NASA Trap Wing Model
OVERFLOW Analysis

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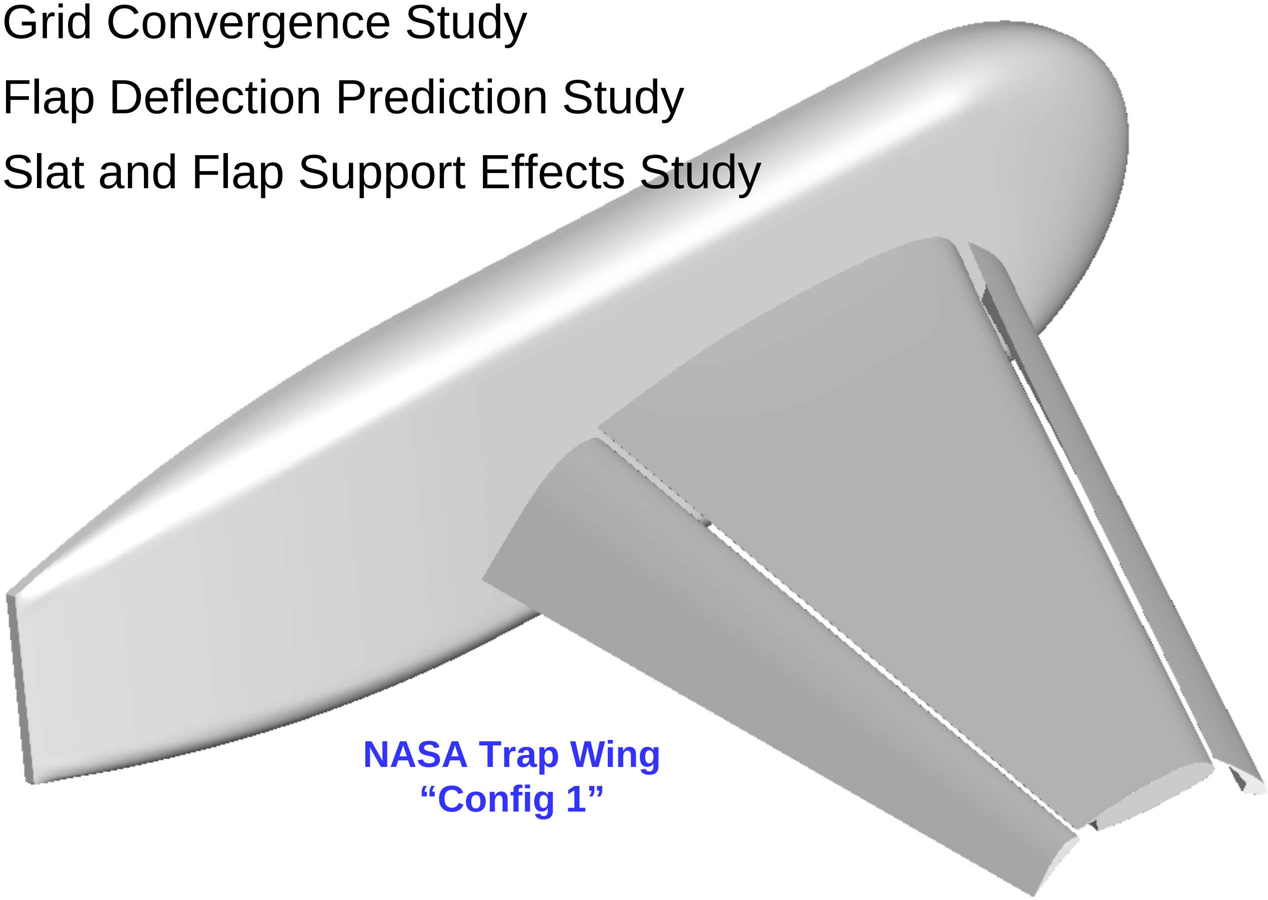
Outline

- Flow Solver / Computing Platform
- Grid Information
- Convergence Histories and Residuals
- Results
  - Test Case 1: Grid Convergence Study
  - Test Case 2: Flap Deflection Prediction Study
  - Test Case 3: Slat and Flap Support Effects Study
- Conclusions
- Future Work



NASA Trap Wing
“Config 1”

OVERFLOW MPI version 2.1ad – *Default Setup for High Lift Studies*

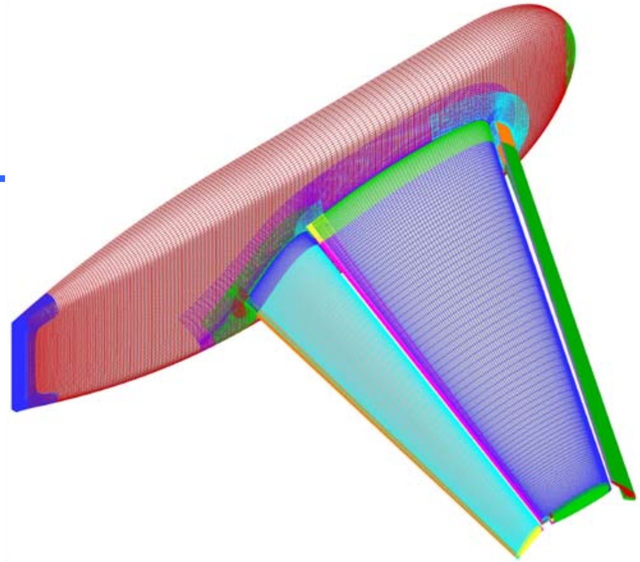
- Roe upwind differencing
- Spalart-Allmaras (SA) turbulence model – version “fv3”
- full Navier-Stokes
- low-Mach preconditioning
- steady state
- all cases run from scratch (i.e., freestream initial condition)

Parallel Processing on a PC Cluster

- Linux 64bit operating system with 1968 CPUs on 578 nodes
  - 120 2.6GHz Opteron dual core nodes with 8GB of RAM
  - 80 3.0GHz Xeon dual dual-core nodes with 12GB of RAM
  - 112 2.2GHz Opteron dual quad-core nodes with 16GB of RAM
- Config 1 medium grid (25 million points) run on 24 processors
  - 18.7 seconds per iteration
  - Full convergence reached after 5000 iterations
  - Roughly 26 hours of wall clock time needed per case

NASA Trap Wing OVERFLOW Analysis

Grid Information for "Str-Overset-A-v3"



Structured Overset Grid Systems

- 34 zones for Bracket-Off (28 surface abutting)
- 62 zones for Bracket-On (56 surface abutting)

Config 1 and Config 8 (body-slat-wing-flap)

Grid	Points	$1/N^{2/3} \times 10^5$	1st Cell Size	y^+	Constant Cells	Growth Rate
Coarse	10,653,004	2.07	.00017 in	.87	2	1.25
Medium	24,965,818	1.17	.00013 in	.66	3	1.18
Fine	83,302,438	0.52	.00009 in	.44	4	1.12
Extra-Fine	281,560,012	0.23	.00006 in	.29	6	1.08

Config 1 (body-slat-wing-flap-brackets)

Grid	Points	$1/N^{2/3} \times 10^5$	1st Cell Size	y^+	Constant Cells	Growth Rate
Medium	58,175,676	0.67	.00013 in	.66	3	1.18

NASA Trap Wing OVERFLOW Analysis
Convergence Histories – Lift

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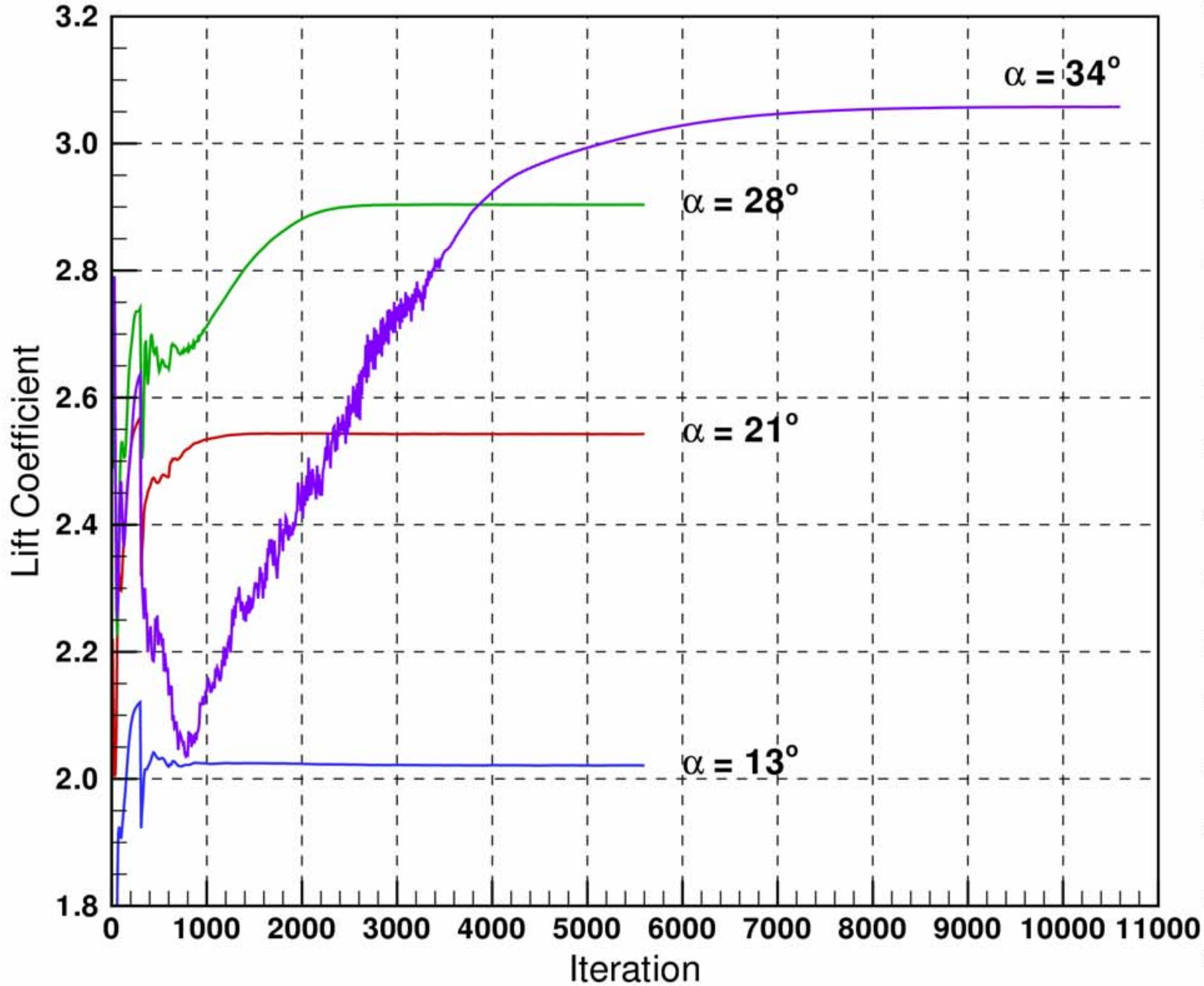
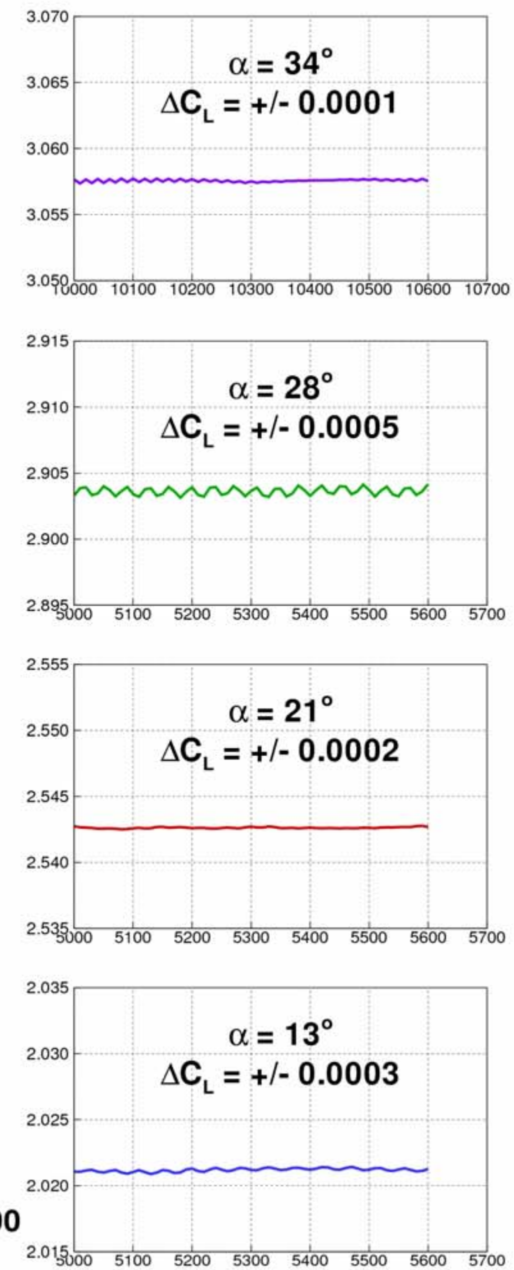
OVERFLOW Convergence Histories - Lift

- > Config 1 Medium Grid Solutions
- > Slat/Flap Brackets Off
- > Fully Turbulent, Free Air
- > RN = 4.3 million, Mach = 0.2





NASA Trap Wing OVERFLOW Analysis
Convergence Histories – Drag

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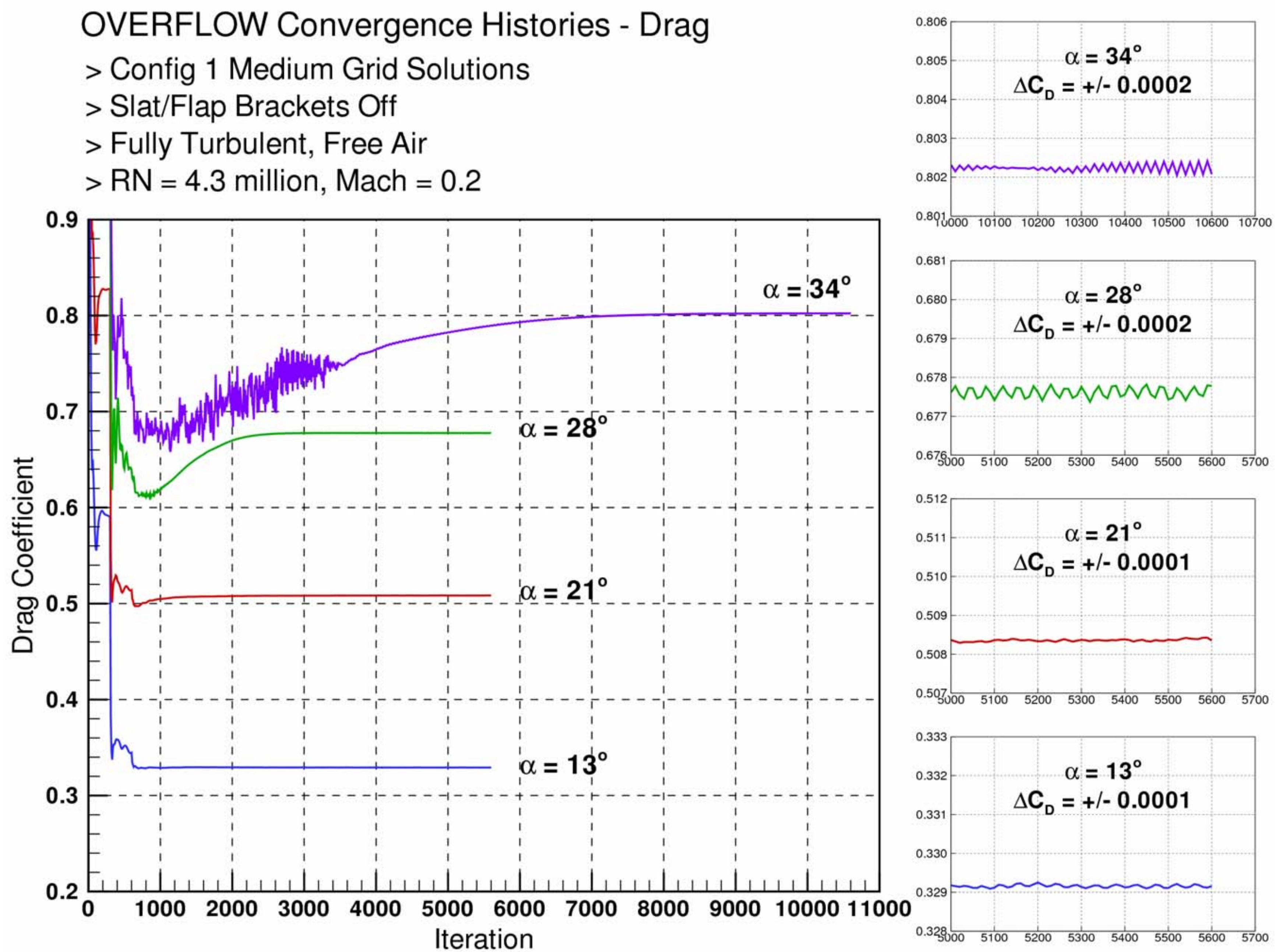

NASA Trap Wing OVERFLOW Analysis
Convergence Histories – Pitching Moment

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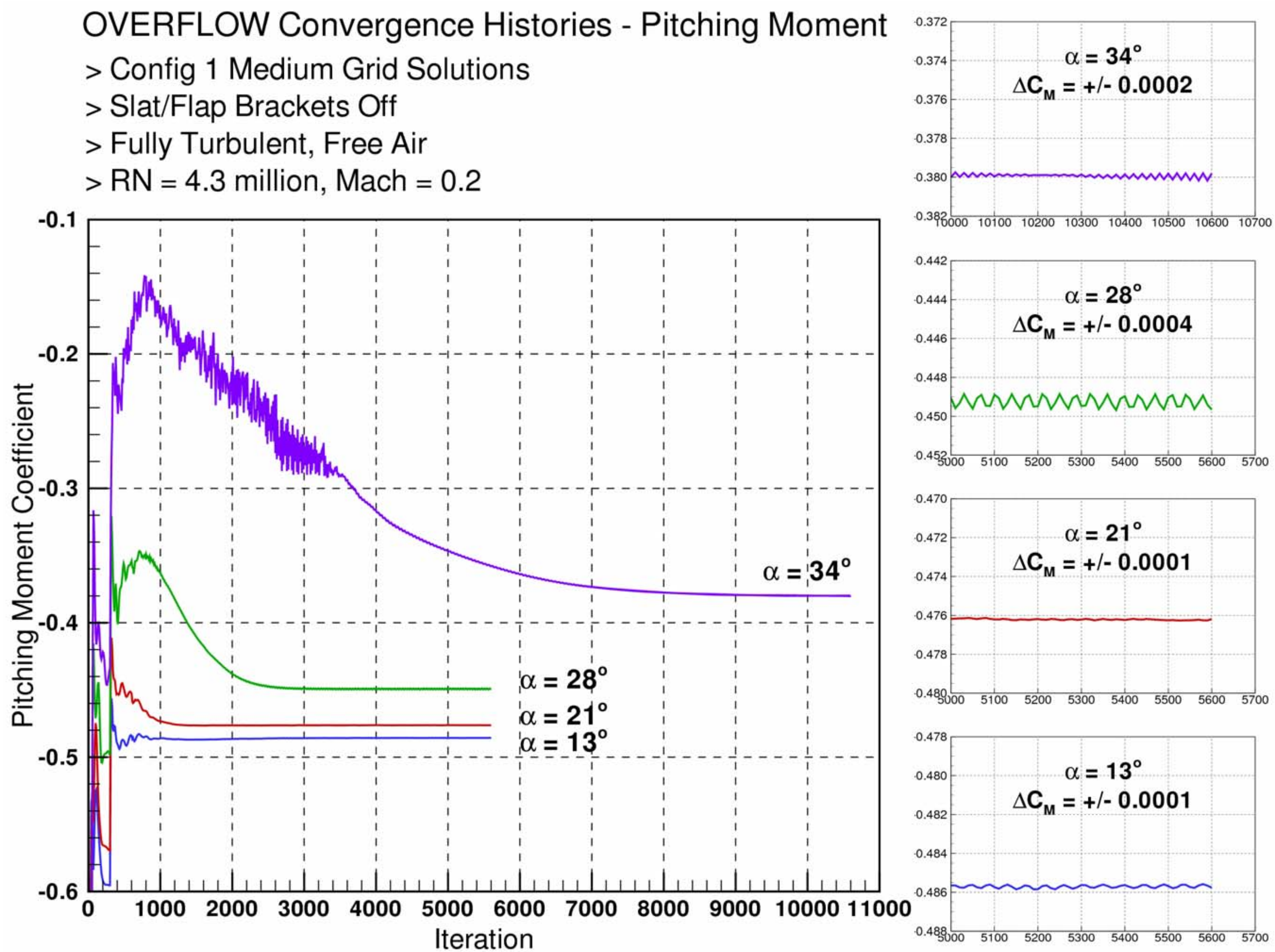

Config 1 Force and Moment Plus/Minus "Error Band"

Given as Percent Total

Medium Grid

α	ΔC_L	ΔC_D	ΔC_M
13°	.03	.05	.06
21°	.02	.03	.03
28°	.03	.07	.19
34°	.01	.04	.10

$\alpha = 13^o$

grid	ΔC_L	ΔC_D	ΔC_M
coarse	.01	.03	.02
medium	.03	.05	.06
fine	.06	.13	.16
extra-fine	1.01	1.45	1.33

NASA Trap Wing OVERFLOW Analysis
Config 1 Residuals

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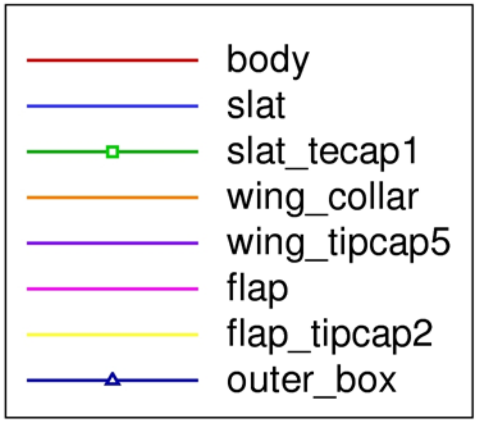
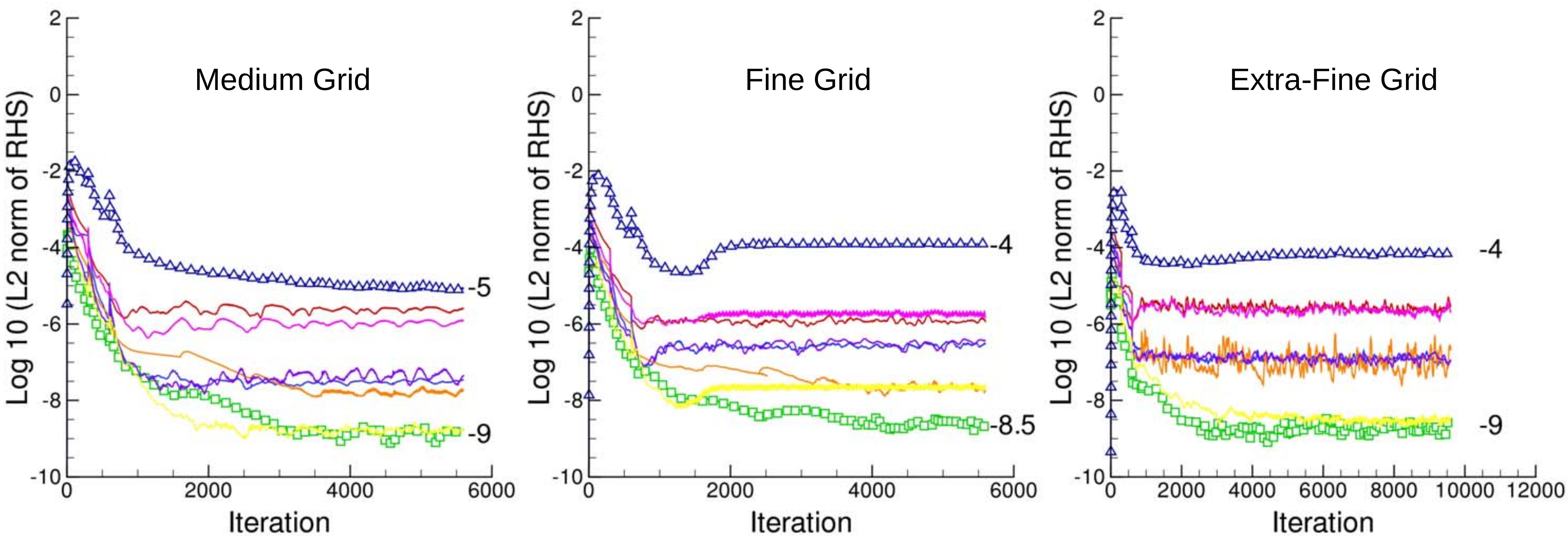
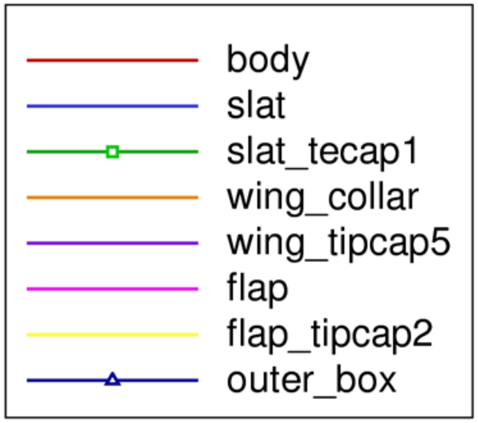
- Slat/Flap Brackets Off
- Fully Turbulent, Free Air
- RN = 4.3 mil, Mach = 0.2
- $\alpha = 13^o$
- Higher alpha solutions have similar residuals

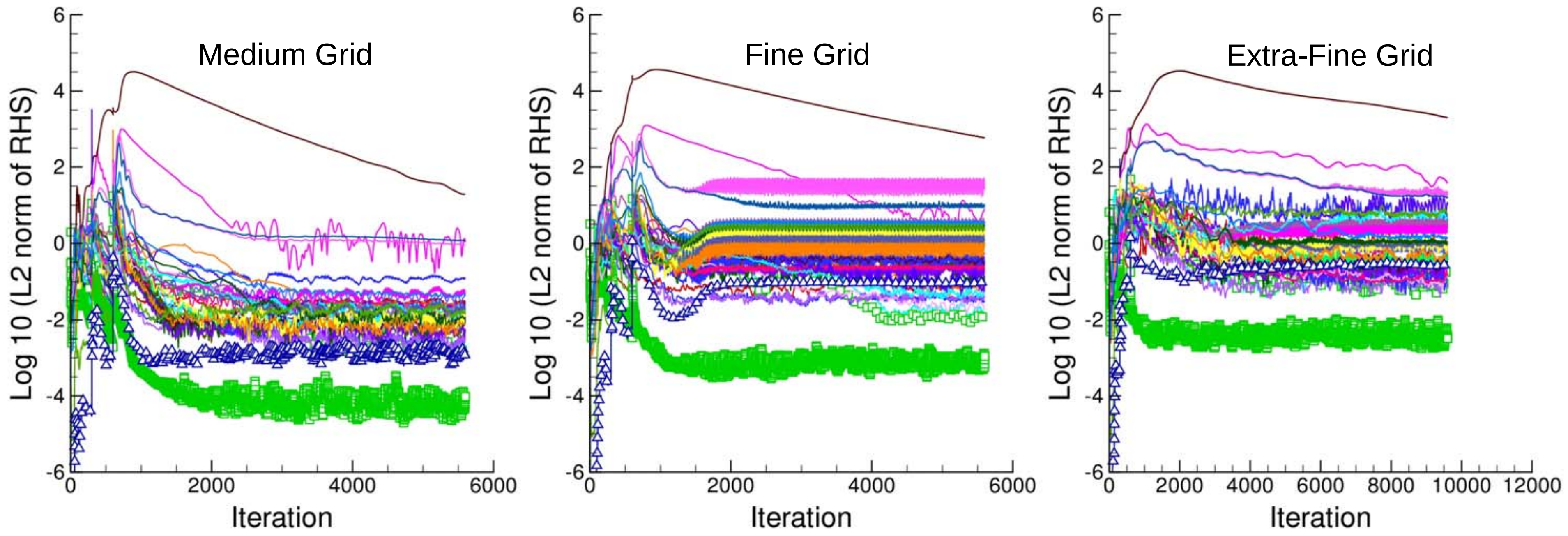




NASA Trap Wing OVERFLOW Analysis
Config 1 Turbulence Model Residuals

- Slat/Flap Brackets Off
- Fully Turbulent, Free Air
- RN = 4.3 mil, Mach = 0.2
- $\alpha = 13^o$





When comparing CFD with wind tunnel data, remember the following.

- Brackets
- Transition
- Walls
- Aeroelastics

Test Case 1

Grid Convergence Study

Test Case 1 – Grid Convergence Study

Config 1: Total Lift at $\alpha = 13^o$

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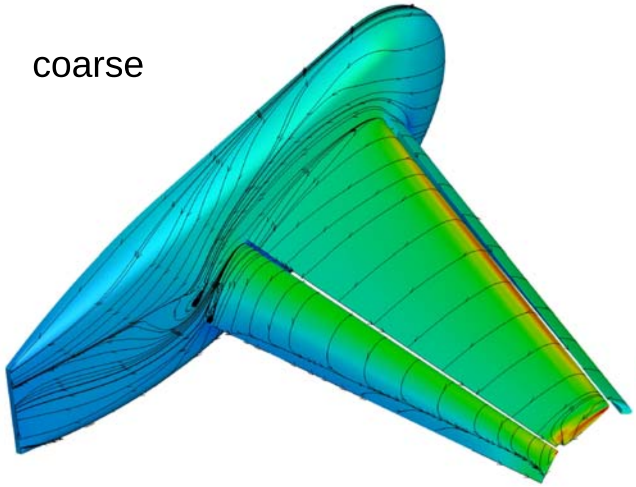
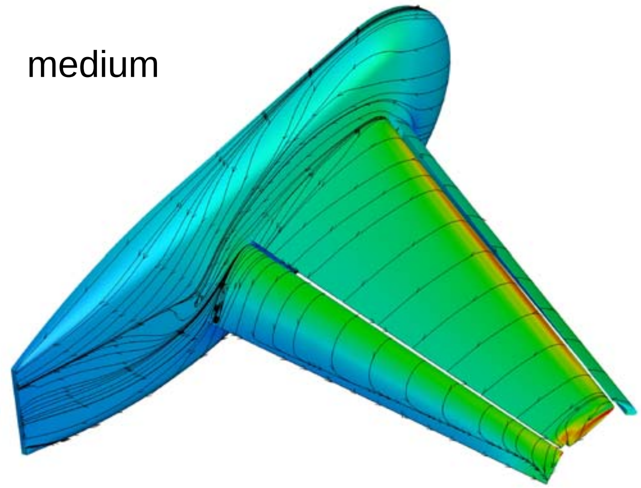
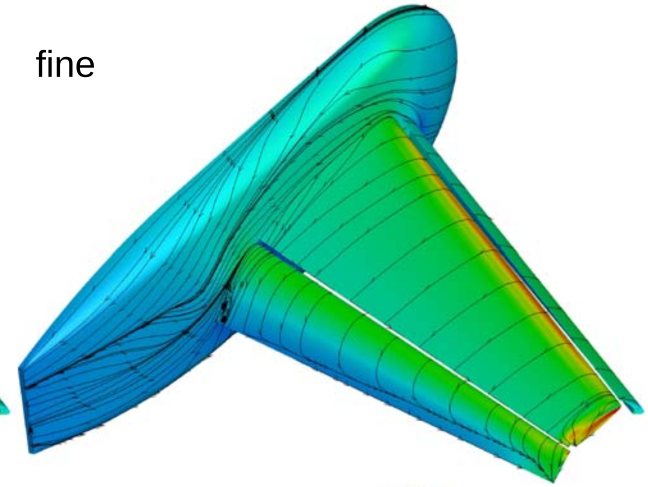
coarse

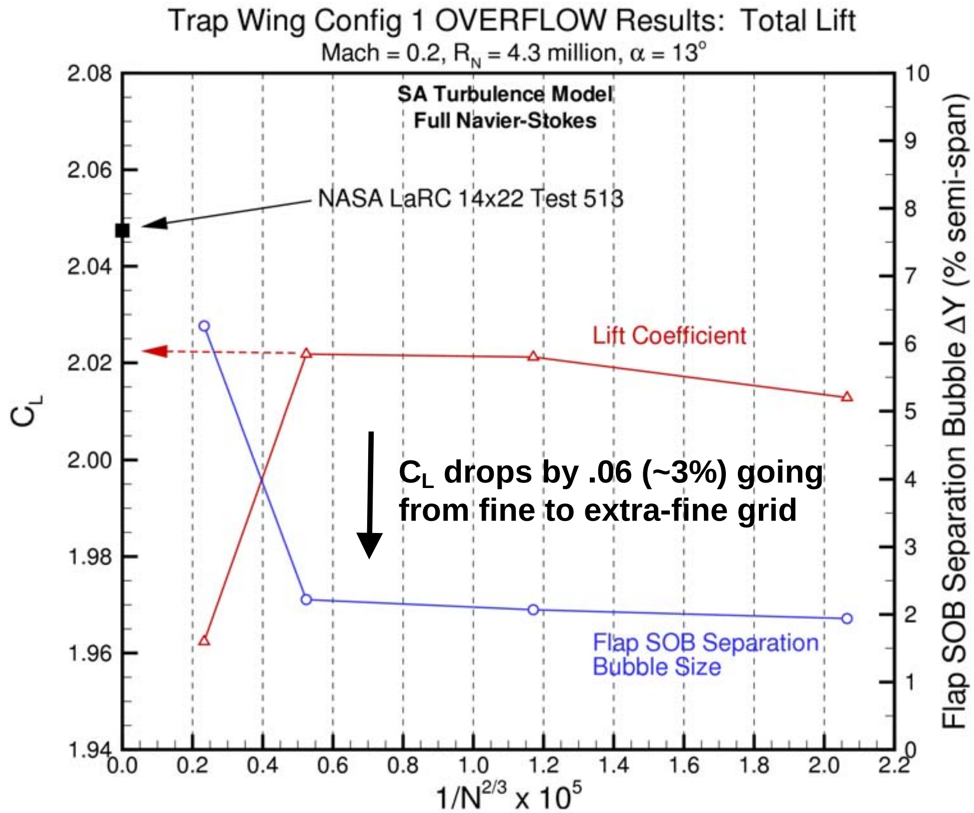


medium

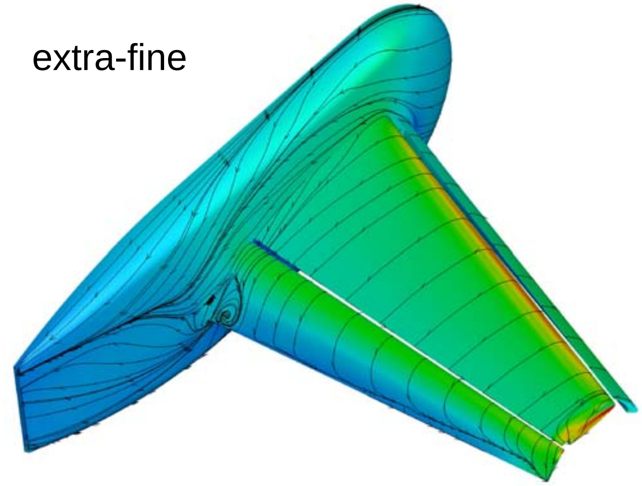


fine





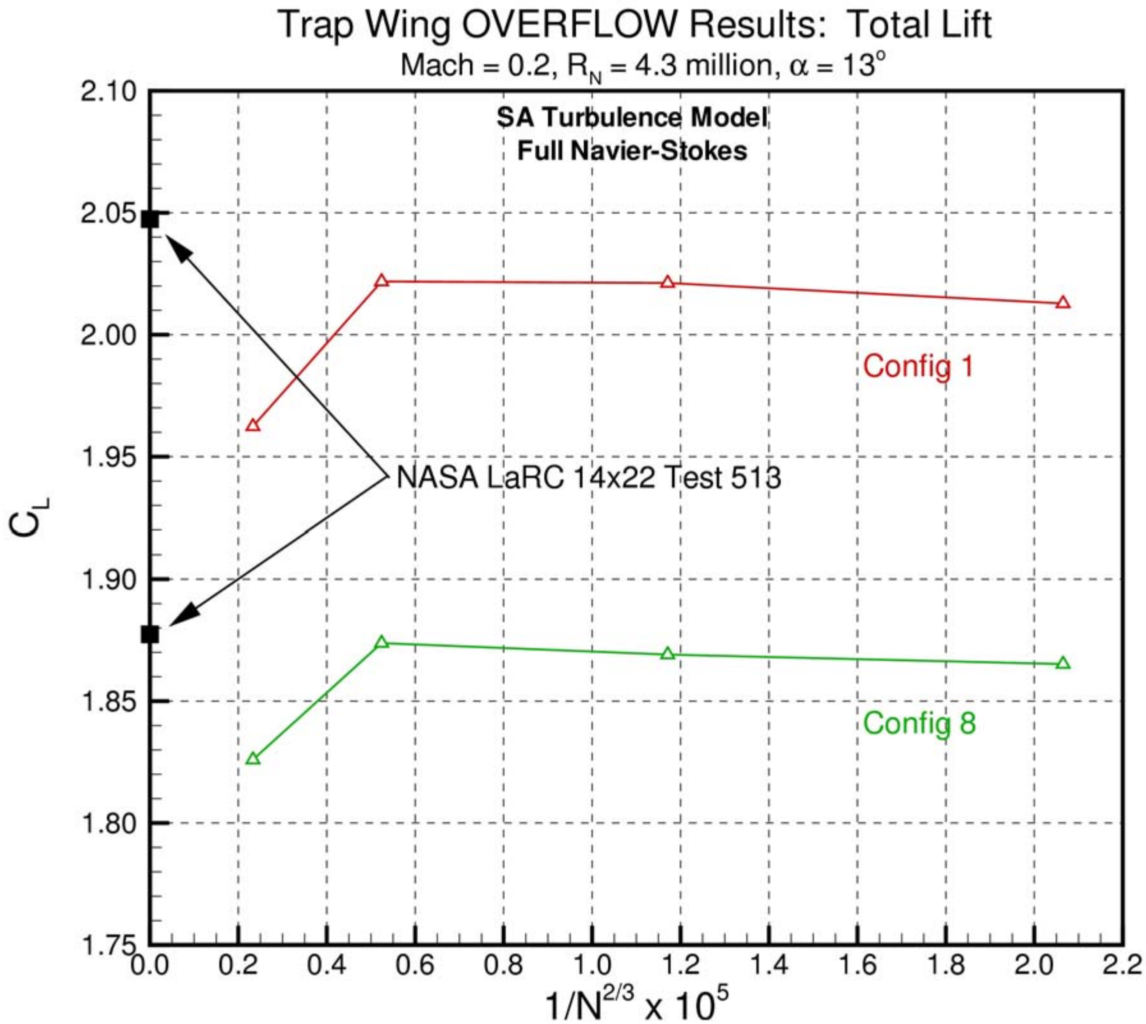
extra-fine



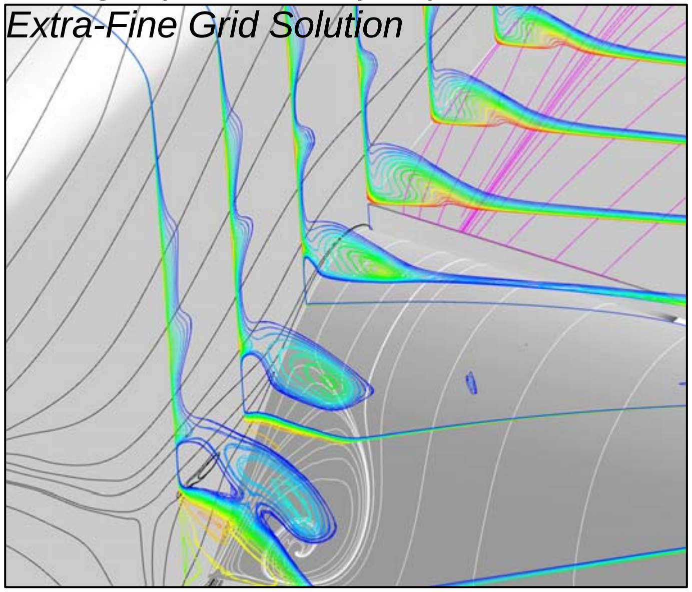
- Extra-fine grid solution represents a severe break in the grid convergence plot.
  - Extent of inboard flap separation may be related.
- Extrapolating from medium and fine grid C_Ls gives 2.023 at the continuum, ~1% less than experiment.
- Flap TE separation is reduced with grid refinement.

Test Case 1 – Grid Convergence Study

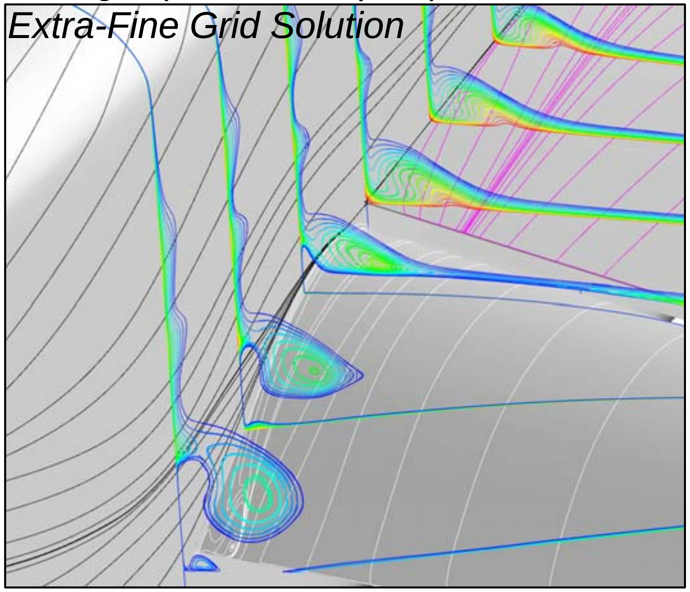
Config 1 and Config 8: Total Lift at $\alpha = 13^o$



Config 1 (Slat 30, Flap 25)



Config 8 (Slat 30, Flap 20)

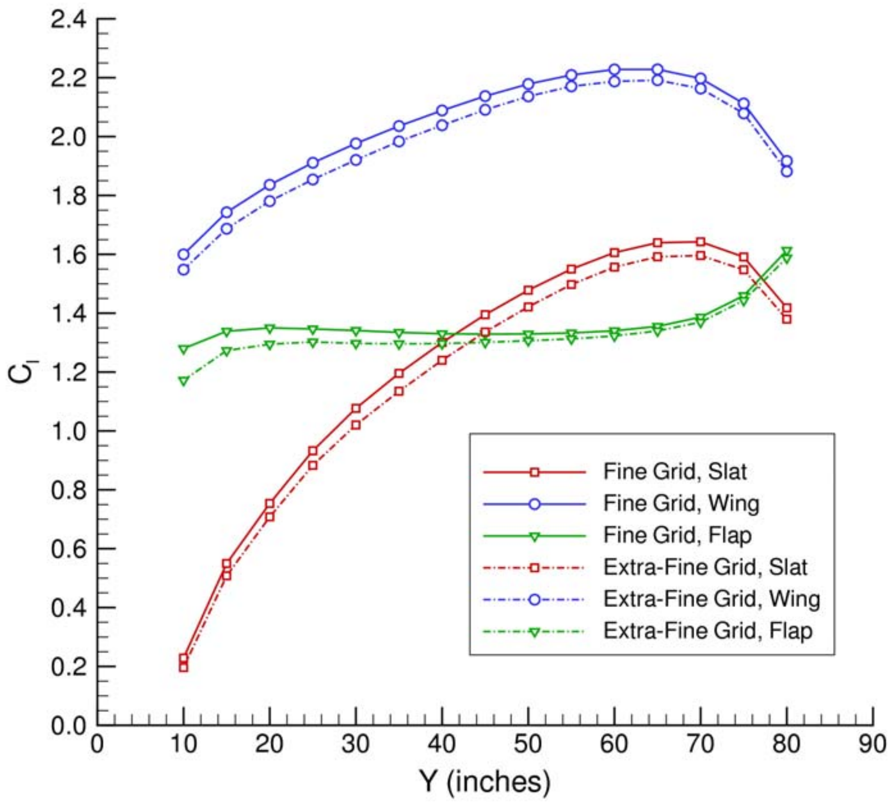


- Config 8 extra-fine grid solution shows a similar break in lift but the inboard flap separation is relatively small.
- **The drop in lift at $\alpha = 13^o$ going from the fine grid to the extra-fine grid does not appear to be driven by inboard flap separation.**

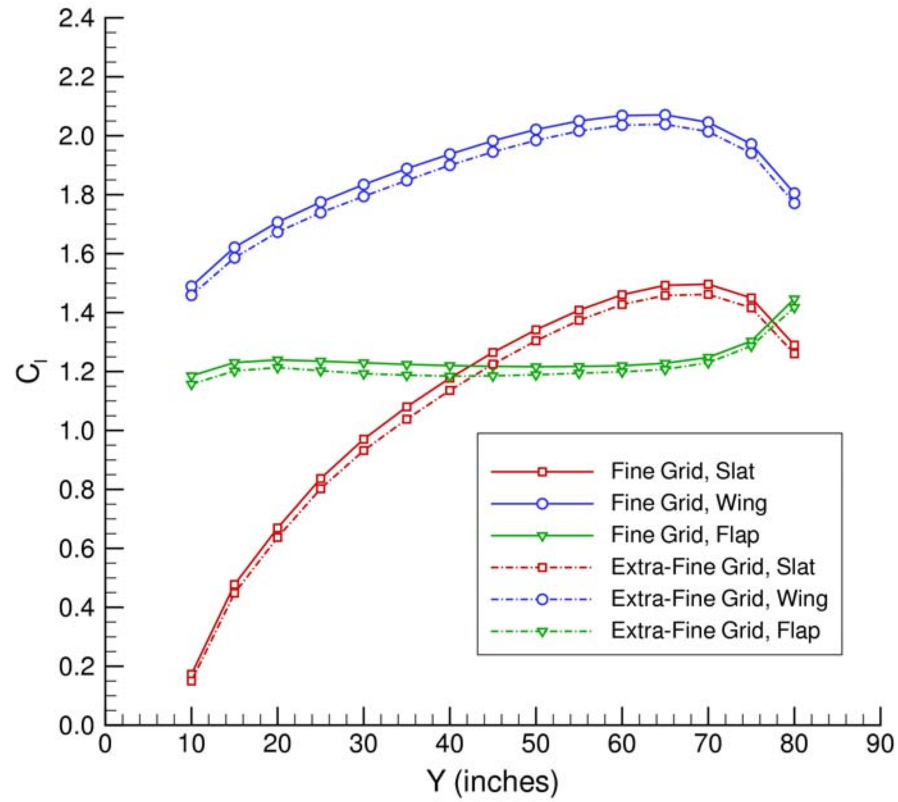
Test Case 1 – Grid Convergence Study

Section C_l Comparison at $\alpha = 13^o$

Config 1



Config 8



- The extra-fine grid solution has reduced loading across the entire semi-span for all three elements.

Test Case 1 – Grid Convergence Study

Config 1: Total Lift at $\alpha = 28^o$

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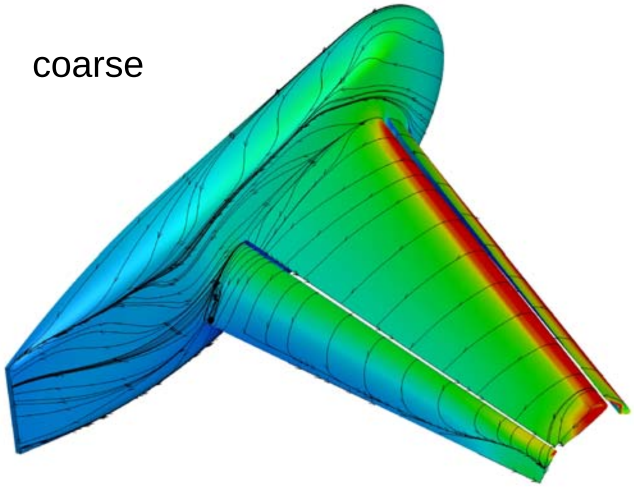
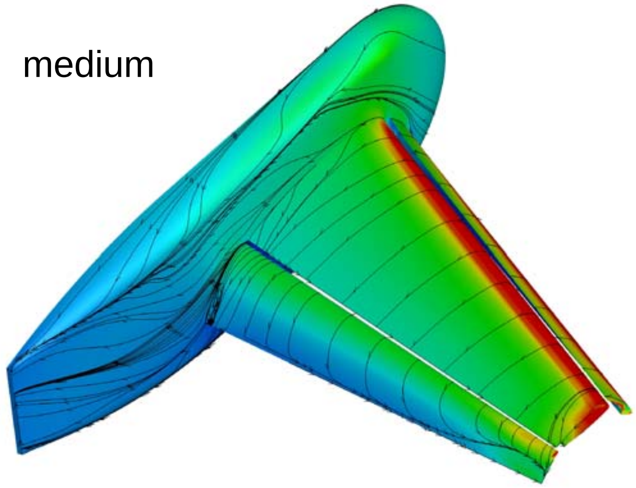
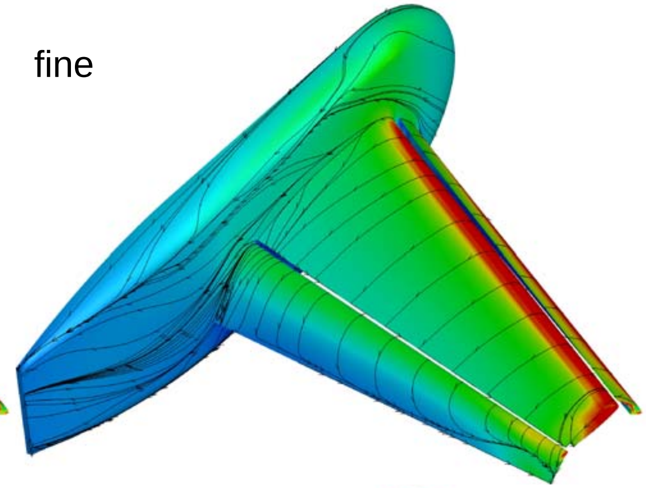
coarse

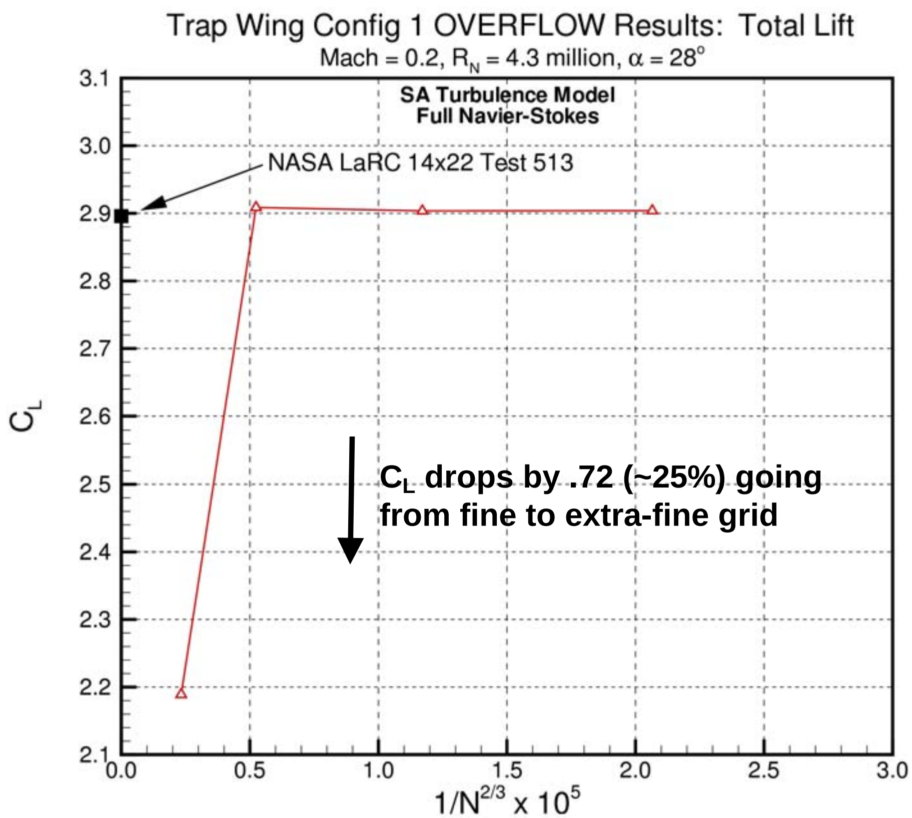


medium

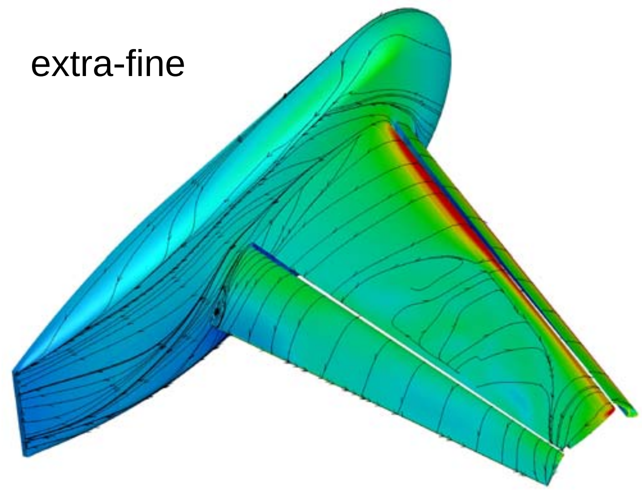


fine



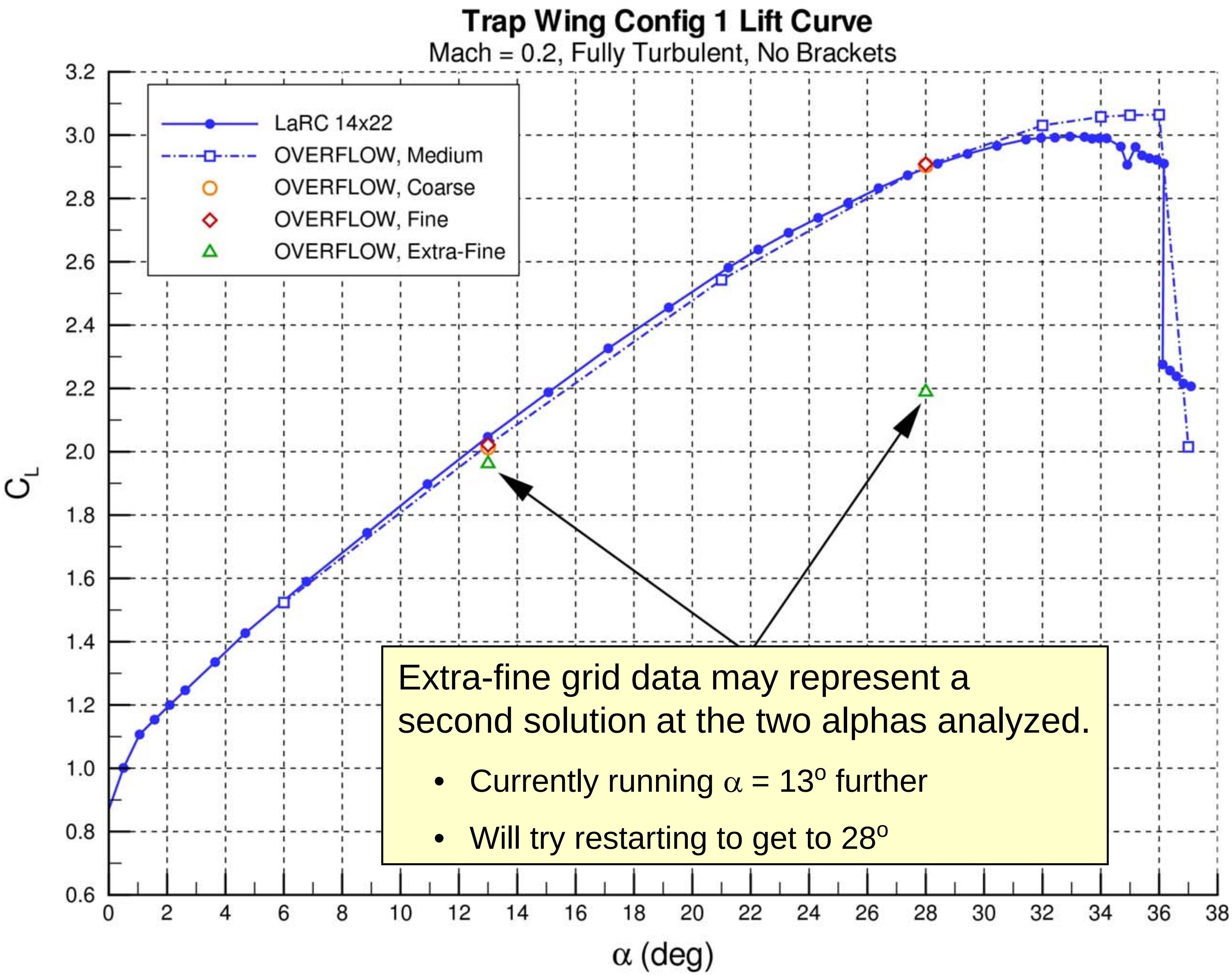


extra-fine



- Extra-fine grid solution represents an extremely large break in the grid convergence plot.
  - Surface streamlines show main wing flow separation (early stall).
- The coarse, medium, and fine grid C_L agrees very well with test data.

Test Case 1 – Grid Convergence Study
Config 1 Lift Curve Comparison – Grid Effect



Extra-fine grid data may represent a second solution at the two alphas analyzed.

- Currently running $\alpha = 13^o$ further
- Will try restarting to get to 28^o

Test Case 1 – Grid Convergence Study
Config 1: Total Drag & Pitching Moment

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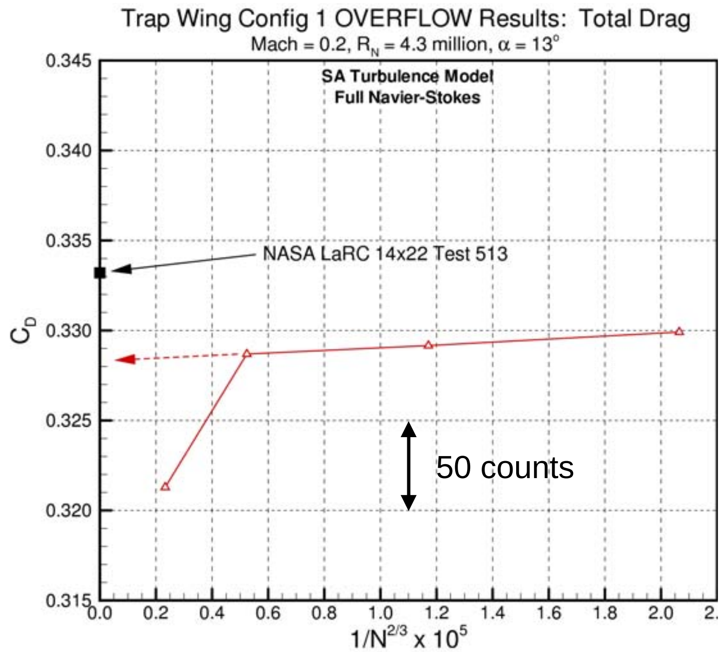
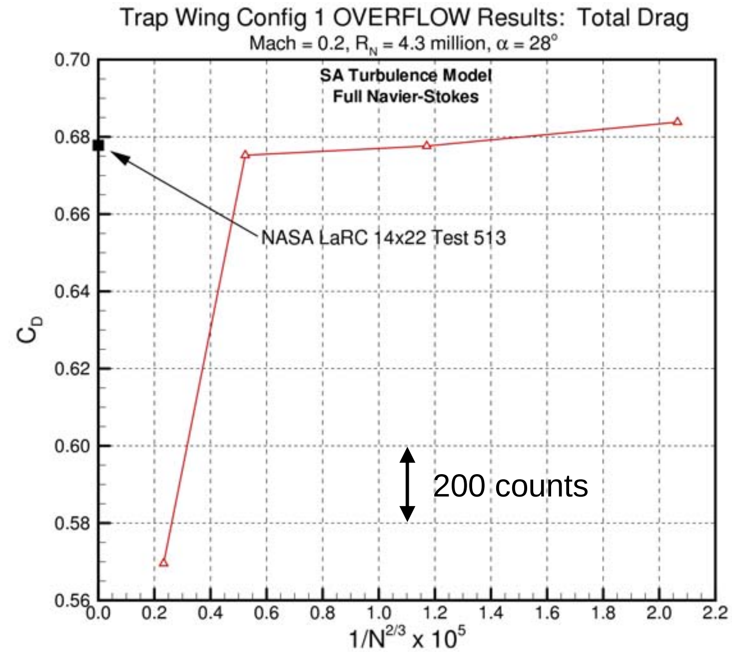
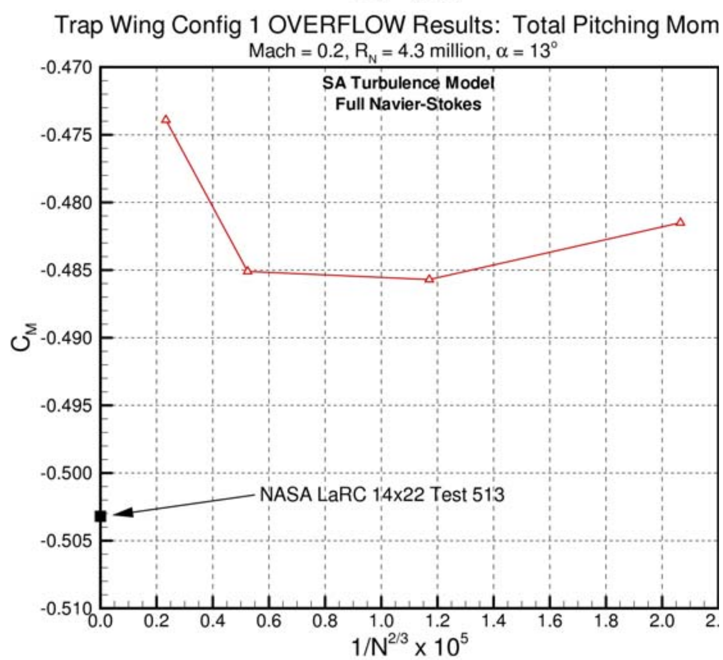
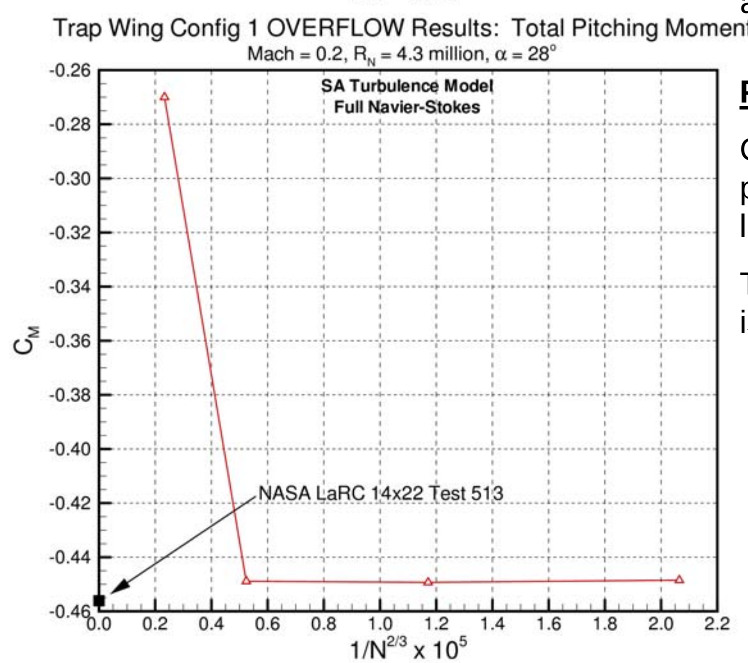








Drag

Coarse, medium, and fine grid drag levels agree reasonably well with experiment.

- At 13°, grid-converged drag is under-predicted by about 45 counts (~1.3%).
- At 28°, grid-converged drag is under-predicted by about 50 counts (~0.8%).

The extra-fine grid data breaks away from the linear trend indicating asymptotic grid convergence is not achieved.

Pitching Moment

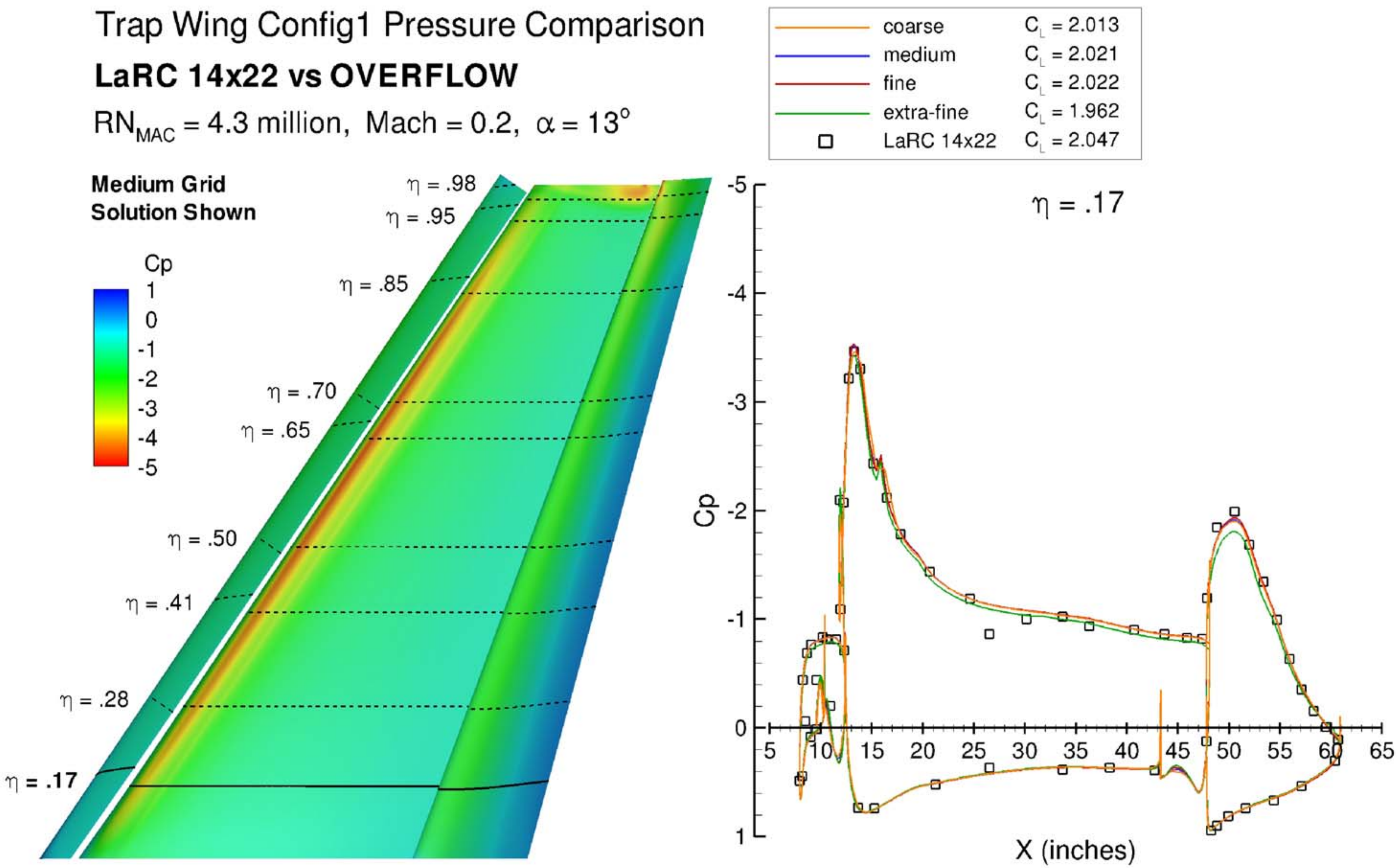
Coarse, medium, and fine grid pitching moment data is not linear at 13°.

The extra-fine grid pitch break is nose-up for both alphas.

- At 13°, nose-up break most likely driven by reduced C_L.
- At 28°, nose-up break caused by outboard wing separation.

Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at $\alpha = 13^o$, $\eta = .17$



Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at $\alpha = 13^o$, $\eta = .65$

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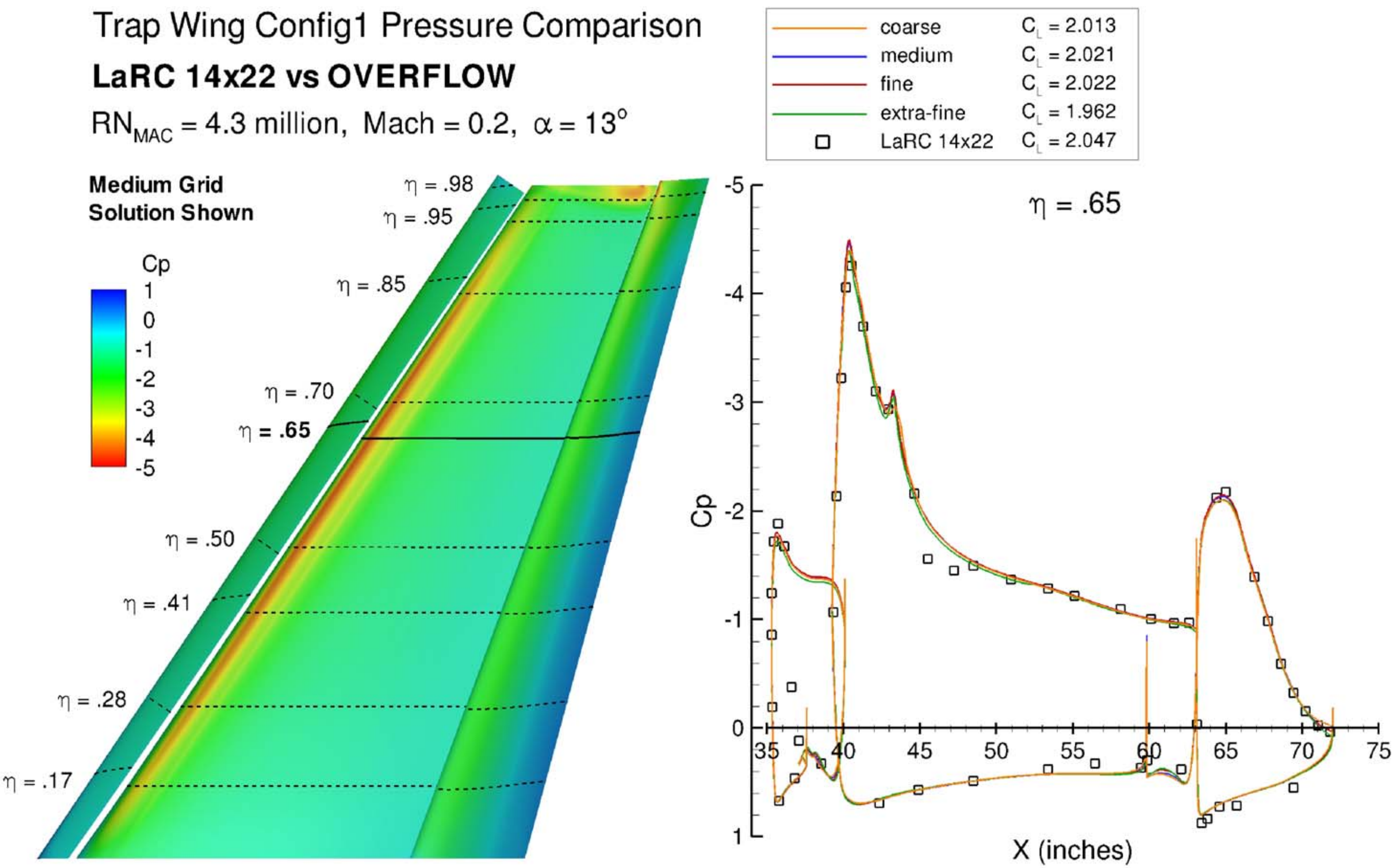
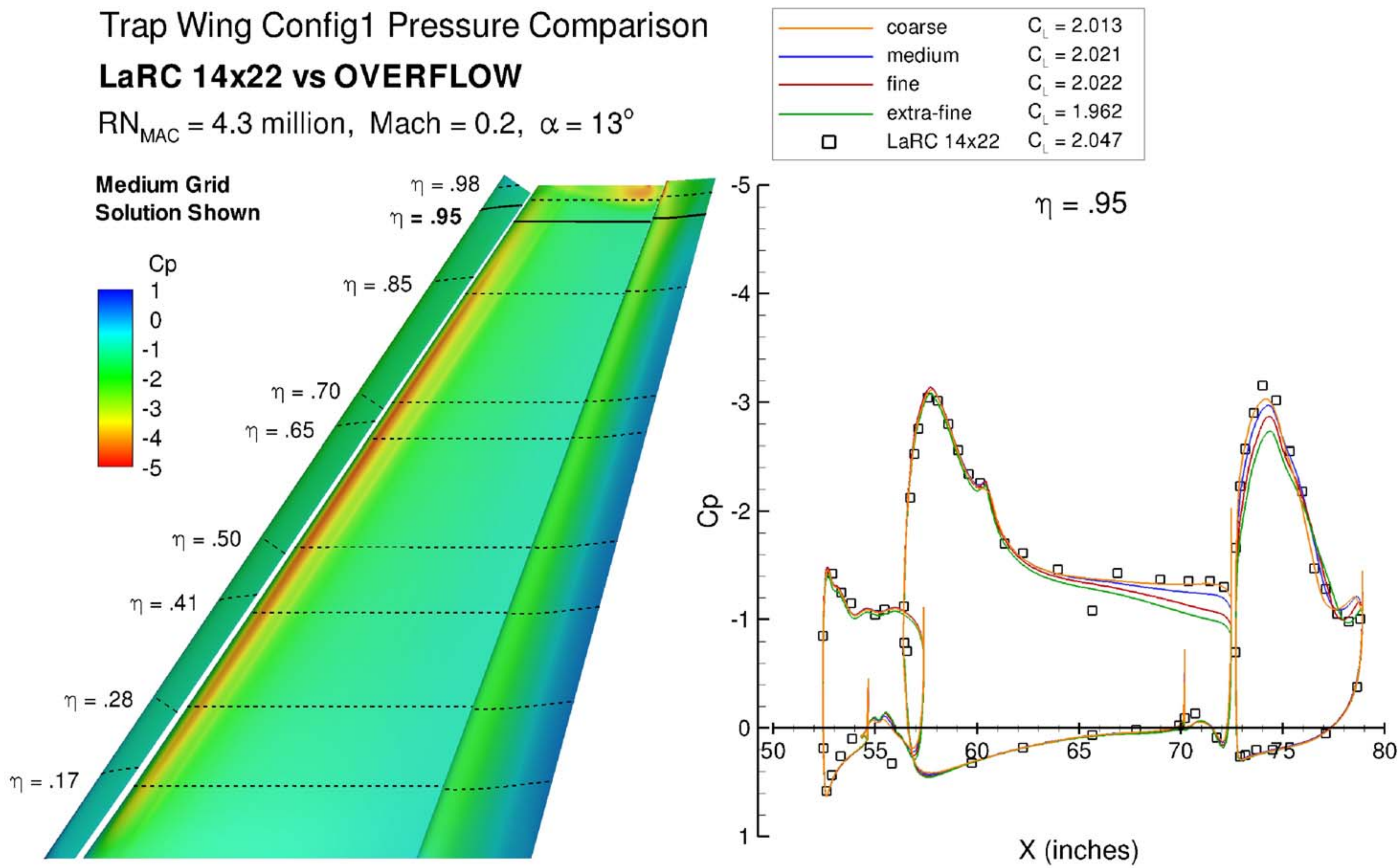


Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at $\alpha = 13^o$, $\eta = .95$



Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at $\alpha = 13^o$, $\eta = .98$

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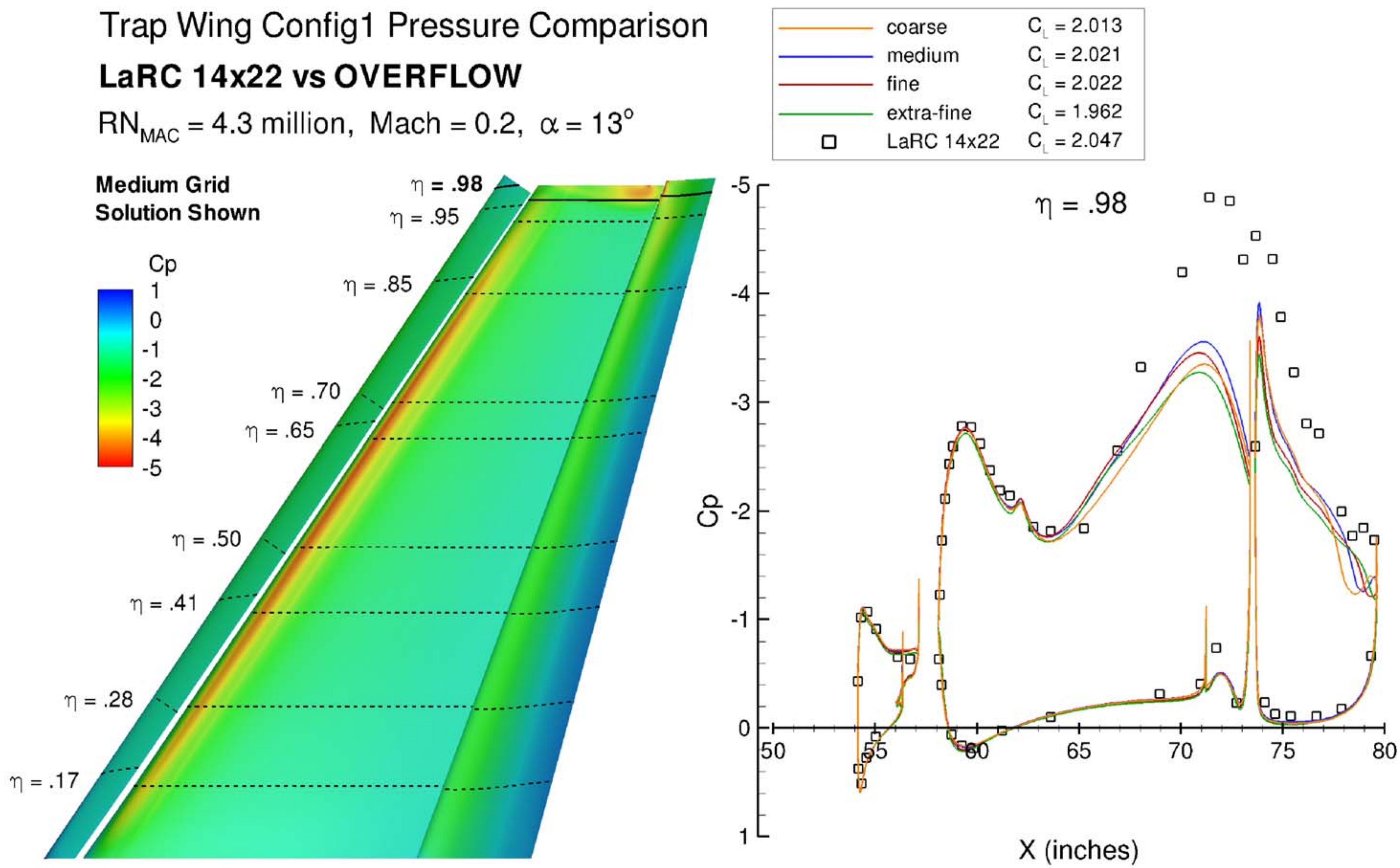

Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at Flap Forward Span

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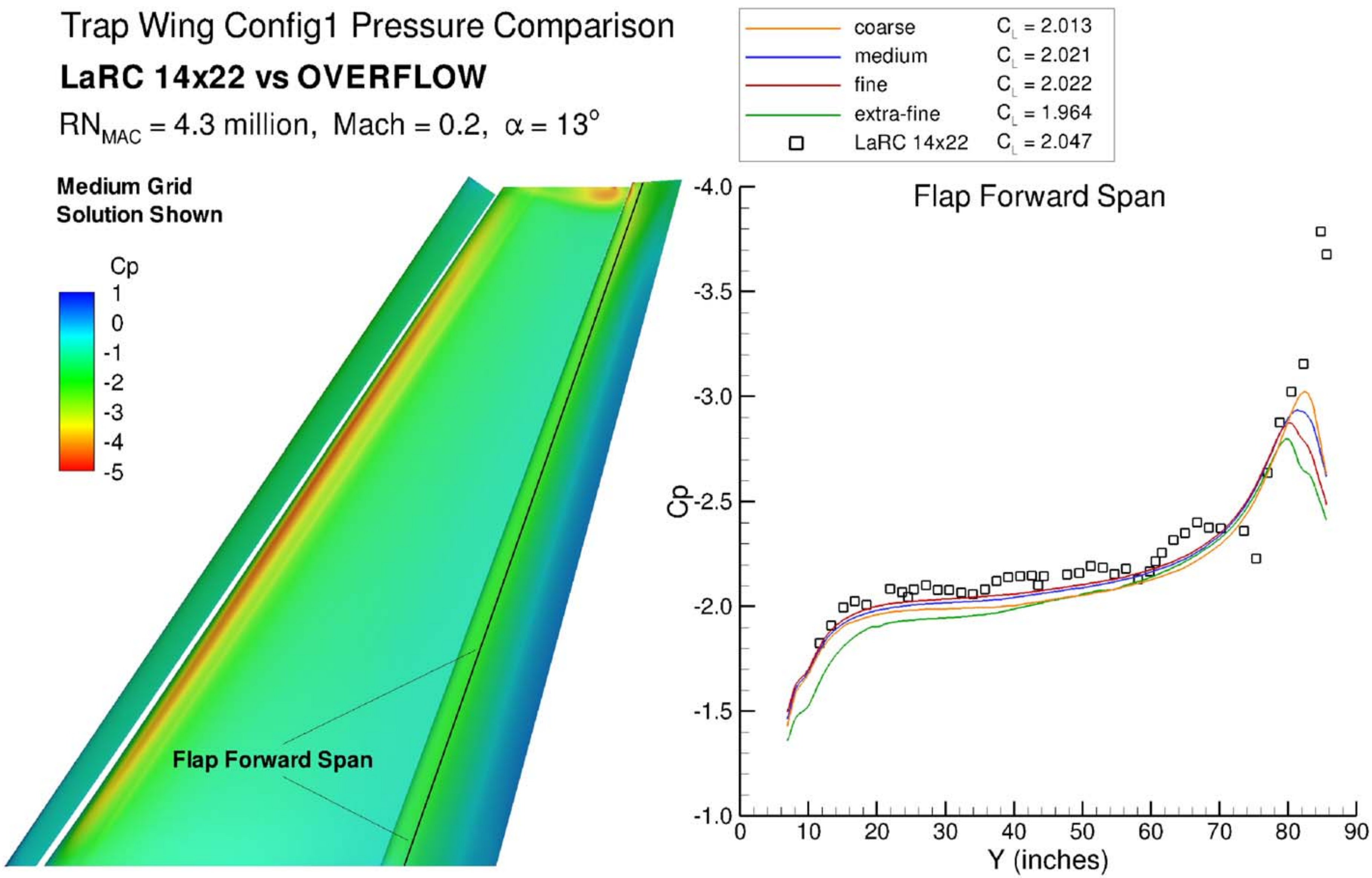

Test Case 1 – Grid Convergence Study

Config 1: Pressure Comparison at Flap Aft Span

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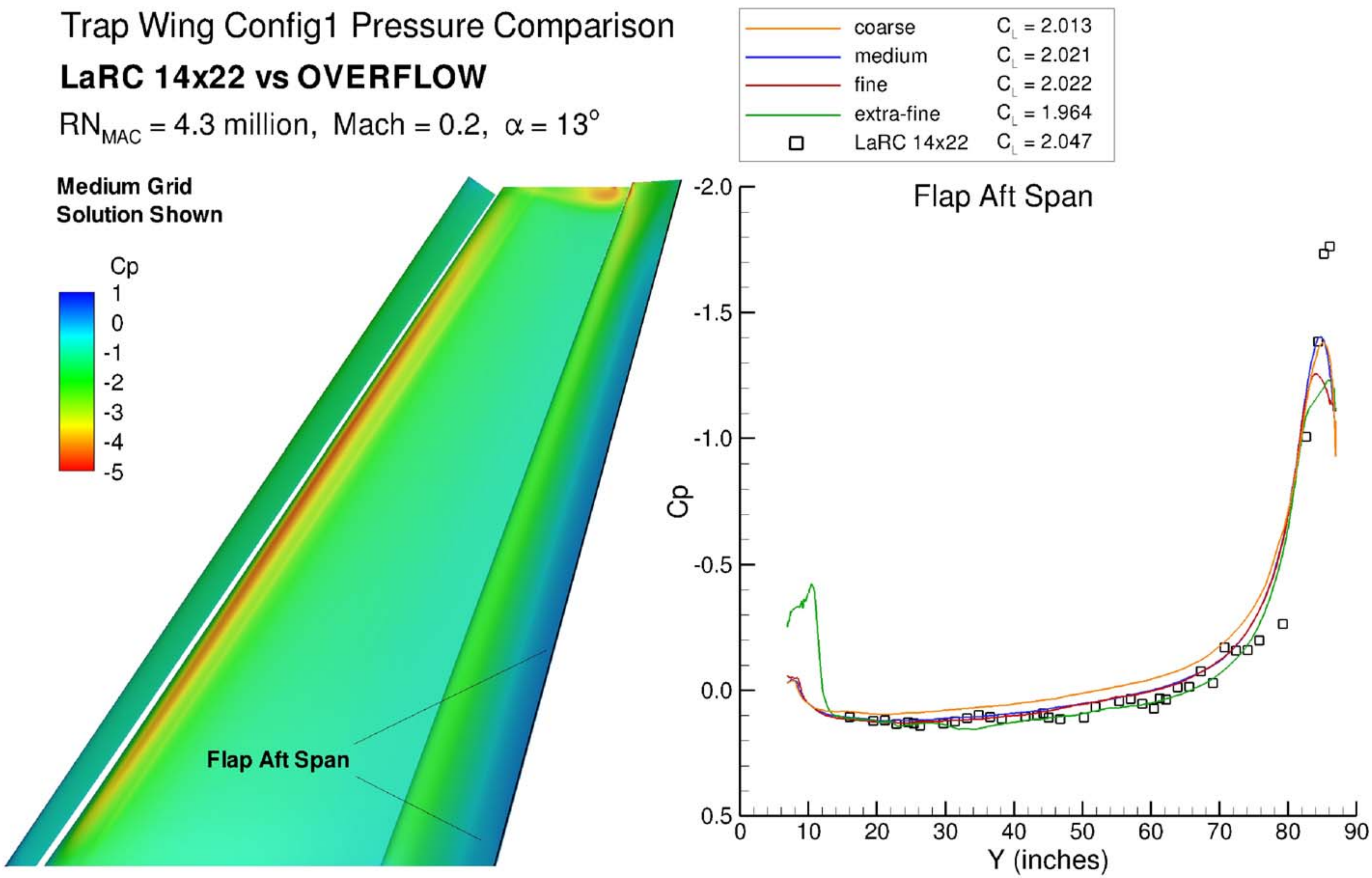
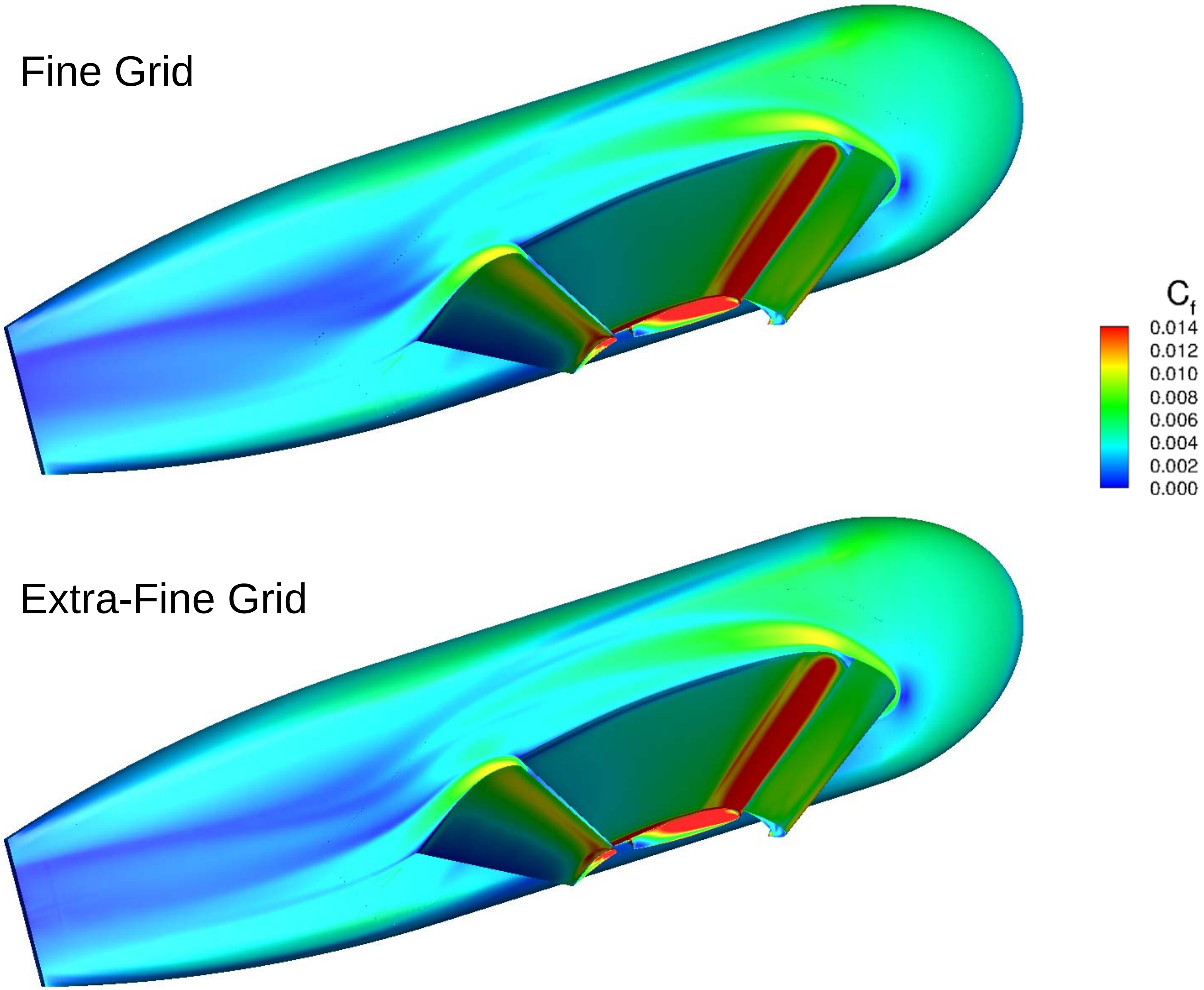


NASA Trap Wing OVERFLOW Analysis
Skin Friction for Config 8, $\alpha = 13^o$



Test Case 2

Flap Deflection Prediction Study

Test Case 2 – Flap Deflection Prediction Study
Lift Comparison

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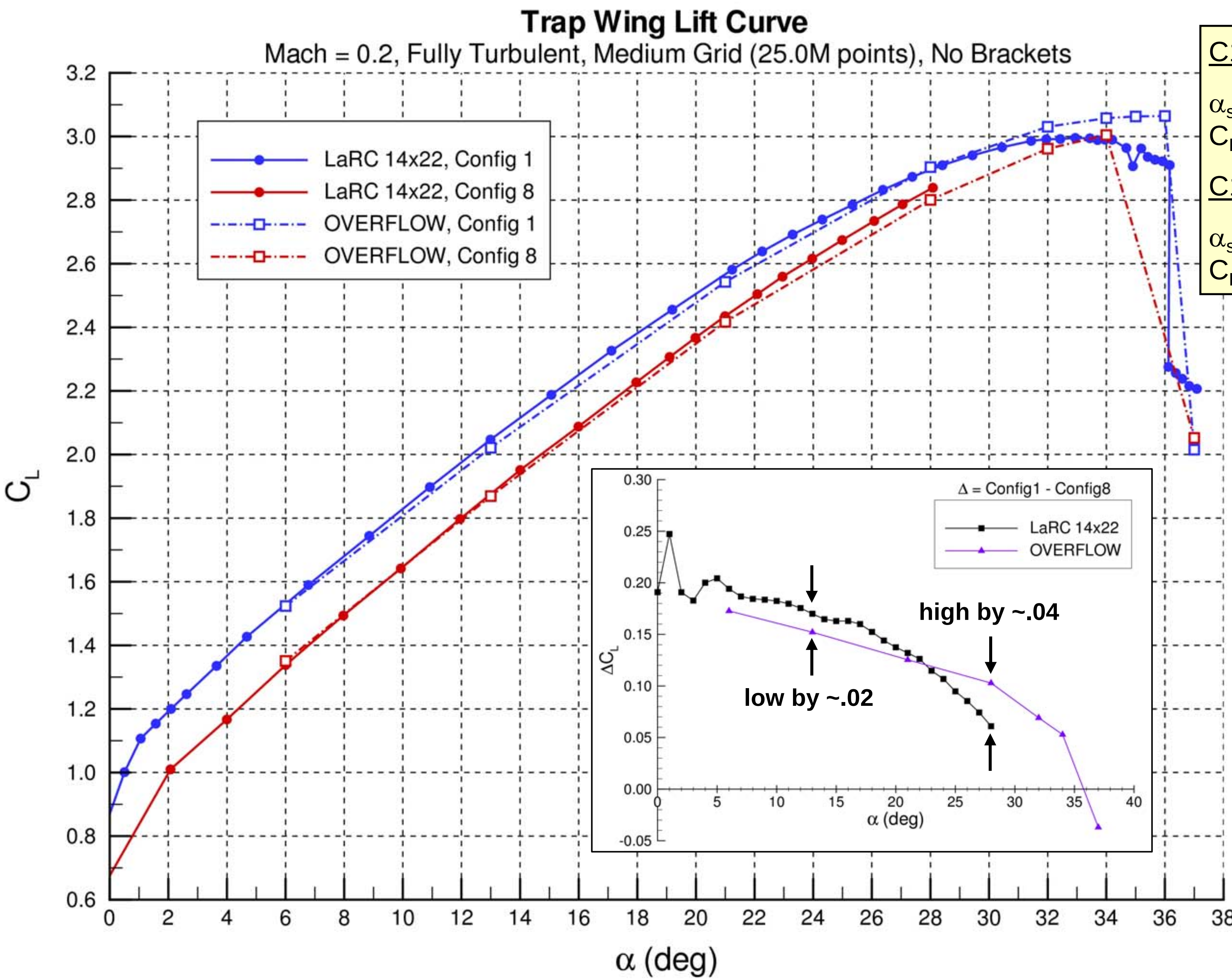


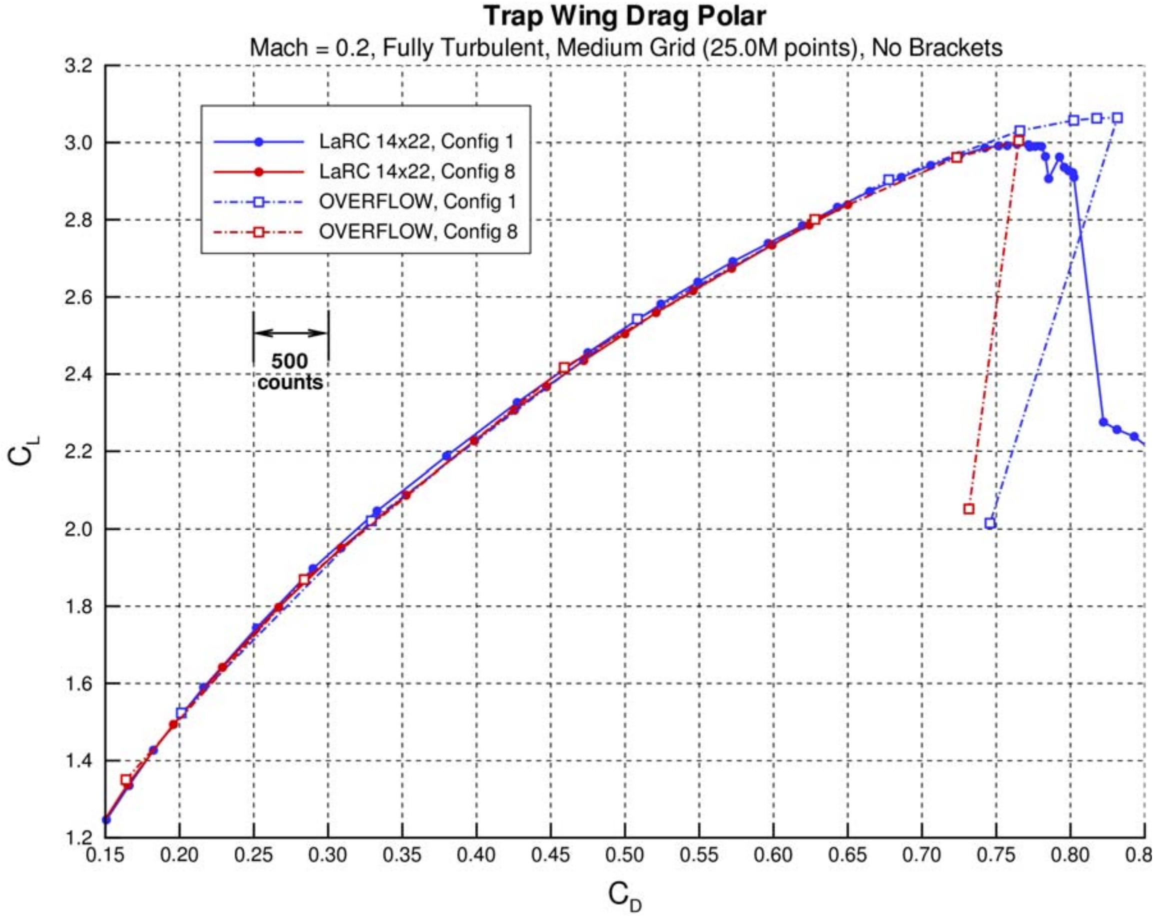
C1 LaRC

α_{stall} = 33°
C_{Lmax} = 3.00

C1 OVERFLOW

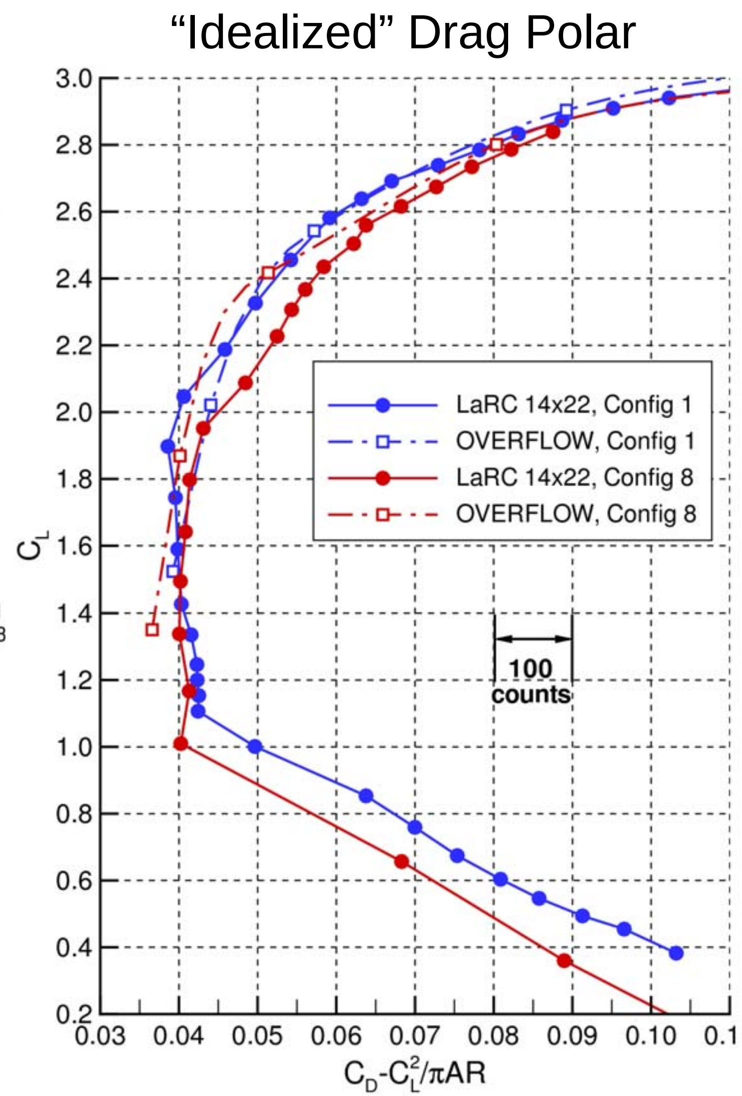
α_{stall} = 35° to 36°
C_{Lmax} = 3.06

Test Case 2 – Flap Deflection Prediction Study
Drag Comparison: C_L vs C_D and C_L vs C_D-$C_L^2/\pi AR$



By removing idealized induced drag, a more detailed polar comparison can be made.

- LaRC data show cross-over C_L to be at 1.5, above which Config 8 has higher drag
- OVERFLOW C_L cross-over is at 2.4
- Larger difference seen in Config 8 polar



Test Case 2 – Flap Deflection Prediction Study
Drag Comparison: C_D vs α

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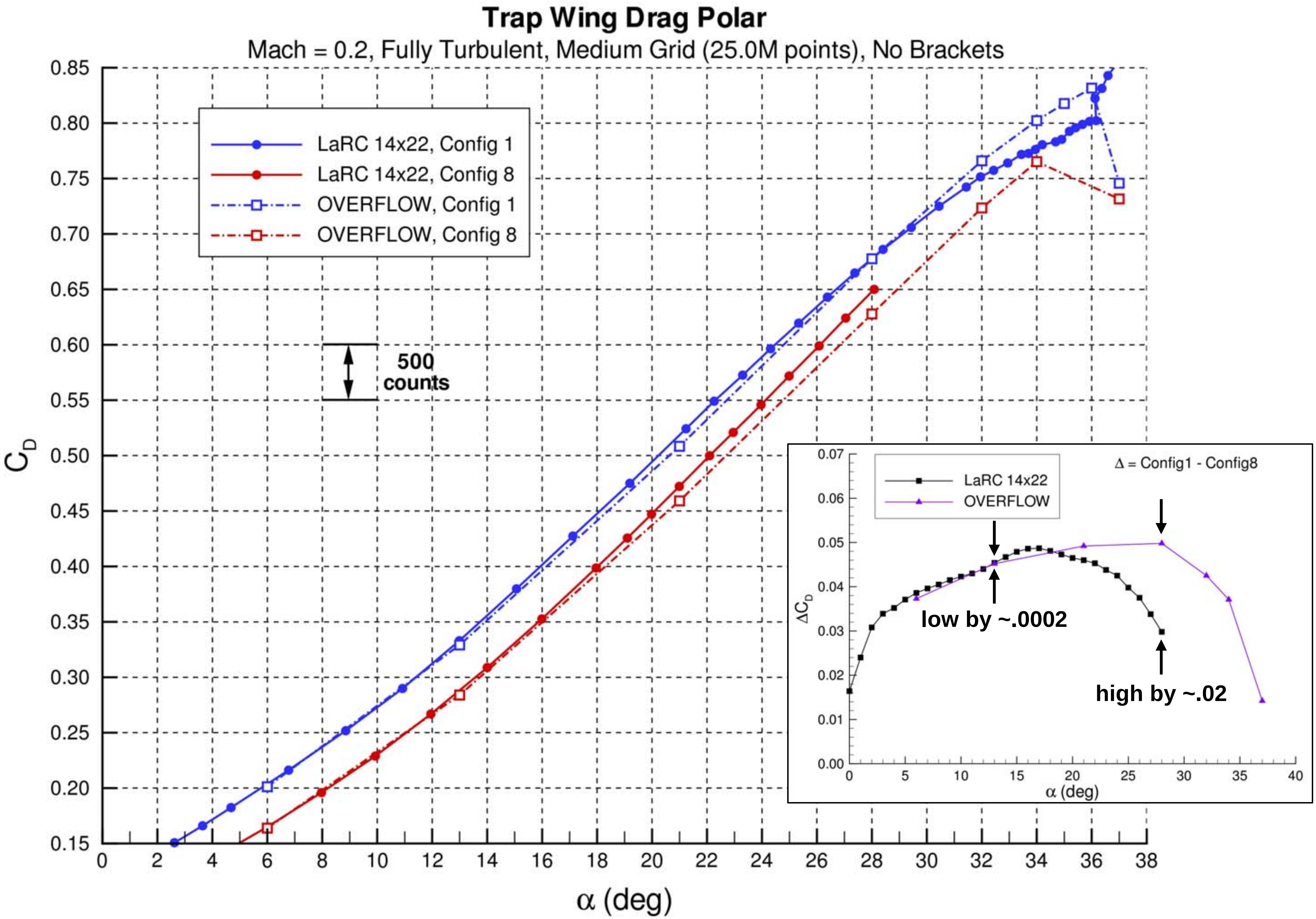
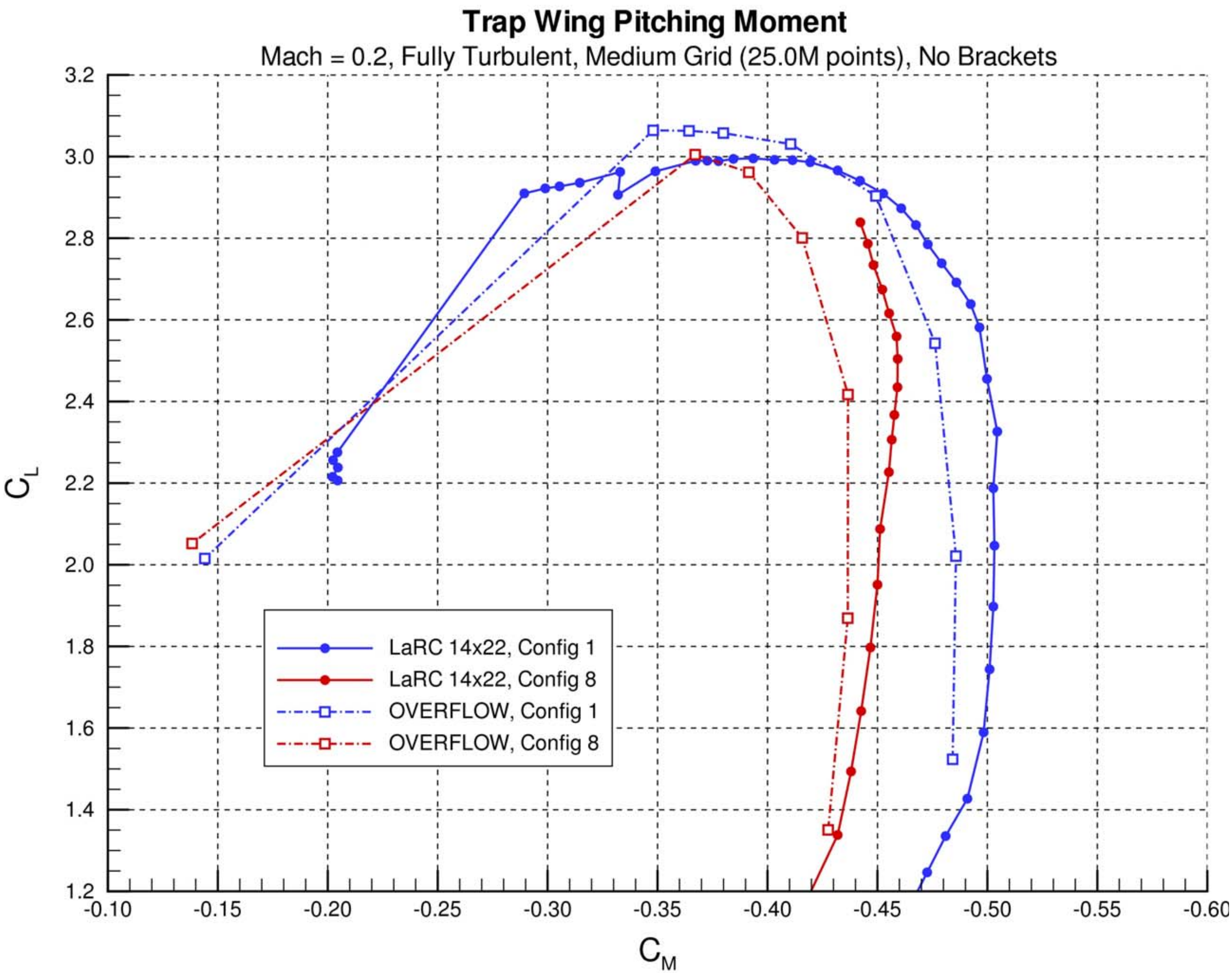


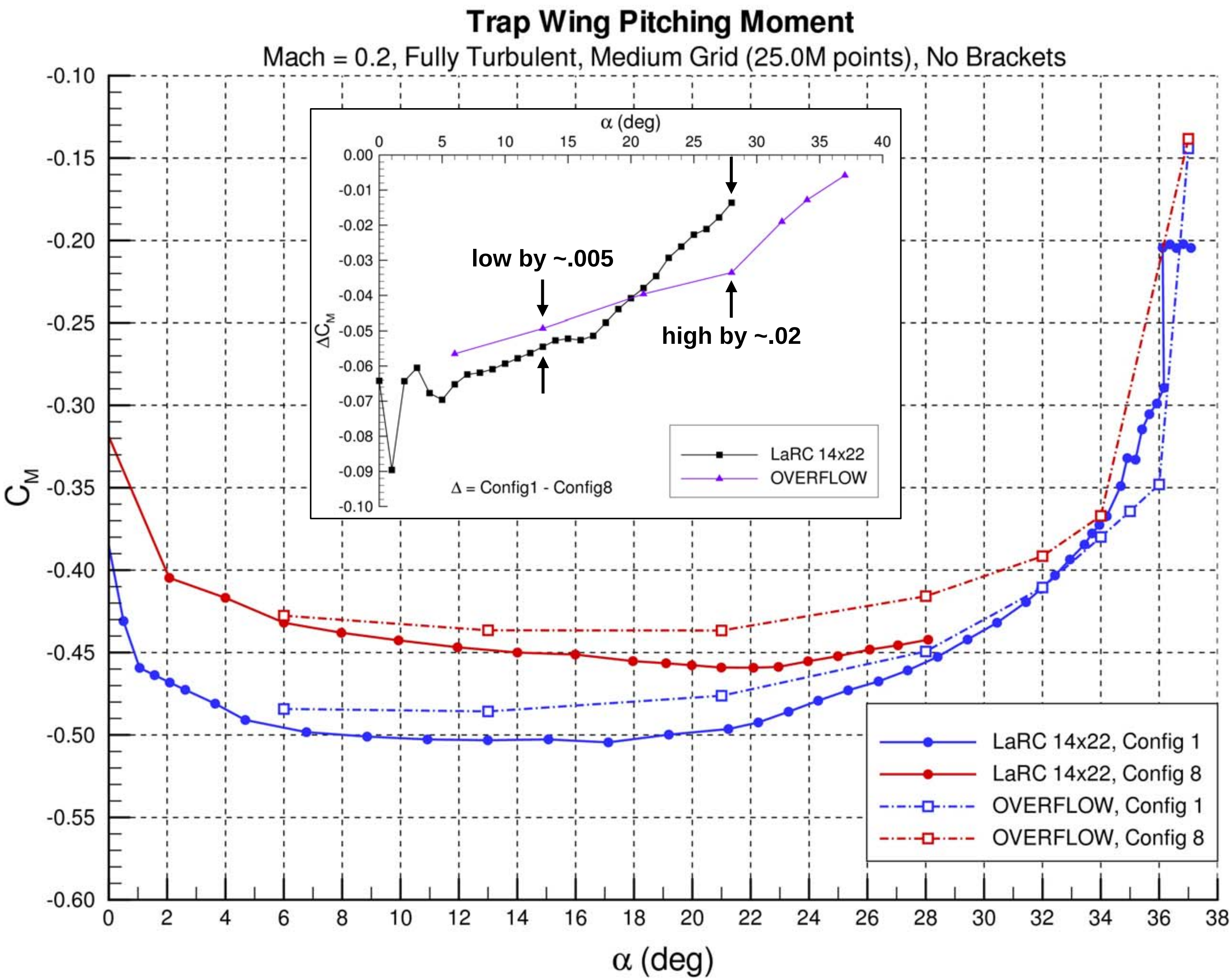
Test Case 2 – Flap Deflection Prediction Study

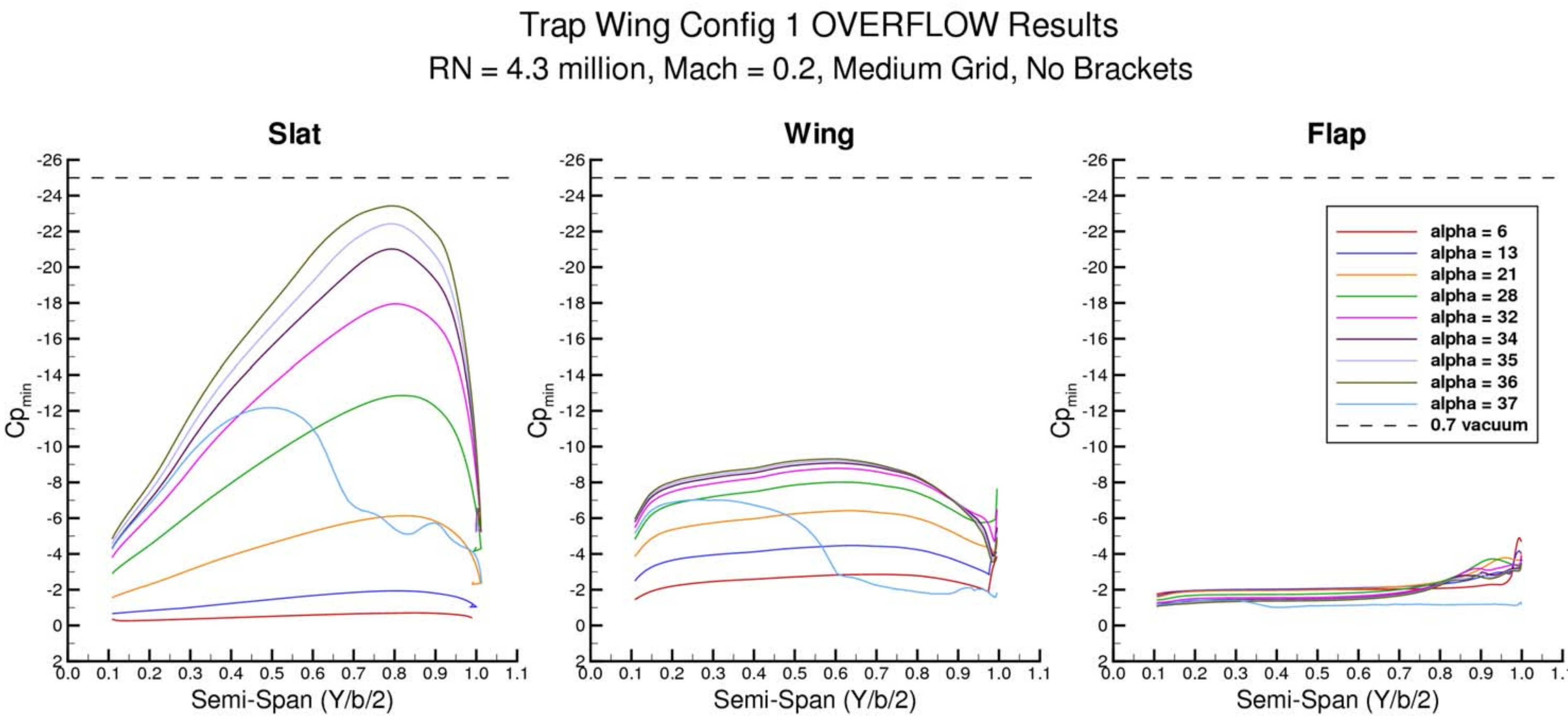
Pitching Moment Comparison: C_L vs C_M



Test Case 2 – Flap Deflection Prediction Study

Pitching Moment Comparison: C_M vs α





Using J. P. Mayer's 0.7 vacuum ($M^2_\infty C_p = -1$) presented by A.M.O. Smith*

- Slat suction pressure reaches 0.7 vacuum ($C_p = -25$) at $36^o < \alpha < 37^o$
  - Critical semi-span station is $\eta = 0.8$
- **Stall appears to be driven by the slat → slat stalls first followed by wing**

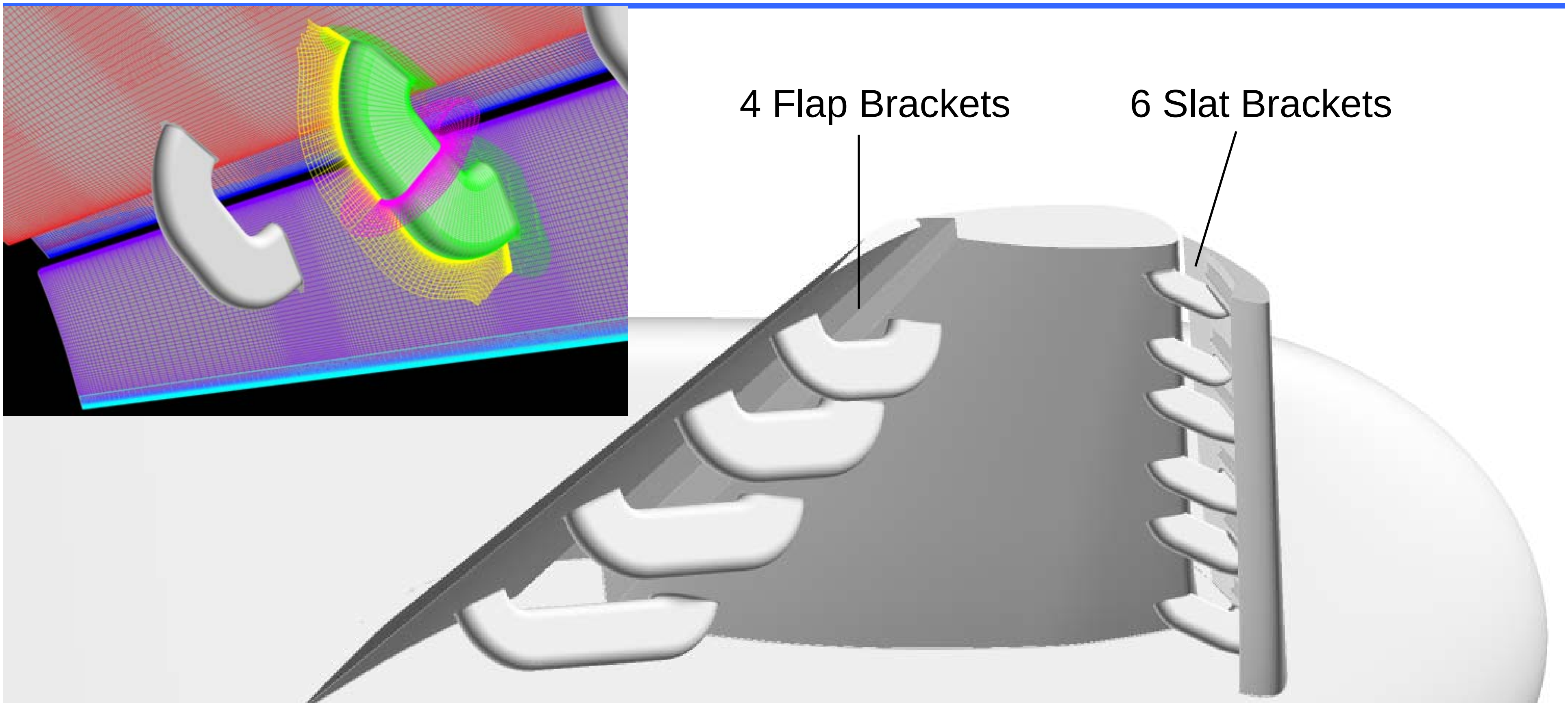
*Smith, A. M. O., "High Lift Aerodynamics", 37th Wright Borthers Lecture, Vol. 12 No. 6, JOA, June 1975

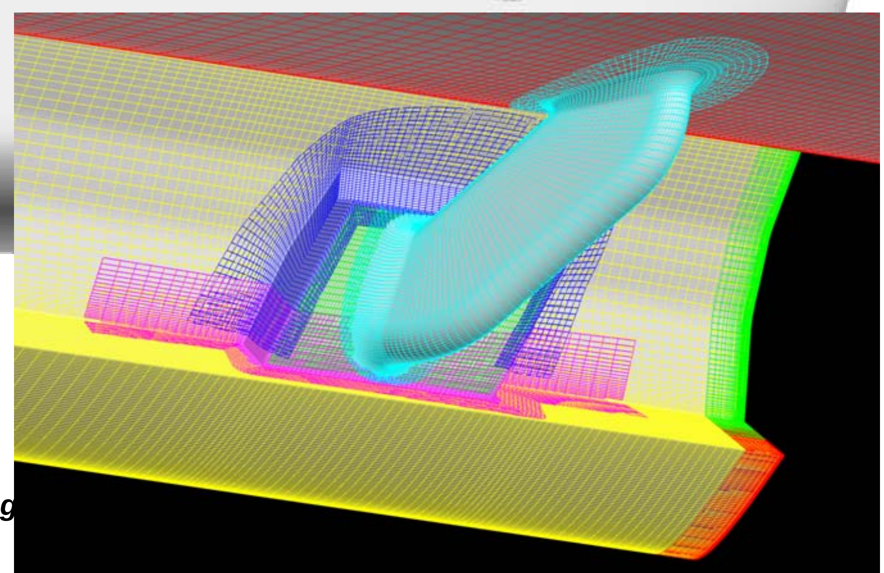
Test Case 3

Slat and Flap Support Effects Study

Test Case 3 – Support Effects Study

*Config 1 Bracket Grids**





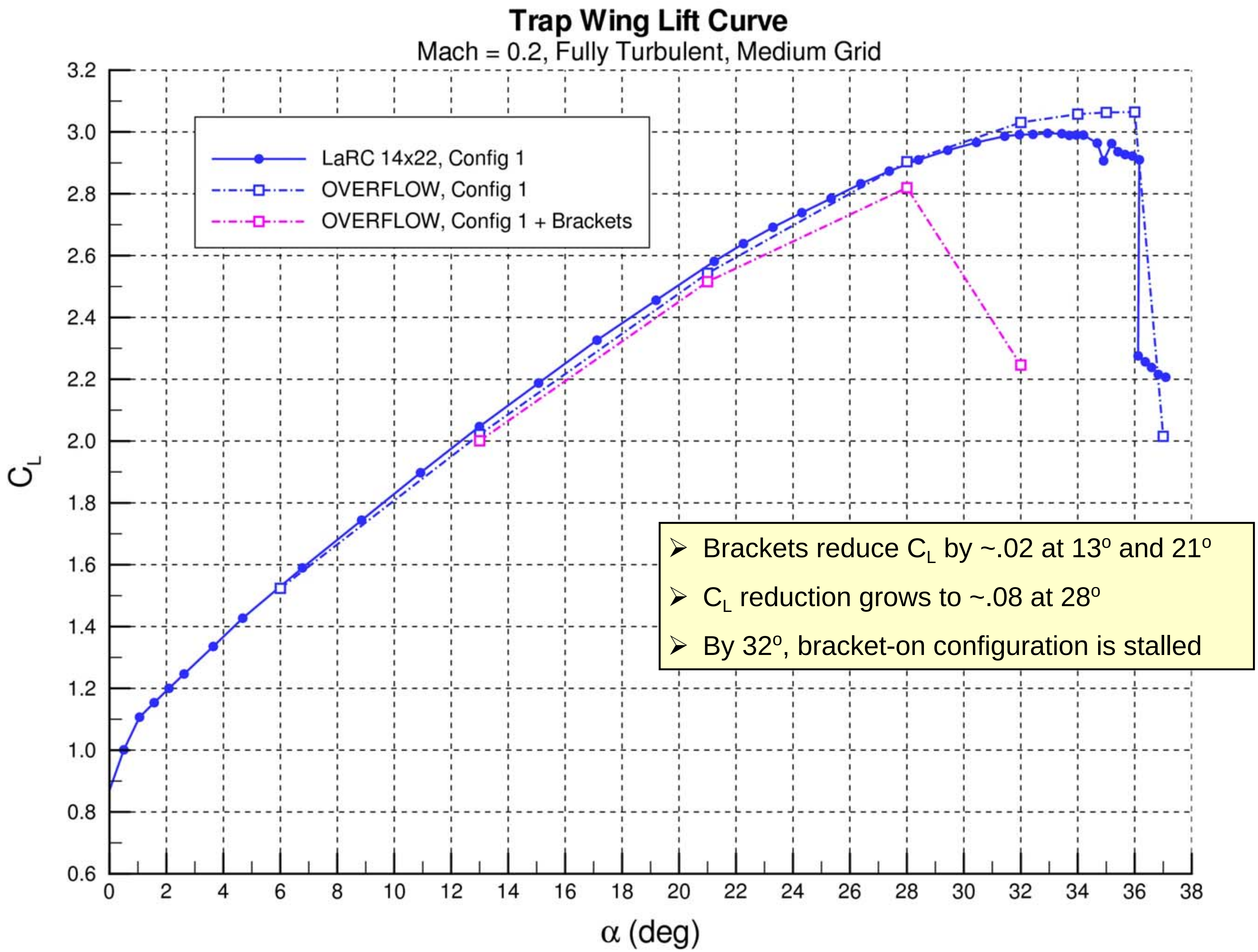
<u>Medium Grid Sizes</u>

- Bracket-off = 25.0 million
- Bracket-off with refined c-mesh grids = 47.0 million
- Bracket-on with refined c-mesh grids = 58.2 million

**** Bracket grids built by Leonel Serrano and Neal Harrison***

Test Case 3 – Support Effects Study

Lift Comparison



- Brackets reduce C_L by ~.02 at 13° and 21°
- C_L reduction grows to ~.08 at 28°
- By 32°, bracket-on configuration is stalled

Test Case 3 – Support Effects Study
Drag and Pitching Moment Comparison

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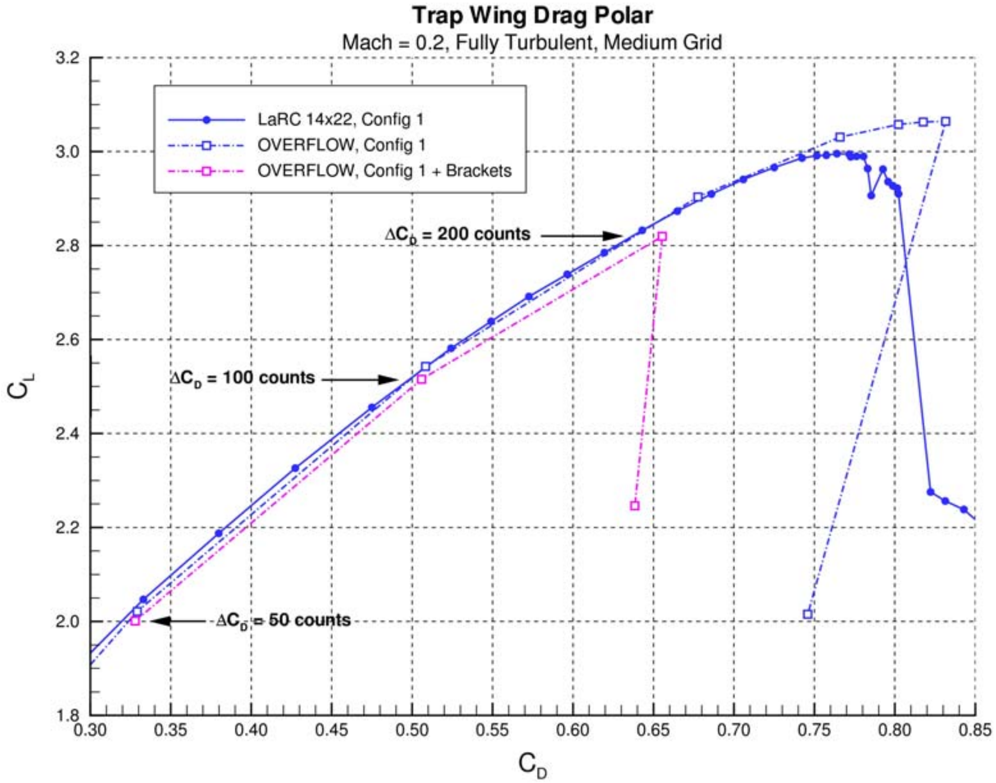
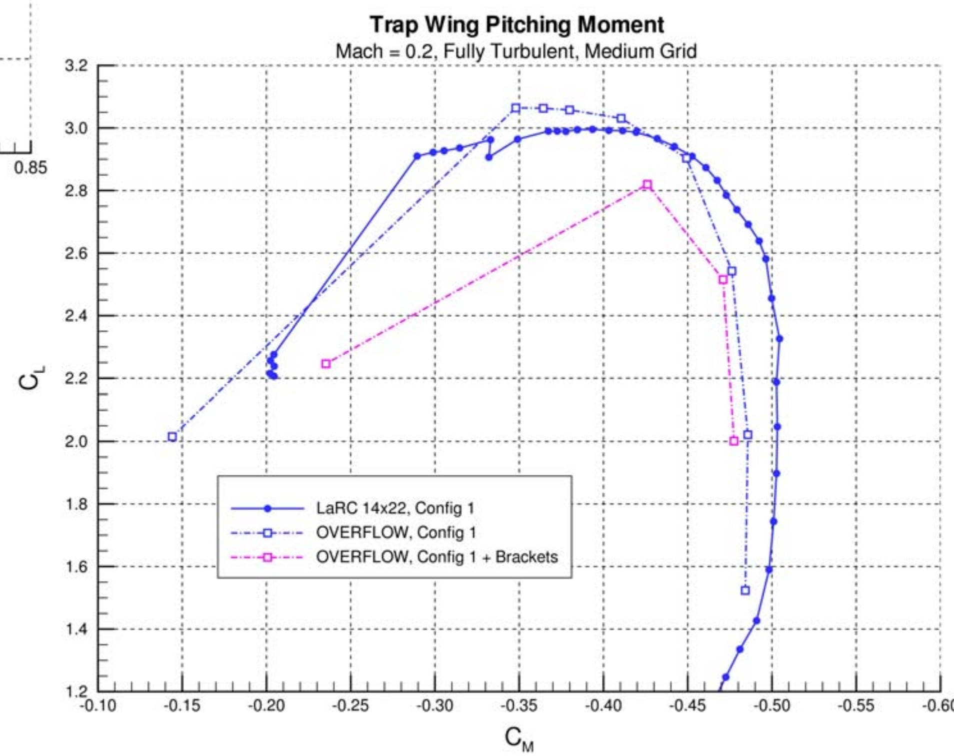


- Brackets increase drag by 50 to 200 counts depending on C_L
- Brackets drive pitching moment less negative (nose-up)



Test Case 3 – Support Effects Study
Skin Friction and Surface Streamline Comparison

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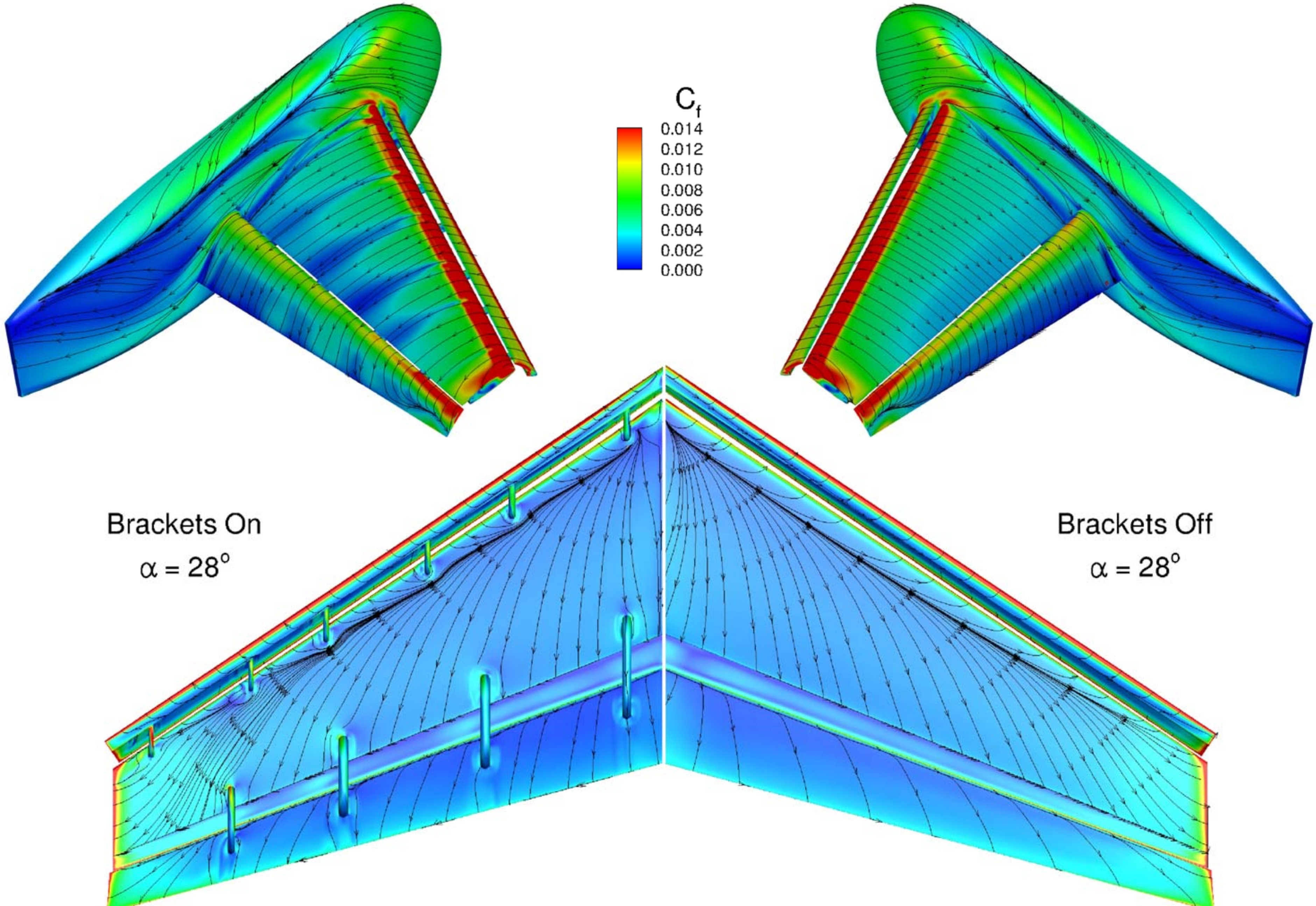
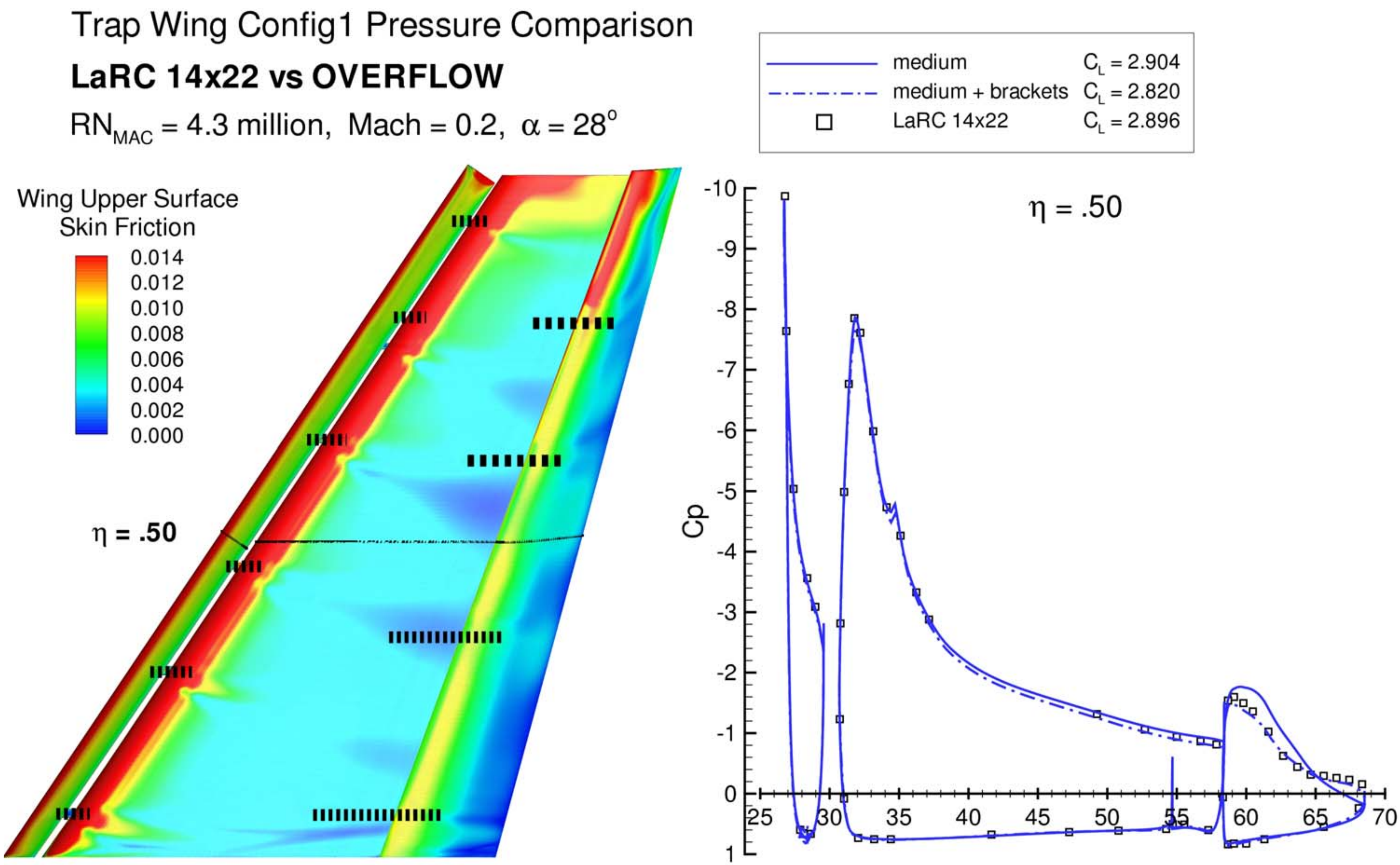


Test Case 3 – Support Effects Study

Pressure Comparison at $\alpha = 28^o$, $\eta = 50\%$



Test Case 1 – Grid Convergence Study

- The extra-fine grid produces solutions that appear to be in a different family than the coarse, medium, and fine grid.
  - hysteresis may be the cause … additional runs are being made
- The coarse, medium, and fine grid C_L results are close to linear when plotted against $1/N^{-2/3}$ and agree reasonably well with test data.
- In general, pressures are in good agreement with test data.
  - wing and flap pressures at the tip are the exception
  - flap trailing-edge pressures predicted best by extra-fine grid

Test Case 2 – Flap Deflection Prediction Study

- Config 1 lift, drag, and pitching moment agree well with test data through stall.
  - C_{Lmax} is over-predicted by 2%
- More discrepancy seen in the Config 8 force and moment data comparison.

Test Case 3 – Slat and Flap Support Effects Study

- Bracket-on results move away from test data indicating the bracket-off data is not as good as it appears.
- As with the extra-fine grid solutions, adding the supports leads to early stall.

- Hysteresis, extra-fine grid solutions
- Brackets
- Laminar flow
- Off-body grid refinement at tip
- SA with Rotational and Curvature Correction (SARC)