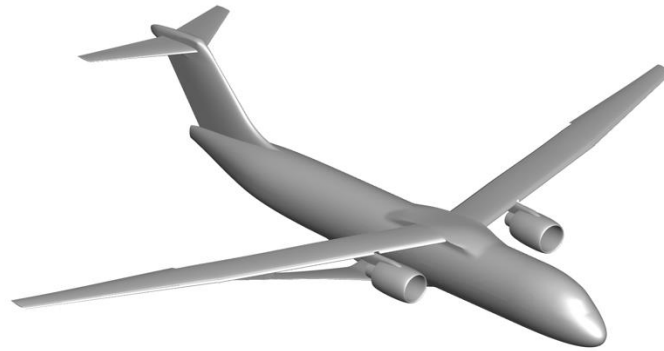


Simulation of the Transonic Truss-Braced Wing High-Lift Configuration at Mach 0.20 using USM3D-Mixed Element Solver



Tausif Jamal, Seth Kelly, Craig Hunter, William Milholen, T.J. Wignall, and Steve Krist*

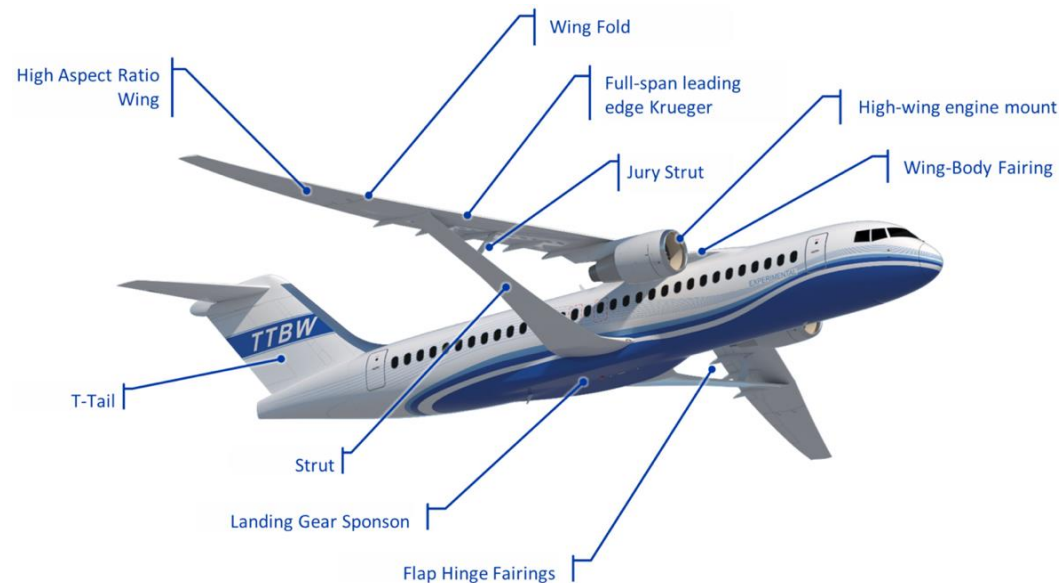
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**Presented by
Brent Pomeroy**

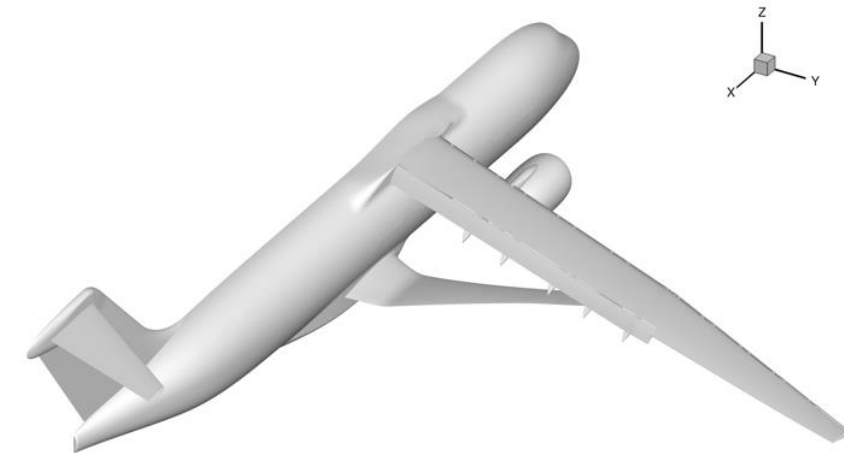
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Introduction & Configuration

- Flow complexity increases when when simulating complex designs such as the NASA/Boeing Transonic Truss-Braced Wing (TTBW).
- Studies have shown that Computational Fluid Dynamics (CFD) codes predict separated wedges known as ‘pizza slices’.
- Discussions regarding the physical validity of these ‘pizza slices’ are ongoing.
- The aerodynamic components included: wing, strut, fuselage, empennage, Kruegers, flaps, flap support fairings, and nacelle and pylon.



SUGAR TTBW Concept Mach 0.80 Configuration¹



Oblique view of the semi-span geometry

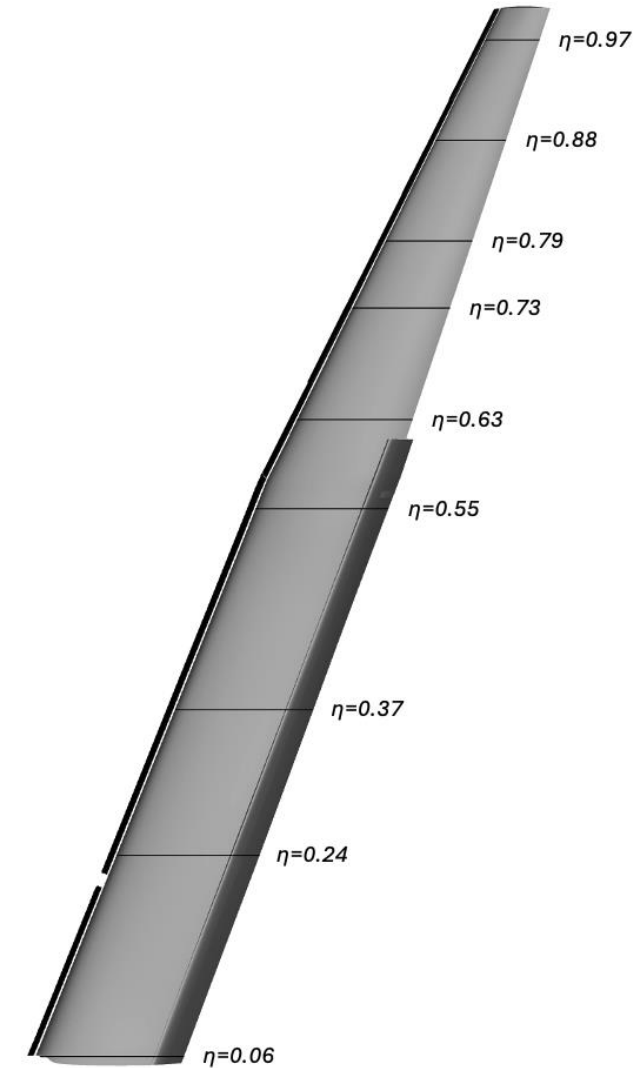
¹Harrison, N.A., Hoffman, K., Lazzara, D.S., Reichenbach, E.Y., Sclafani, A.J., and Droney, C.K., “Subsonic Ultra Green Aircraft Research: Phase IV Final Report–Volume I Mach 0.80 Transonic Truss-Braced Wing High-Speed Design Report,” 2023

Experimental Setup

- Wind tunnel tests were performed at the **14- by 22-Foot Subsonic Wind Tunnel at NASA Langley Research Center**.
- The wind tunnel model is a full-span 8% scale representation of the **SUGAR TTBW Mach 0.80** vehicle.
- Tests were conducted at $Mach = 0.2$ at a Reynolds Number of 0.98×10^6 .
- The primary instrumentation devices used for comparison include:
 - 9 chordwise surface pressure orifice rows on the wing.
 - 4 chordwise rows along the flaps.
 - No instrumentation was included on the Krueger flaps.



Aerial view of the 14- by 22-Foot Subsonic Wind Tunnel [Photo: NASA]



Pressure tap locations on the wing and flap.

Computational Geometry

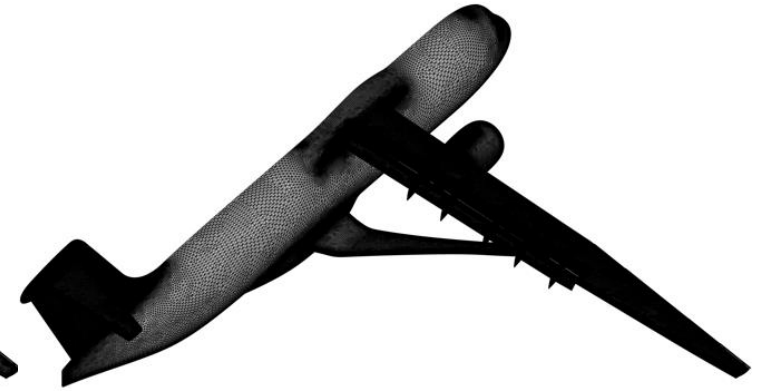
- Three versions of the **SUGAR TTBW** mesh were generated using **HeldenMesh**⁹.
- The first cell height was kept at a y^+ value of 1 (y^+ of **0.5 at the cell center**).
- Three grids including coarse (~48.8m), nominal (~96m), and fine (~212m) cells.



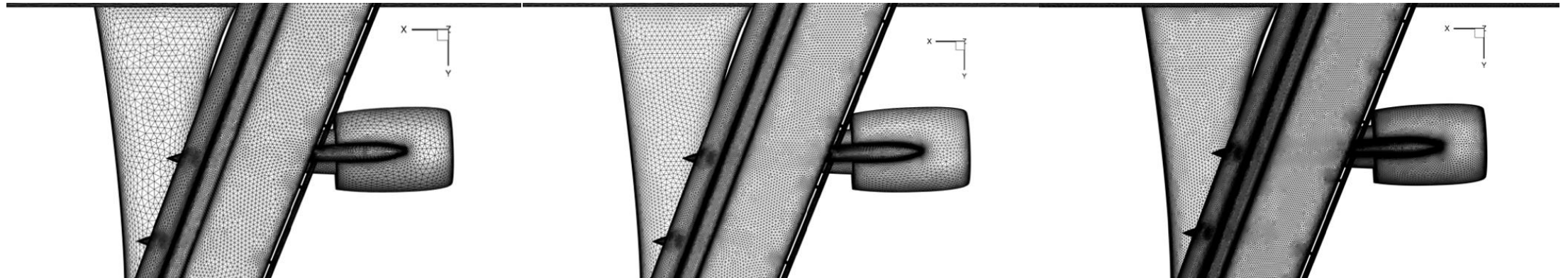
Coarse Grid



Nominal Grid



Fine Grid



Comparison of mesh density

Numerical Method

- **Solver**

- ***USM3D-Mixed Element (ME)²** – Developed at NASA Langley Research Center and successor to the **USM3D³** solver.
- **USM3D-ME** uses a strong linear solver that significantly increases computational robustness and efficiency called Hierarchical Adaptive Non-Linear Iteration Method (**HANIM**)⁴.
- The convective terms were discretized with 2nd order.
- Inviscid fluxes were computed with Roe's flux-difference-splitting (**FDS**) scheme.

- **Turbulence Modeling**

- Variants of the the negative version (**SA-Neg⁴**) of the Spalart-Allmaras turbulence model are used.
 - ❖ SA-Neg with Rotation Correction⁵ (**SA-Neg-R**).
 - ❖ SA-Neg with Rotation and Curvature Correction⁶ – (**SA-Neg-RC**).
 - ❖ SA-Neg-QCR2000⁷ – (**SA-Neg-QCR**).
 - ❖ SA-Neg-QCR2000 with Rotation Correction – (**SA-Neg-R-QCR**).
 - ❖ SA-Neg-QCR2000 with Rotation and Curvature Correction – (**SA-Neg-RC-QCR**).

*USM3D-ME Software webpage - <https://tetruss.larc.nasa.gov/>

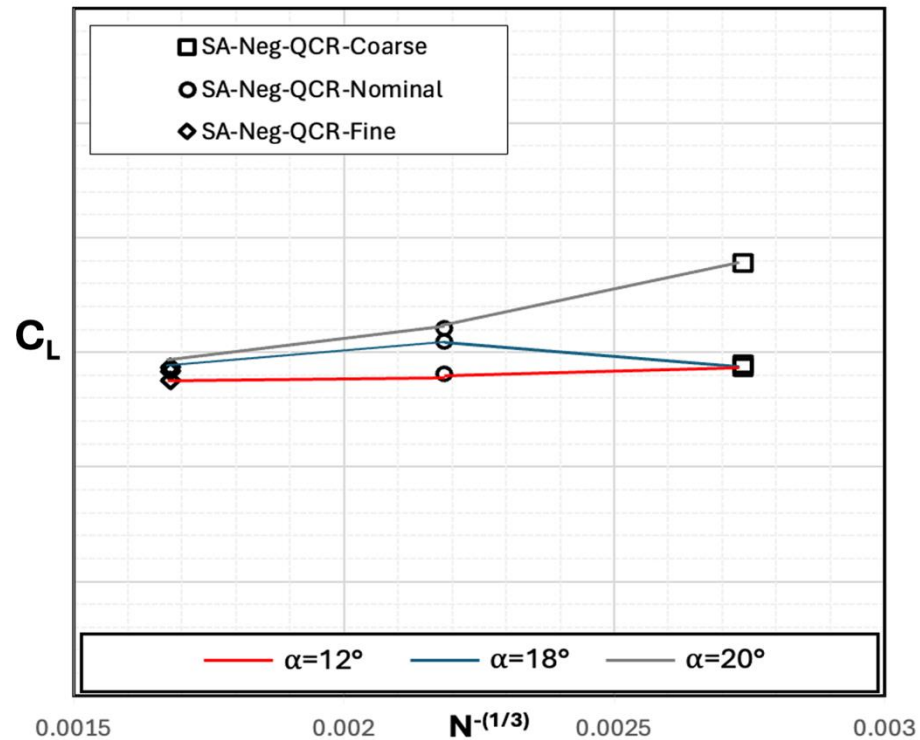
Numerical Method

- **Simulation Setup**

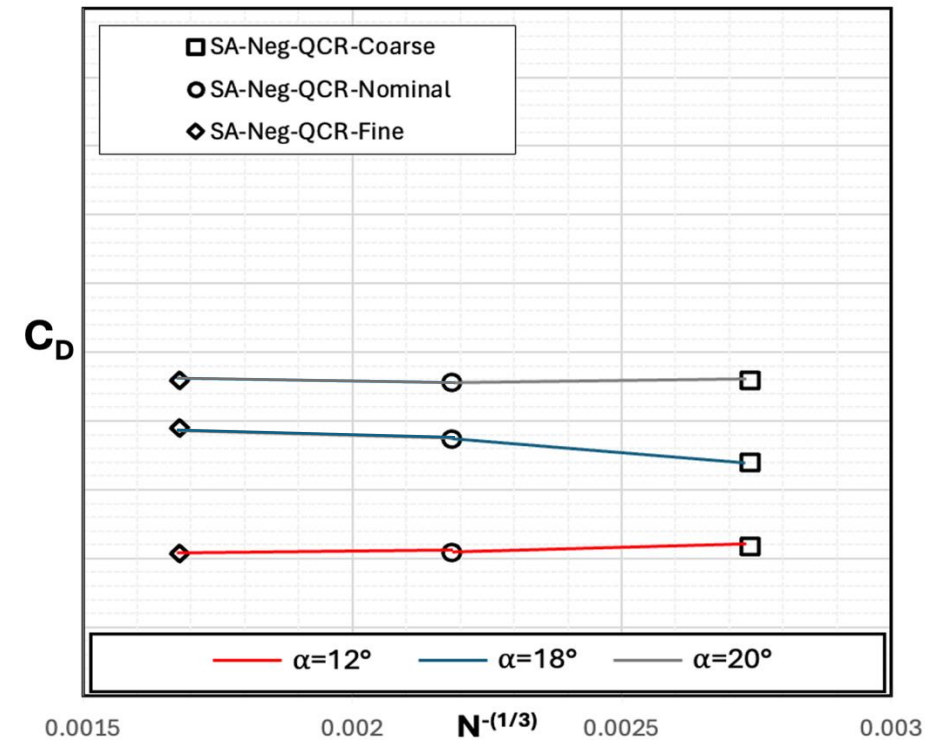
- Steady-state simulations were first run using local time-stepping and implicit defect-correction schemes.
- Once steady-state solutions were deemed to be converged, unsteady (**URANS**) simulations were carried out.
- All cases used **50 time-steps per convective time unit (CTU)** based on $M_\infty = 0.20$ and mean-chord length.
- Additionally, a maximum of **20 inner iterations per time-step** were specified for improved convergence.
- On average, we observed 5-20 sub iterations based on angle of attack.
- Variety of angles of attack (α) tested : -4° to 22° .
- Variety of turbulence models evaluated across the run matrix.
- All simulations are run steady then warm started for time-accurate simulations.
- Once the integrated forces and moments enter limit-cycle behavior, they are then averaged over the last 30 CTU's.

Mesh Sensitivity

- Some sensitivity due to grid resolution is observed for the C_L when going from coarse to the nominal grid.
- Overall, the solutions show little mesh sensitivity going from coarse to fine grid.
- Y-axis values removed for export control considerations.



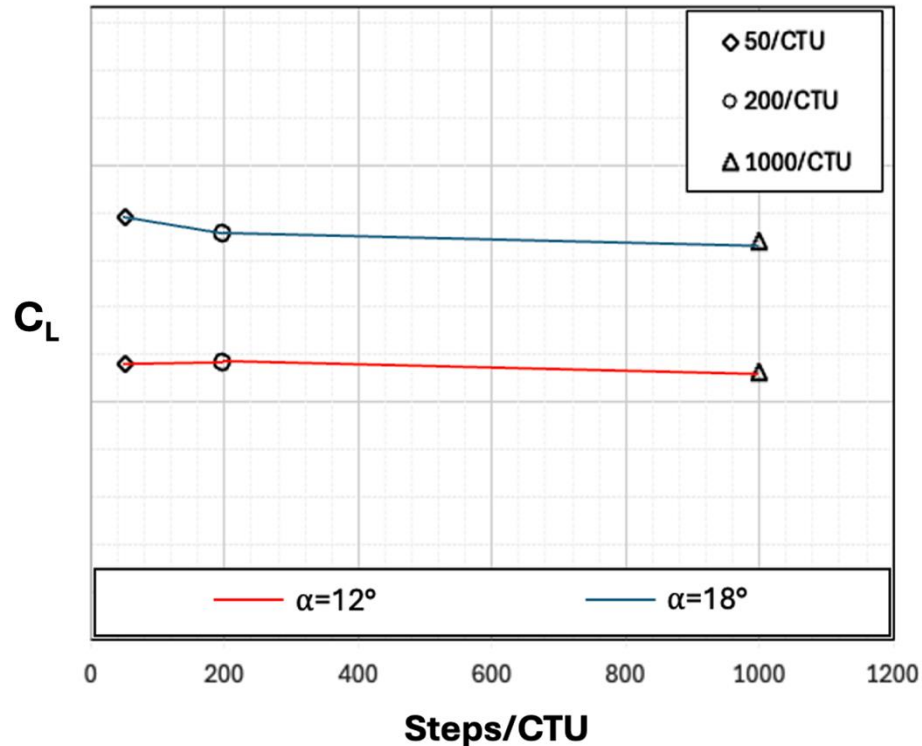
Comparison of C_L predictions for each grid



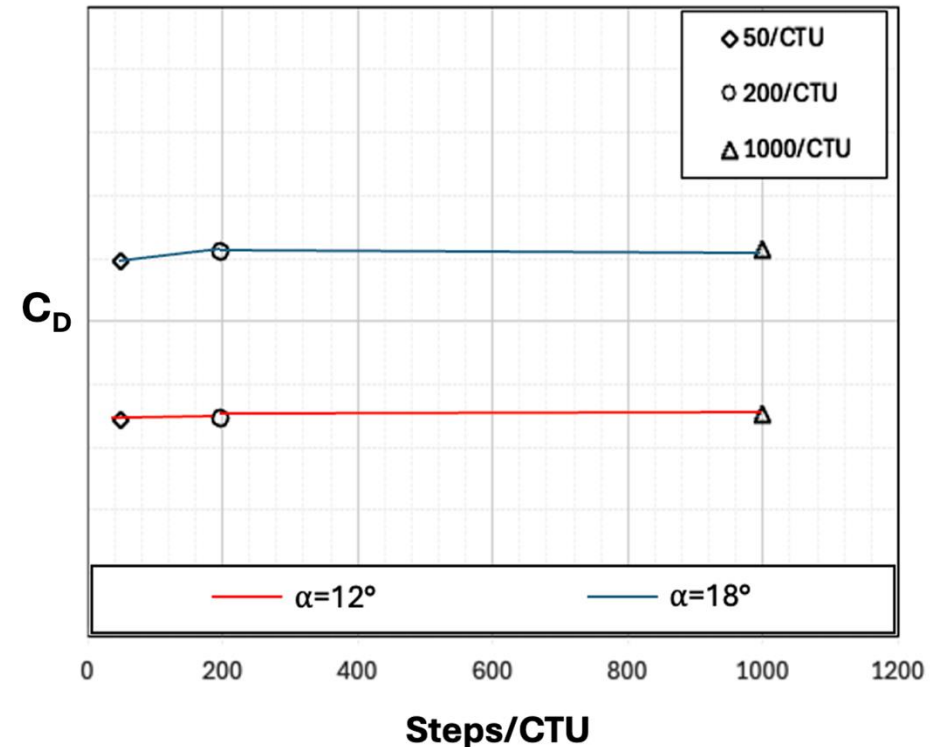
Comparison of C_D predictions for each grid

- **Time-Step Size Sensitivity (Nominal Grid)**

- Increasing the number of time-steps per CTU results in minor differences at high angles of attack.
- These minor differences are insignificant compared to the differences between simulation results and experimental observation.



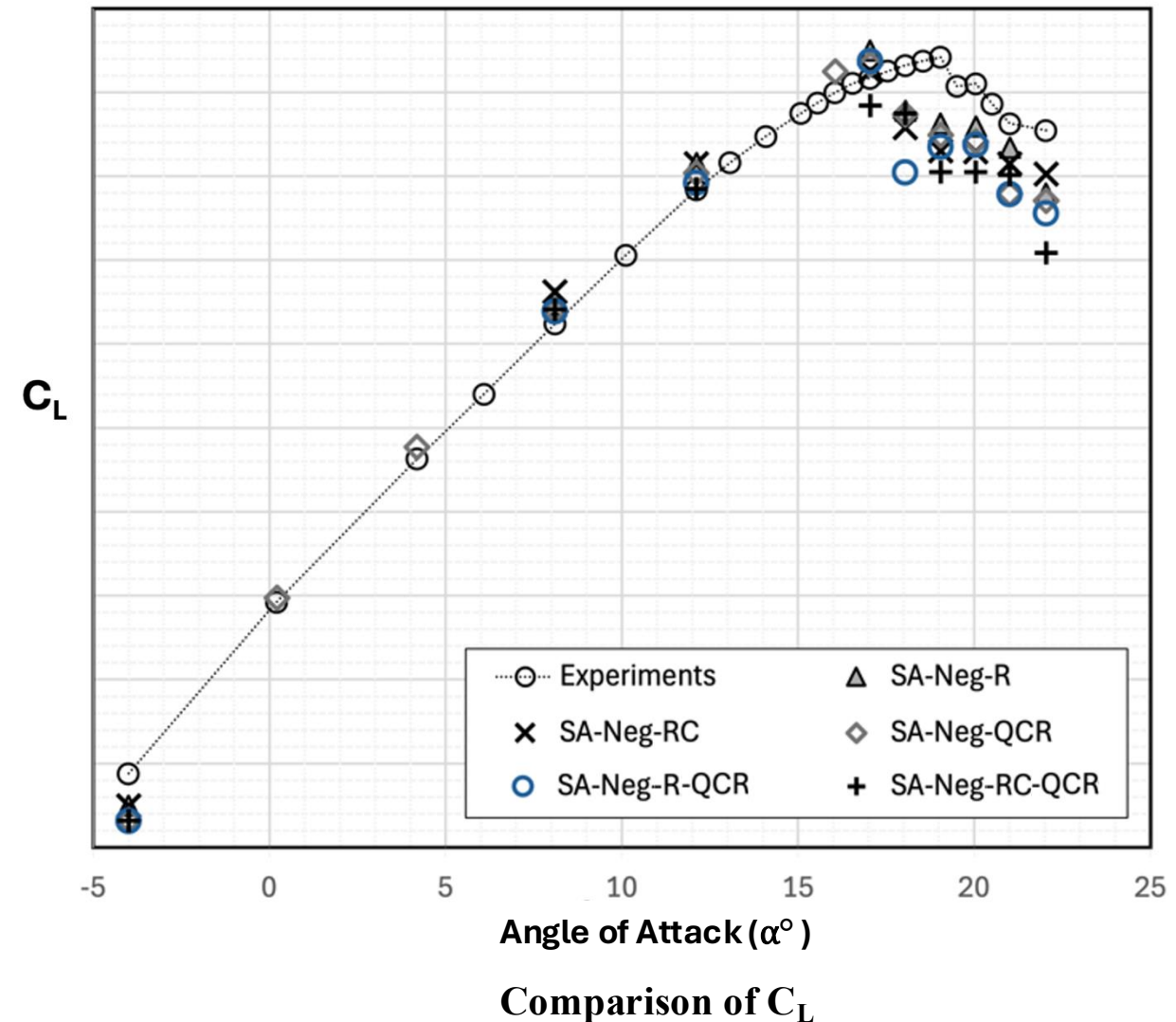
Comparison of C_L predictions for different CTU



Comparison of C_D predictions for different CTU

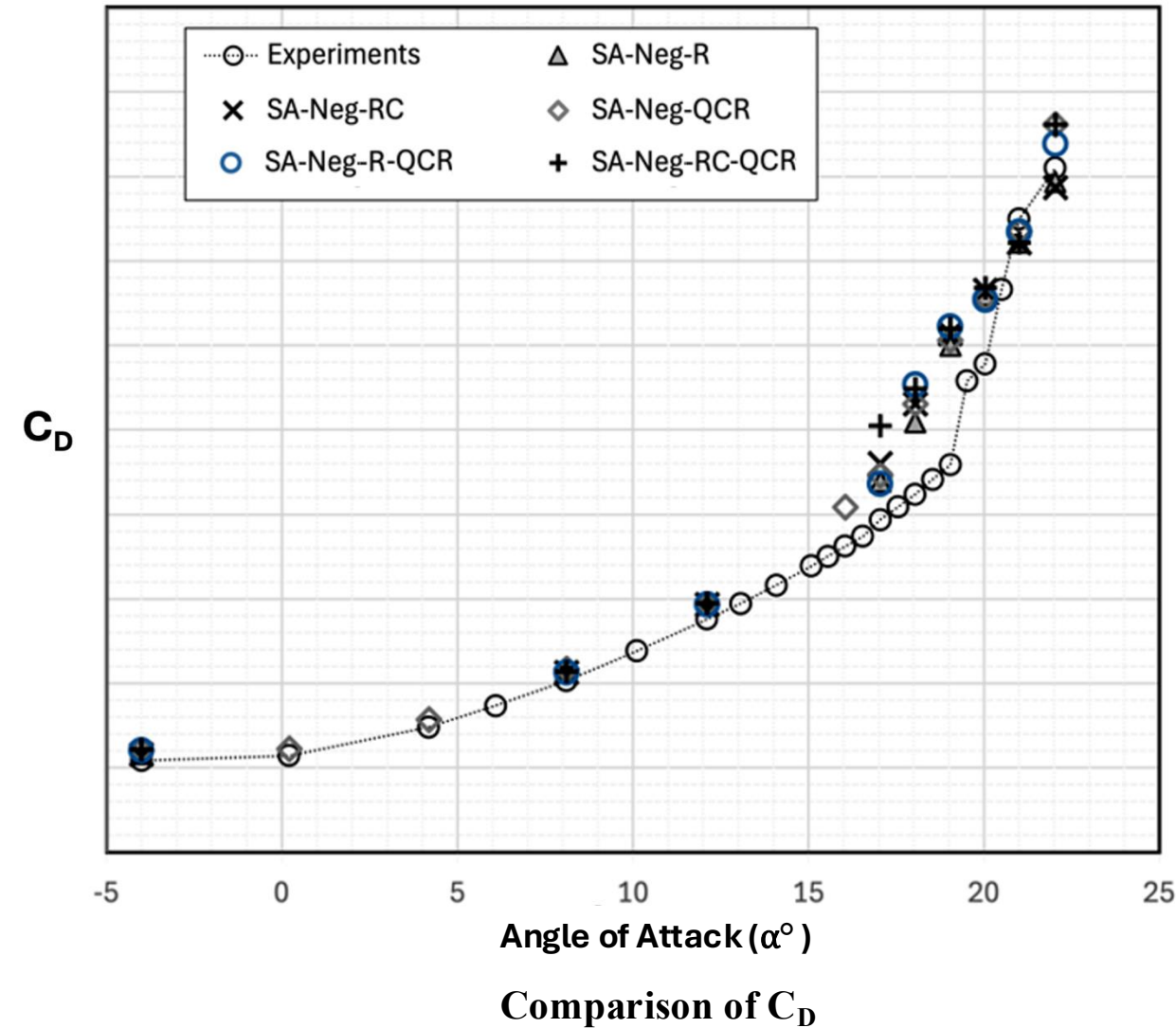
• Lift Coefficient (C_L)

- Lift and drag are predicted with relatively high accuracy for the linear region of the lift curve.
- Although at $\alpha = -4^\circ$ all the models underpredict lift.
- Lift break past $\alpha = 12^\circ$ is also well captured.
- Models predict stall between $\alpha = 17^\circ$ - 18° .
- Post-stall, both the SA-Neg variants' (R and RC) predictions are in best agreement with experimental measurements.
- Although the post-stall trends are similar to experimental observations, all the models underpredict lift significantly.
- A new variant of the SA model has been recently shown to improve predictive capabilities. More information will be shared in the future.



- **Drag Coefficient (C_D)**

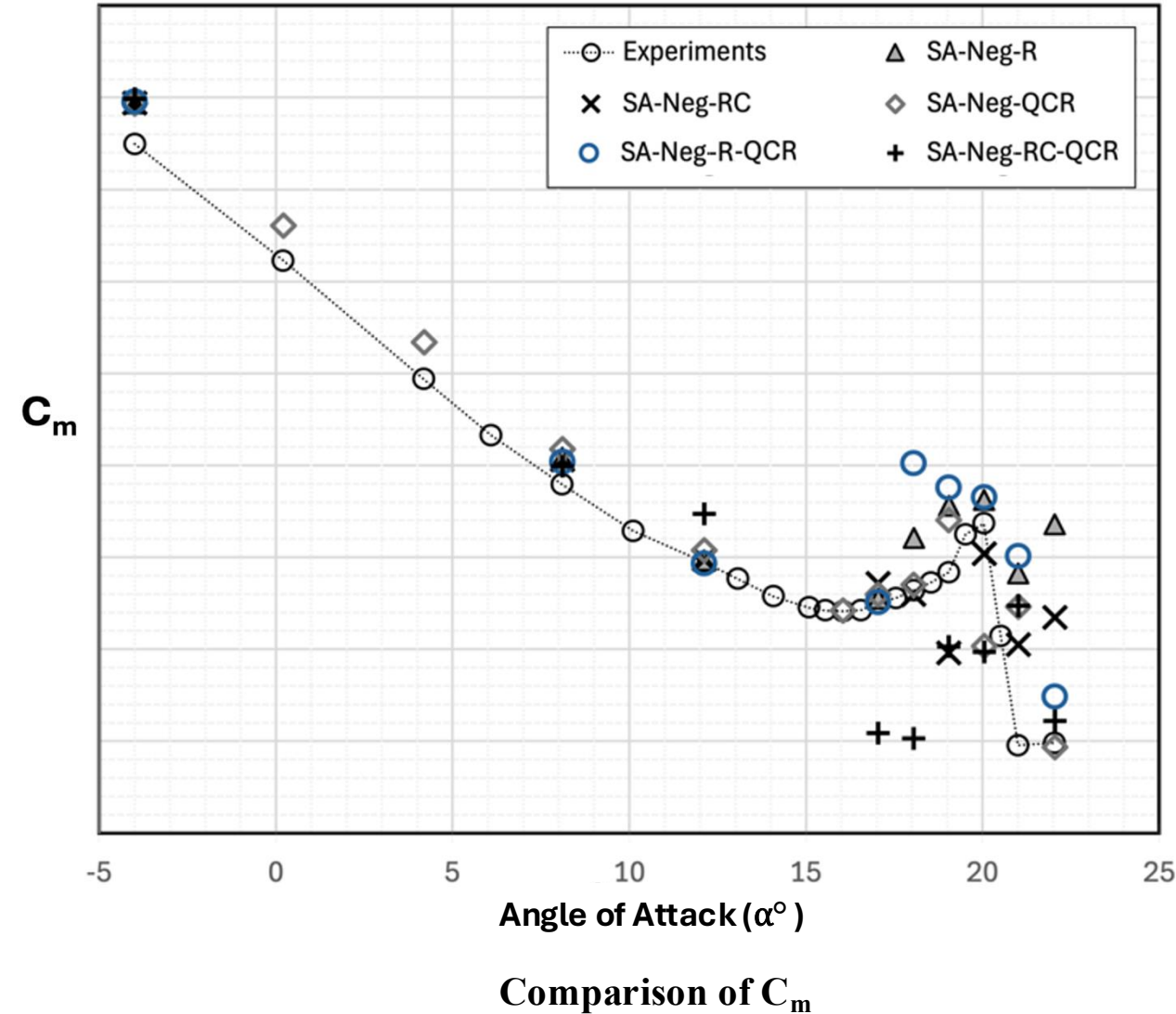
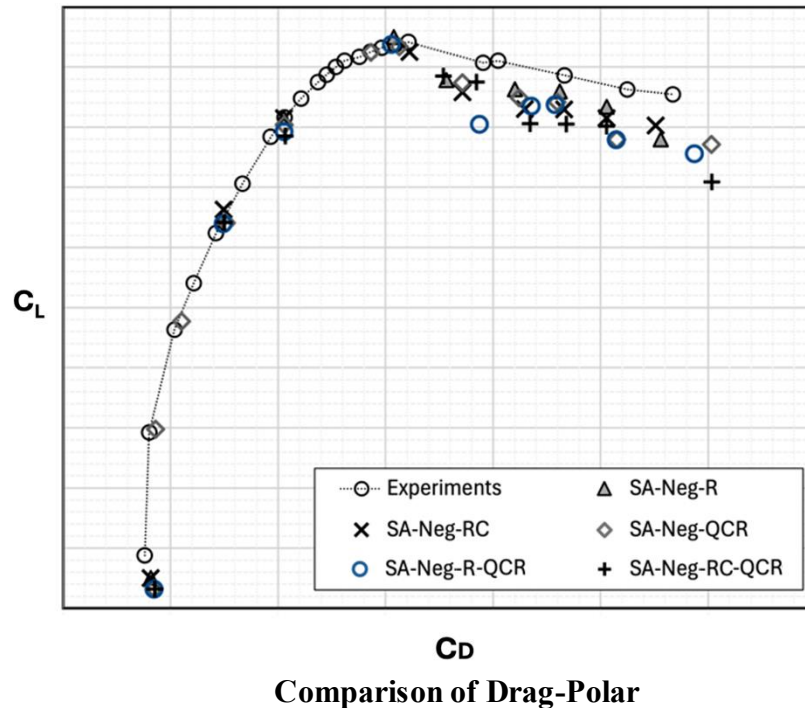
- Most of the pre-stall angles are well predicted.
- Major differences start to appear near stall between $\alpha = 17^\circ$ - 18° .
- All the models behave similarly and overpredict drag.
- For $\alpha = 20^\circ$ - 22° , drag is once again predicted with higher accuracy.



Results

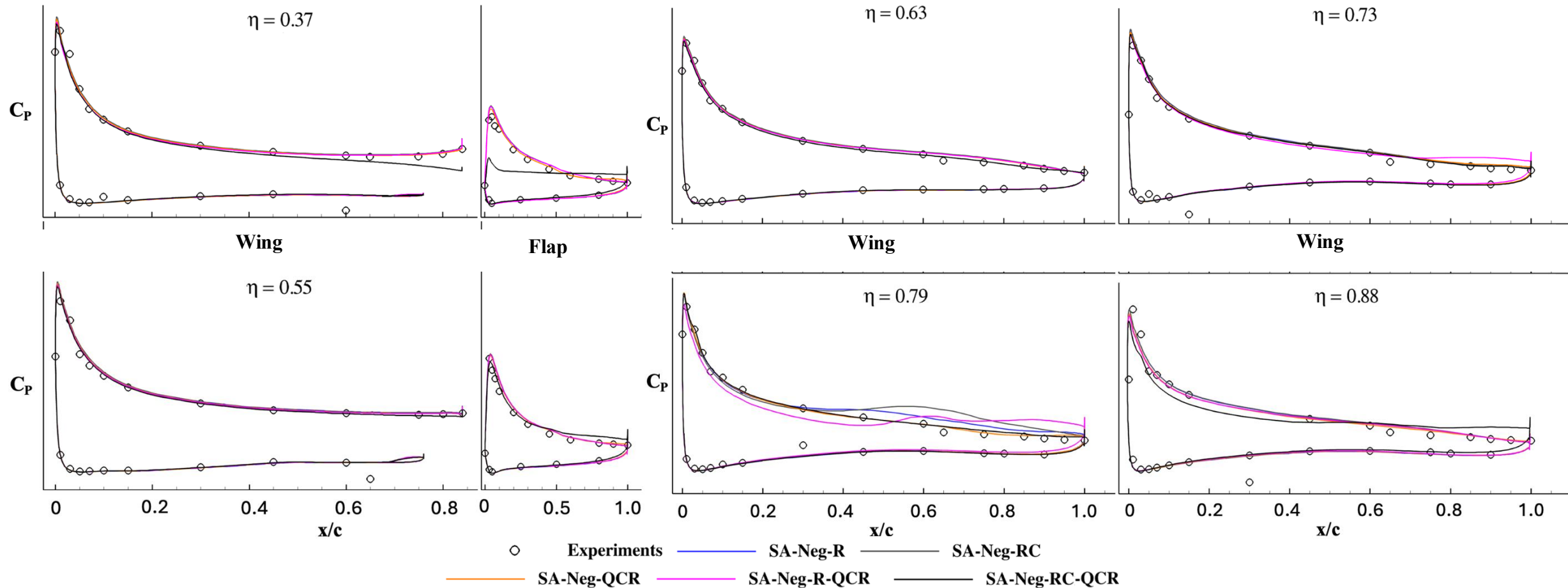
• Drag Polar (C_D vs C_L) and Pitching Moment (C_m)

- Pitching moment is predicted with relatively high accuracy for $\alpha < 15^\circ$.
- Post pitch-break, the SA-Neg-QCR performs the best.
- Overall, all the model predictions are in reasonable agreement until stall.



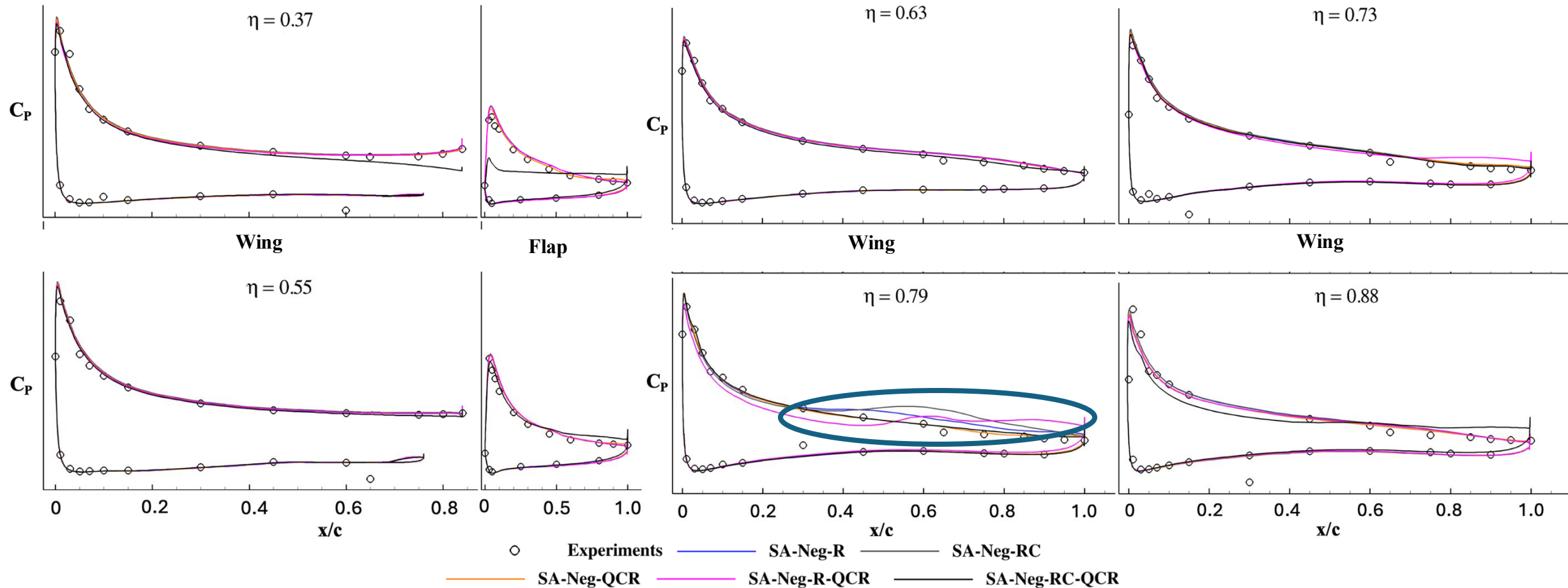
Results (Pressure Coefficient (C_p) – Wing and Flap ($\alpha = 12^\circ$))

- For $\alpha = 12^\circ$ all the models are in relative agreement with experimental data.
- SA-Neg-RC-QCR model predicts a separated flap at $\eta = 0.37$.
- On the main wing for at $\eta \geq 0.73$, some disagreements between the experimental data and the simulations are observed.



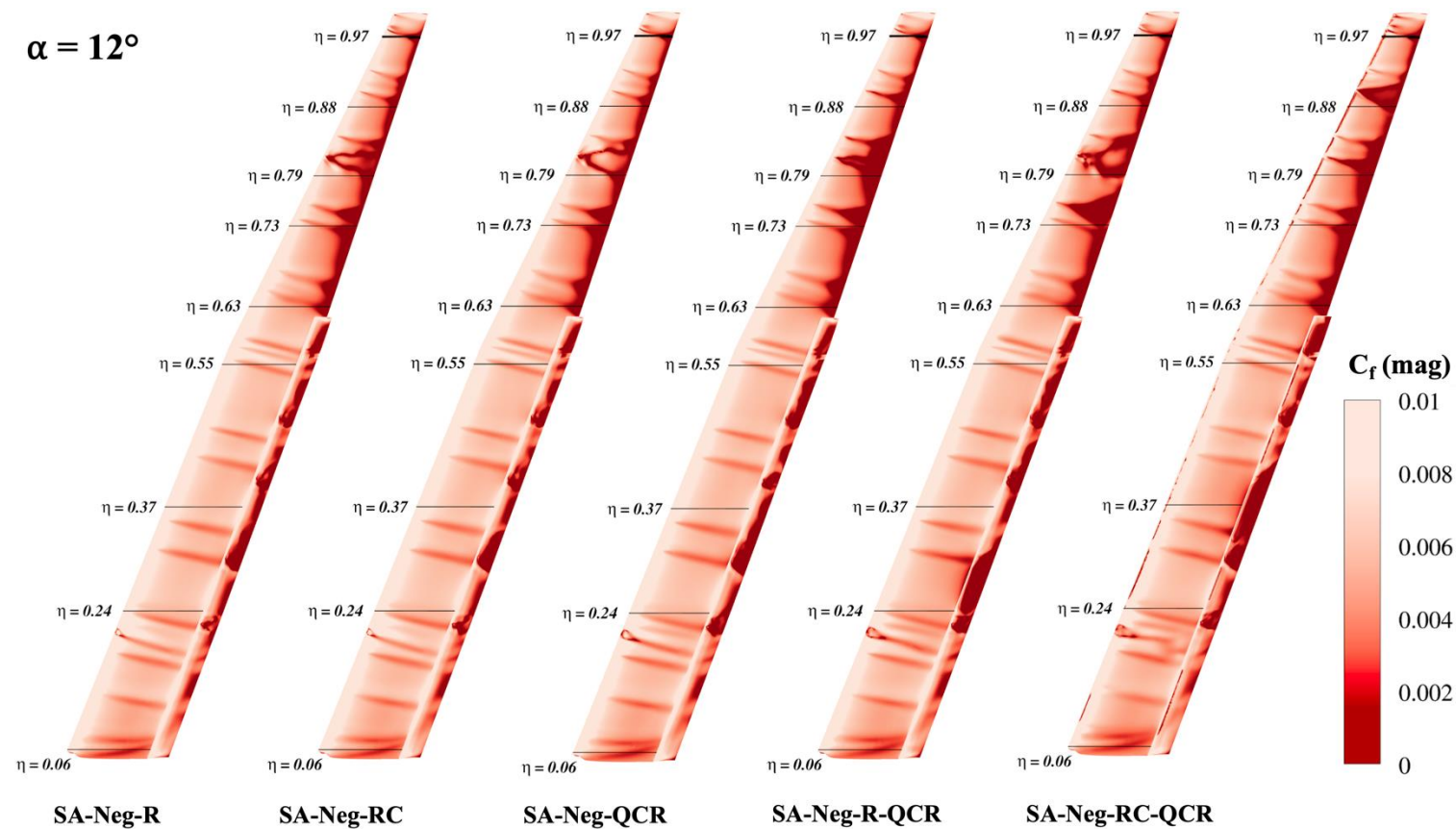
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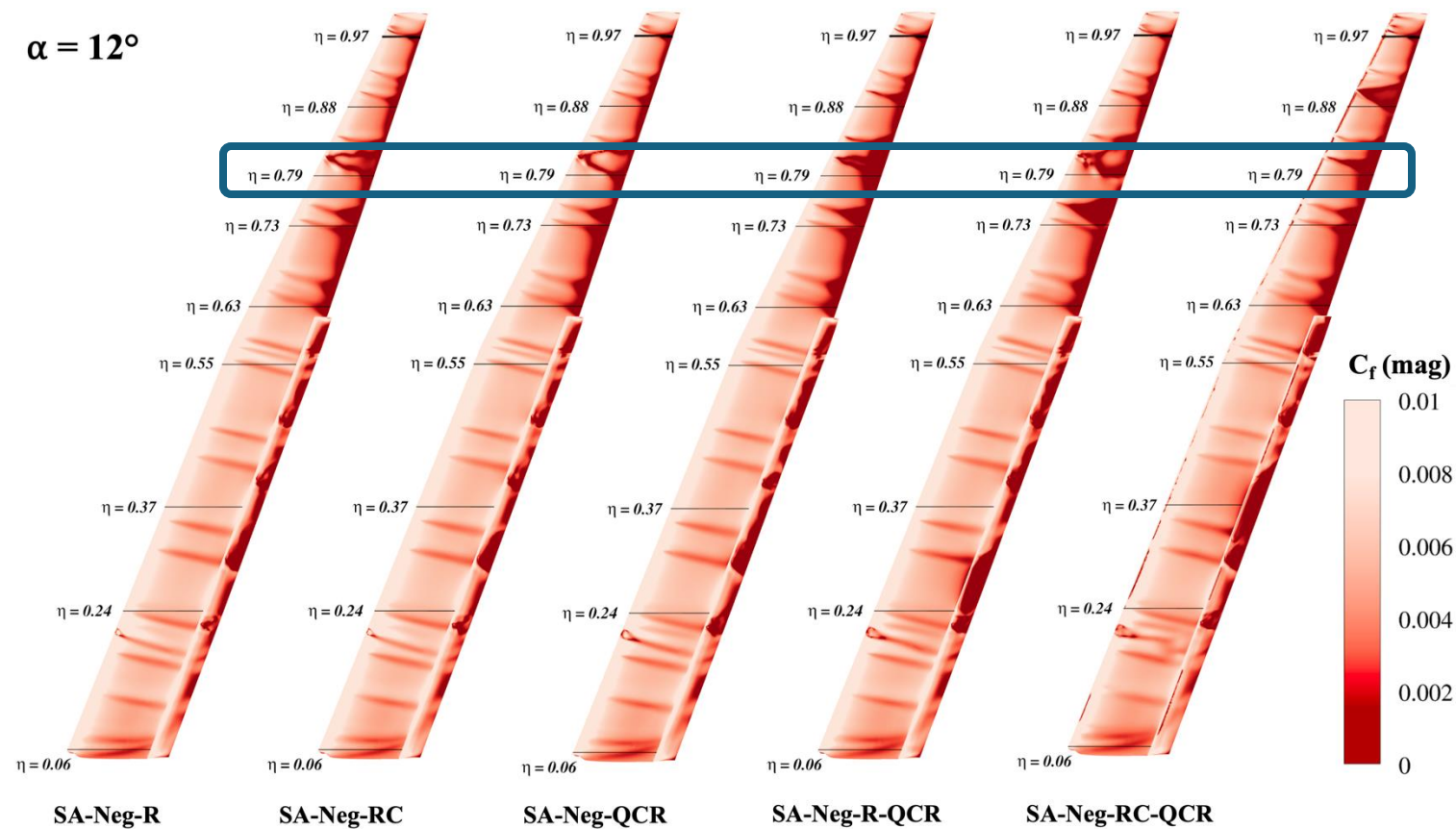
Results (Instantaneous Skin Friction (C_f) Magnitude ($\alpha = 12^\circ$))

- On the main wing for at $\eta \geq 0.73$, some disagreements begin to arise where low skin friction zones appear indicating separated flow.
- These regions keep growing as angle of attack is increased and for the separated wedges also known as ‘pizza slices’.



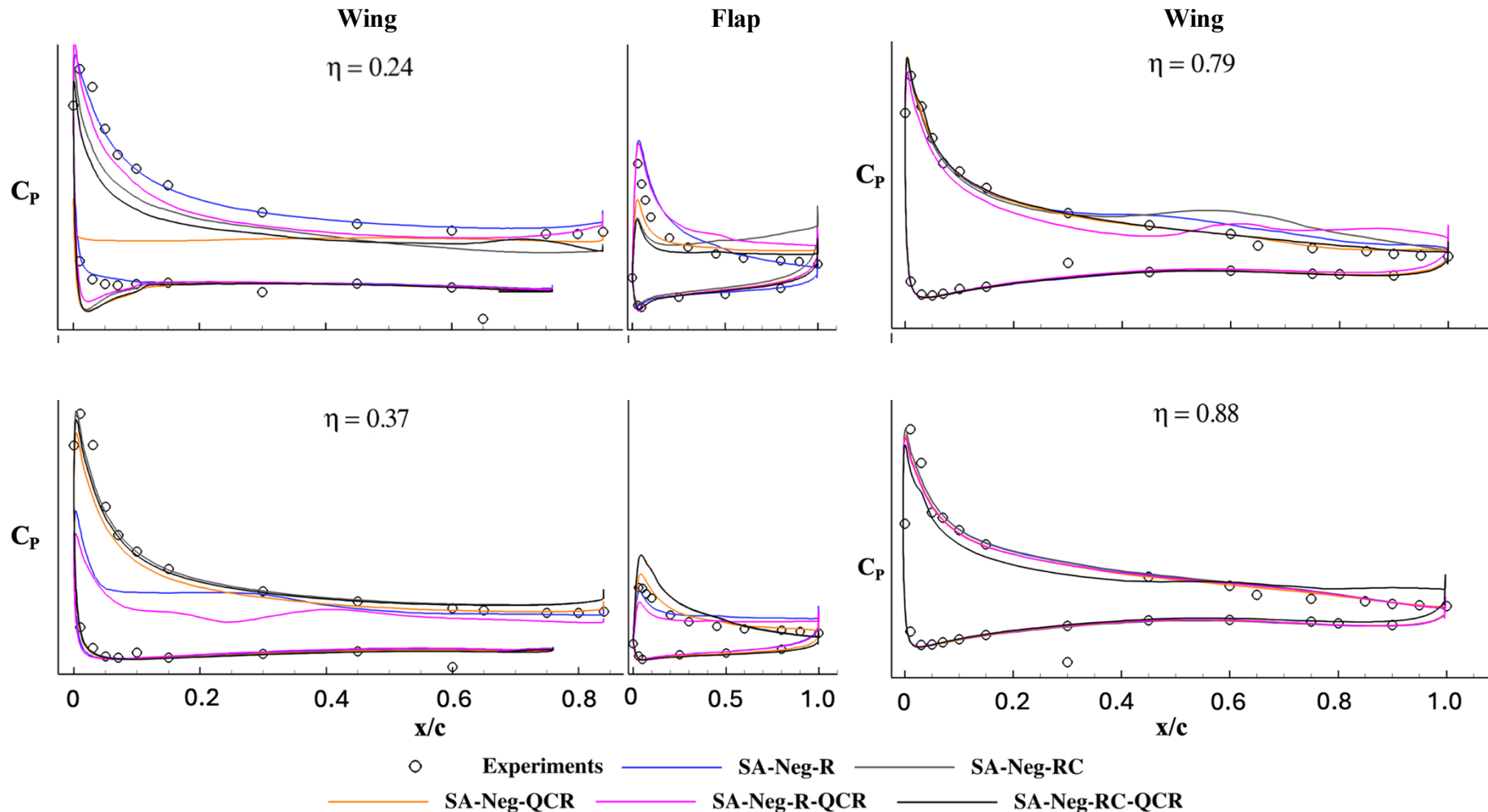
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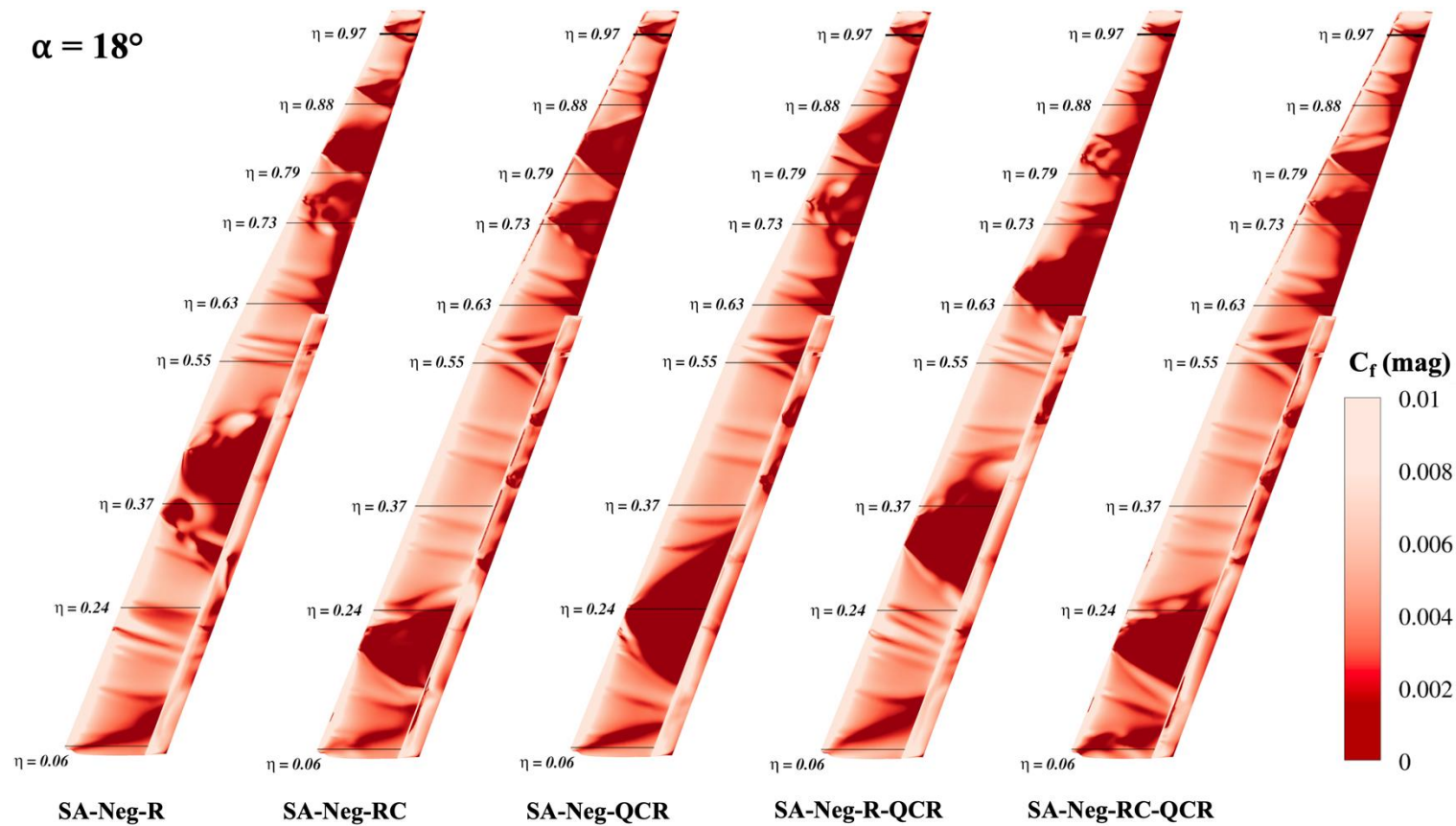
Results (Pressure Coefficient (C_p) – Wing and Flap ($\alpha = 18^\circ$))

- For $\alpha = 18^\circ$, at $\eta = 0.24$, the SA-Neg-QCR model predicts separation, while all the other models predict attached flow.
- At $\eta = 0.37$, the SA-Neg-R and the SA-Neg-R-QCR models predict separation. SA-Neg-QCR predicts a separated zone at $\eta = 0.24$.



Results (Instantaneous Skin Friction (C_f) Magnitude ($\alpha = 18^\circ$))

- Large patches of separated flow appear on the inboard side of the wing from the wakes shed by the nacelle ($\eta \sim 0.20$).
- Regions of separated flow or 'pizza slices' appear throughout the wing.



- Time-accurate numerical simulations of the SUGAR TTBW high-lift configuration are carried out using USM3D-ME solver for
 - $\alpha = -4^\circ$ to 22° at $M_\infty = 0.20$ based on $Re_c = 0.98 \times 10^6$.
 - Using multiple SA turbulence models.
- Predictions are close to experiments in the linear region of the lift-curve except for $\alpha = -4^\circ$.
- The models also predict features, such as lift-break, relatively accurately, which are sometimes challenging for RANS models.
- All models inaccurately predict early stall around $\alpha \sim 17^\circ$ while experiments predict stall at $\alpha \sim 19.5^\circ$.
- Early stall and inconsistent pitching moment predictions are attributed to separated wedges also known as ‘pizza slices’.
- ‘Pizza slices’ initially dominate the outboard side of the wing at low angles of attack before migrating inboard around stall.
- Overall, it is concluded that:
 - RANS based models are able to predict the aerodynamic behavior of high-lift configurations in the linear region of the lift curve.
 - Predictions deteriorate near stall where large scale unsteadiness dominates the flowfield.
 - Due to these challenges, at high angles of attack, scale-resolving simulations such as hybrid RANS-LES models should be considered.

References (presentation)

1. Harrison, N.A., Hoffman, K., Lazzara, D.S., Reichenbach, E.Y., Sclafani, A.J., and Droney, C.K., “Subsonic Ultra Green Aircraft Research: Phase IV Final Report–Volume I Mach 0.80 Transonic Truss-Braced Wing High-Speed Design Report,” 2023
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QUESTIONS?

