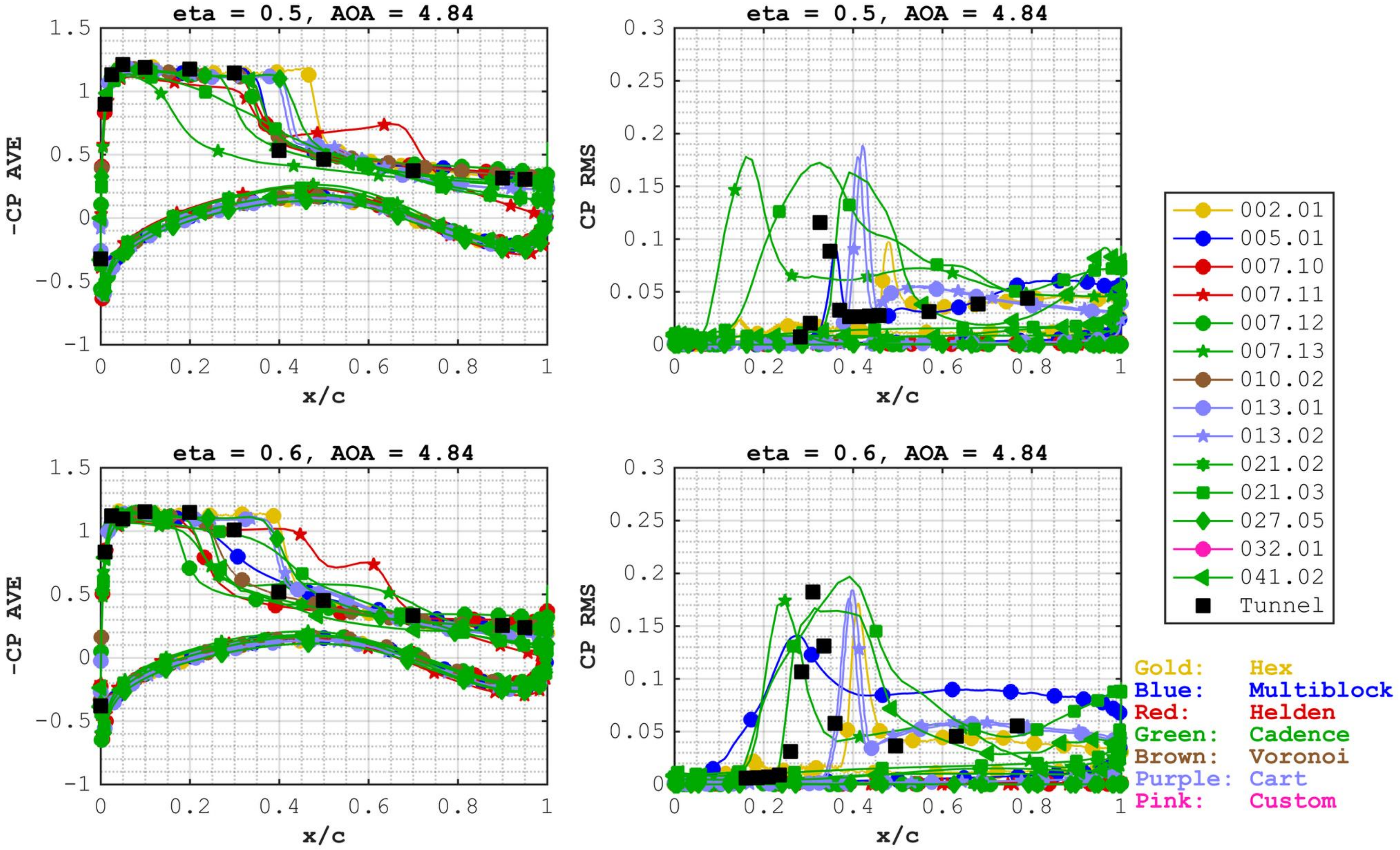
Grid Type Effect – Unsteady Cuts, AoA = 1.22 deg.



Grid Type Effect – Unsteady Cuts, AoA = 2.29 deg.



Grid Type Effect – Unsteady Cuts, AoA = 4.84 deg.



Grid Type Effect – Unsteady Cuts, AoA = 5.89 deg.