Extended OVERFLOW Analysis of the NASA Trap Wing Wind Tunnel Model

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Outline

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- Results
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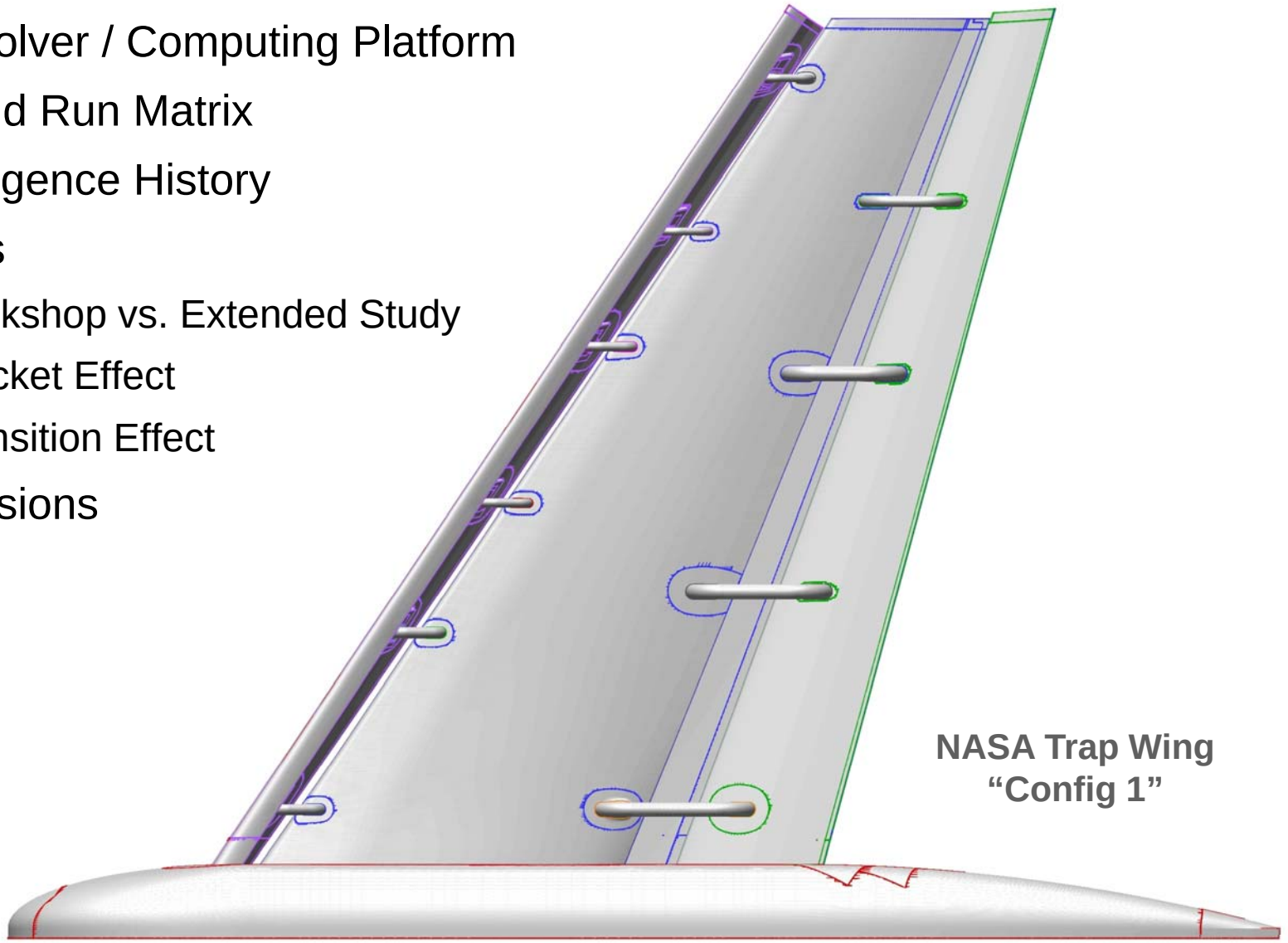
- Conclusions



NASA Trap Wing
"Config 1"

Applying Lessons Learned

Workshop

adjust time step for finer grids

SA with rotation and curvature corrections

use grid with bracket clustering for all runs

exact wall distance calculation

restarts for higher angles-of-attack

low Mach preconditioning

Extended Study

new baseline dataset

Flow Solver / Computing Platform

OVERFLOW Version 2.1ad, 2.2c and 2.2e

- No significant differences due to code version
- Default mode of operation
  - upwind differencing
  - SA-RC turbulence model (SA-Ia with rotation/curvature corrections)
  - full N-S, exact wall distance calculation, low Mach preconditioning
  - restart from lower α solution starting at 21^o
- Transition Study
  - Langtry-Menter version CFX-v-1.1 of the γ-Re_θ transition model with SST-RC

Linux PC Cluster

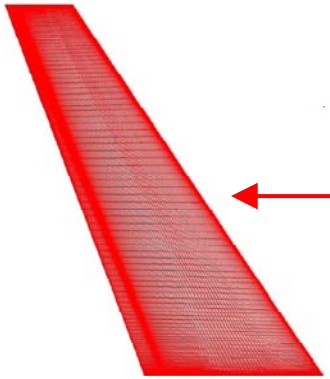
- Used for all SA-RC runs
- Bracket-off medium grid required 6.3 hrs of wall clock time per 1000 steps on 24 cores

Pleiades Supercomputer

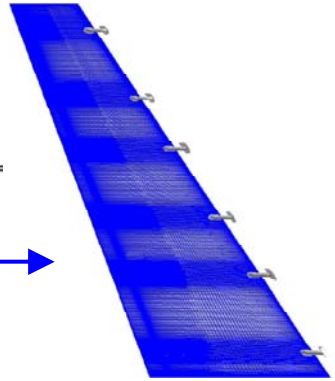
- Used for all SST-RC runs
- Same grid required 1.8 hrs of wall clock time per 1000 steps on 192 cores

Grid and Run Matrix

- Medium overset mesh with clustering for bracket grids, no wind tunnel walls



grid	slat/flap bracket clustering	slat/flap brackets	points (in millions)	number of zones
1	no	off	25.0	34
2	yes	off	47.0	34
3	yes	on	58.2	62



- Angles-of-attack analyzed:

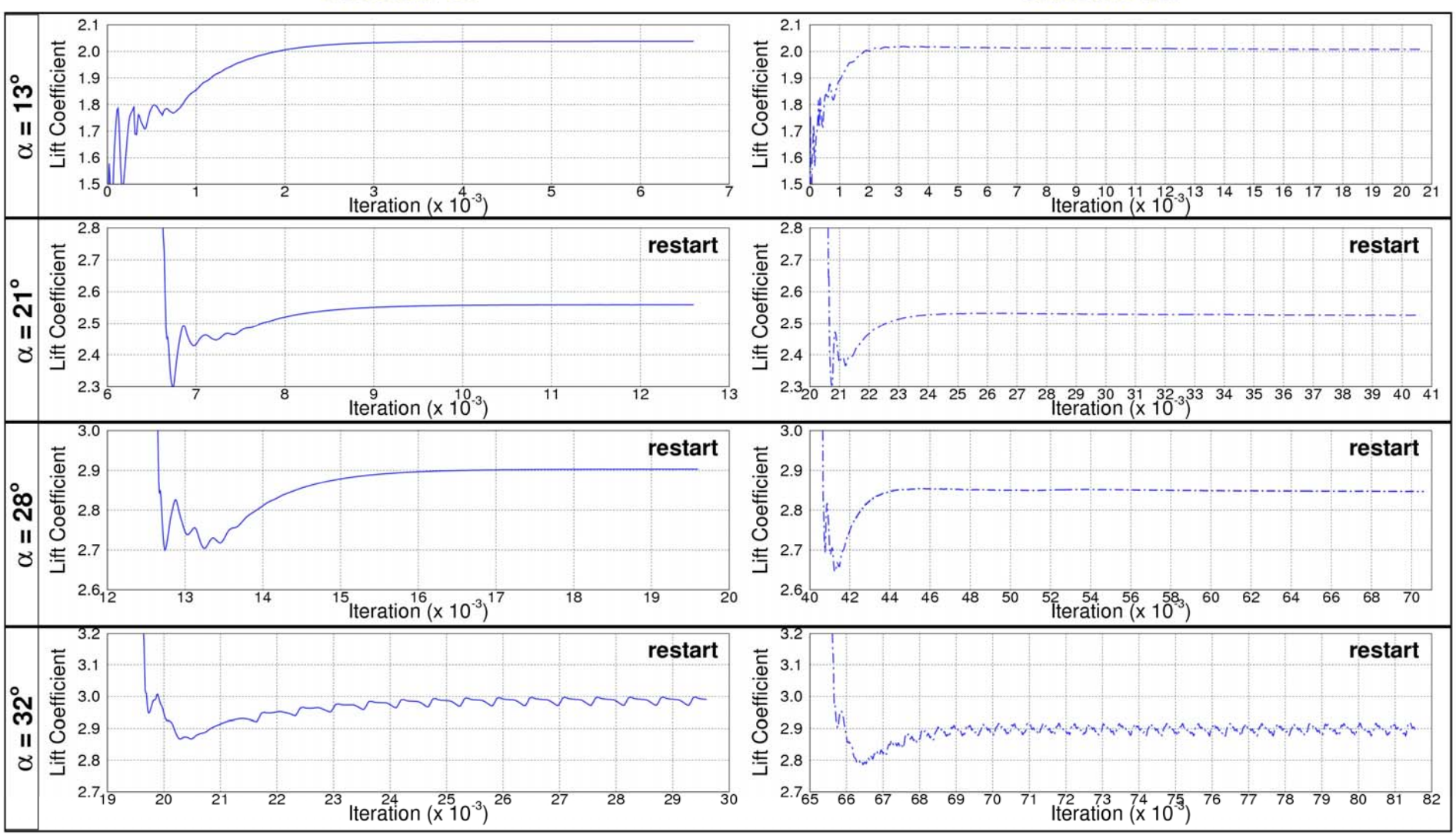
SA-RC Turbulence Model			
Brackets (grid #)	**BASELINE Fully Turbulent**	**BRACKET EFFECT Fully Turbulent**	**TRANSITION EFFECT Specify Laminar Regions**
off (2)	**6º → 37º**		**6º → 28º**
on (3)		**6º → 34º**	**6º → 28º**

SST-RC Turbulence Model			
Brackets (grid #)	**BASELINE Fully Turbulent**	**BRACKET EFFECT Fully Turbulent**	**TRANSITION EFFECT γ-Re_θ Transition Model**
off (2)	**6º → 32º**		**6º → 32º**
on (3)		**6º → 28º**	**6º → 28º**

Convergence History
Lift – Bracket Effect

OVERFLOW Trap Wing Config 1: Lift Convergence Histories

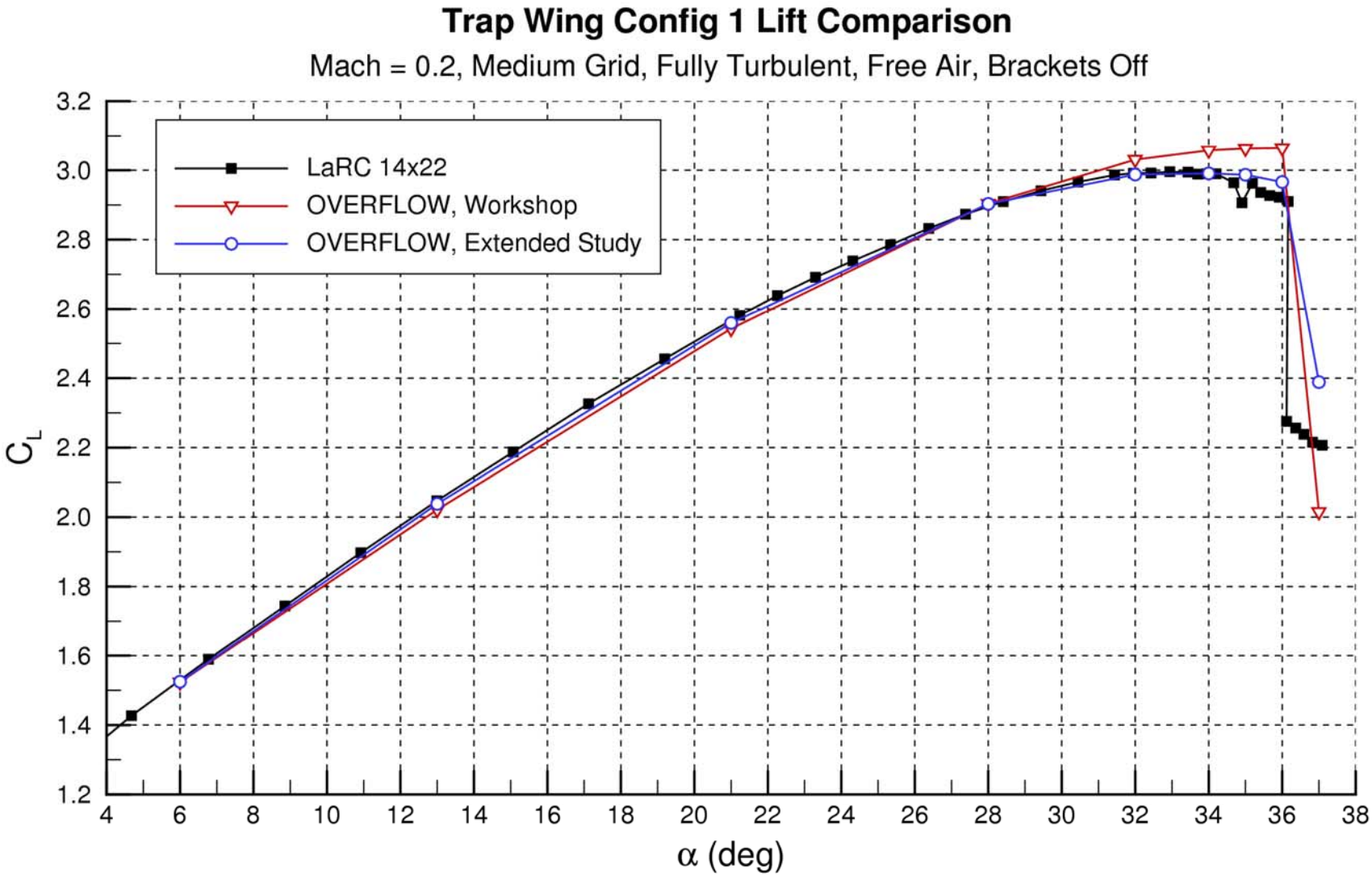
RN = 4.3 mil, Mach = 0.2, Fully Turbulent, SA-RC



Results:

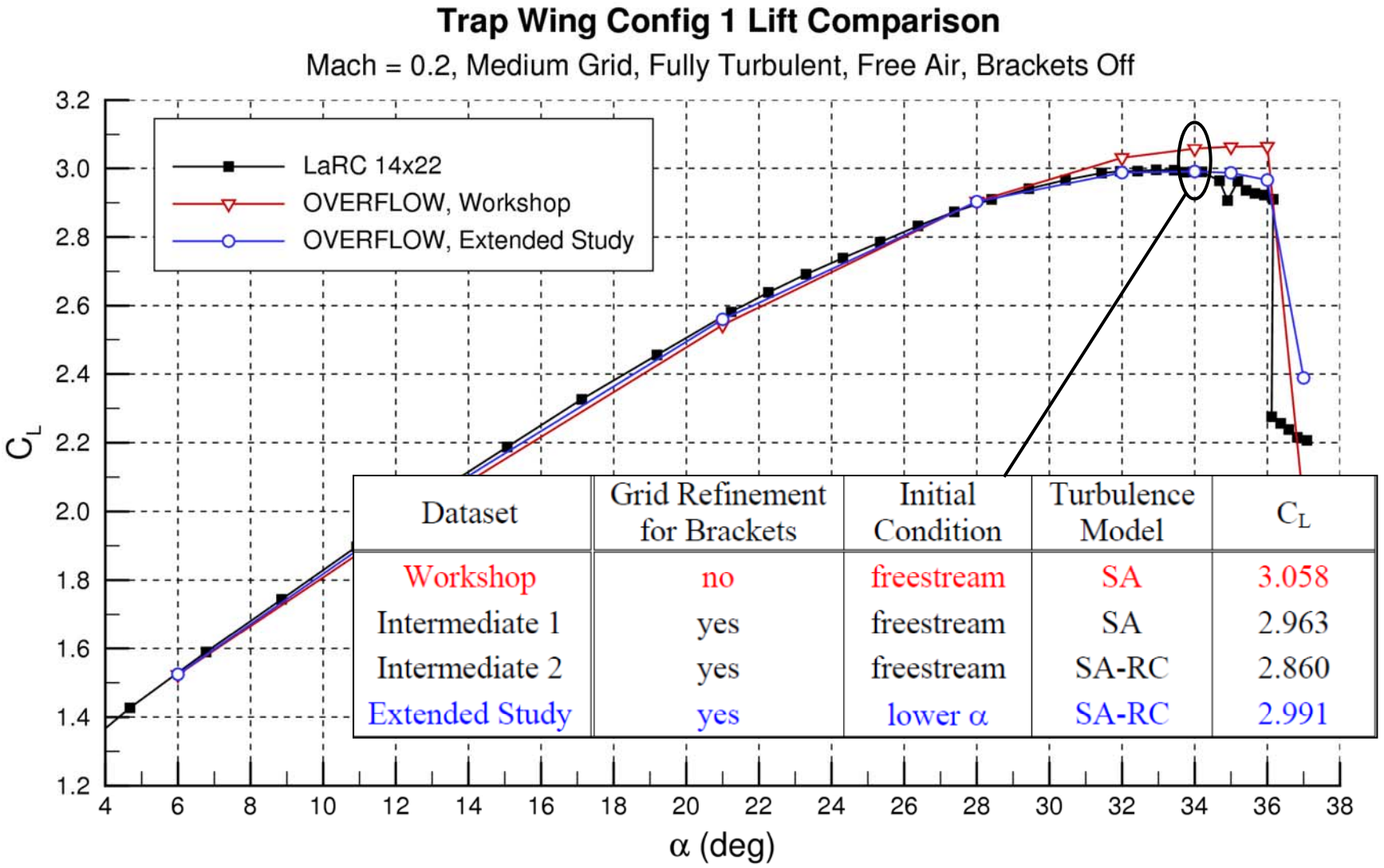
Workshop vs. Extended Study

Workshop vs. Extended Study
Lift Curve Comparison



- Extended Study results are closer to experiment at angles-of-attack near stall.
- This is a fully turbulent, bracket-off analysis. Improved correlation is fortuitous.

Workshop vs. Extended Study
Lift Curve Comparison



Dataset	Grid Refinement for Brackets	Initial Condition	Turbulence Model	C_L
Workshop	no	freestream	SA	3.058
Intermediate 1	yes	freestream	SA	2.963
Intermediate 2	yes	freestream	SA-RC	2.860
Extended Study	yes	lower α	SA-RC	2.991

- At $\alpha = 34^o$, $\Delta C_L = -0.07$
- ΔC_L due to: Grid = -0.1 Turbulence Model = -0.1 Initial Condition = 0.13

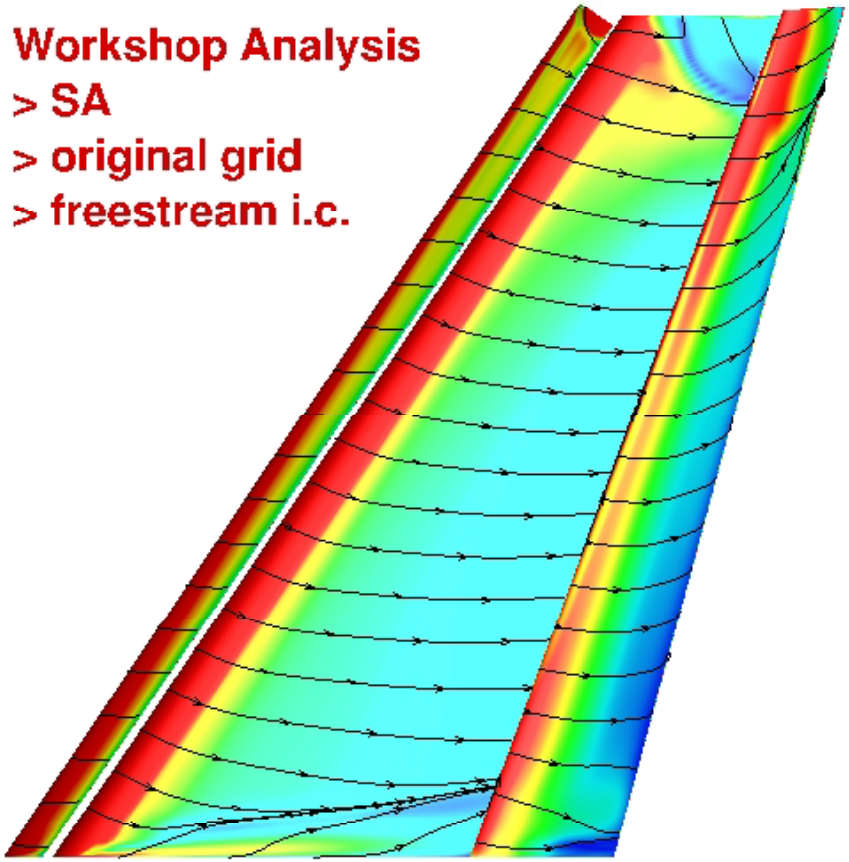
Workshop vs. Extended Study
Surface Streamline Comparison

Trap Wing Config 1 OVERFLOW Solutions

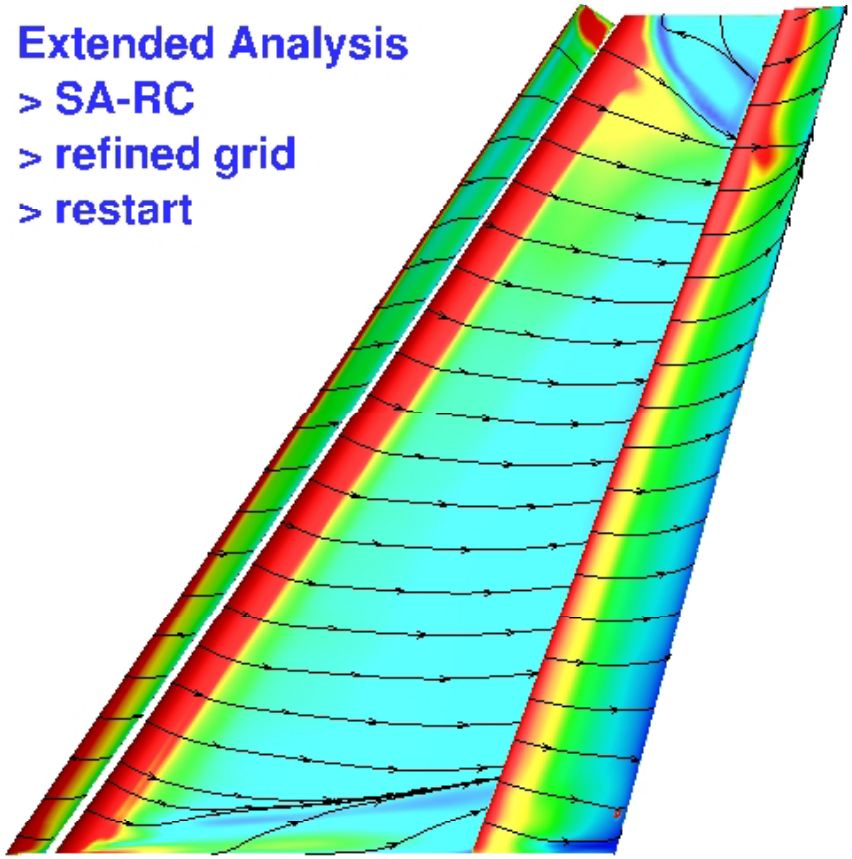
RN = 4.3 mil, Mach = 0.2, $\alpha = 34^{\circ}$

C_f 0.000 0.002 0.004 0.006 0.008 0.010

Workshop Analysis
> SA
> original grid
> freestream i.c.

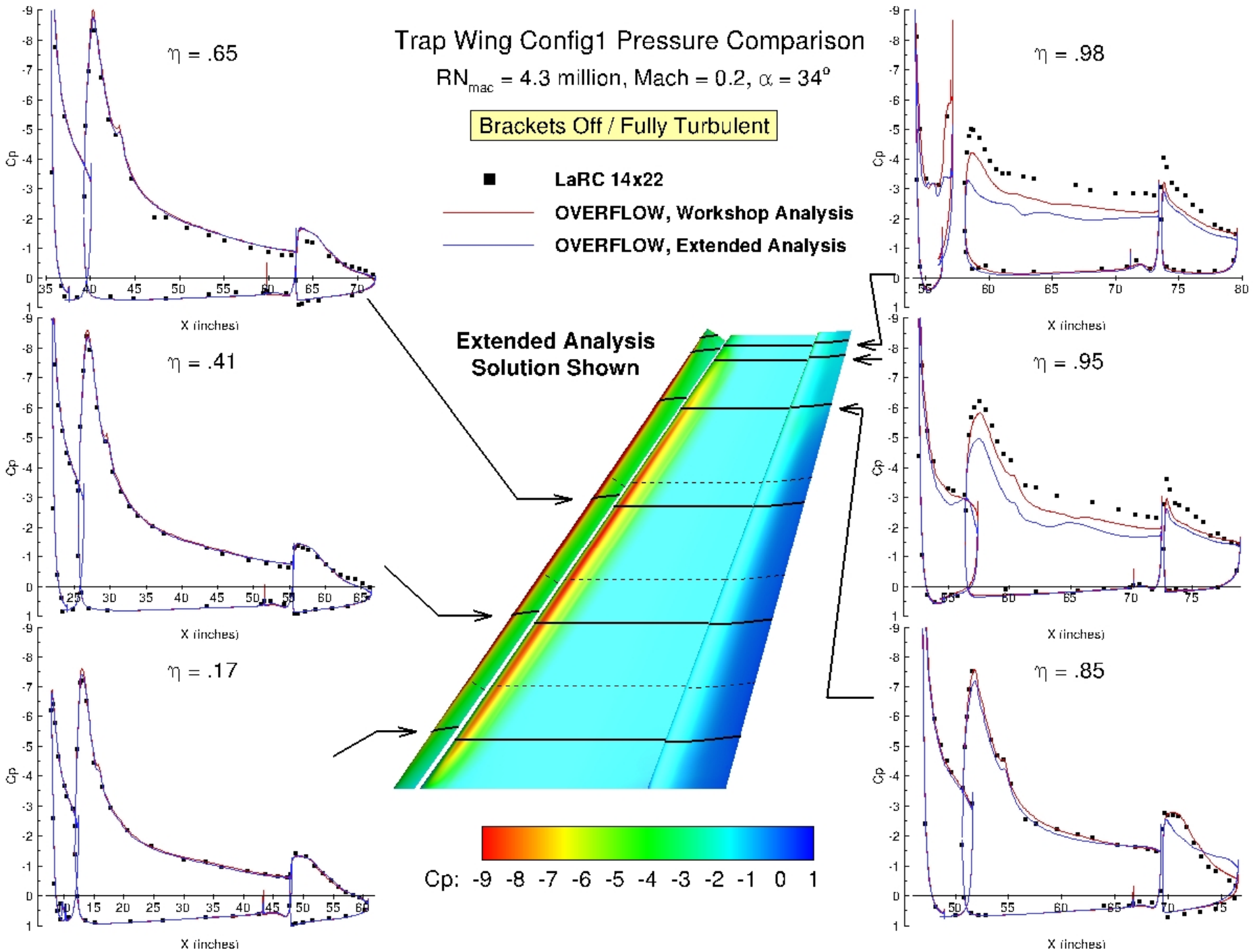


Extended Analysis
> SA-RC
> refined grid
> restart



- Significant difference in skin friction and streamlines seen at the tip.

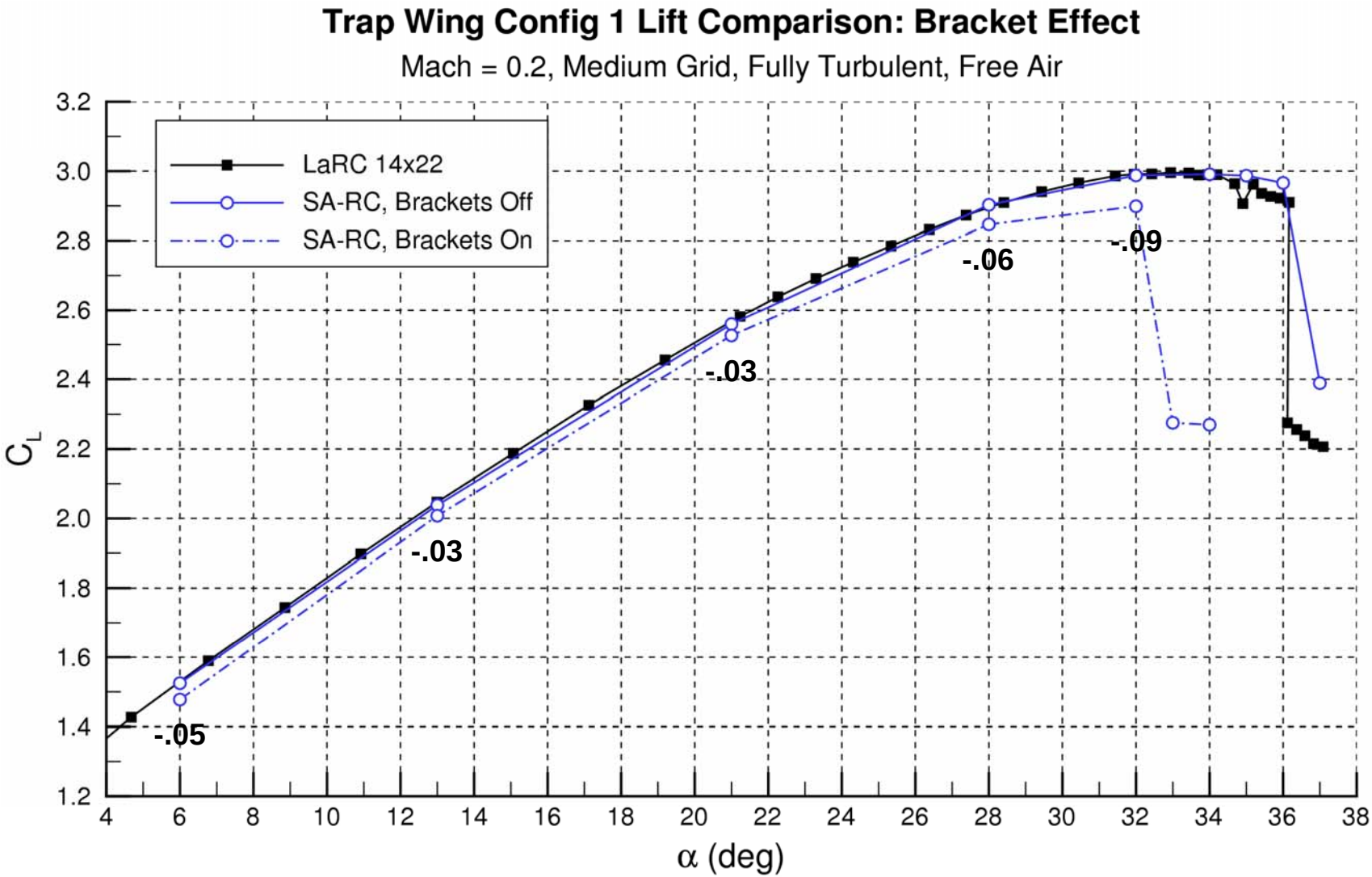
Workshop vs. Extended Study
Pressure Comparison



Results:

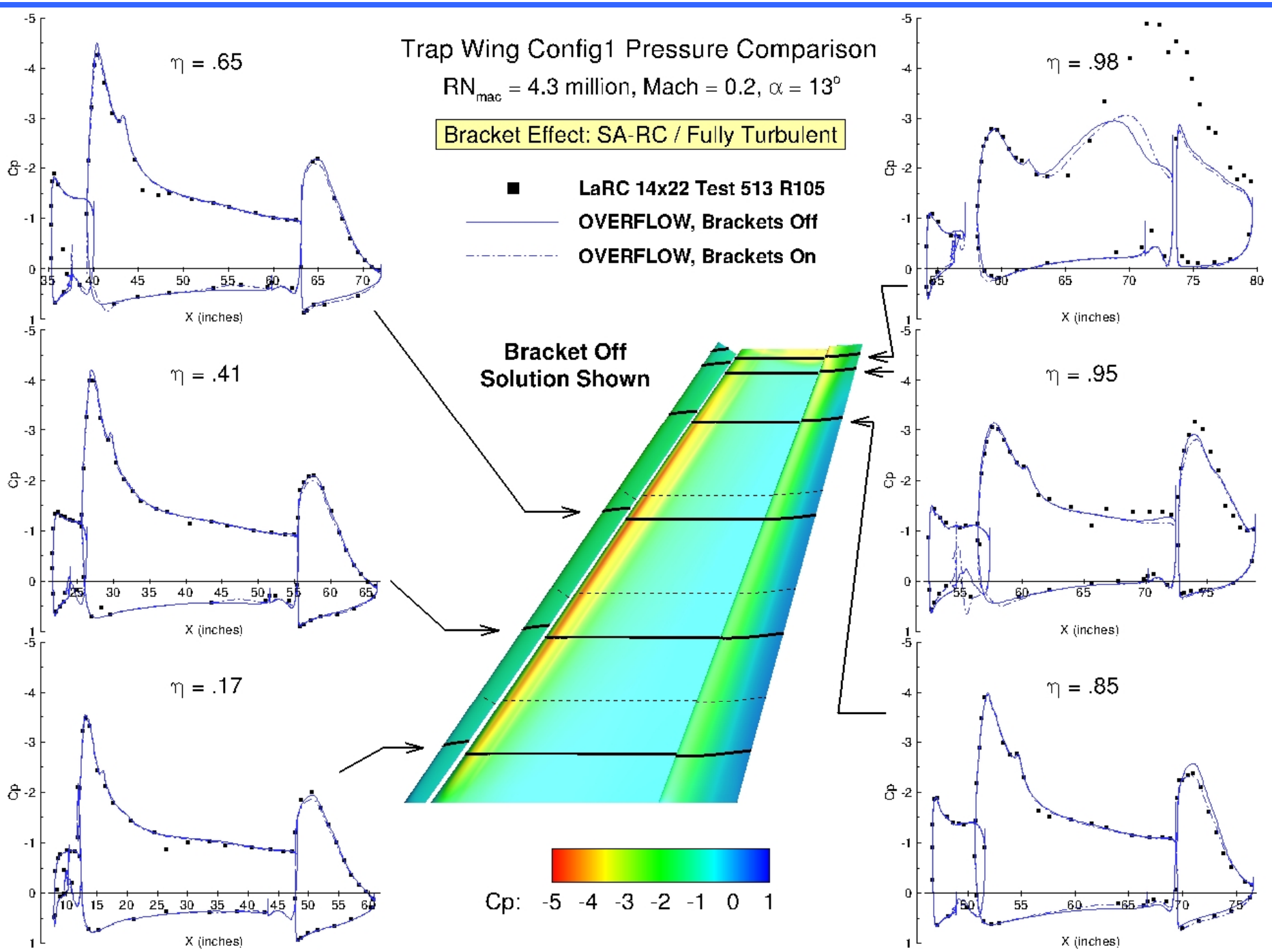
Bracket Effect

Bracket Effect
Lift Curve Comparison



- Brackets reduce C_L by indicated amounts.
- Early stall behavior with brackets-on not well understood, may be grid related.

Bracket Effect
Pressure Comparison



Results:

Transition Effect

Transition Effect
Specified vs. Computed Transition

The Trap Wing was analyzed with transition using two methods.

1. Define regions of laminar flow in OVERFLOW input deck via grid indicies using transition locations from Eliasson, et al. (AIAA 2011-3009).

SA-RC Turbulence Model			
Brackets	BASELINE Fully Turbulent	BRACKET EFFECT Fully Turbulent	TRANSITION EFFECT Specify Laminar Regions
off	6º → 37º		6º → 28º
on		6º → 34º	6º → 28º

2. Use the Langtry-Menter γ-Re_θ transition model (version CFX-v-1.1) which is coupled with the SST turbulence model only.

SST-RC Turbulence Model			
Brackets	BASELINE Fully Turbulent	BRACKET EFFECT Fully Turbulent	TRANSITION EFFECT γ-Re_θ Transition Model
off	6º → 32º		6º → 32º
on		6º → 28º	6º → 28º

Transition Effect: Specified using SA-RC
Lift Comparison

Trap Wing Config 1 OVERFLOW Results

Reynolds Number = 4.3 million, Mach = 0.2

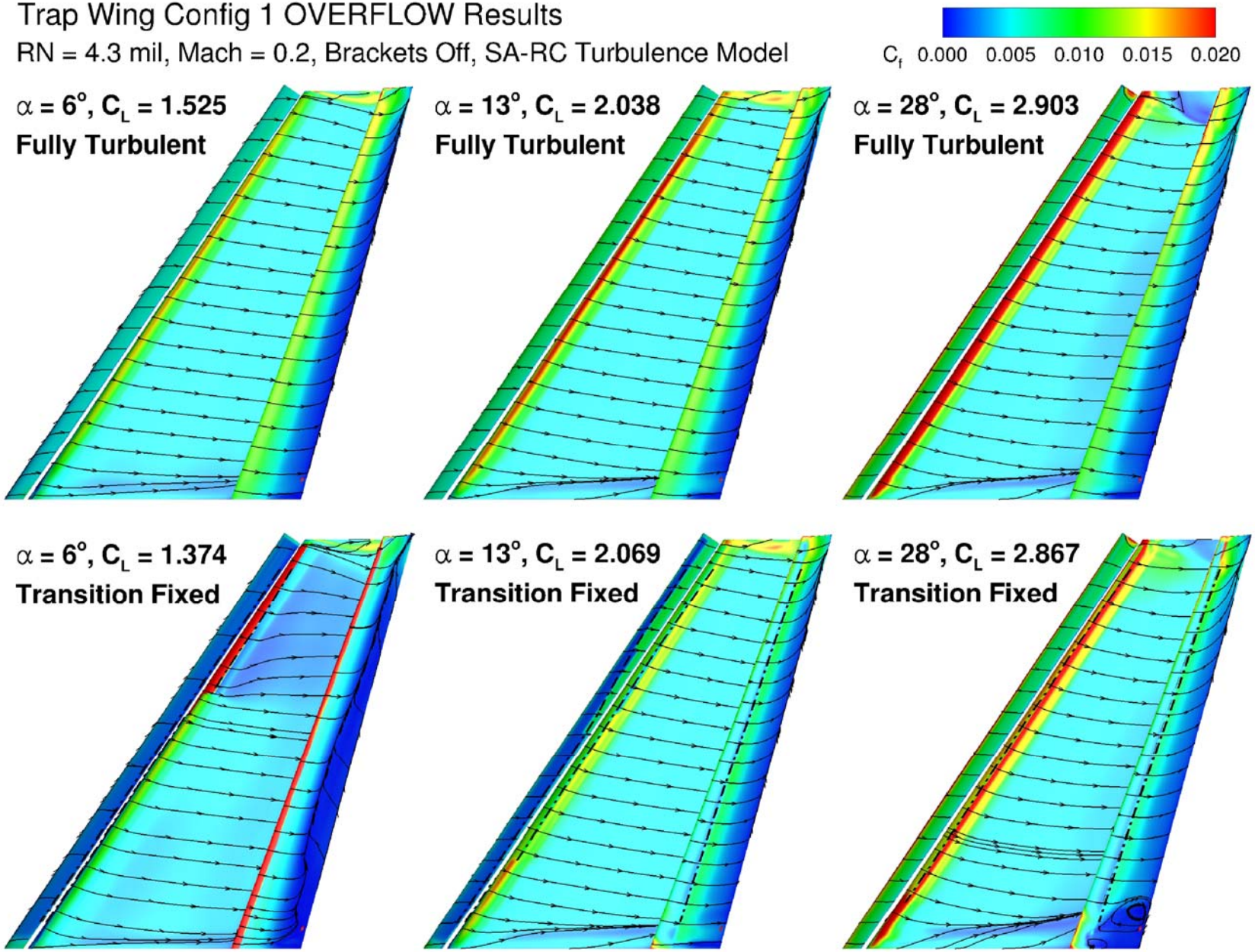
	BRACKET EFFECT			FIXED TRANSITION EFFECT			
alpha	fully turbulent C_L			brackets off C_L		brackets on C_L	
(deg)	brackets off	brackets on	delta (on - off)	transition	delta (trans - turb)	transition	delta (trans - turb)
6	1.525	1.478	-0.047	1.374	-0.151	1.259	-0.218
13	2.038	2.008	-0.030	2.069	0.031	1.987	-0.021
21	2.559	2.526	-0.033	2.589	0.030	2.466	-0.060
28	2.903	2.847	-0.056	2.867	-0.036	n/a	n/a

- Inconsistent trend in bracket-off ΔC_L with angle-of-attack
  - 13º and 21º deltas are as expected
  - Reduced lift at 6º and 28º caused by flap separation
- Reduced lift due to transition for all angles-of-attack with brackets on

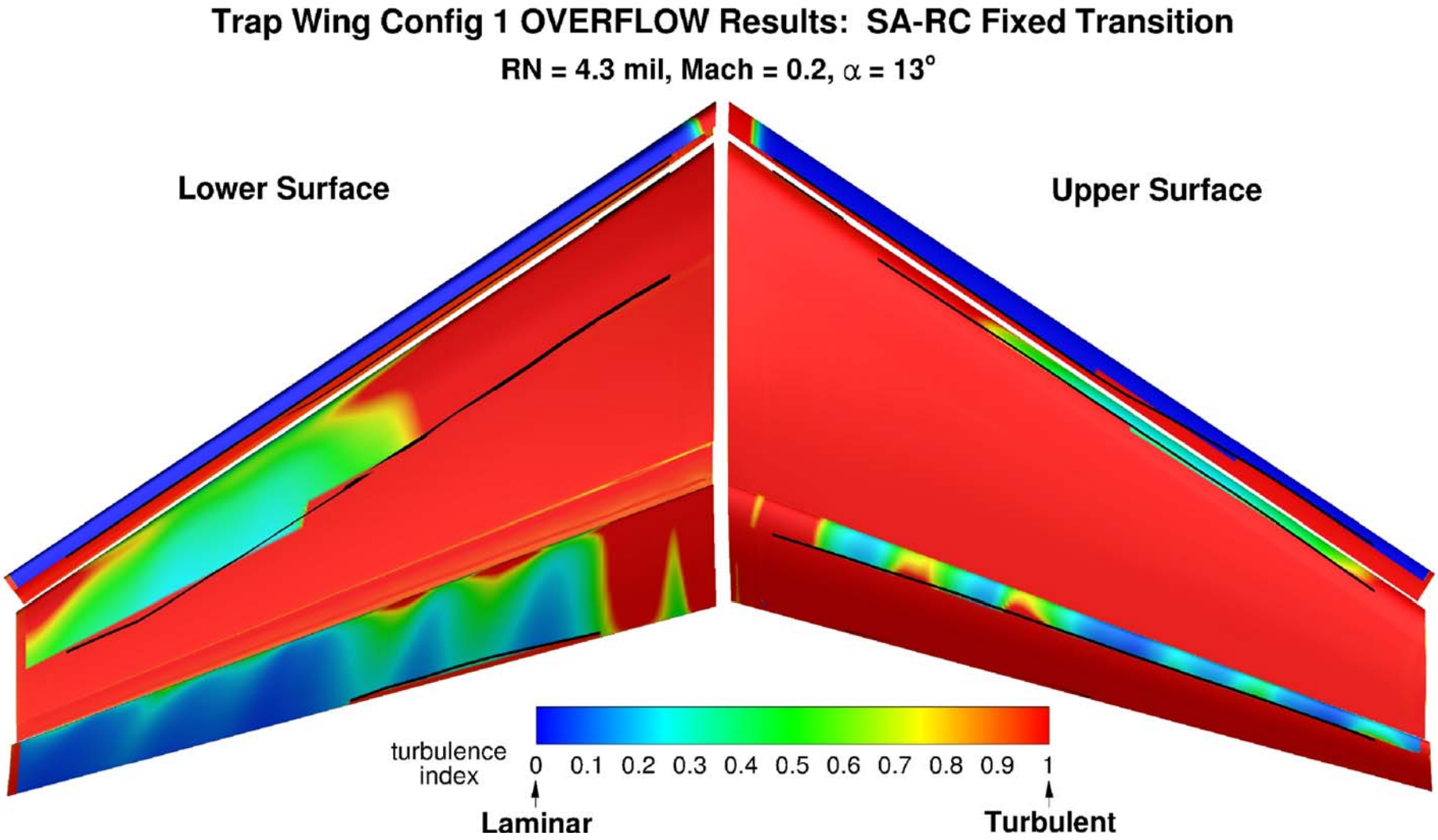
Transition Effect: Specified using SA-RC
Surface Streamline Comparison

Trap Wing Config 1 OVERFLOW Results

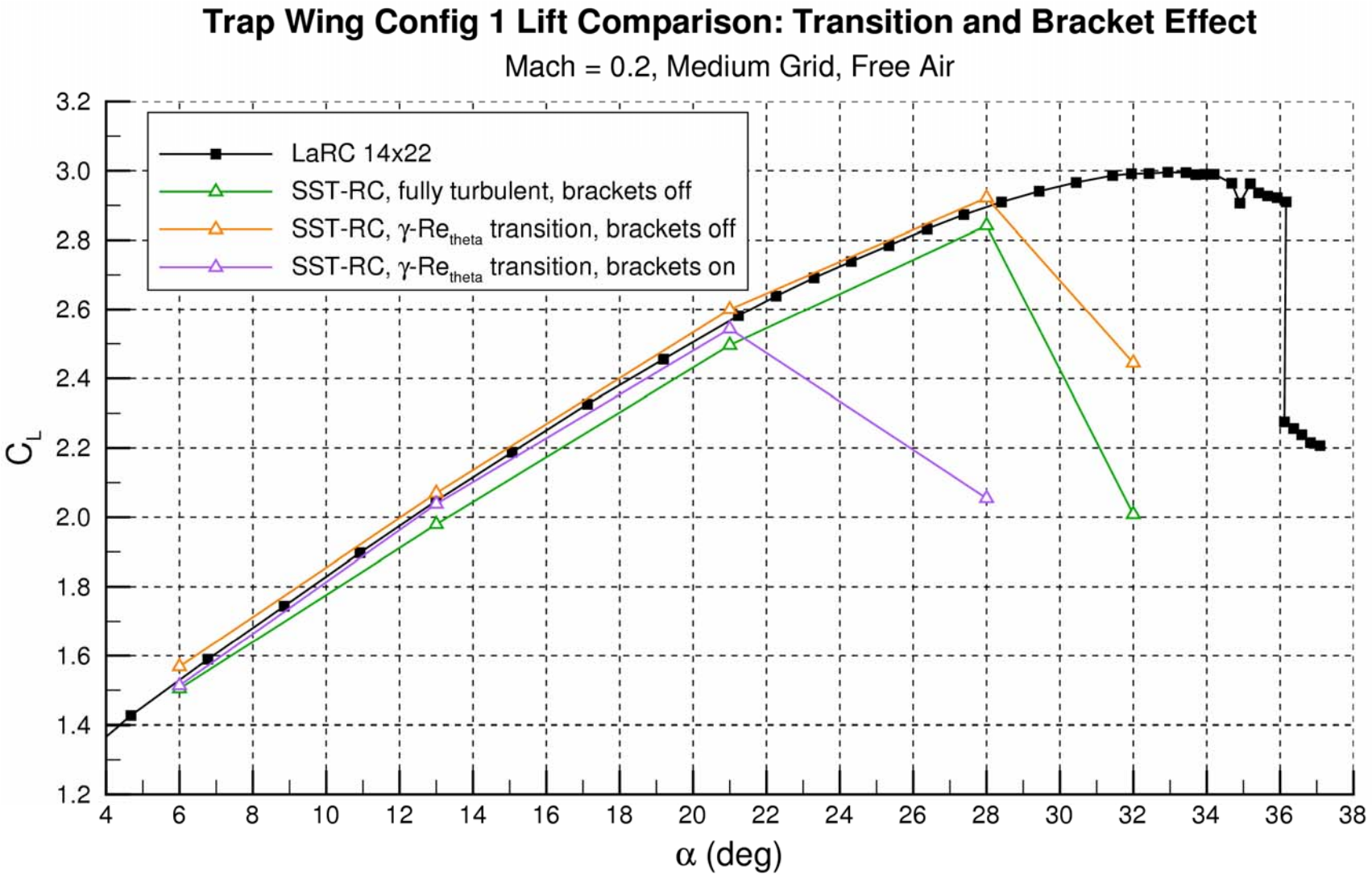
RN = 4.3 mil, Mach = 0.2, Brackets Off, SA-RC Turbulence Model



Transition Effect: Specified using SA-RC
Turbulence Index

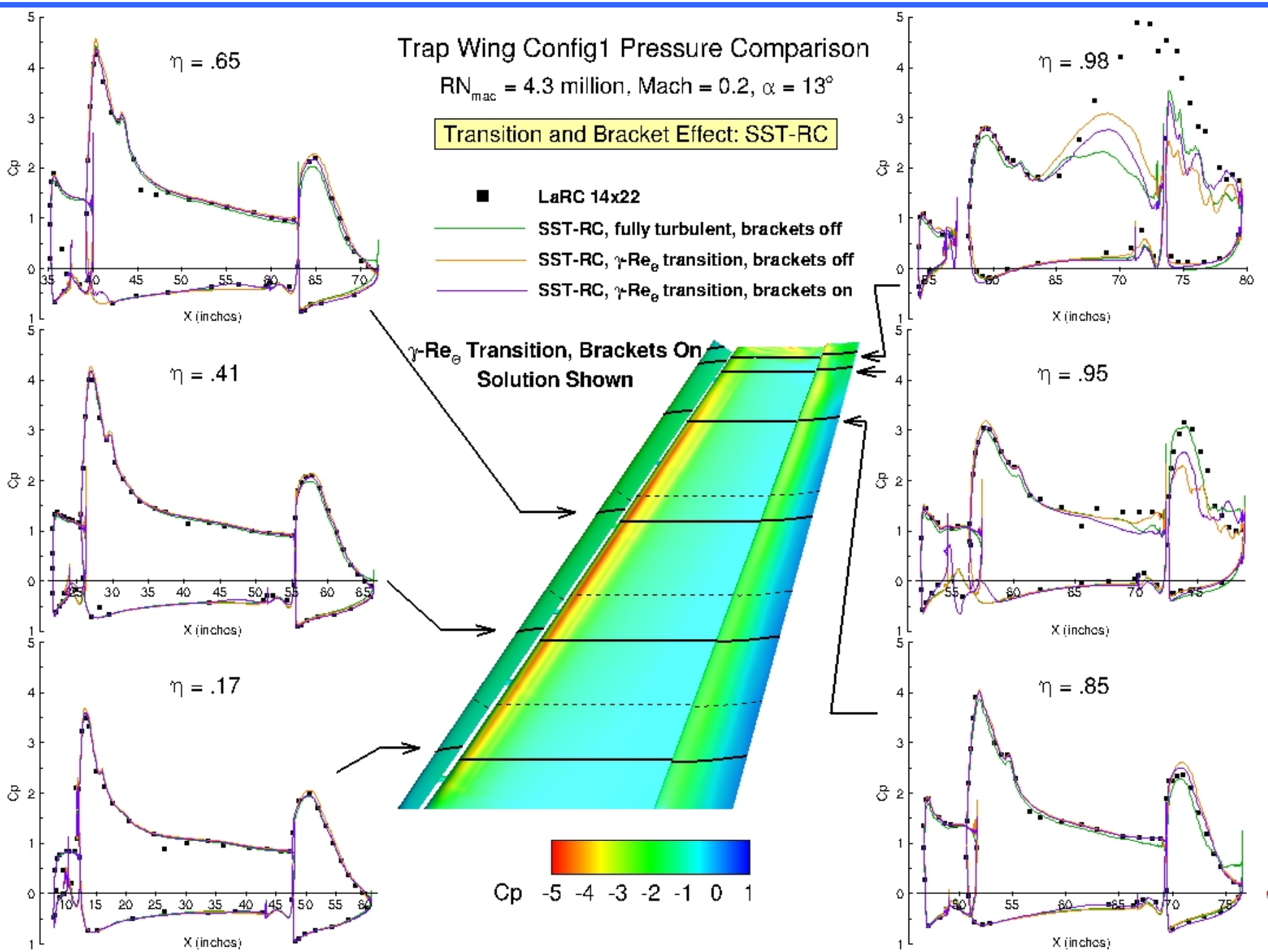


Transition Effect: Computed using SST-RC
Lift Comparison



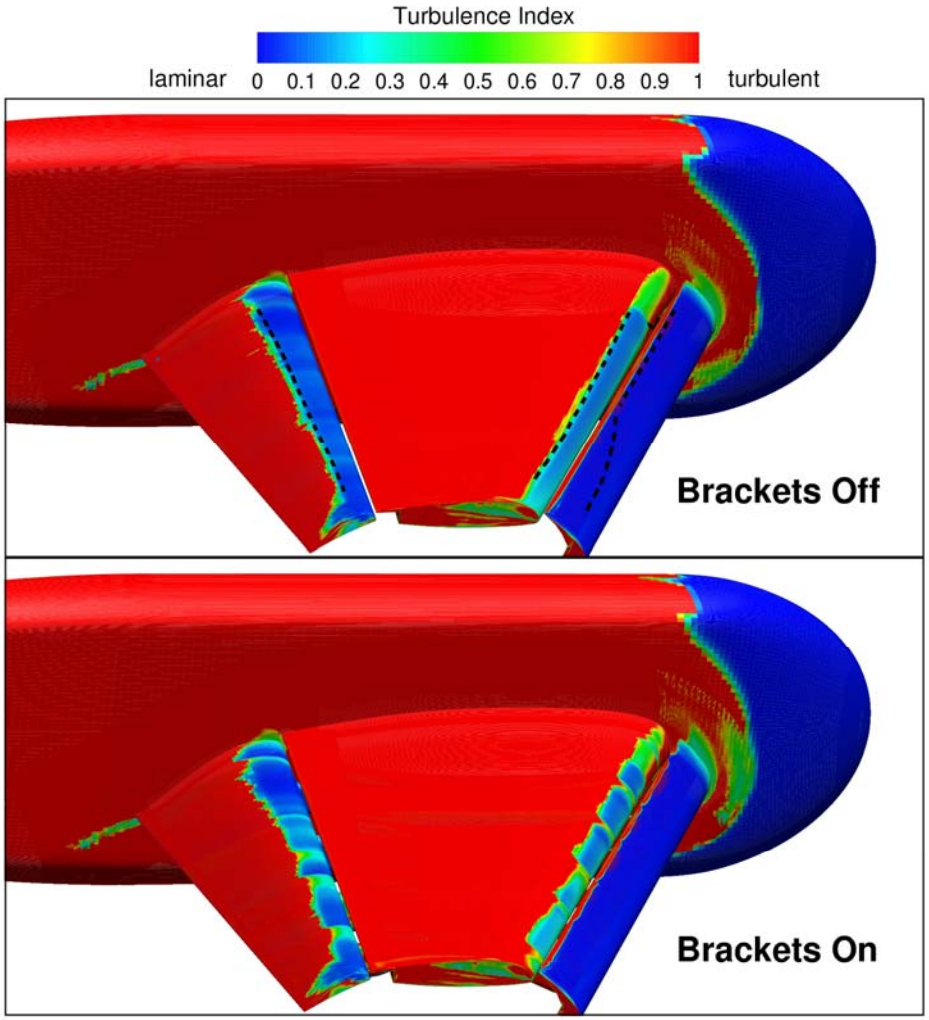
- Transition increases lift while brackets decrease lift.
- Early stall predicted with brackets-on. This is consistent with SA-RC results.

Transition Effect: Computed using SST-RC
Pressure Comparison

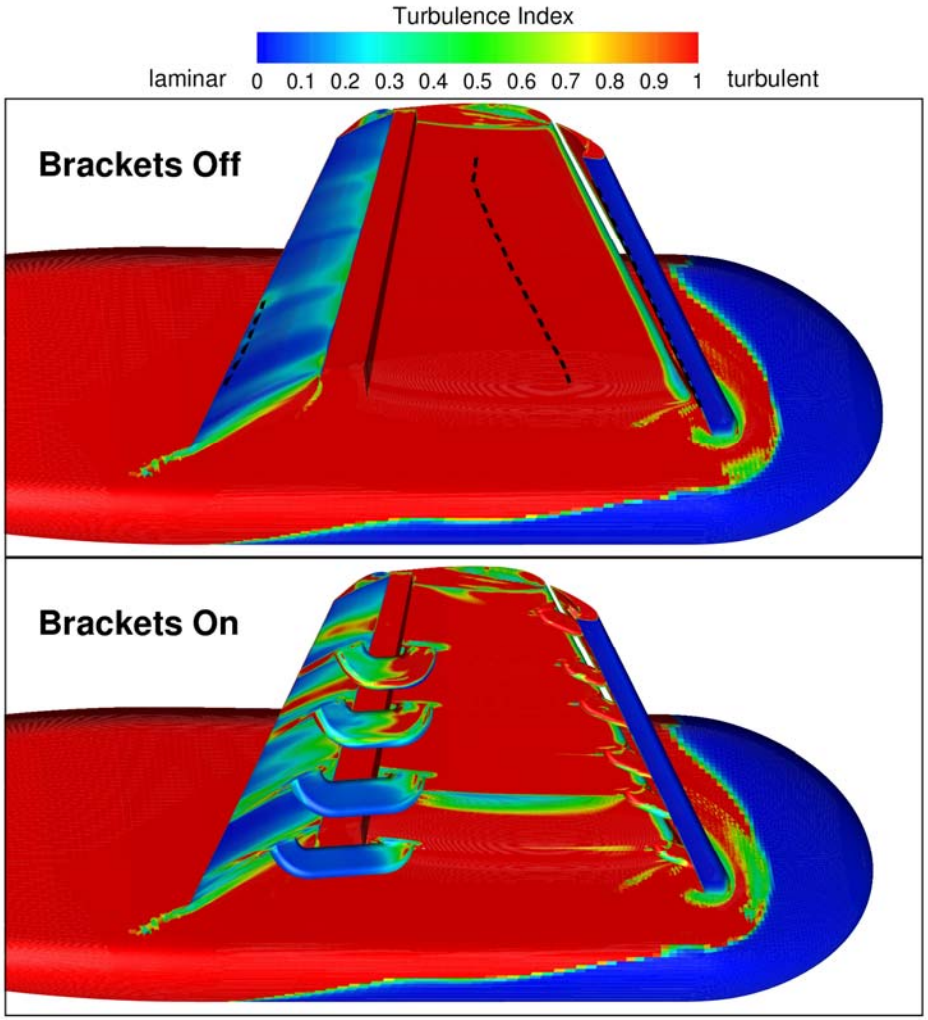


Transition Effect: Computed using SST-RC
Turbulence Index for $\alpha = 13^o$

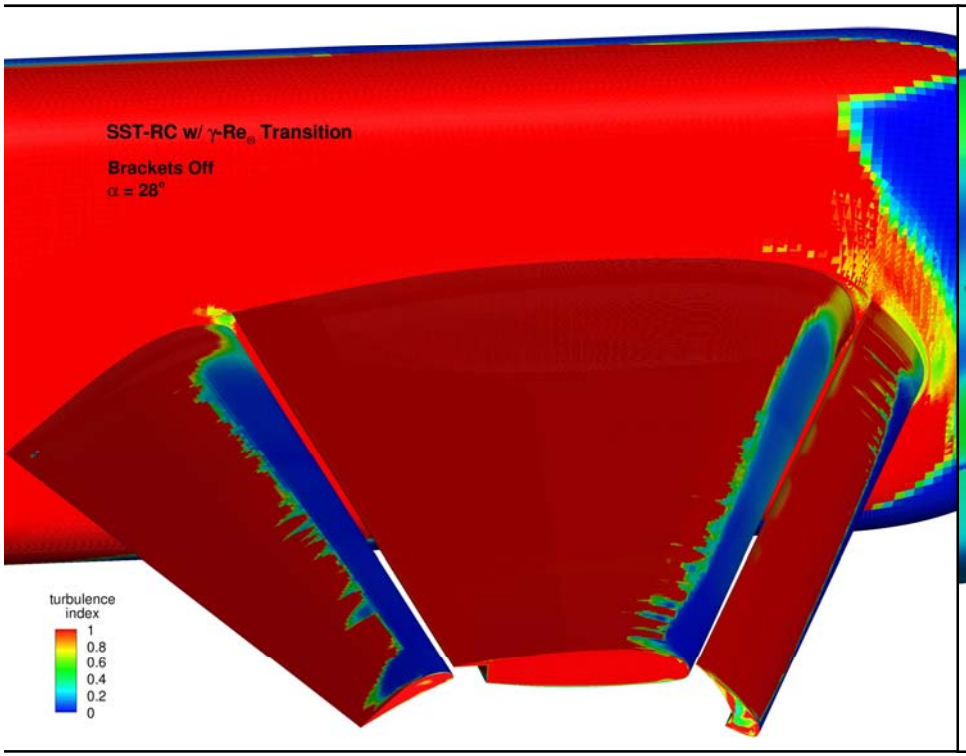
Trap Wing Config 1 OVERFLOW Results: SST-RC w/ γ-Re_Θ Transition
RN = 4.3 mil, Mach = 0.2, Medium Grid, Free Air, α = 13°



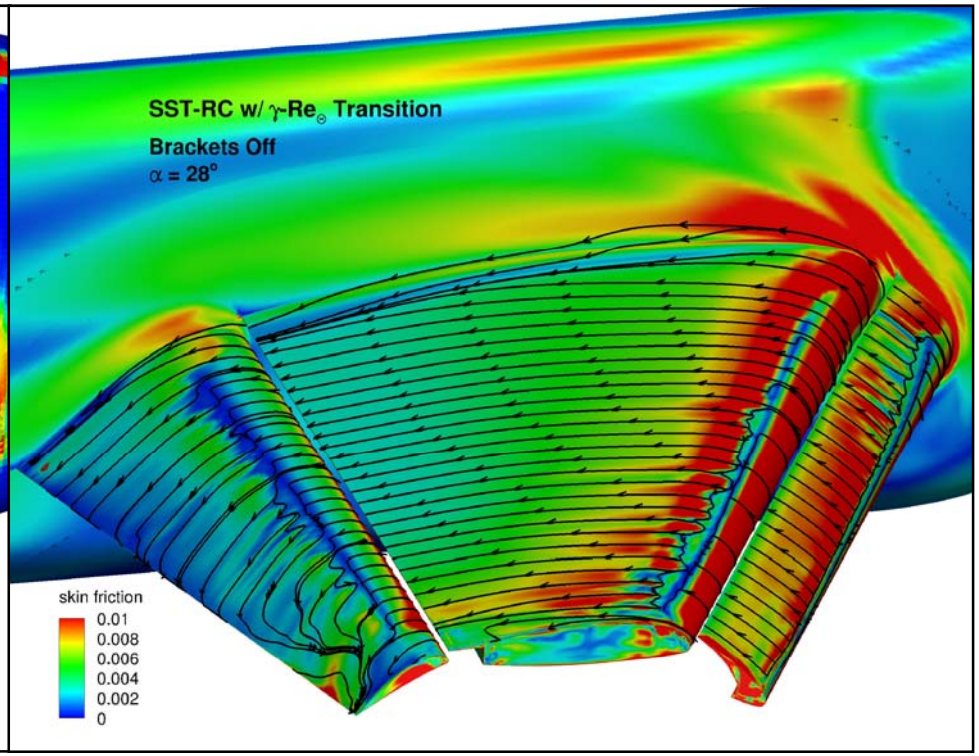
Trap Wing Config 1 OVERFLOW Results: SST-RC w/ γ-Re_Θ Transition
RN = 4.3 mil, Mach = 0.2, Medium Grid, Free Air, α = 13°



Transition Effect: Computed using SST-RC
Turbulence Index and Skin Friction for $\alpha = 28^o$



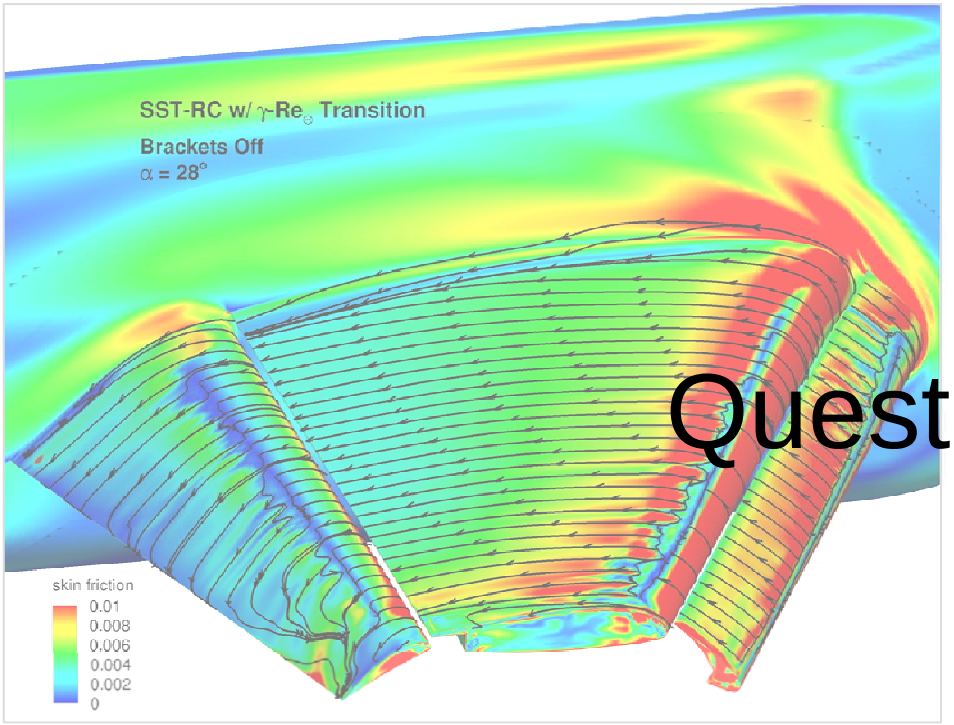
turbulence index



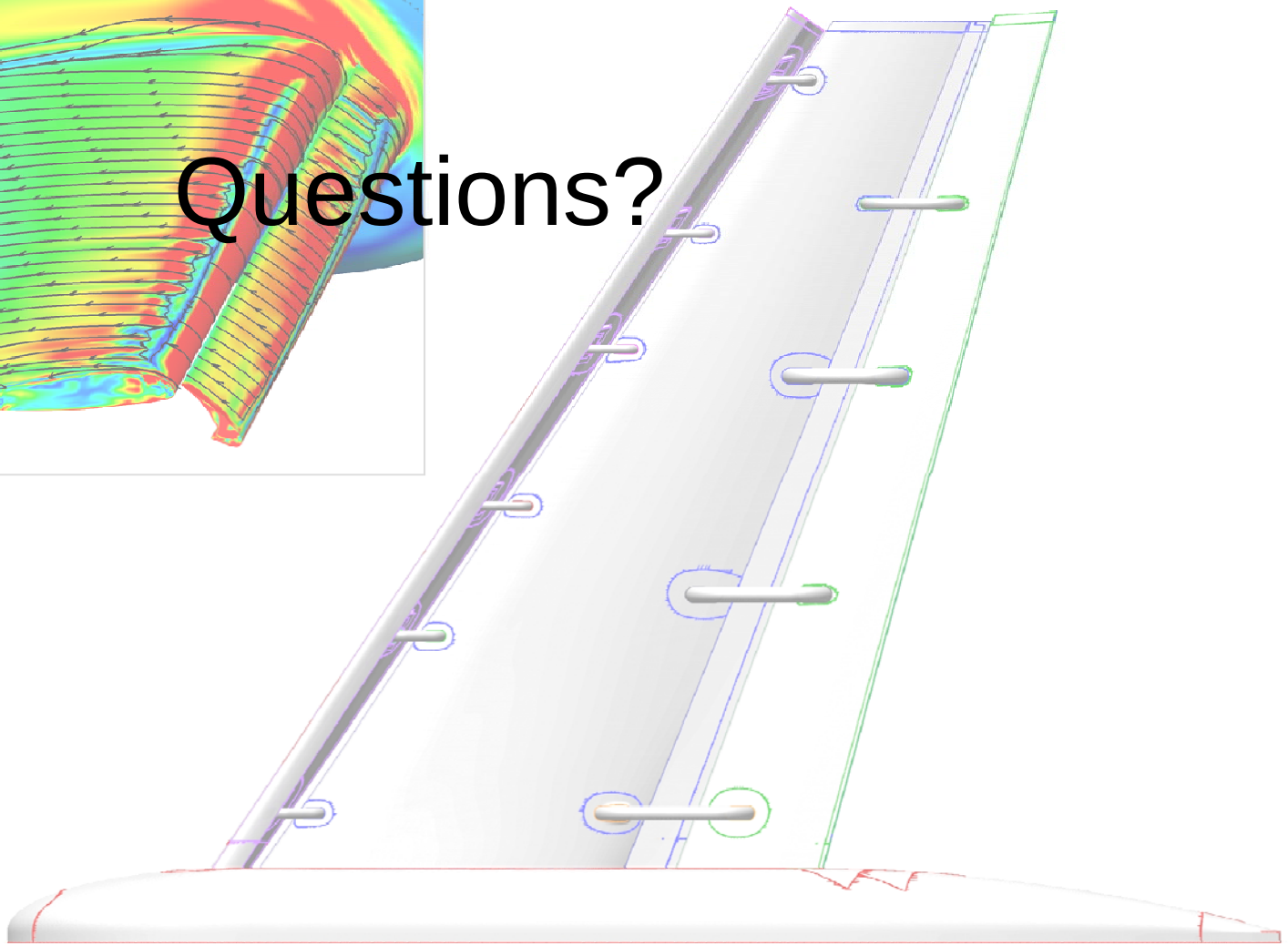
skin friction

Conclusions

- After applying all workshop lessons learned, the fully turbulent bracket-off lift curve is in very good agreement with test data through stall.
  - Implies bracket and transition effects may cancel.
- SA-RC results show brackets have expected impact on data, reducing lift for all angles-of-attack analyzed.
  - Early stall at 32^o requires further investigation. May be grid related.
- Fixed transition SA-RC results are mixed due to excessive flap separation at 6^o and 28^o. Lift increments at 13^o and 21^o show transition does recover the amount of lift lost to brackets.
- Computed transition SST-RC results produce expected incremental lift trends for 6^o, 13^o and 21^o. That is, bracket and transition effects cancel.
  - Brackets-off early stall at 28^o.
  - Brackets-on early stall at 21^o.

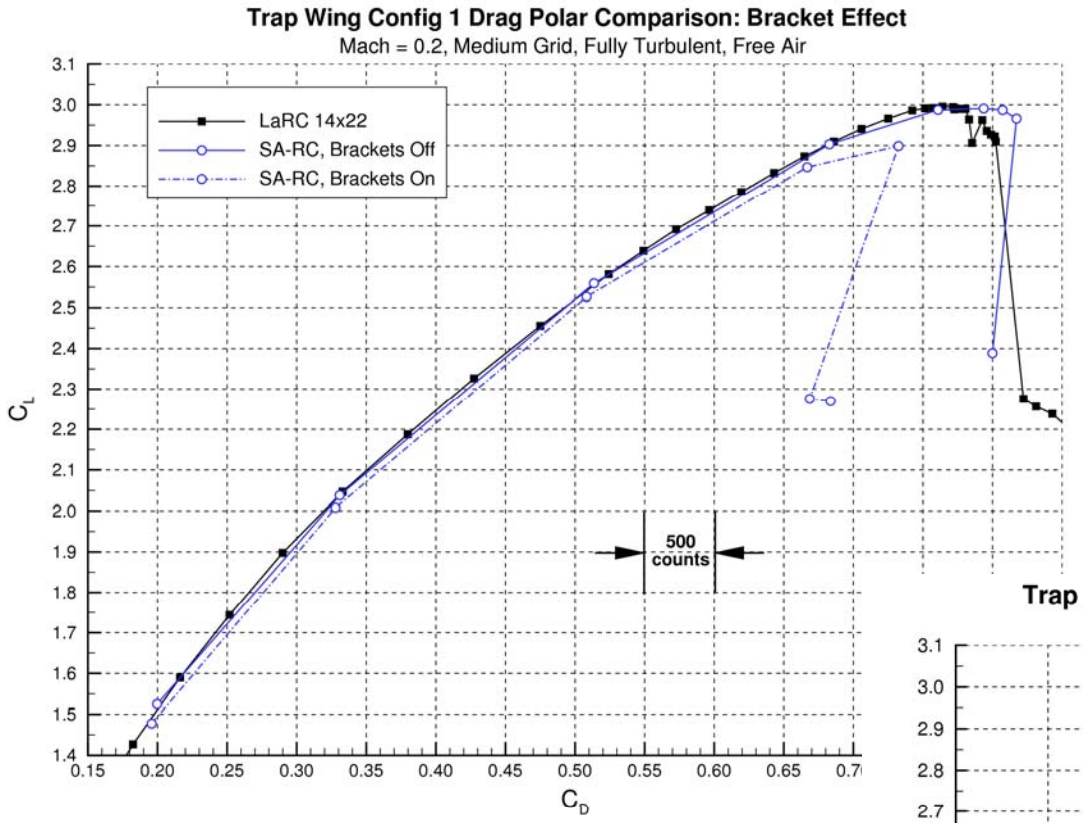

SST-RC w/ γ-Re$_\theta$ Transition
Brackets Off
α = 28°
skin friction
0.01
0.008
0.006
0.004
0.002
0

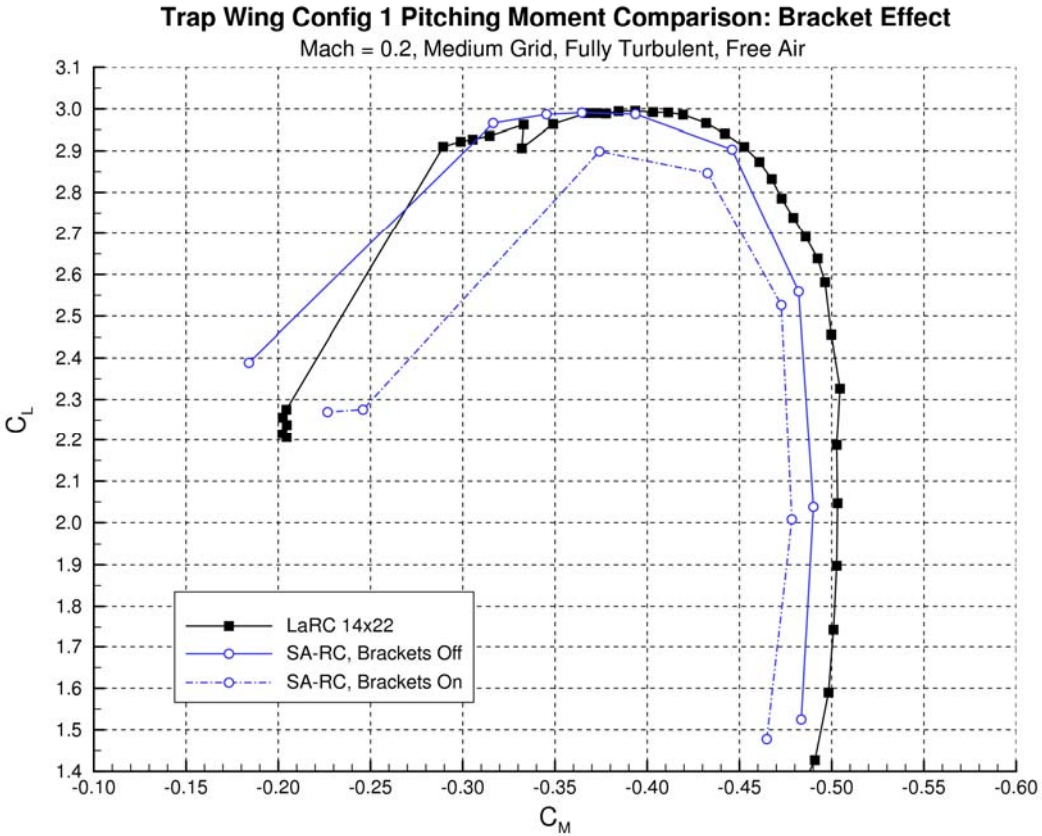
Questions?



Back-Up

Bracket Effect
Drag and Pitching Moment Comparison

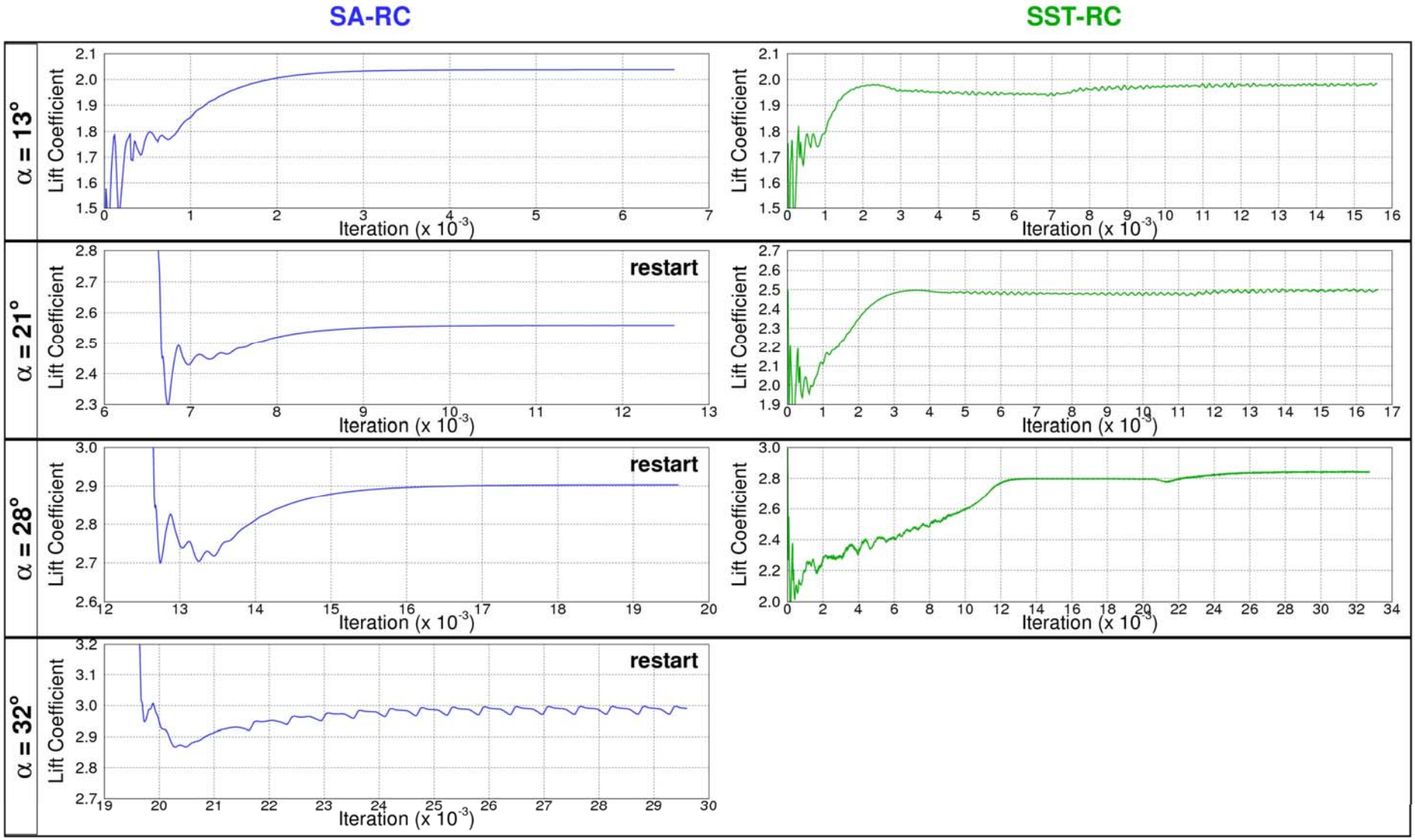




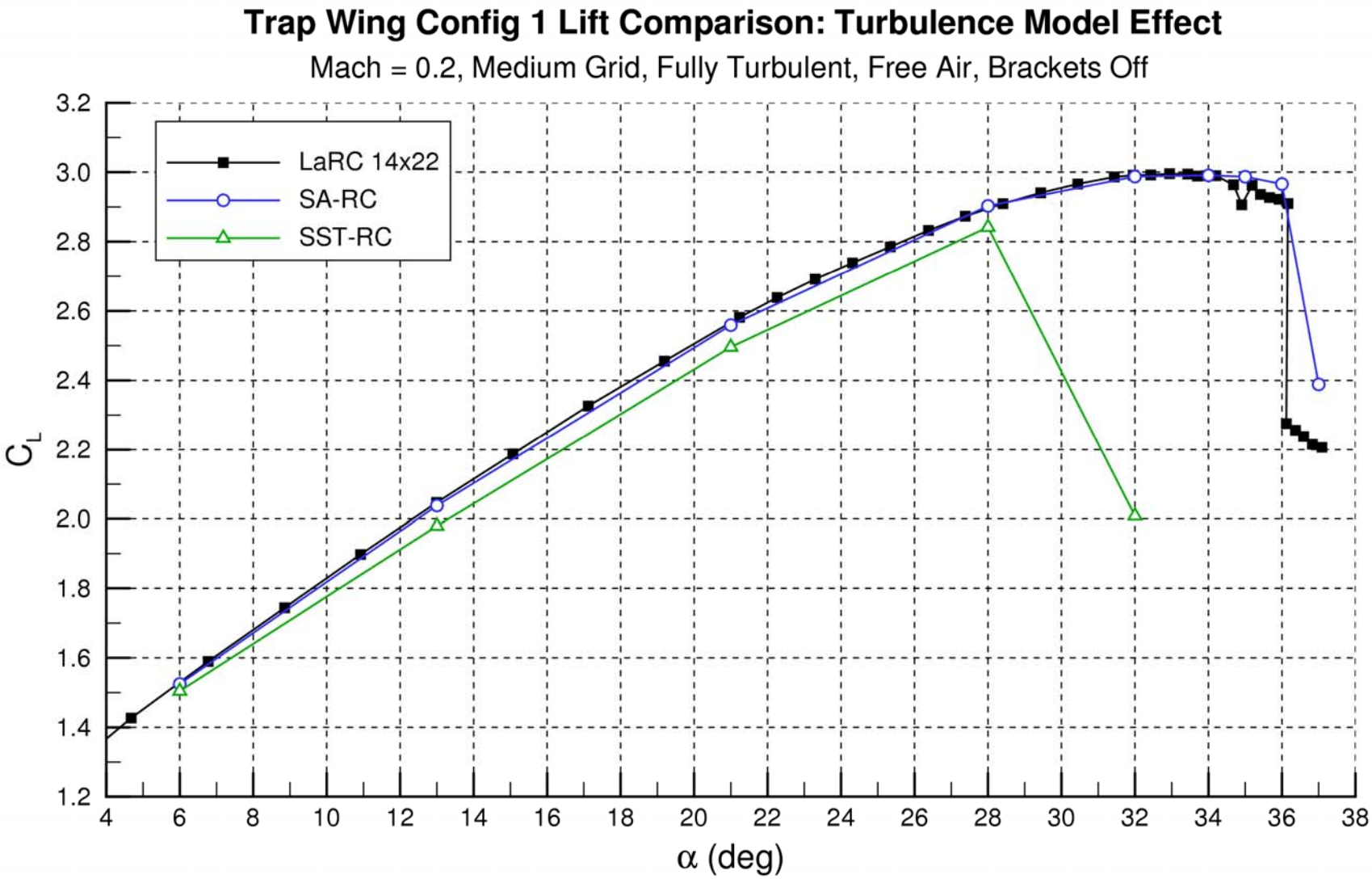
Convergence History
Lift – Turbulence Model Effect

OVERFLOW Trap Wing Config 1: Lift Convergence Histories

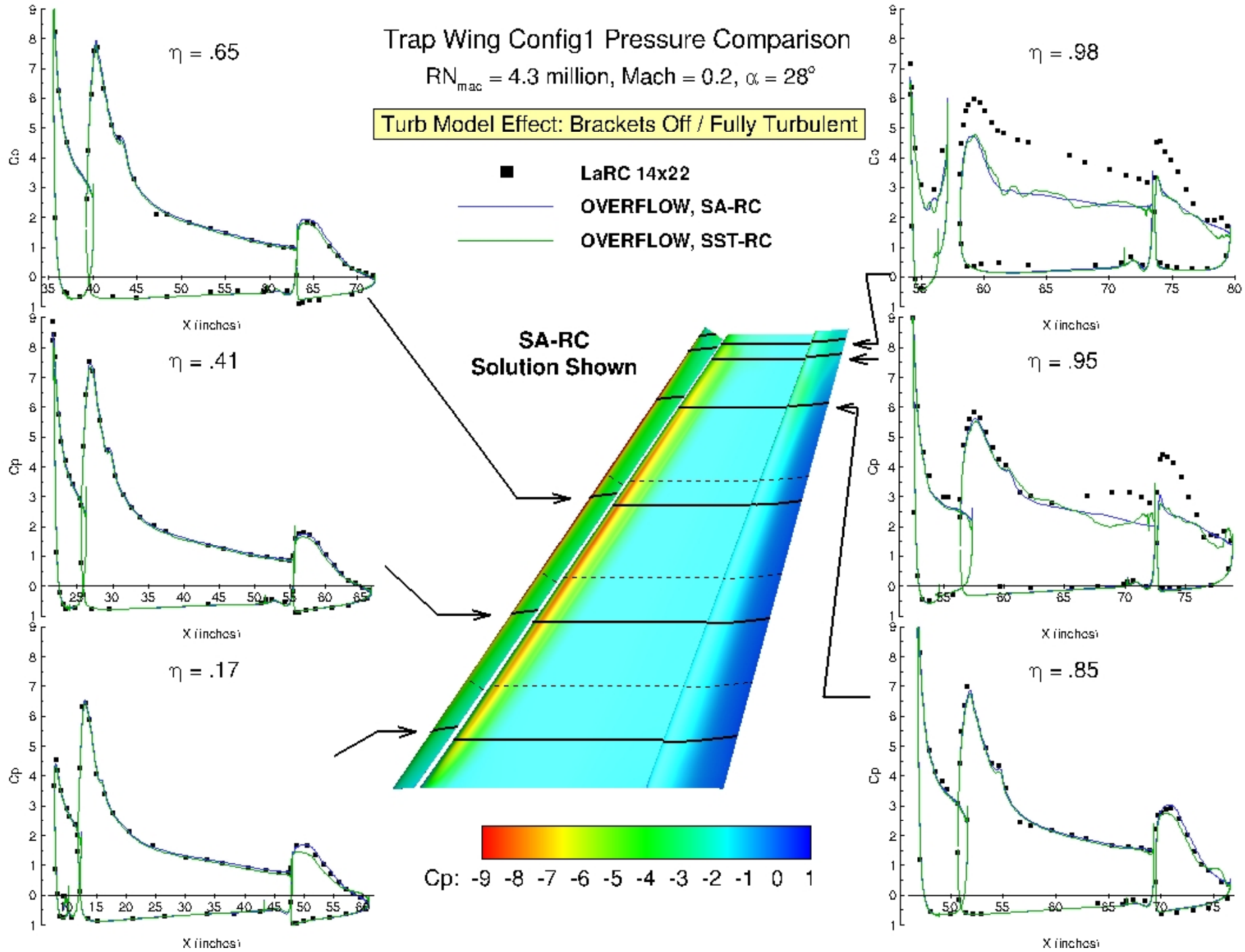
RN = 4.3 mil, Mach = 0.2, Fully Turbulent, Brackets-Off



Turbulence Model Effect
SA-RC vs. SST-RC



Turbulence Model Effect
SA-RC vs. SST-RC



Transition Effect: Computed using SST-RC
Velocity Profile Comparison