High Lift OVERFLOW Analysis of the DLR F11 Wind Tunnel Model

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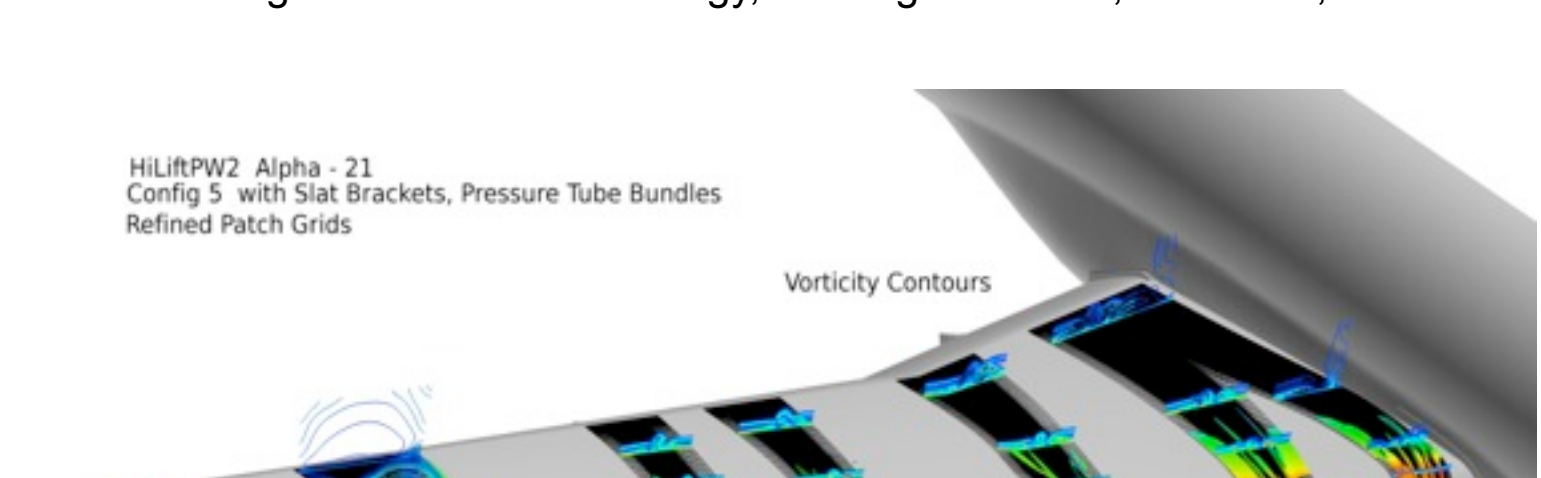

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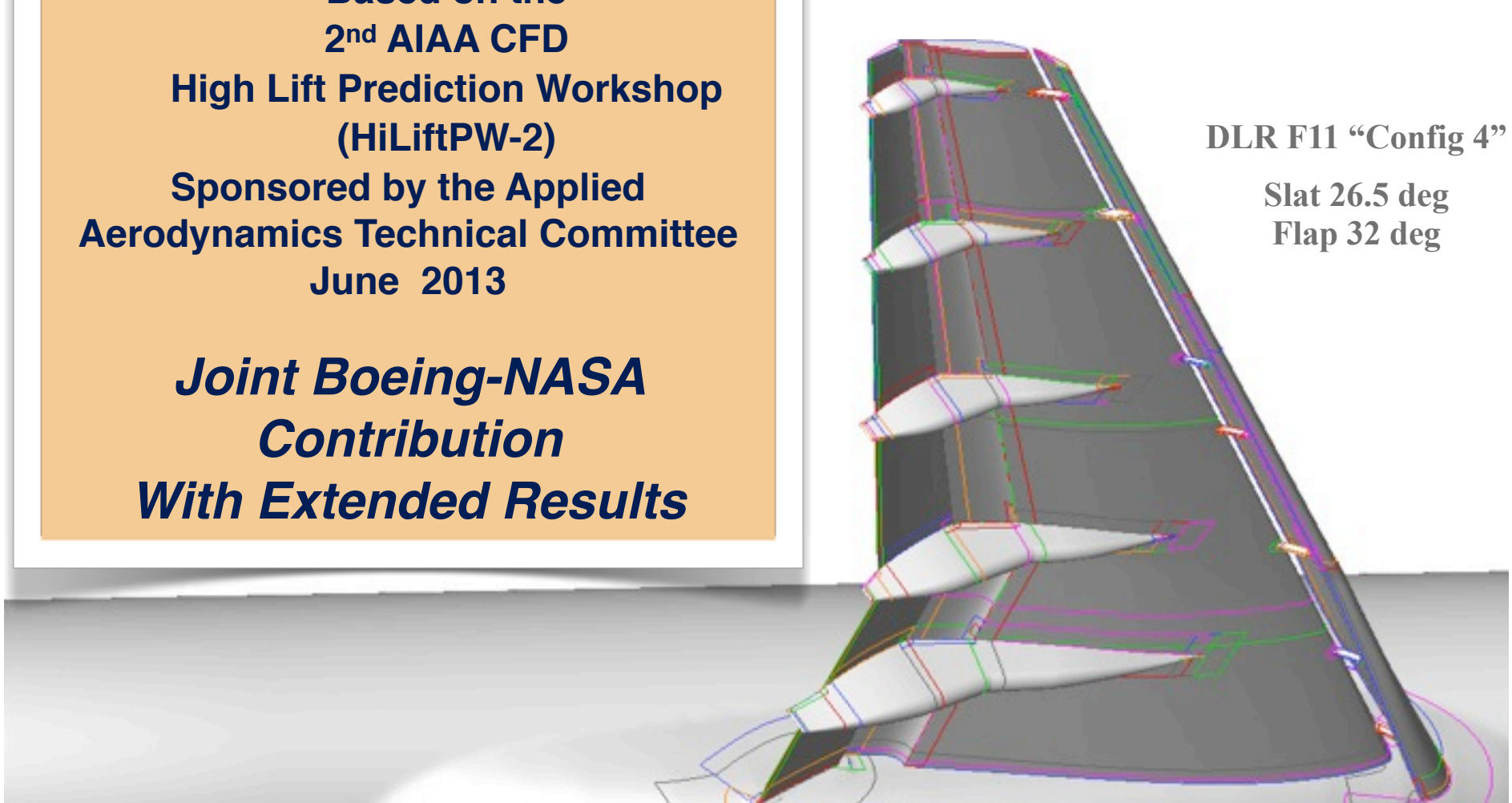
HiLiftPW-2

Based on the
2nd AIAA CFD
High Lift Prediction Workshop
(HiLiftPW-2)
Sponsored by the Applied
Aerodynamics Technical Committee
June 2013

Joint Boeing-NASA
Contribution
With Extended Results



Presentation Goals

- QCR (Quadratic Constitutive Relation)
  - Significant Effect on Forces and Convergence
- Pressure Tube Bundles
  - Effect on Stall
  - Grid Study
- Time Accuracy Requirements
  - Accurate Prediction of Forces
  - Poor Non-Time-Accurate Convergence
  - Small Scale Unsteady Effects

Workshop Cases

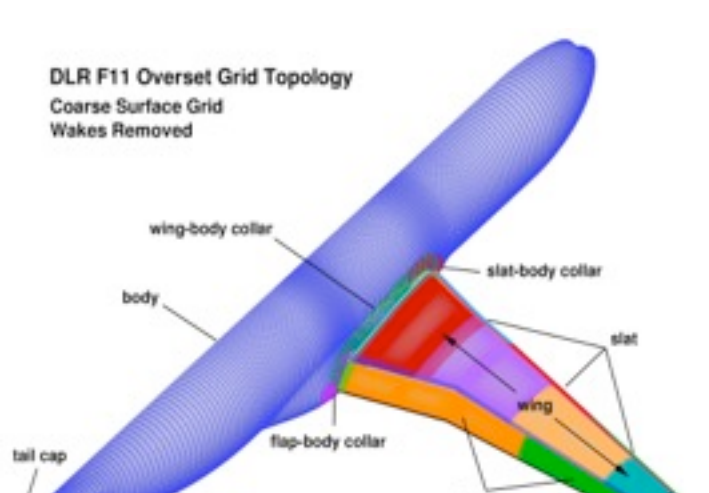
- Workshop Submitted Cases
  - Case1: Grid Refinement
  - Case2: Reynolds Number Study
- Additional Studies
  - Case3: Full Configuration (Config 5)
    - Flap Track Fairing, Slat Brackets
    - Pressure Tube Bundles

Flow Solver

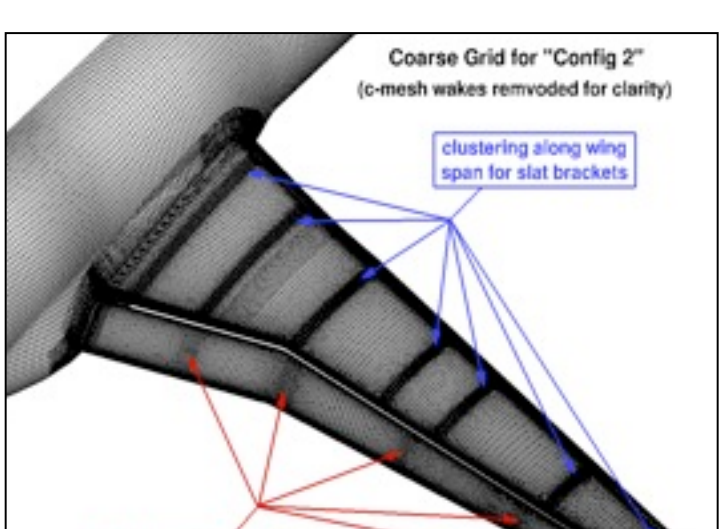
OVERFLOW Version 2.2f and 2.2h

- Default Setup – Steady State, QCR off
  - 3rd order Roe Upwind Differencing
  - Implicit Diagonal Scheme
  - SA-RC Turbulence Model
    - (SA-noft2 with rotation/curvature corrections)
  - Full N-S, Low Mach Preconditioning
  - Restart from Free Stream or Lower α Solution
  - Fully Turbulent

Overset Grids: Workshop Guidelines



Config 2: Brackets/Fairings Off (44 zones)



Config 4: Brackets/Fairings On (163 zones)

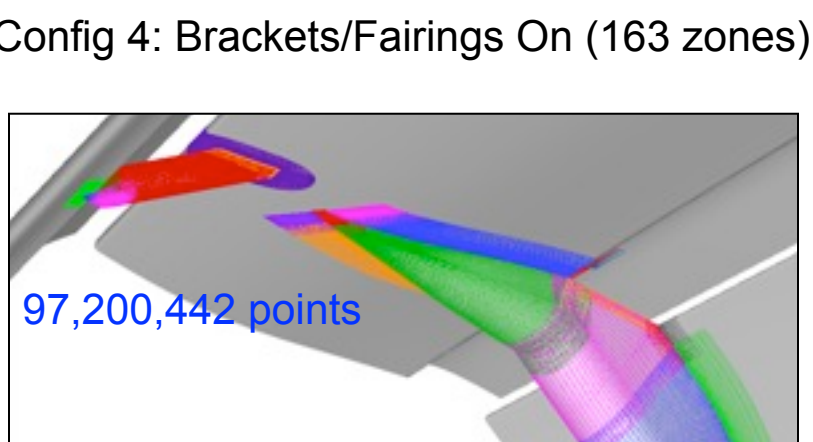
1-to-2

Grid	Points	$1/N^{2/3} \times 10^5$
Coarse	29,386,628	1.050
Medium	69,014,980	0.594
Fine	230,770,520	0.266
Extra-Fine	544,468,508	0.150

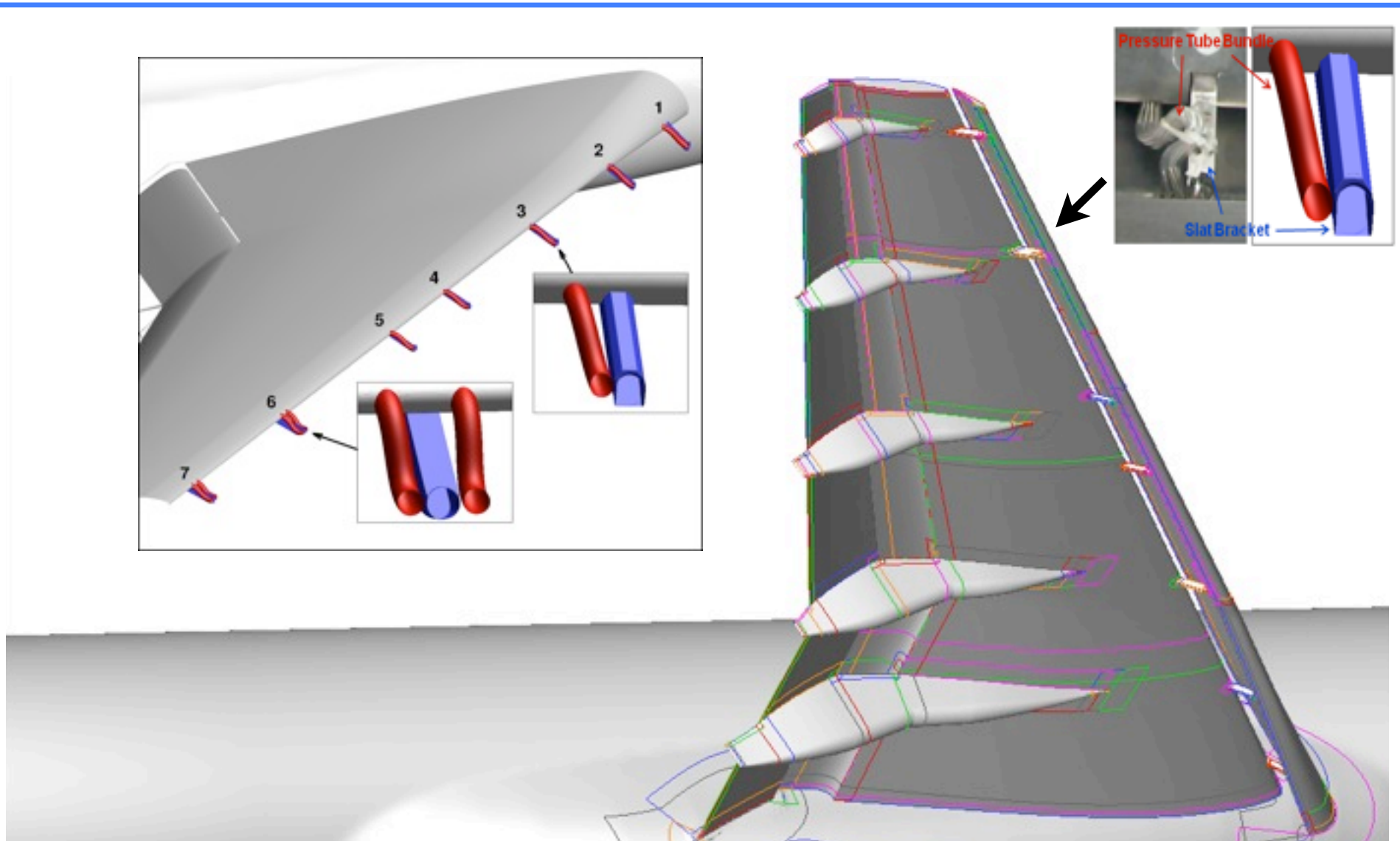
4-to-3

3-to-2

4-to-3



Config 5: Full Configuration



Computing Platform

Pleiades Supercomputer

SGI ICE cluster with >100,000 cores

Solver performance on Pleiades for the medium grid case

Case	Npts	MPIxOMP= Cores	Sec/Step	NanoSec/ Step/Npts
Config 4	69 M	64x4=128	4.4	64
Config 5 No Patch	97M	128x4=512	2.9	30
Config 5 Patches	117M	30x10=300	3.4	29
Config 5 Ref. Patch	131M	100x10=1000	1.1	8.4

For Unsteady Cases: 10 Inner Iterations, 10 X Cost

Case 1 - Grid Convergence Study

DLR F11 "Config 2" - Slat 26.5 deg, Flap 32 deg

(Wing/Body/HL system + SOB Flap Seal)

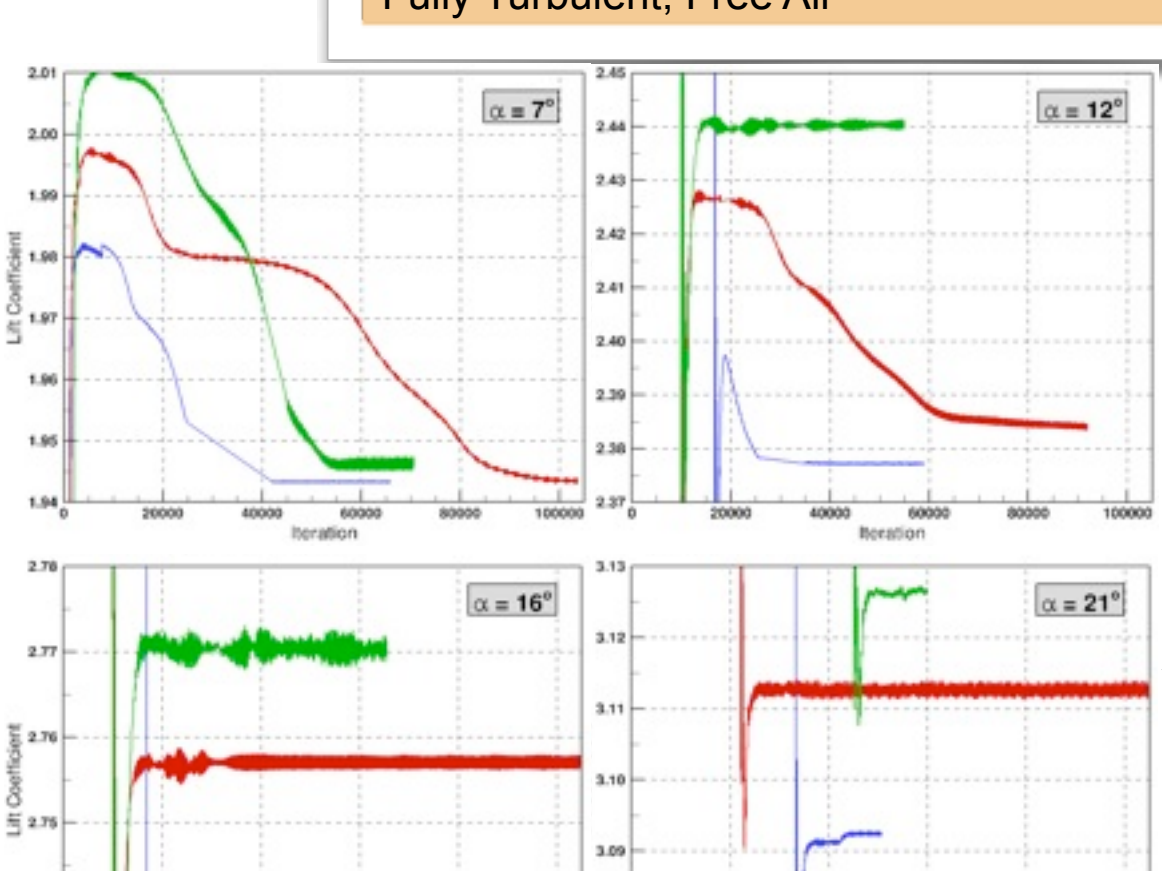
No Flap Track Fairings, Slat Bracket or Pressure Tube Bundles

High Reynolds Number = 15.1 Million Based on MAC

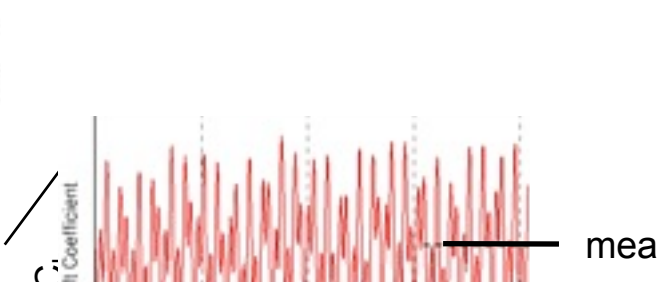
Convergence History

Case 1 C_L – Grid Effect, QCR Off

F11 Config 2: Slat Brackets / Flap Fairings Off
Mach = 0.175, Reynolds number = 15.1 million
Fully Turbulent, Free Air



Coarse
Medium



iteration

Standard deviation on C_L

Convergence History
Case 1 C_L – Grid Effect, QCR Off

F11 Config 2: Slat Brackets / Flap Fairings Off
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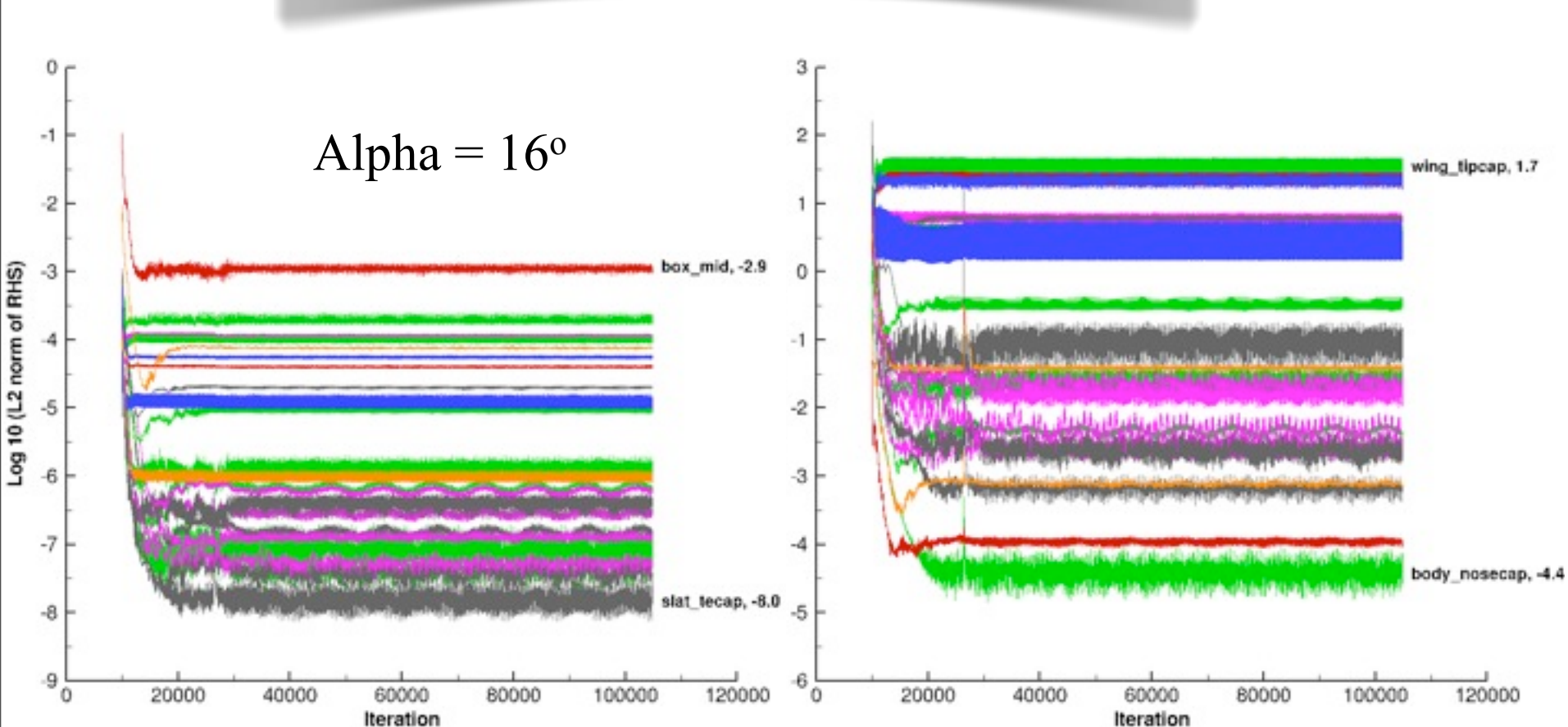

Convergence History

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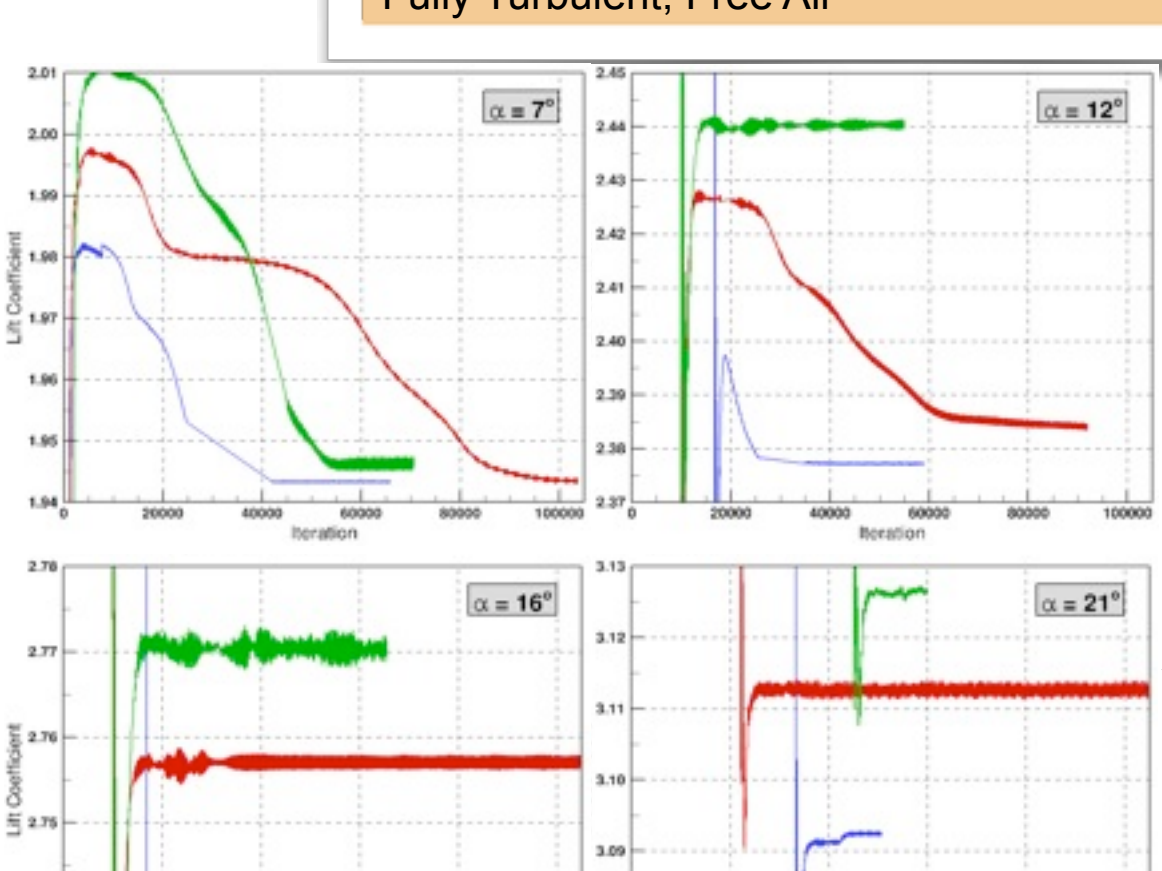
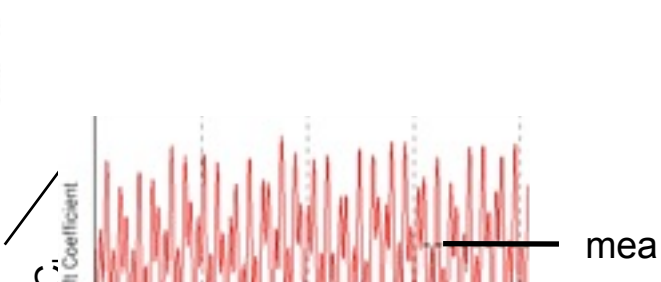


Coarse
Medium

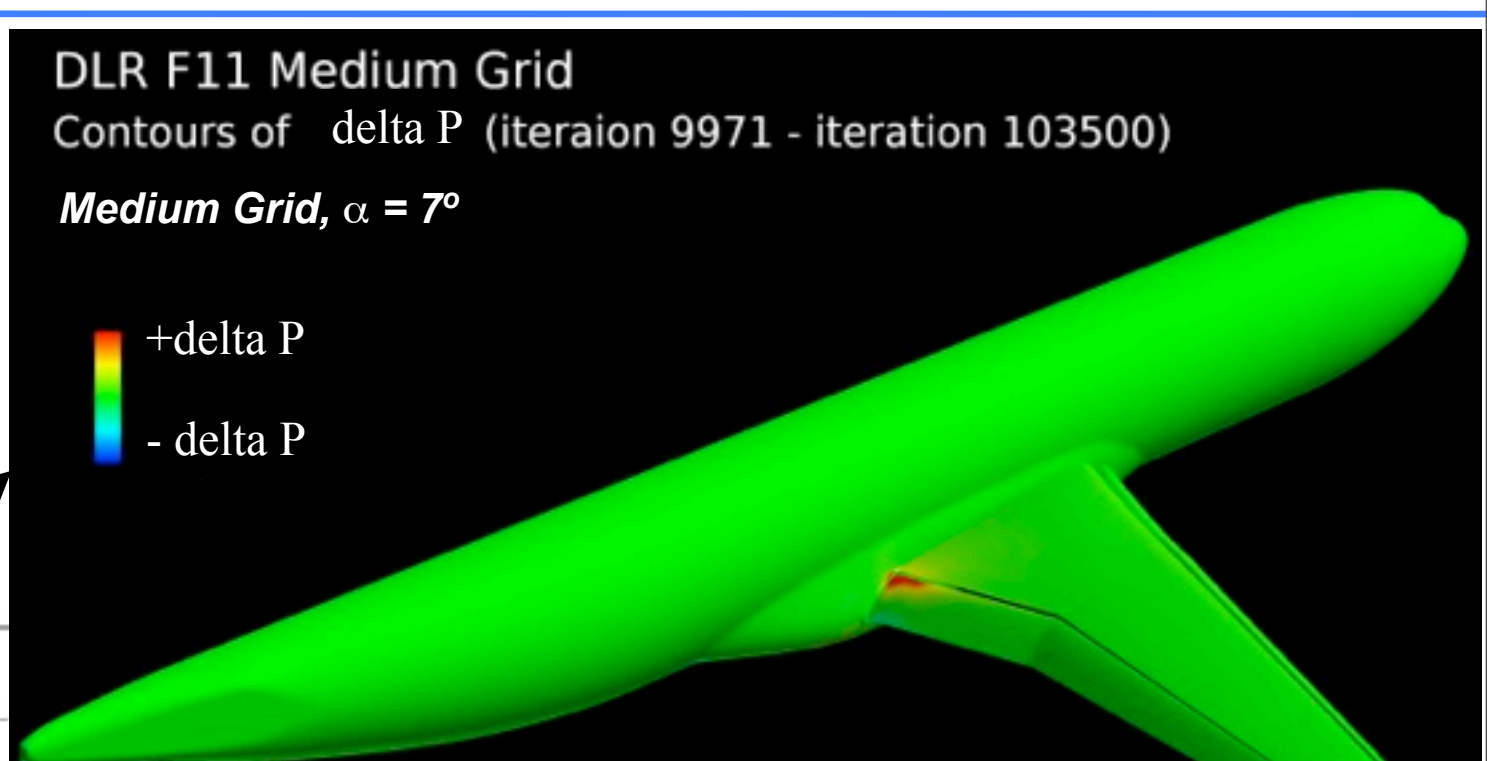


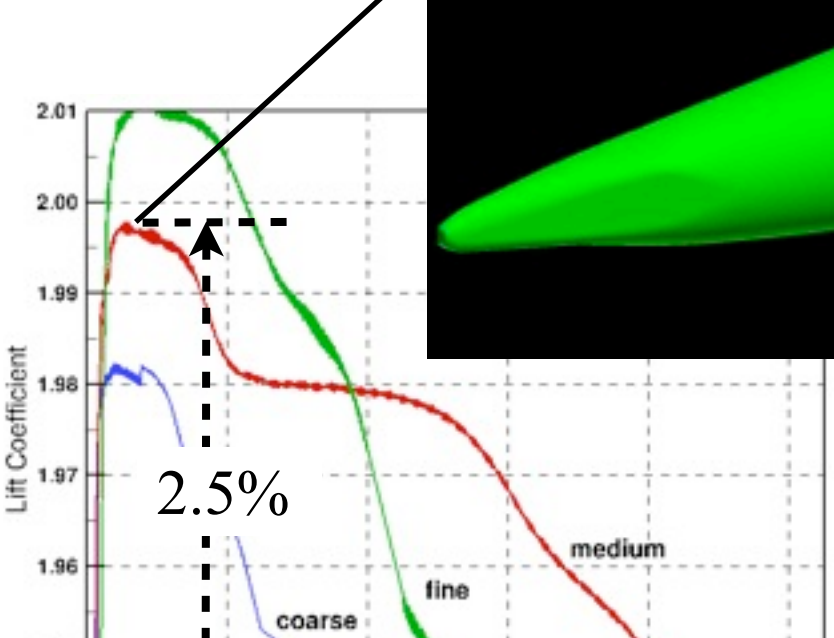
iteration

Standard deviation on C_L

Convergence History

Case 1 C_L – Low Alpha Side-of-Body Flow Field





Lift change isolated to side-of-body

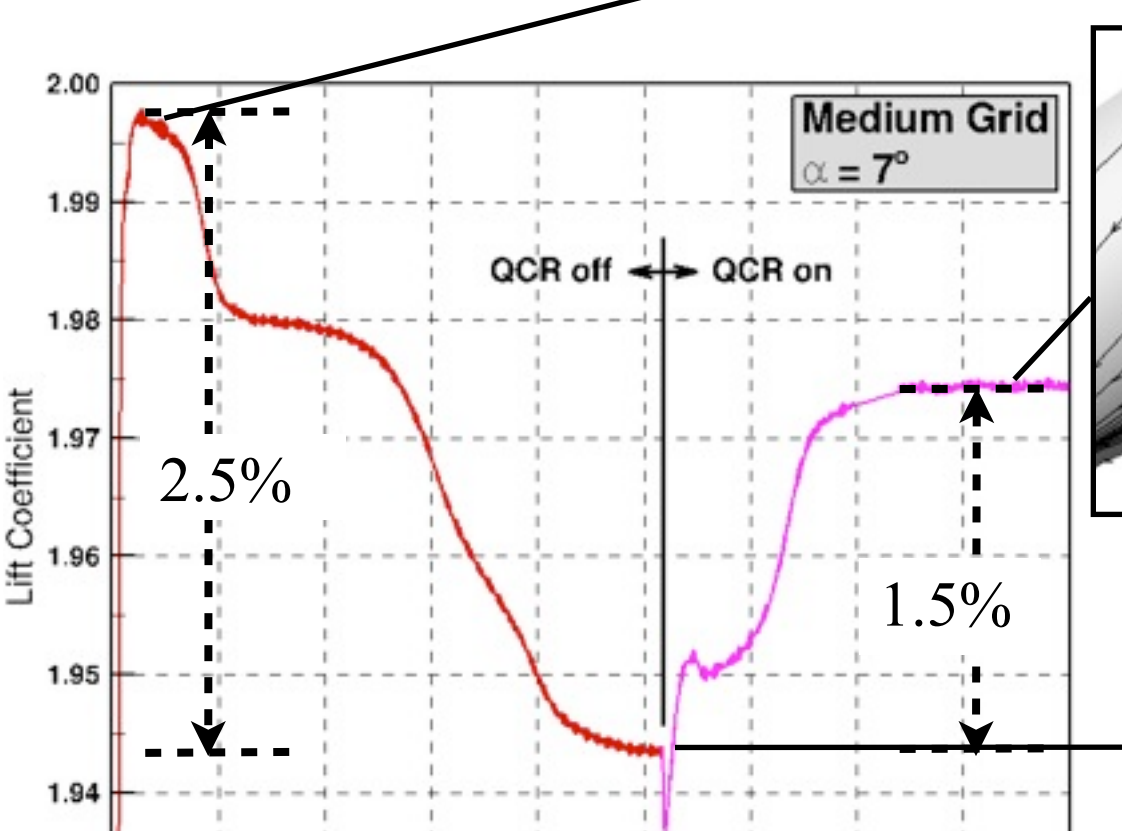
Convergence History: QCR Effect

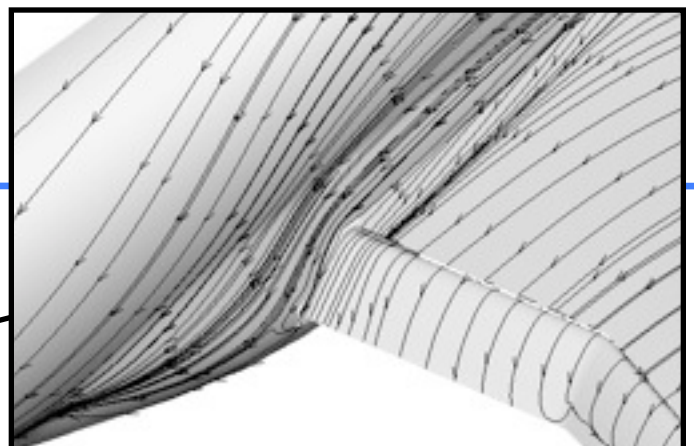
Case 1 C_L – QCR Effect

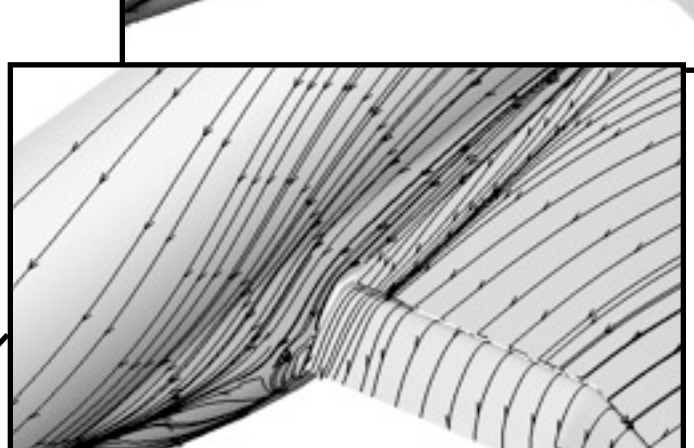
F11 Config 2: Slat Brackets / Flap Fairings Off

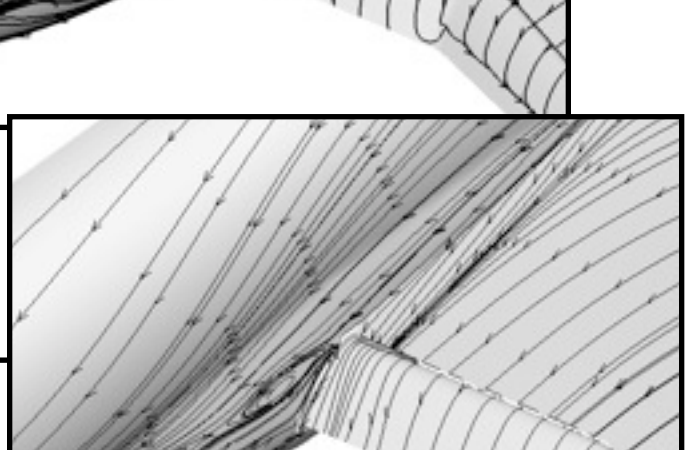
Mach = 0.175, Reynolds number = 15.1 million

Fully Turbulent, Free Air









Quadratic Constitutive Relation (QCR)

- *Approach published by P. Spalart*
- *Improve upon the linear eddy viscosity approximation by using a nonlinear stress term to model the Reynolds stresses directly*

$$\tau_{ij} = \overline{\tau}_{ij} - c_{nl1}\left[O_{ik}\overline{\tau}_{jk} + O_{jk}\overline{\tau}_{ik}\right],$$

where

$$O_{ik} \equiv \frac{\partial_k U_i - \partial_i U_k}{\sqrt{\partial_n U_m \partial_n U_m}}$$

- *Improves solution accuracy for corner flows compared to a linear (i.e., Boussinesq) eddy viscosity model*
- *QCR has been successfully used for*
  - *DPW4 and DPW5 Series*
  - *HiLiftPW1*

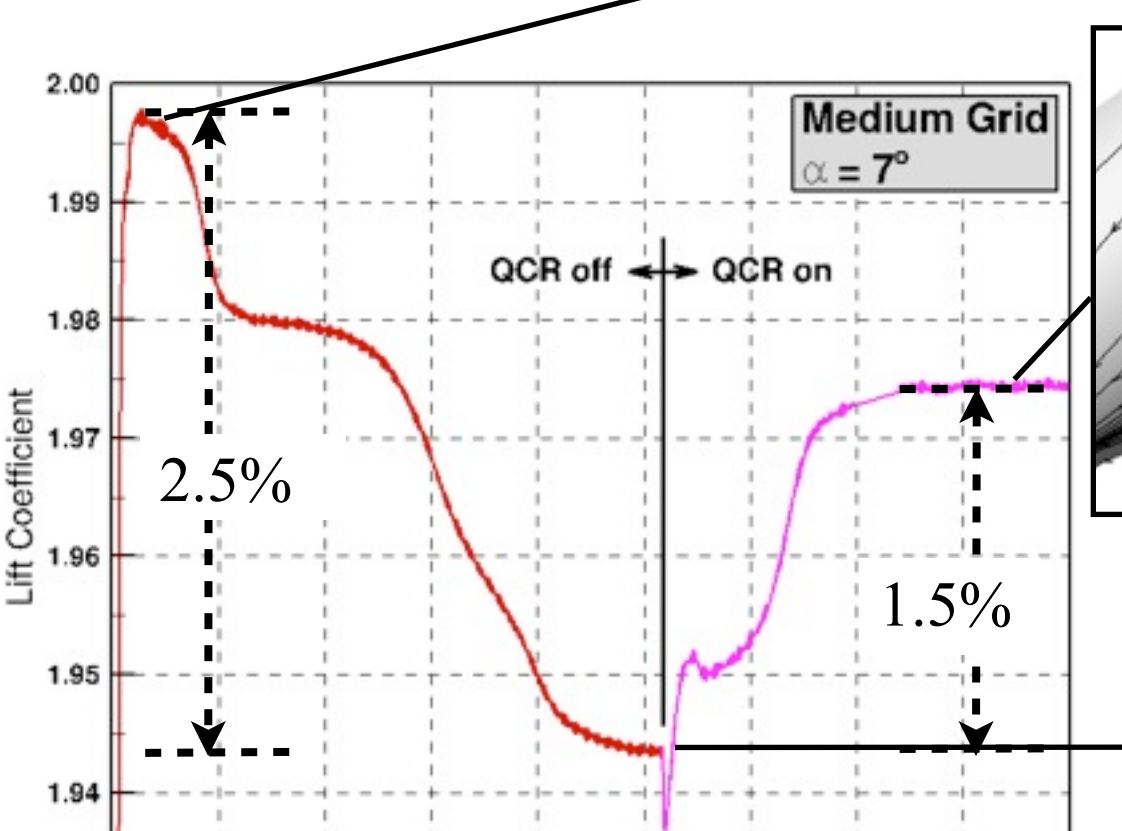
Convergence History: QCR Effect

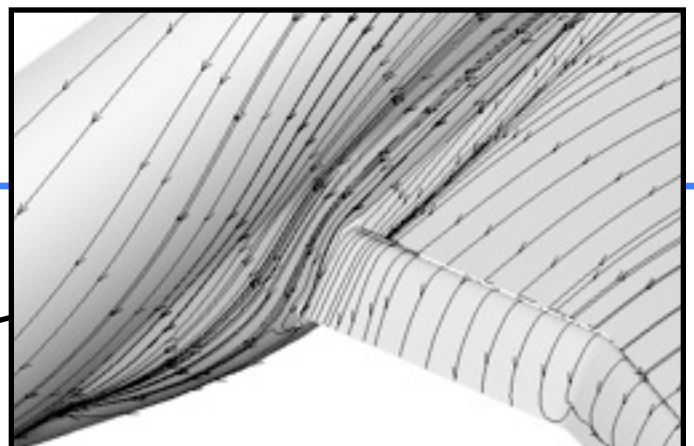
Case 1 C_L – QCR Effect

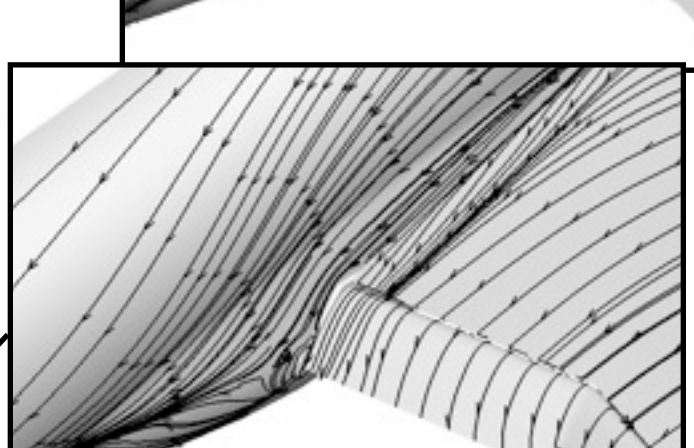
F11 Config 2: Slat Brackets / Flap Fairings Off

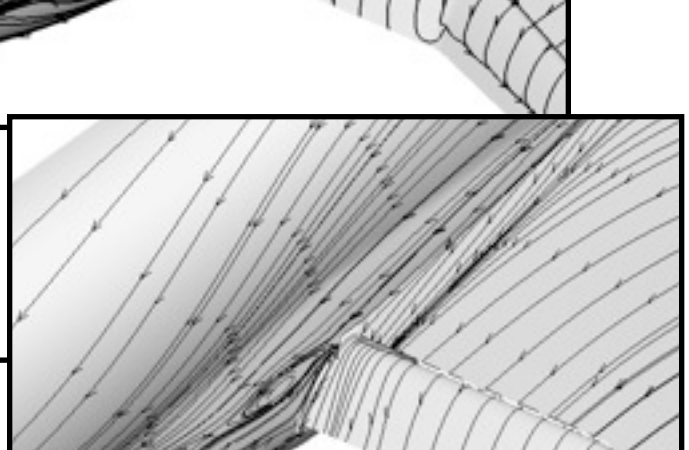
Mach = 0.175, Reynolds number = 15.1 million

Fully Turbulent, Free Air









Case 2 - Reynolds Number Study

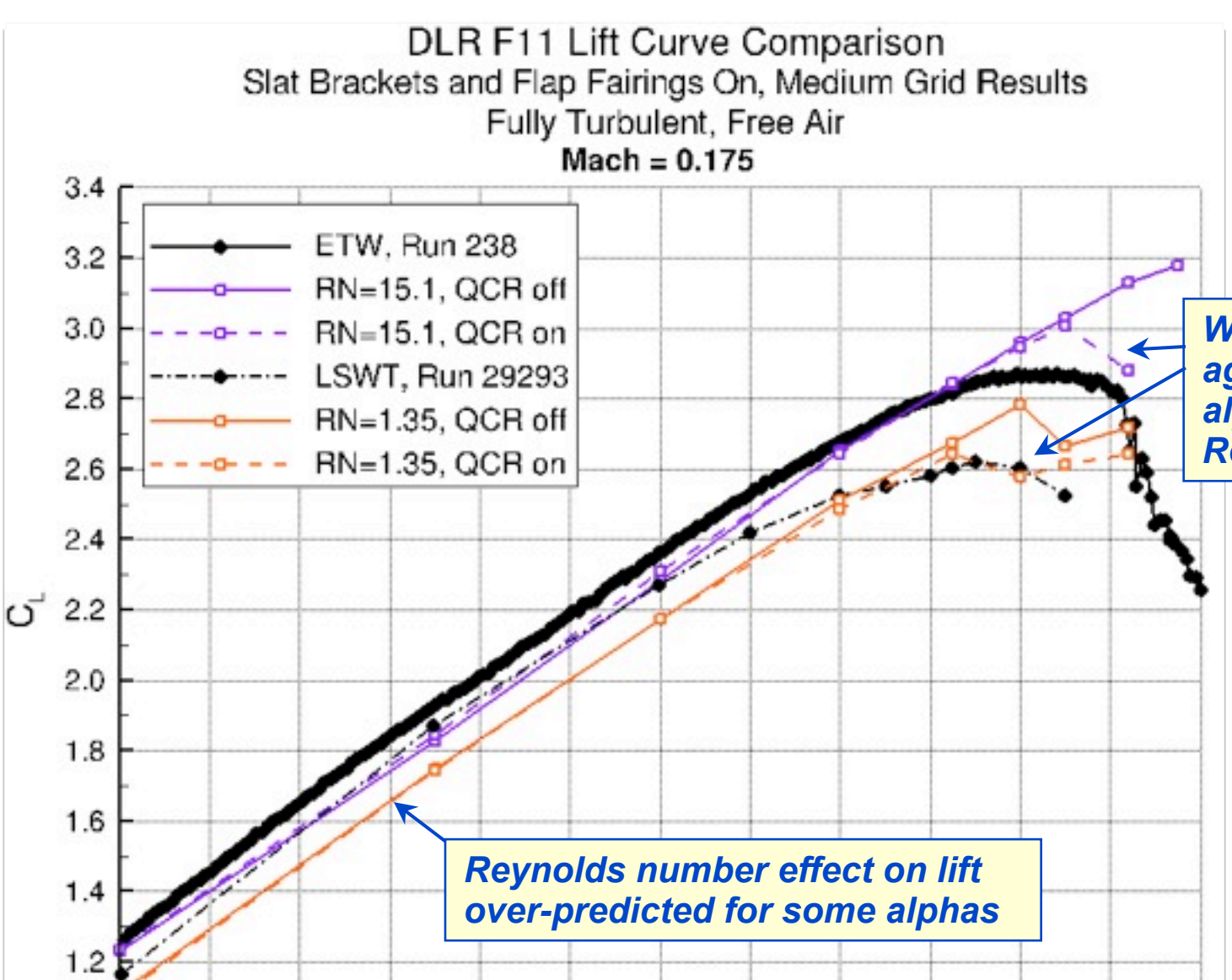
DLR F11 "Config 4" - Slat 26.5 deg, Flap 32 deg

(Config 2 + Slat Tracks and Flap Track Fairings)

Case 2a - Low Reynolds Number = 1.35 Million Based on MAC

Case 2b - High Reynolds Number = 15.1 Million Based on MAC

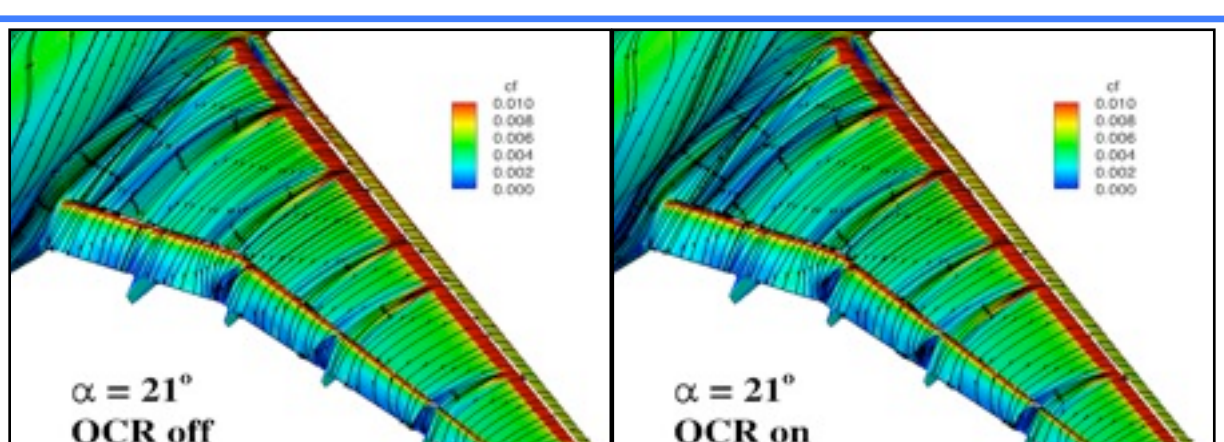
Test Case 2 – Reynolds Number Study



With QCR, better agreement at higher alphas for both Reynolds numbers

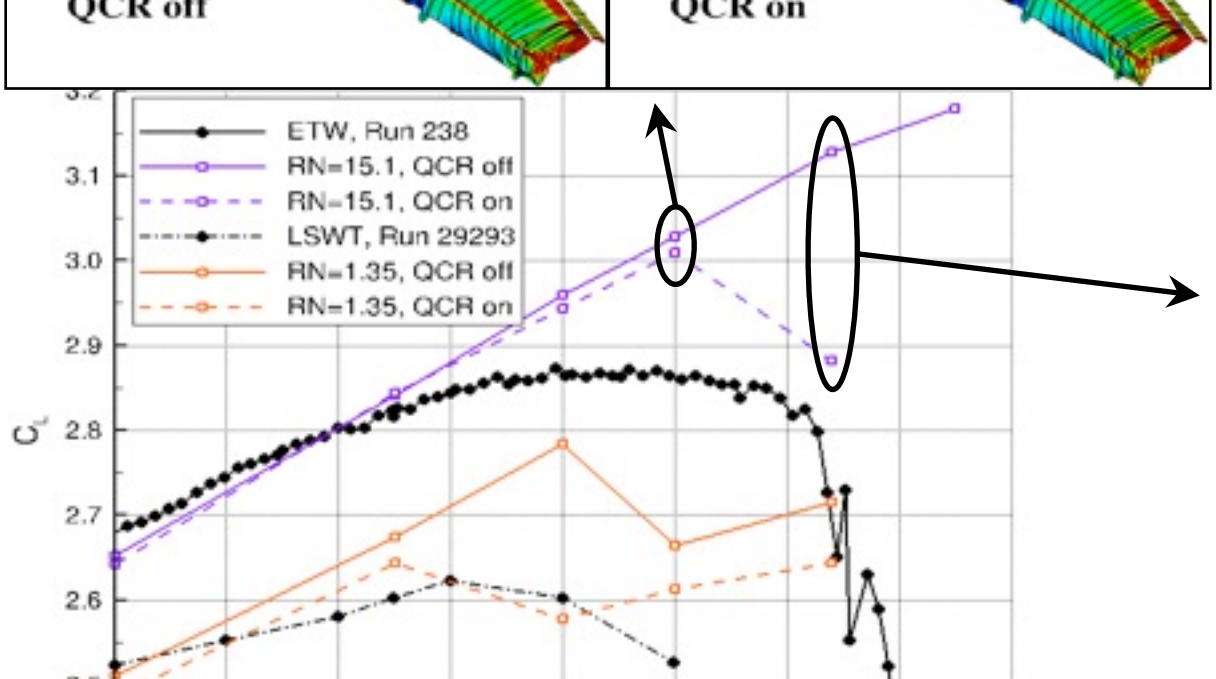
Reynolds number effect on lift over-predicted for some alphas

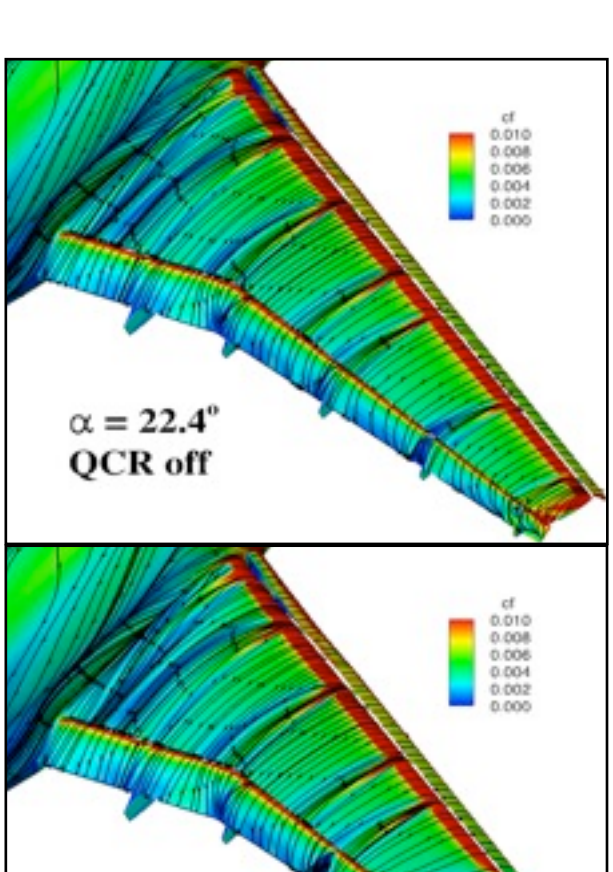
Test Case 2 – Stall at Re = 15.1 M



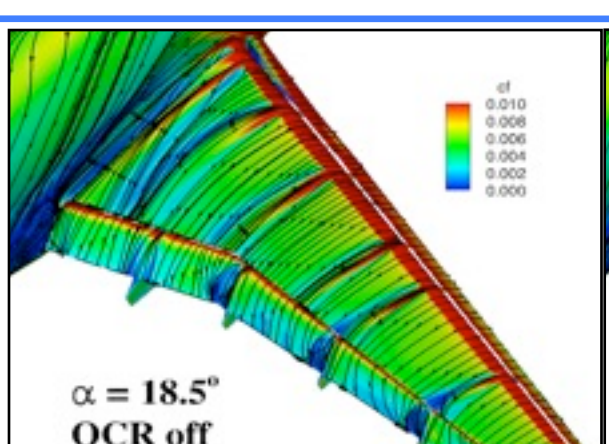
Medium Grid Results

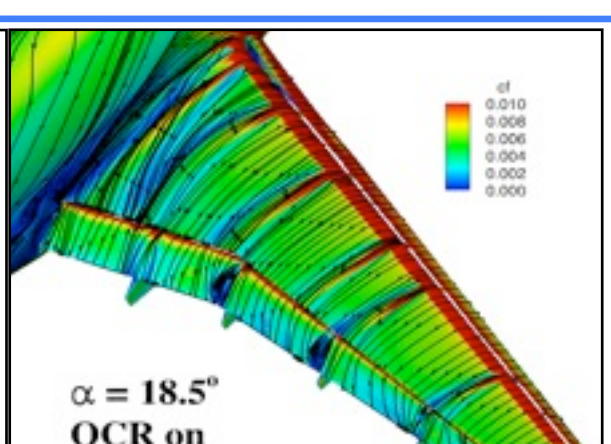
Mach = 0.175





Test Case 2 – Stall at Re = 1.35M





Medium Grid Results

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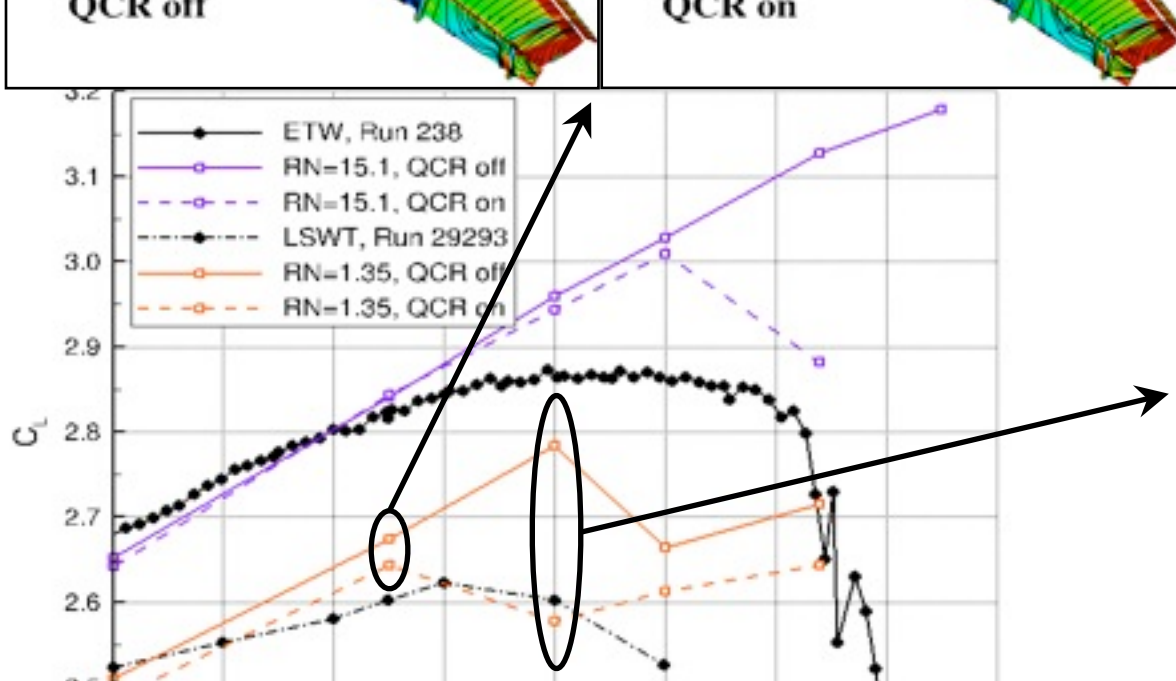
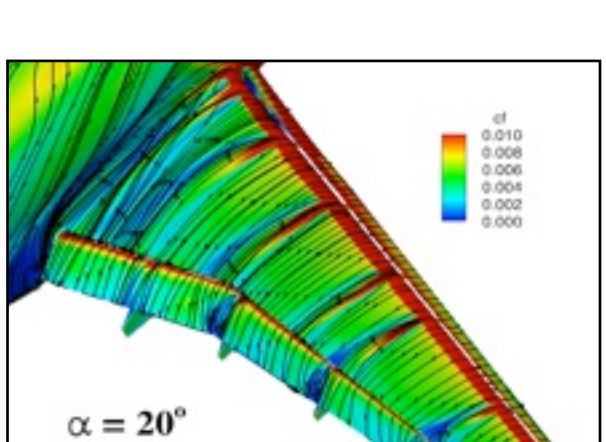
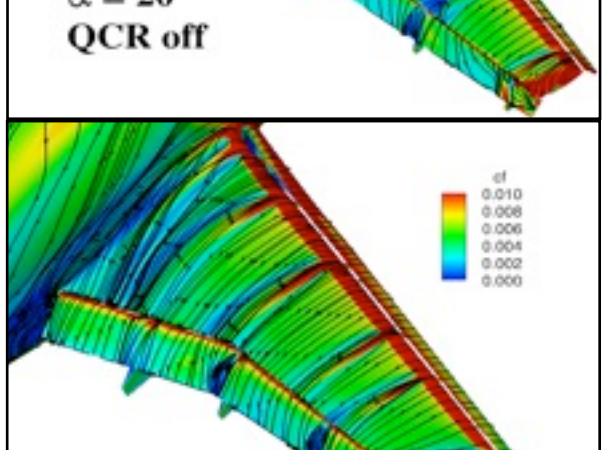
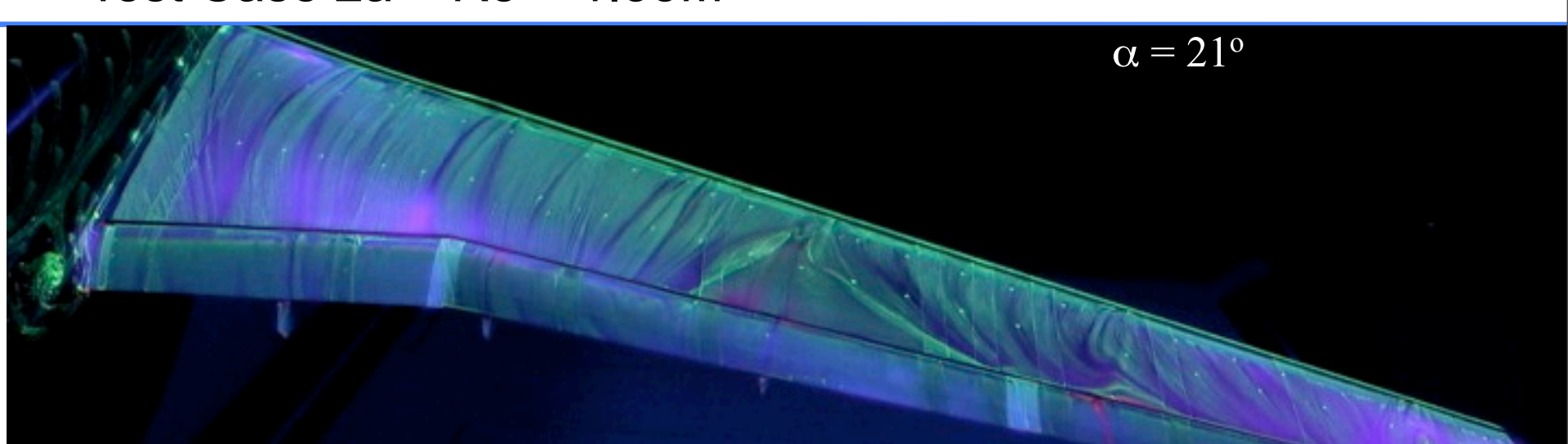
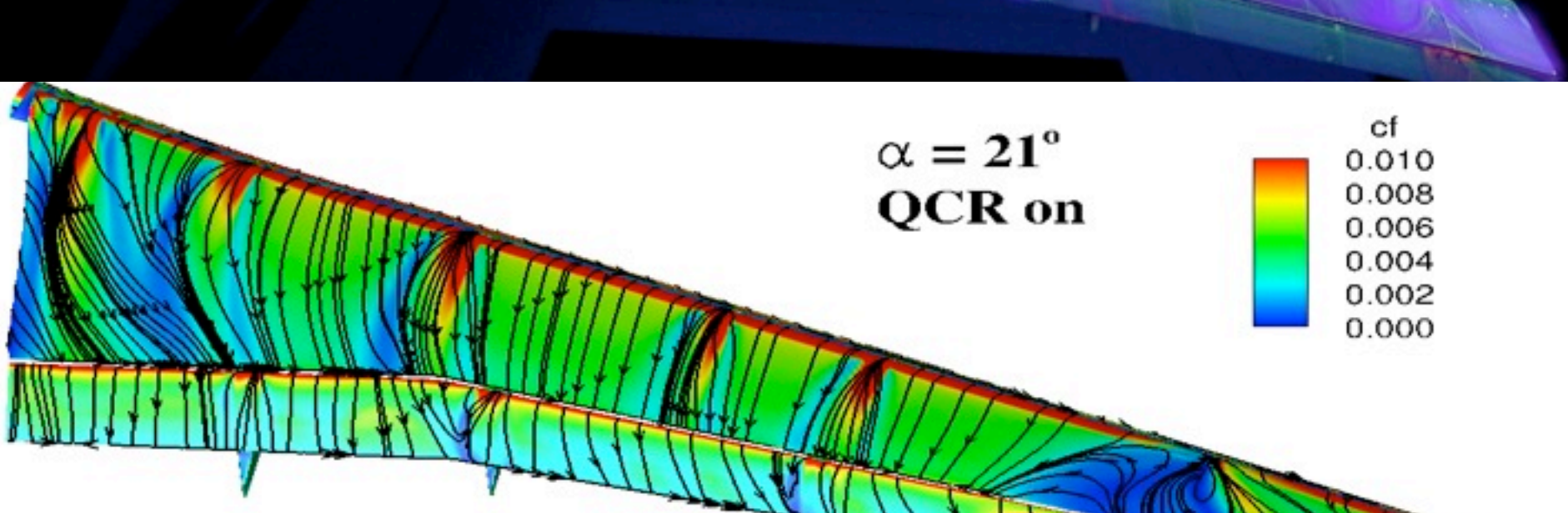






Test Case 2a – Re = 1.35M





Test Case 3 - Full Configuration Study

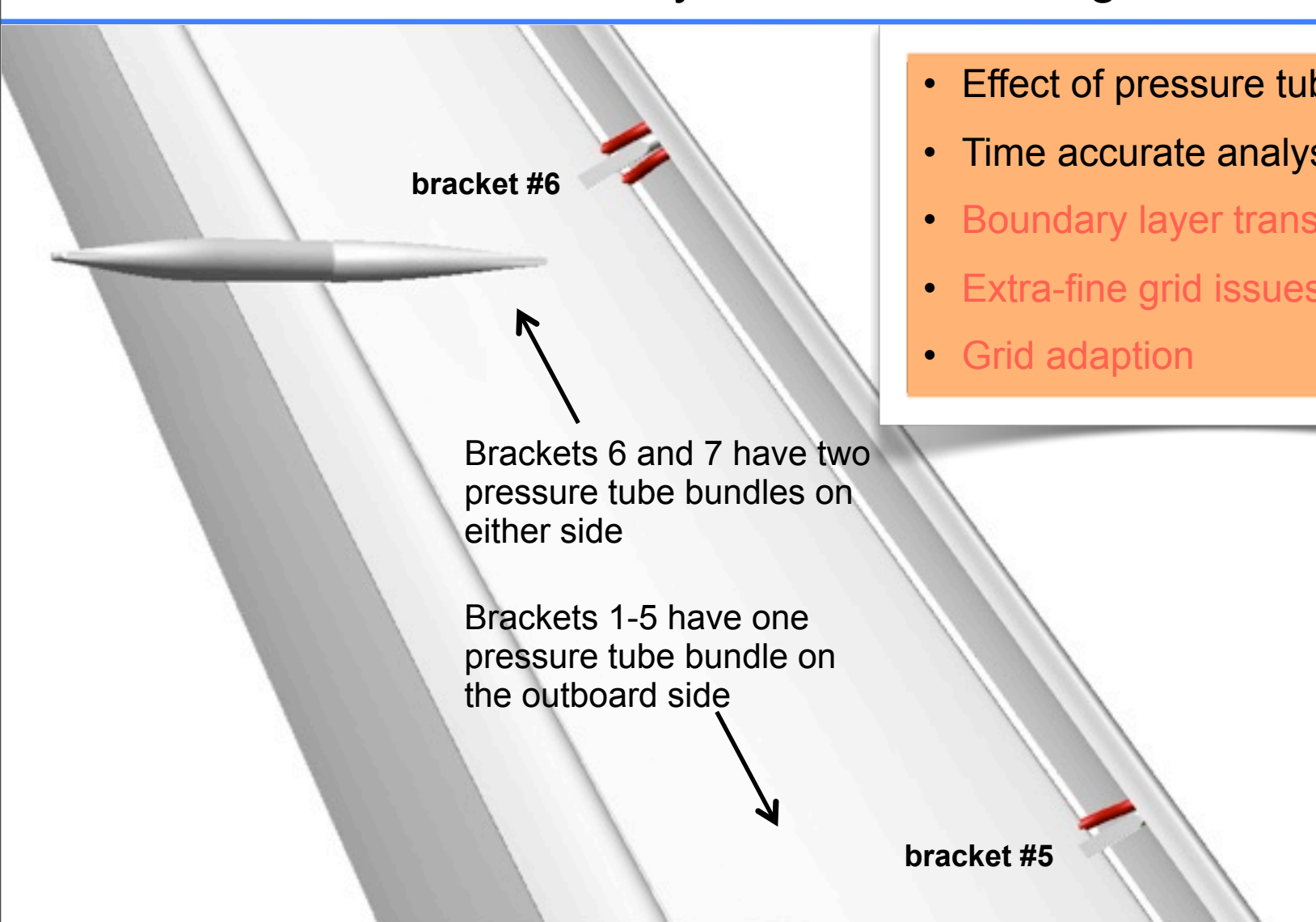
DLR F11 "Config 5" - Slat 26.5 deg, Flap 32 deg

(Config 4 + Slat Pressure Tube Bundles)

Case 3a - Low Reynolds Number = 1.35 Million Based on MAC

Case 3b - High Reynolds Number = 15.1 Million Based on MAC

DLR F11 OVERFLOW Analysis Case 3: Config 5

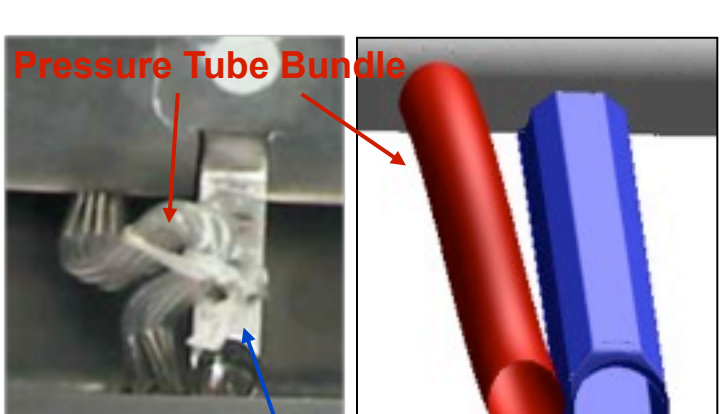


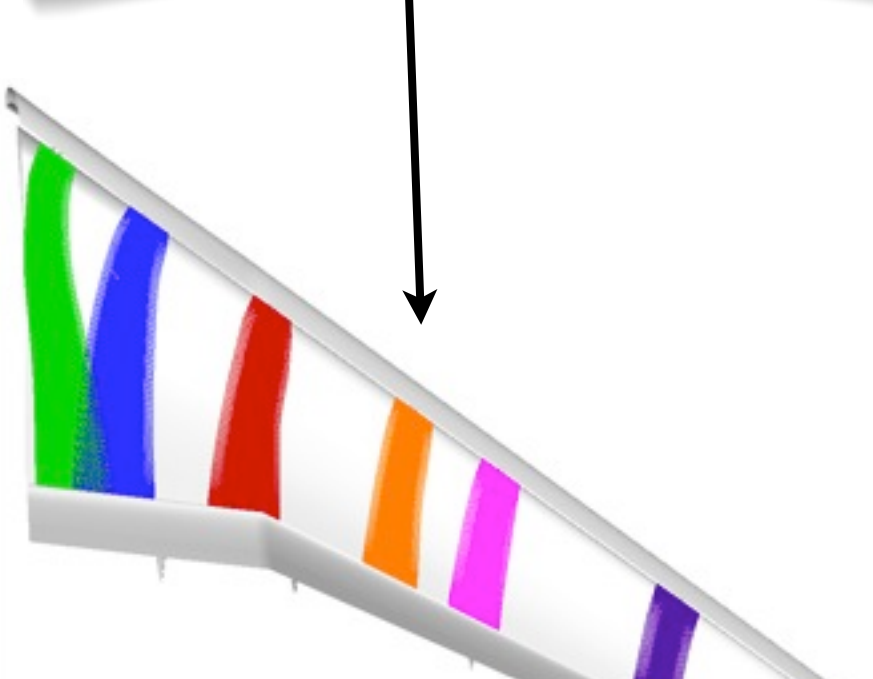
- Effect of pressure tube bundles
- Time accurate analysis
- Boundary layer transition
- Extra-fine grid issues
- Grid adaption

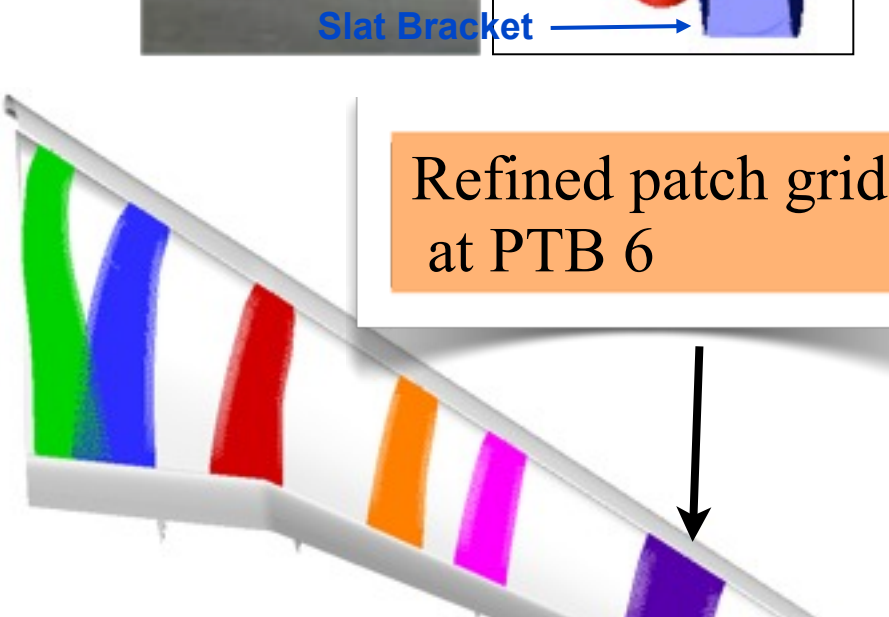
Test Case 3 – Effect of Pressure Tube Bundles

Wing Patch Grid Layout

Patch grids added to capture pressure tube bundle effects



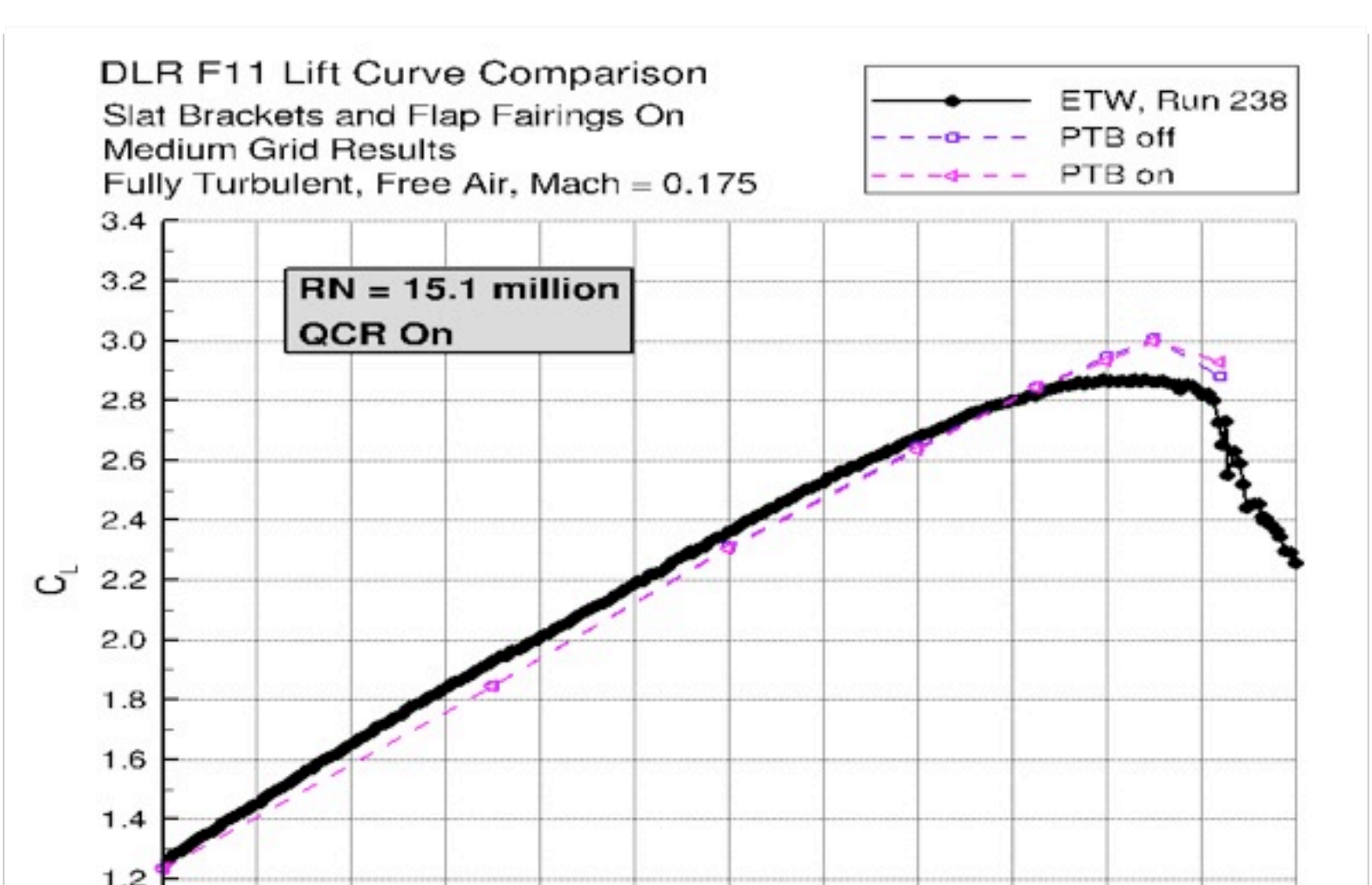




Refined patch grid at PTB 6

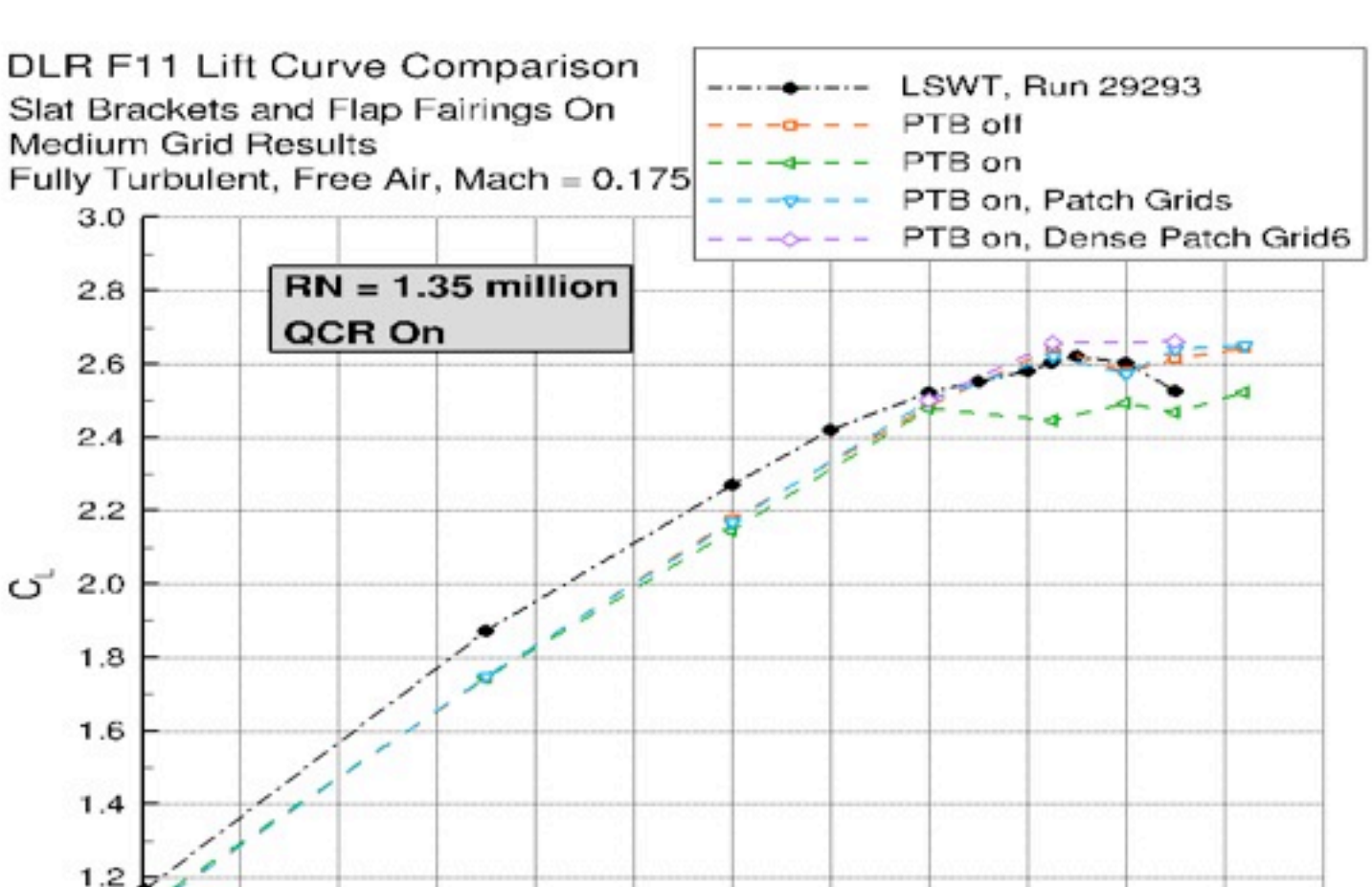
Test Case 3b – Effect of Pressure Tube Bundles

High Reynolds Number Condition - Lift



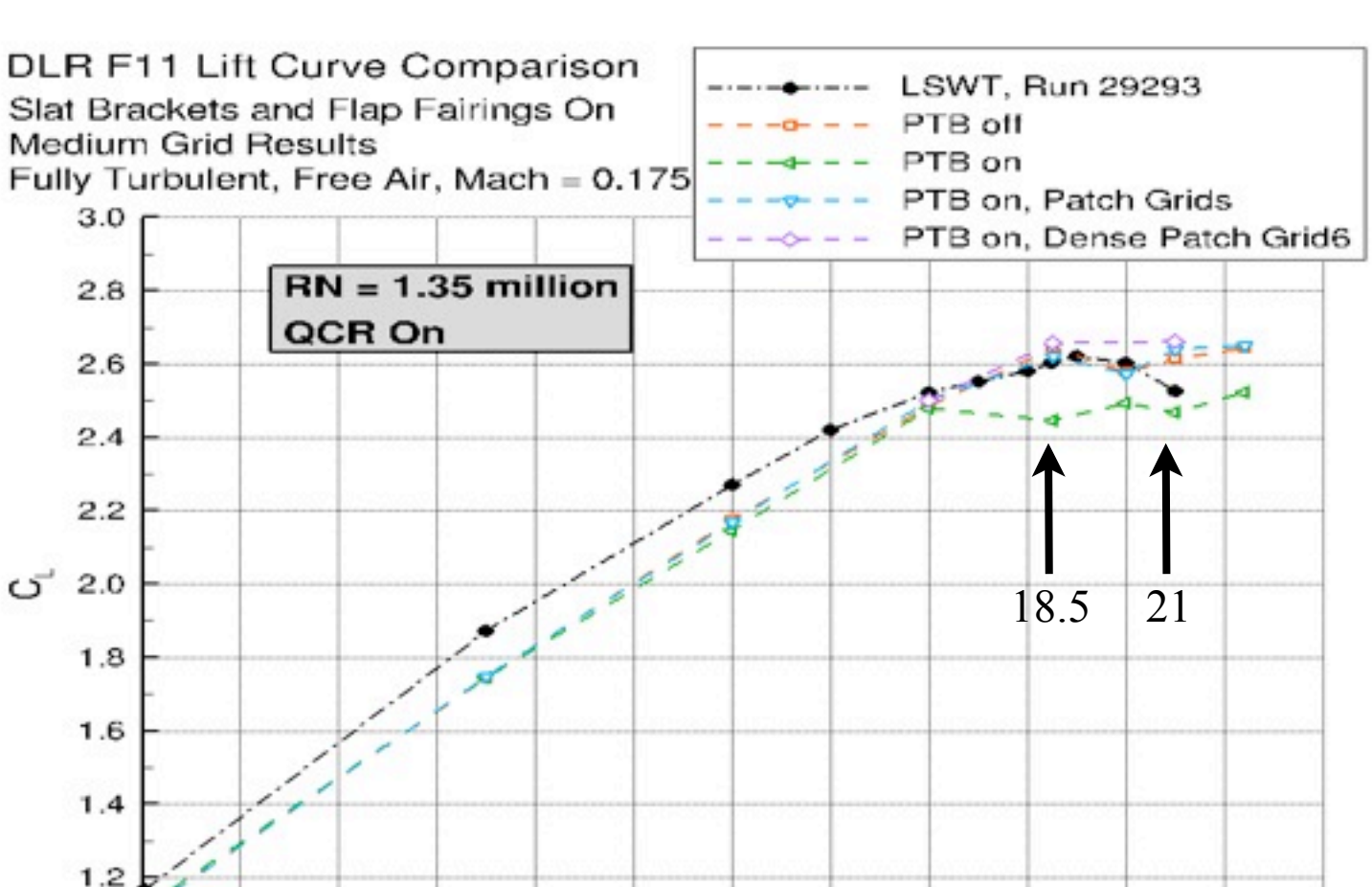
Test Case 3a – Effect of Pressure Tube Bundles

Low Reynolds Number Condition - Lift

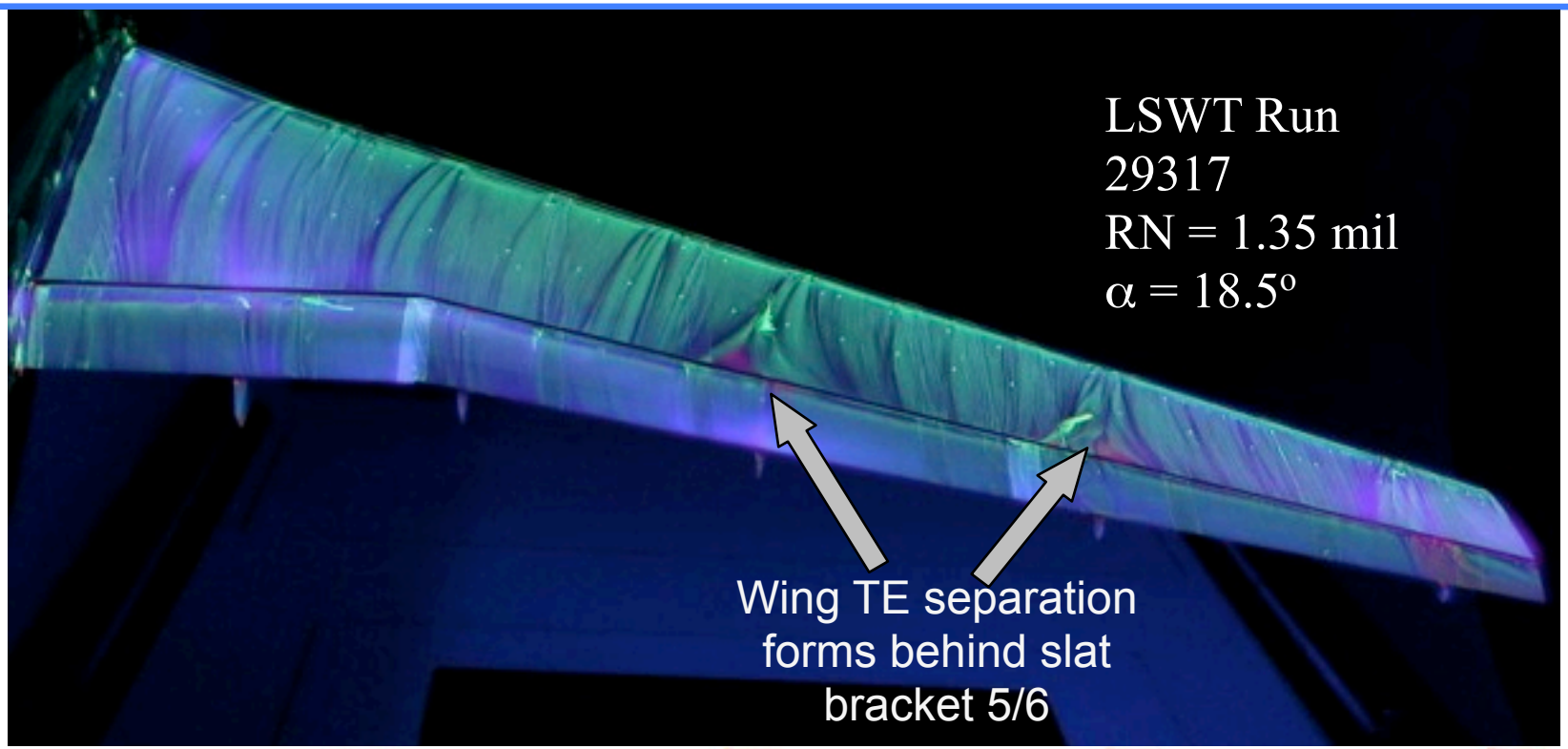


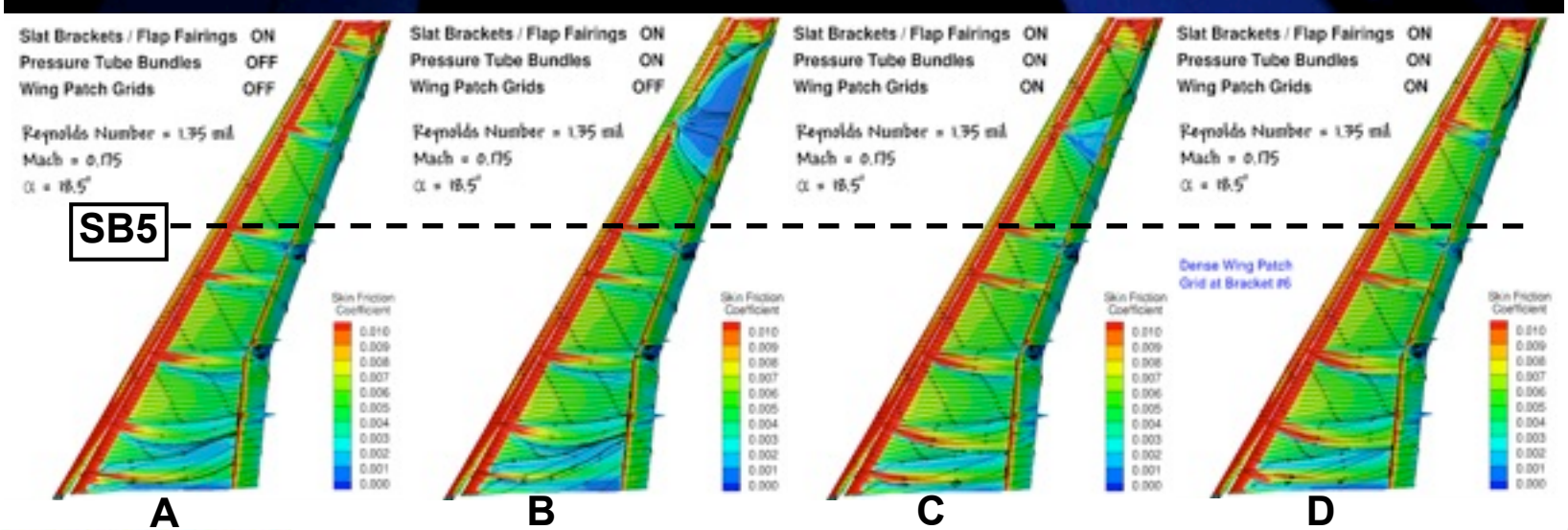
Test Case 3a – Effect of Pressure Tube Bundles

Low Reynolds Number Condition - Lift

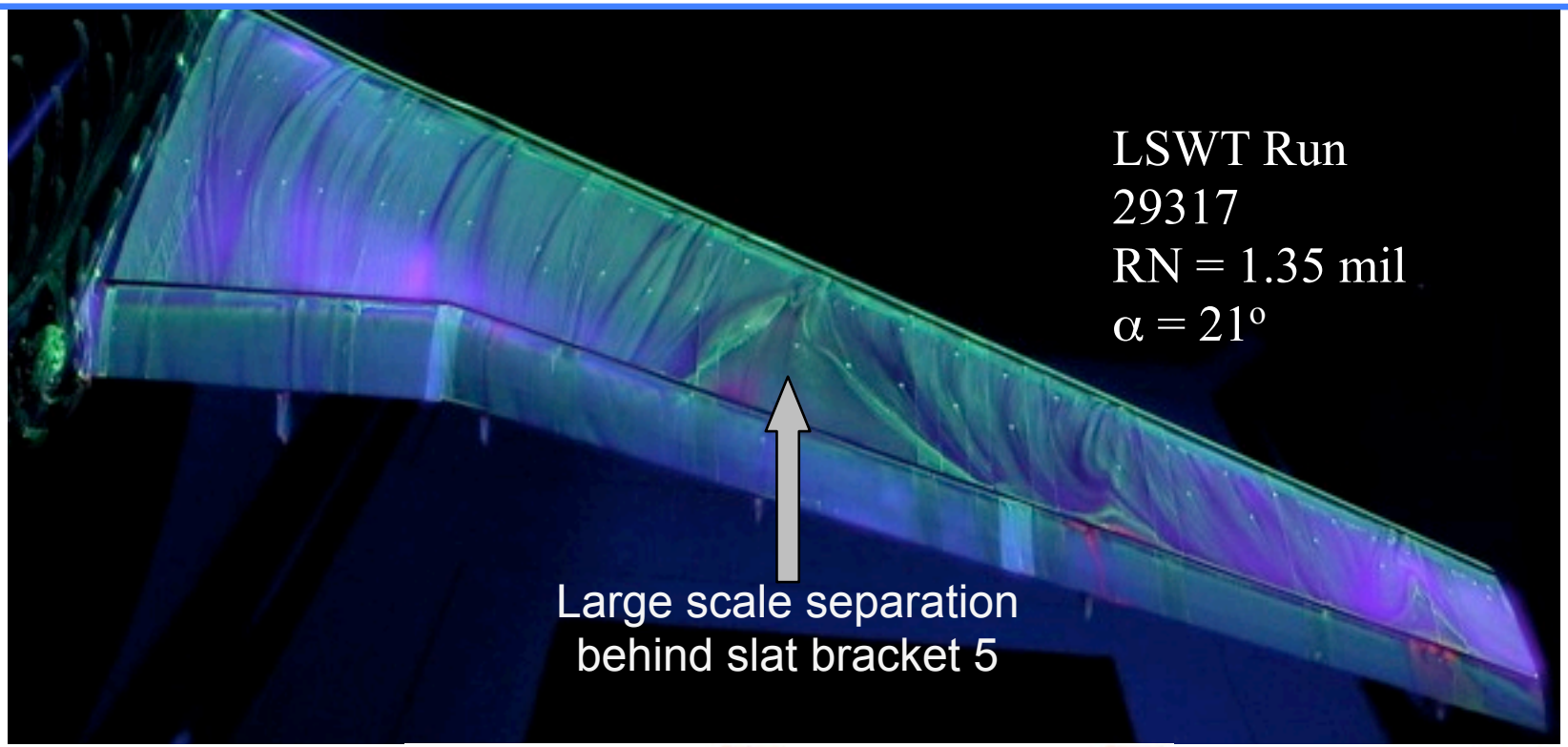


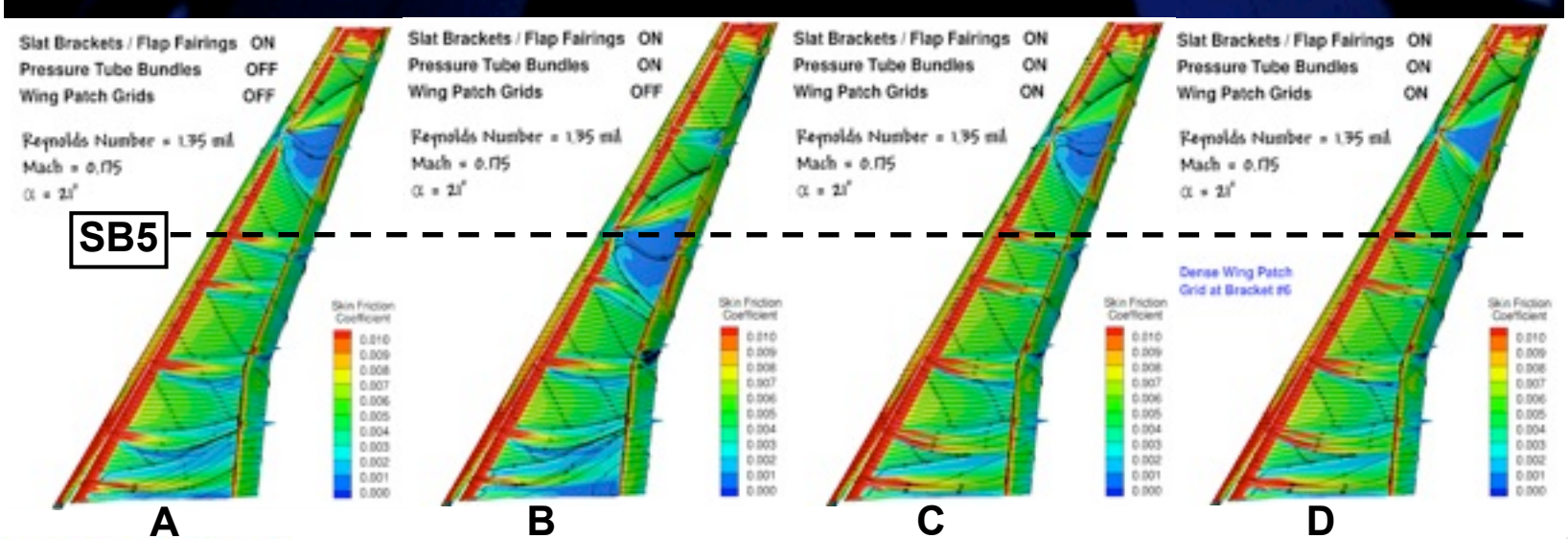
Case 3a: Alpha = 18.5°



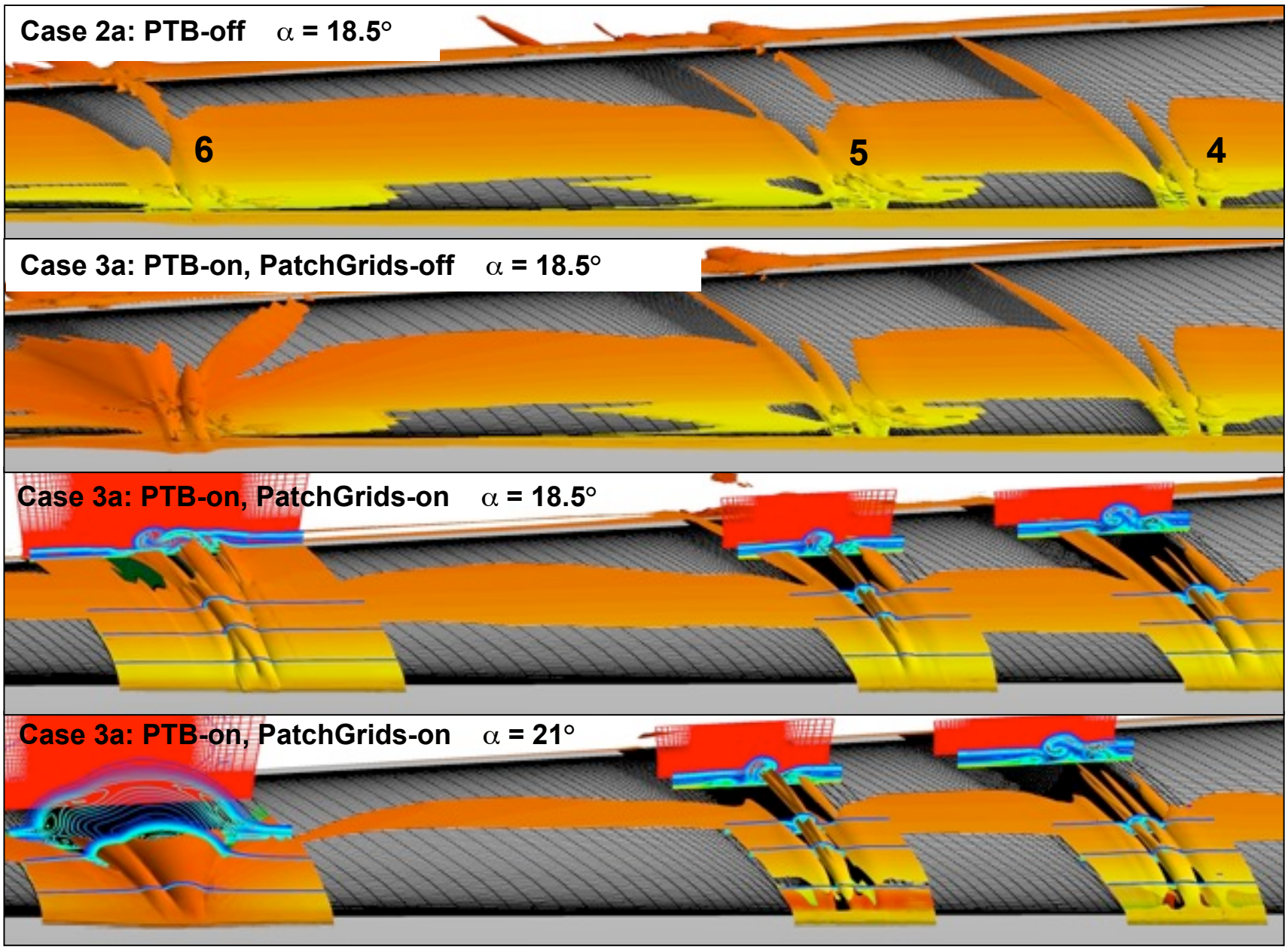


Case 3a: Alpha = 21°

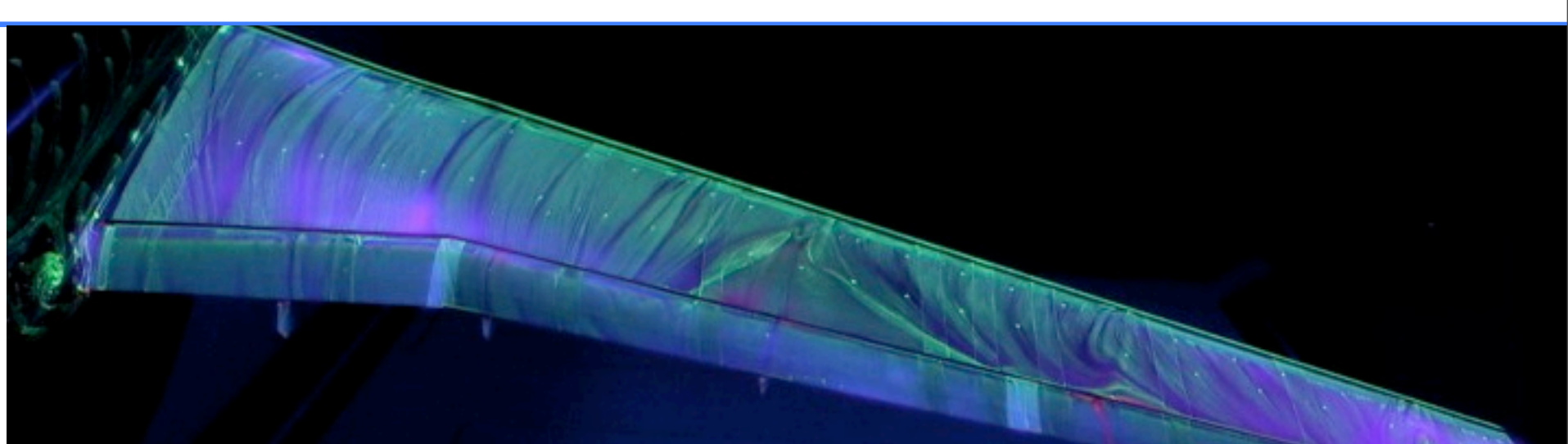


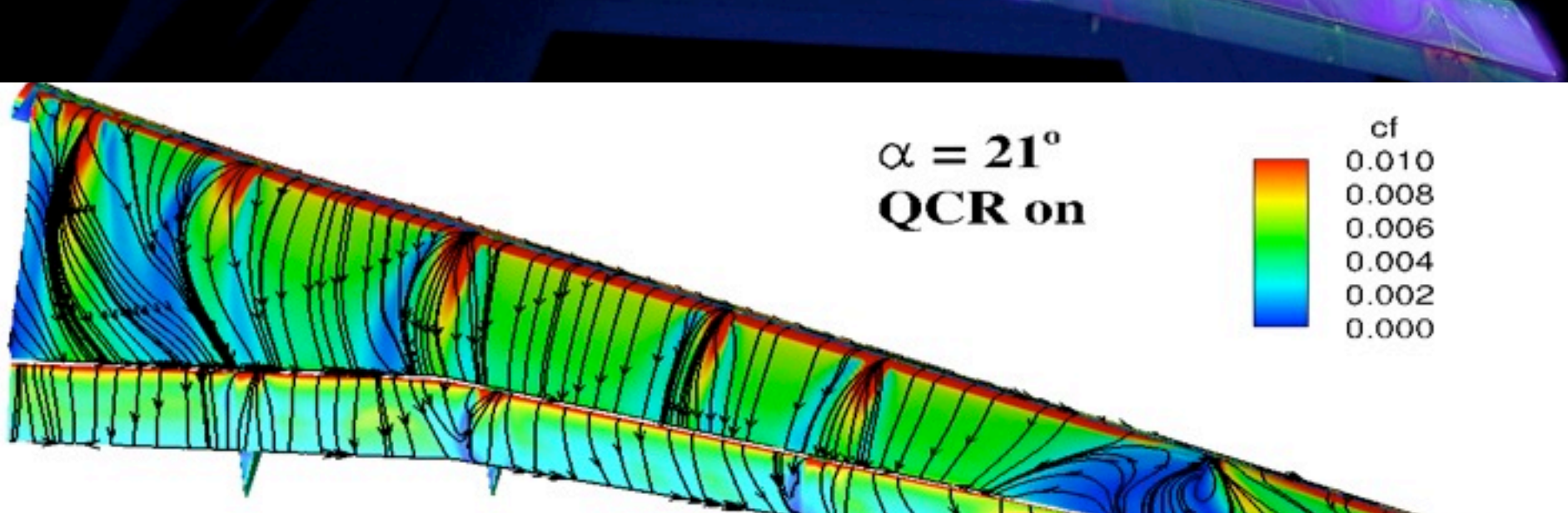


Patch Grids Resolution Effect

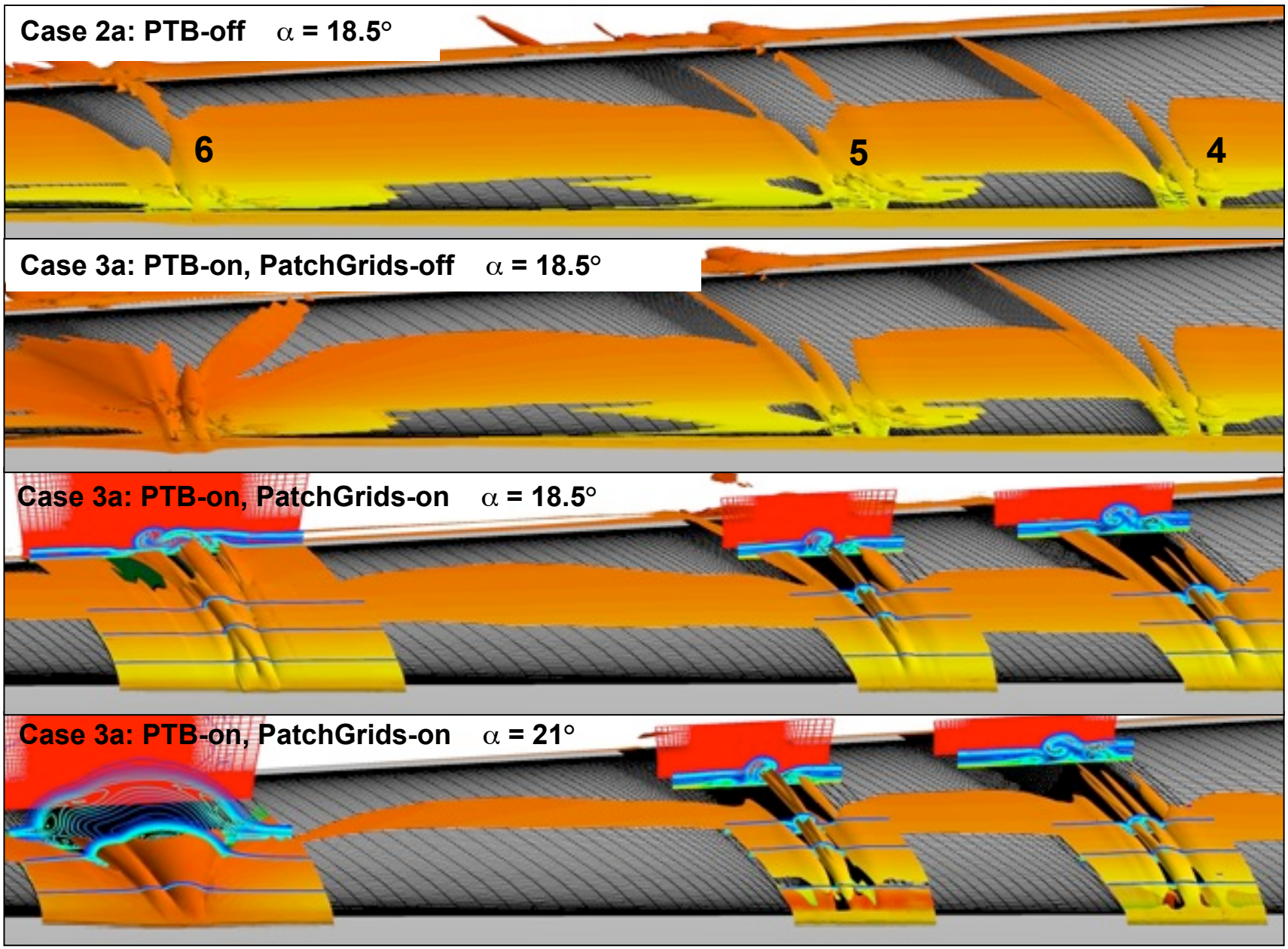


Patch Grids Resolution Effect





Patch Grids Resolution Effect

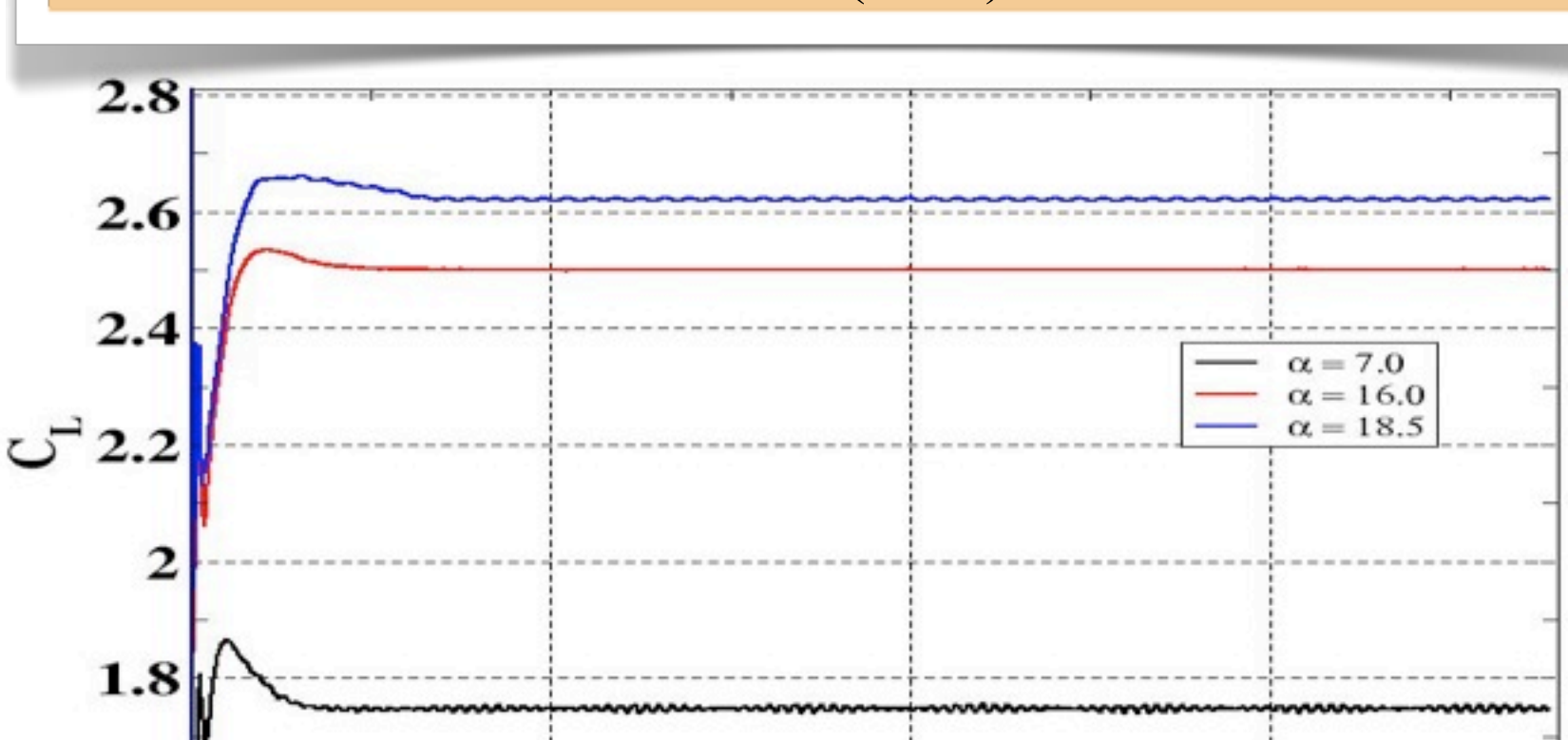


Non-Time-Accurate Convergence Issues
Unsteady Flow Analysis

Test Case 3a – Effect of Pressure Tube Bundles

Re = 1.35Million, Convergence Study

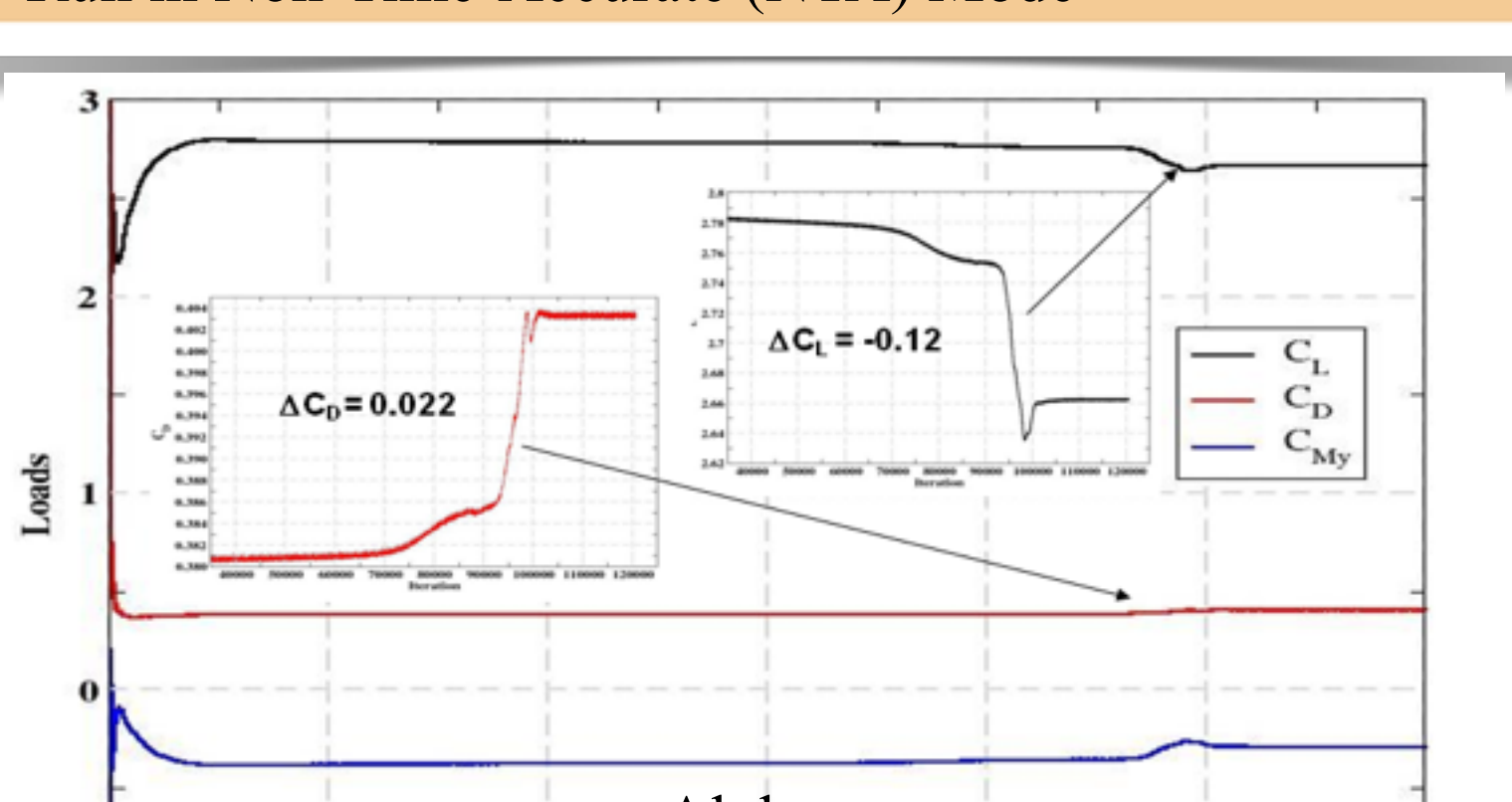
- Case3a with Dense Patch Grids
- Cases:
  - Alpha = 7°,16°, 18.5° and 21° started from free stream
  - Run in Non-Time-Accurate (NTA) Mode



Test Case 3a – Effect of Pressure Tube Bundles

Re = 1.35Million, Convergence Study

- Case3a with Dense Patch Grids
- Cases:
  - Alpha = 7°,16°, 18.5° and 21° started from free stream
  - Run in Non-Time-Accurate (NTA) Mode

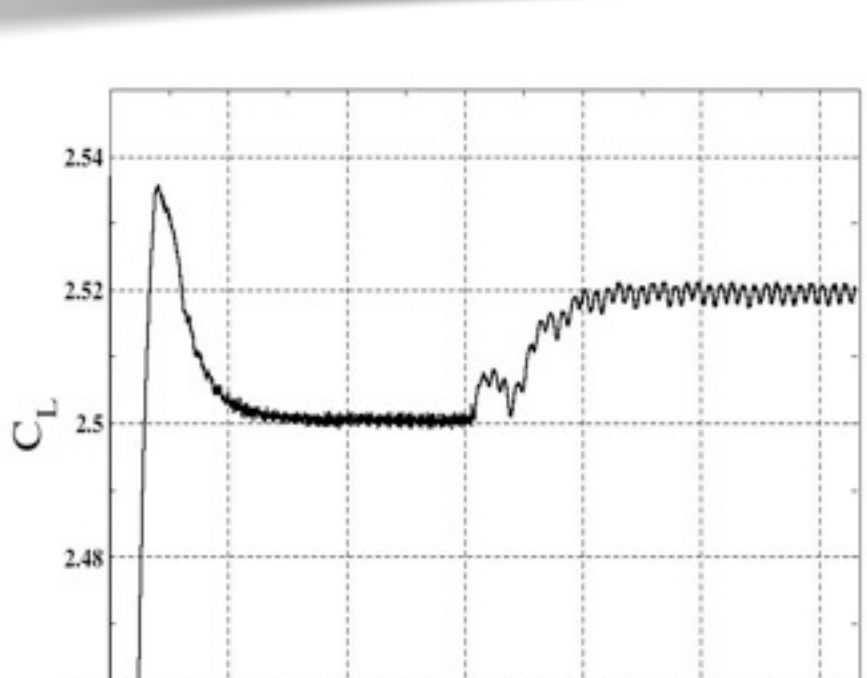


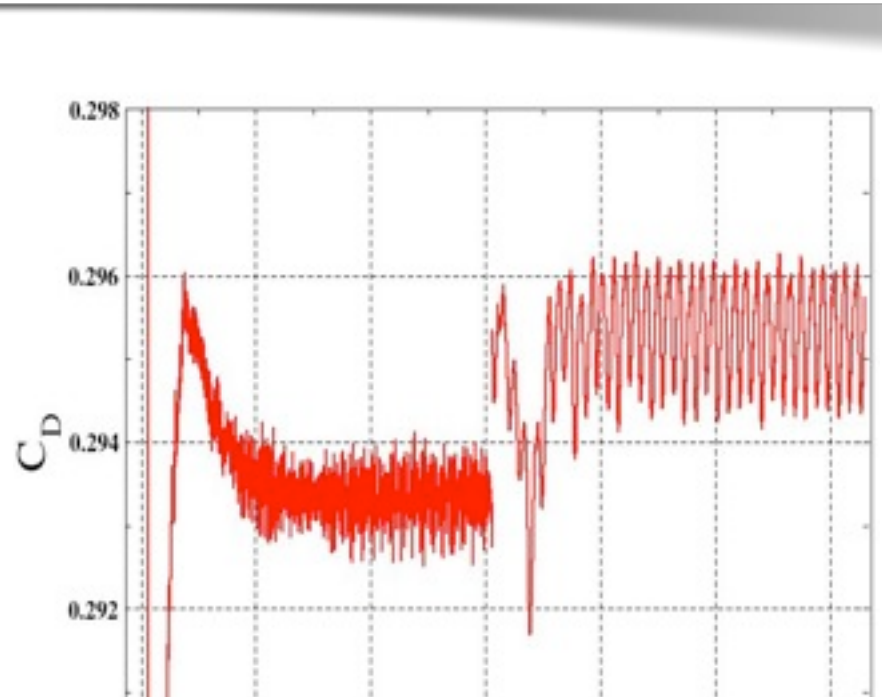
Test Case 3a – Time Accuracy Study

- Alpha = 16° and 21°:
  - Non-Time Accurate (NTA) to convergence
  - Restarted with Time Accurate (TA) run
    - DTPHYS = 0.35
    - Approx 1000 times steps to go 1 MAC = 347.09mm

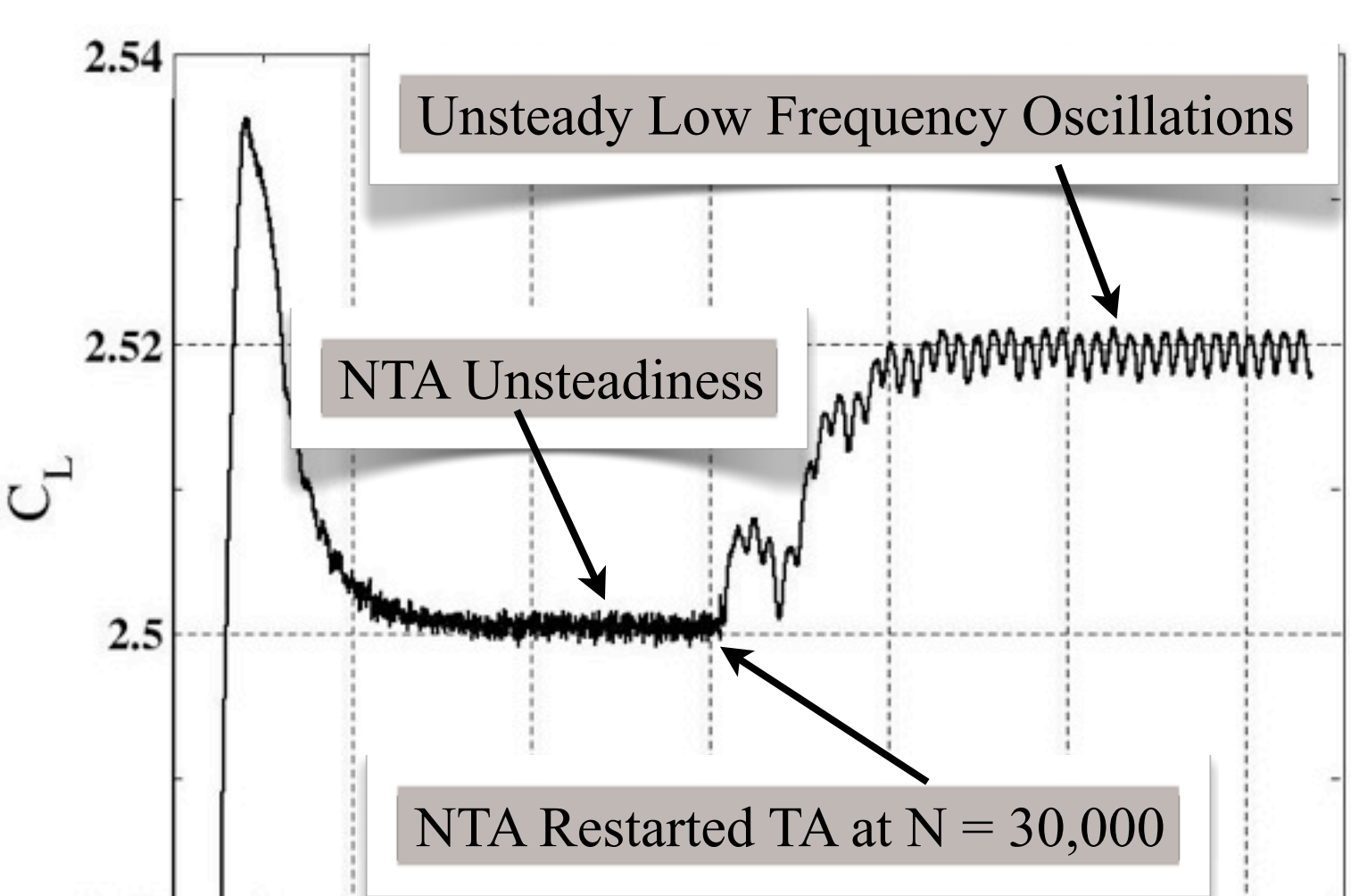
Test Case 3a – Time Accuracy Study

- Alpha = 16°, Switch From NTA to TA at N = 30000
- Small Increase in C_L (~0.7%) and C_D (~14 Counts, 0.5%)
- Note: Low Frequency, Small Amplitude Oscillations

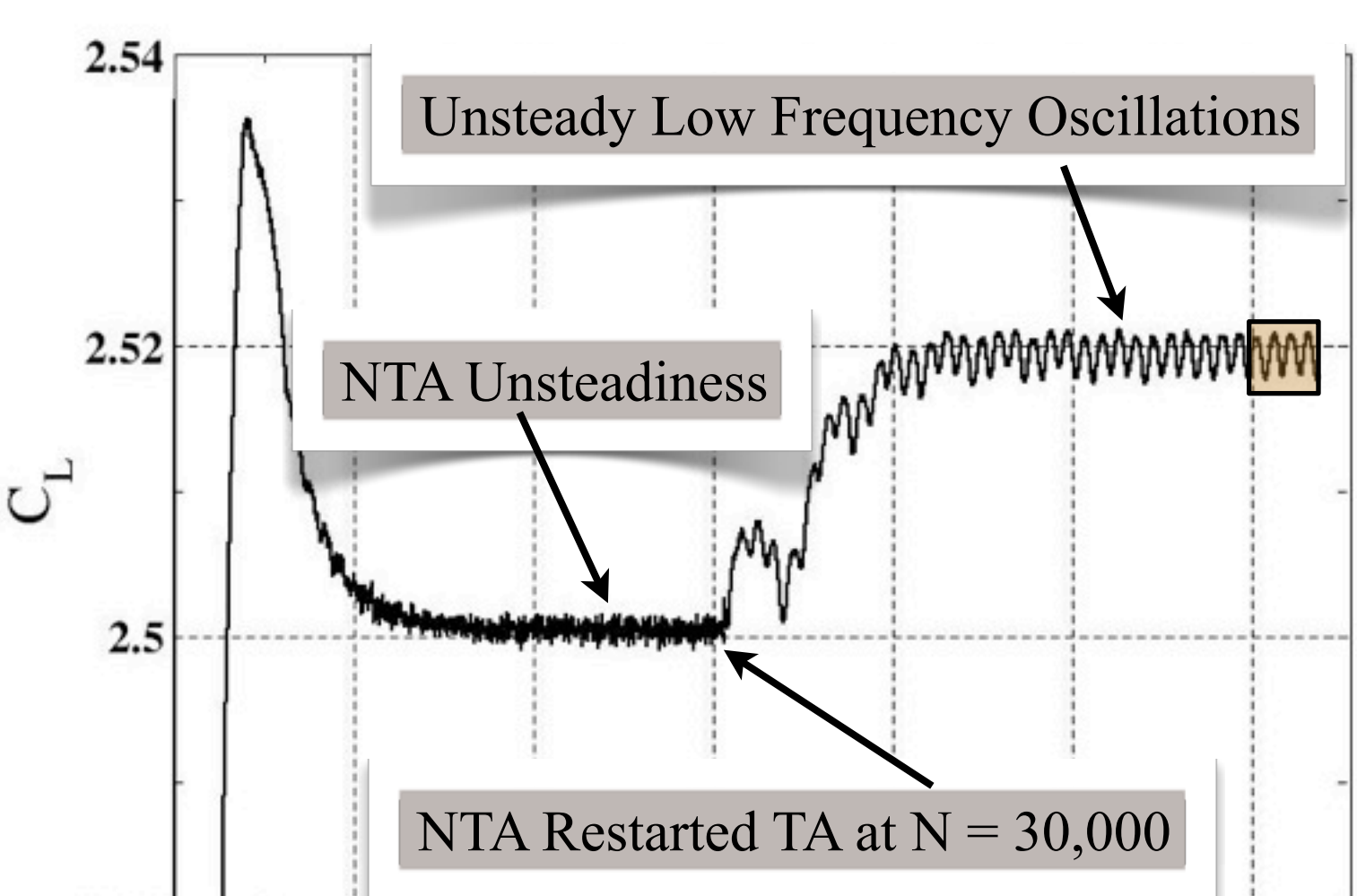




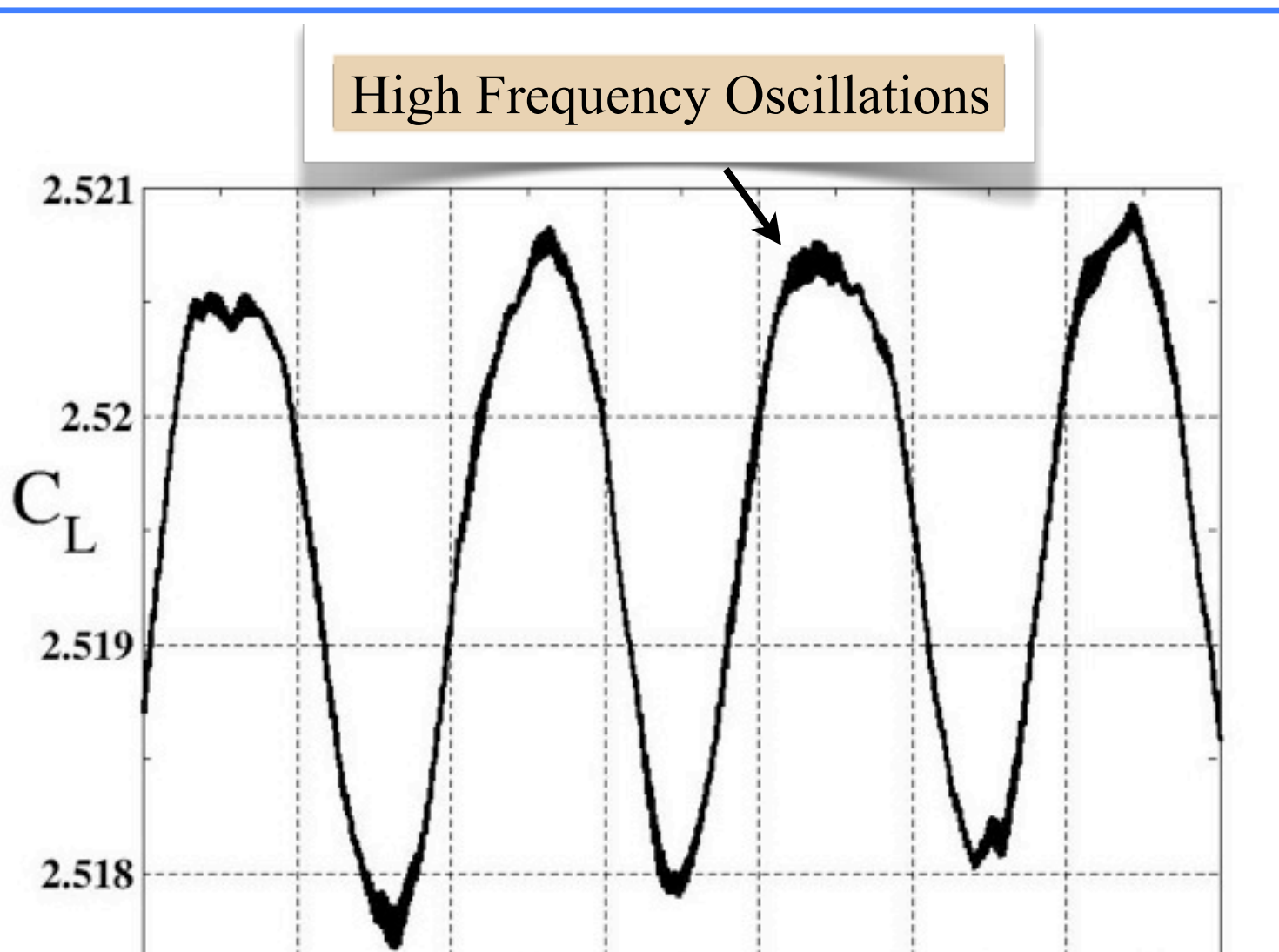
Alpha = 16° Case 3a – Time Accuracy Study



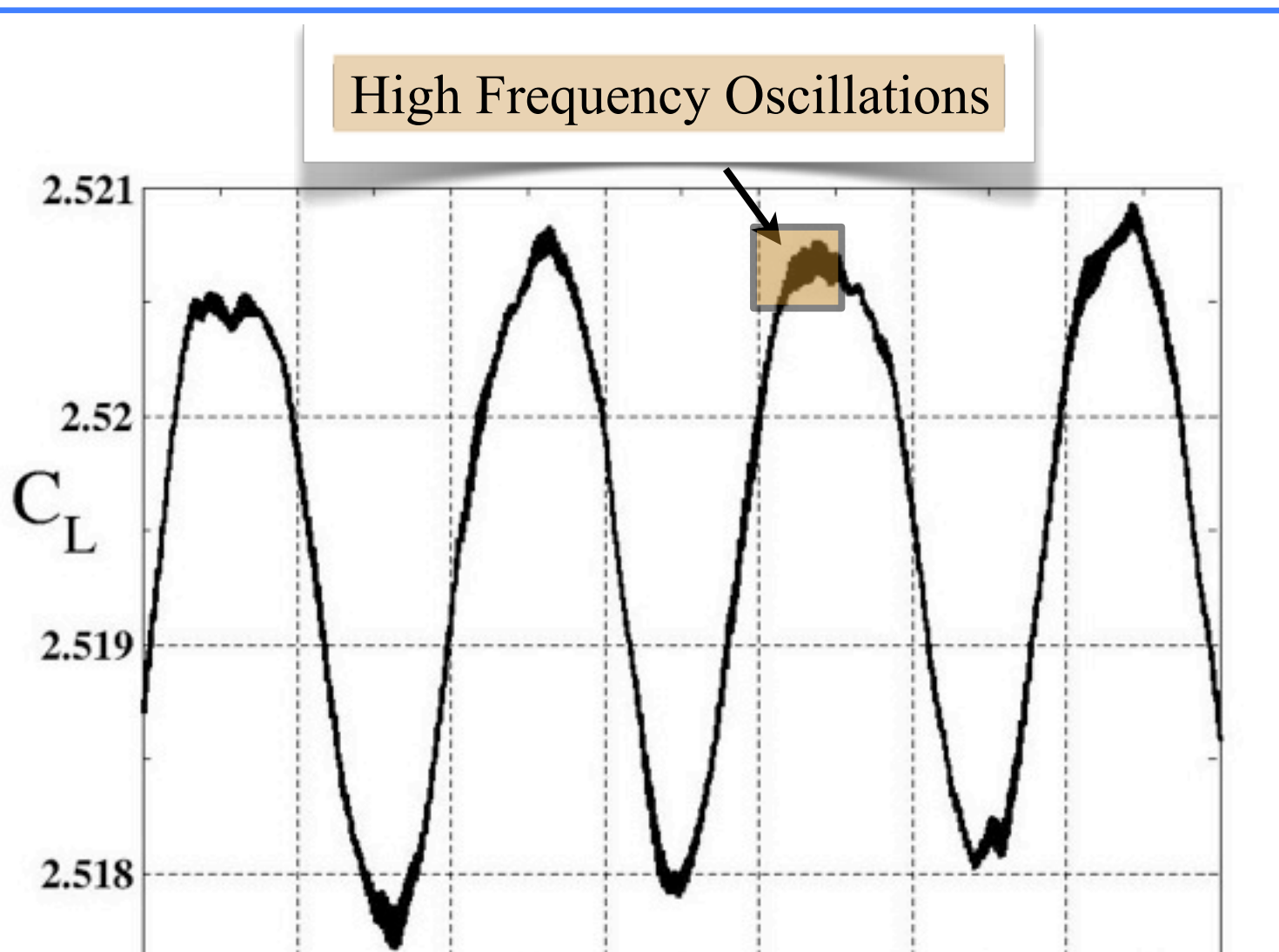
Alpha = 16° Case 3a – Time Accuracy Study



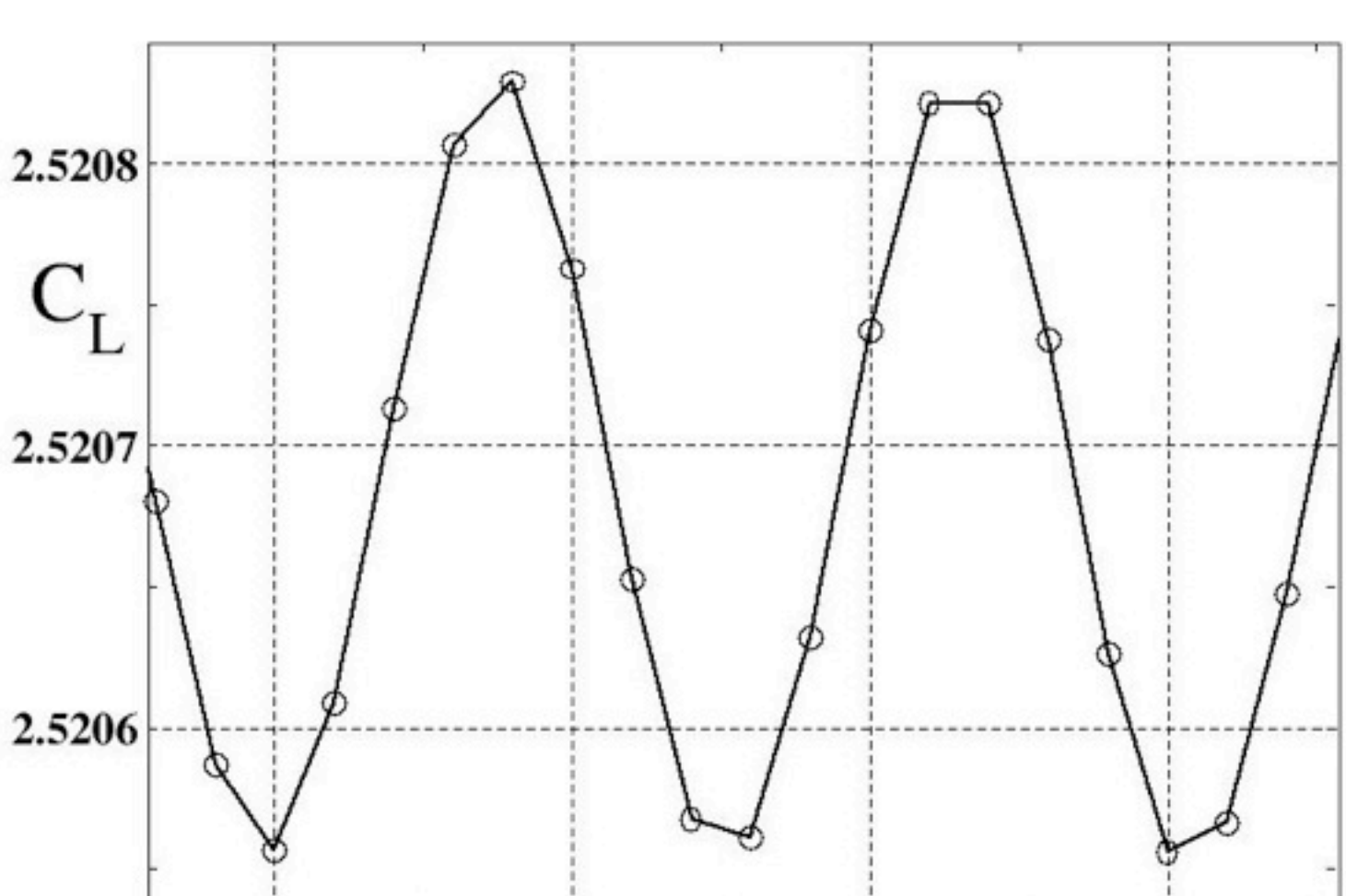
Alpha = 16° Case 3a – Time Accuracy Study



Alpha = 16° Case 3a – Time Accuracy Study

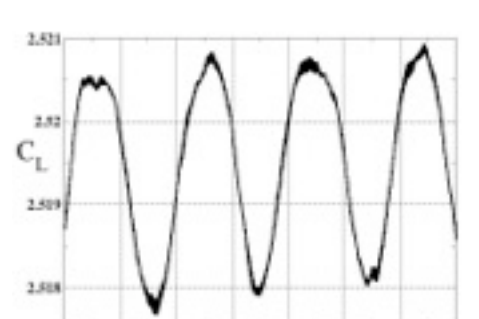


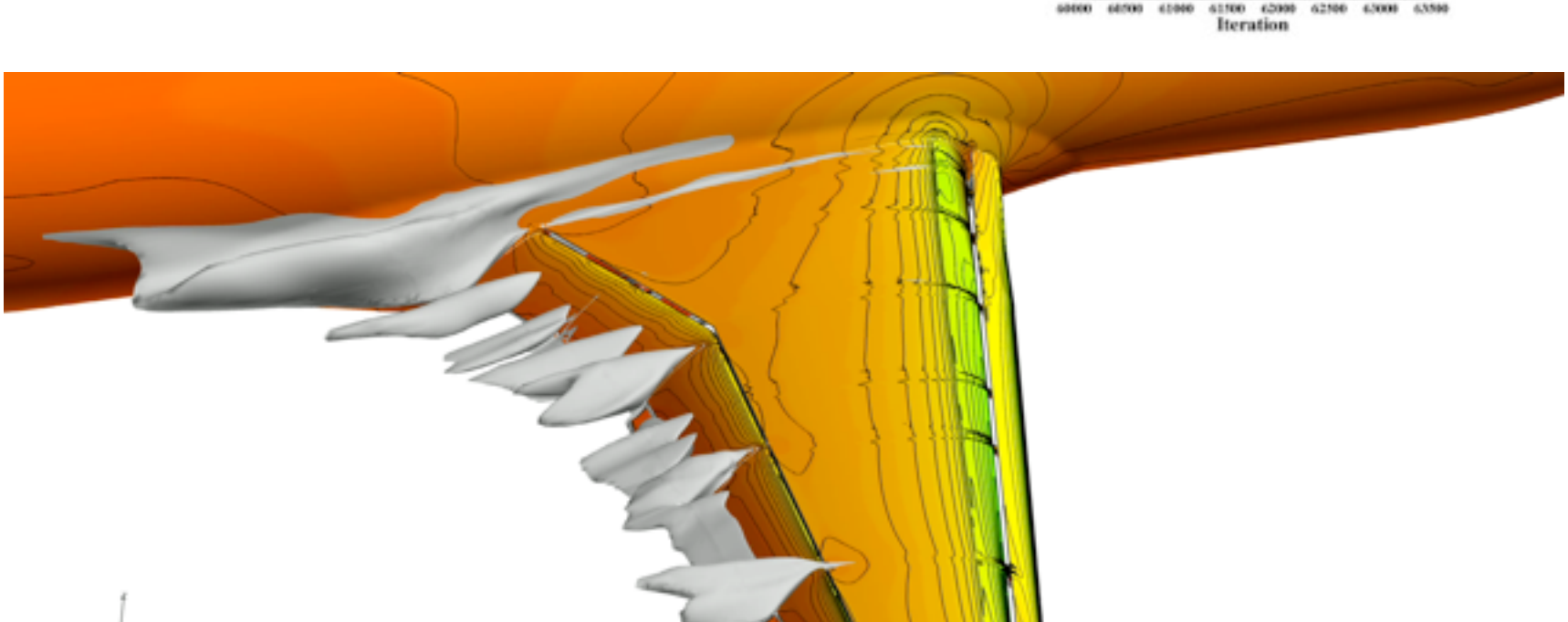
Alpha = 16° Case 3a – Time Accuracy Study



Alpha = 16° Case 3a – Time Accuracy Study

Low-Frequency Oscillations In
Flap Wake Region and Side-of-Body





Alpha = 16° Case 3a – Time Accuracy Study

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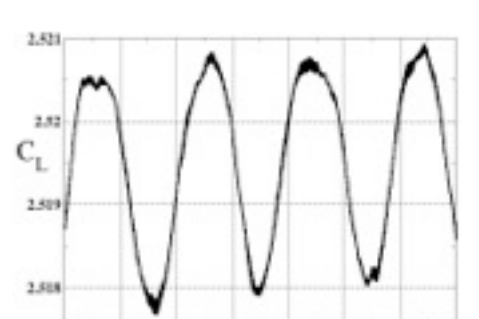
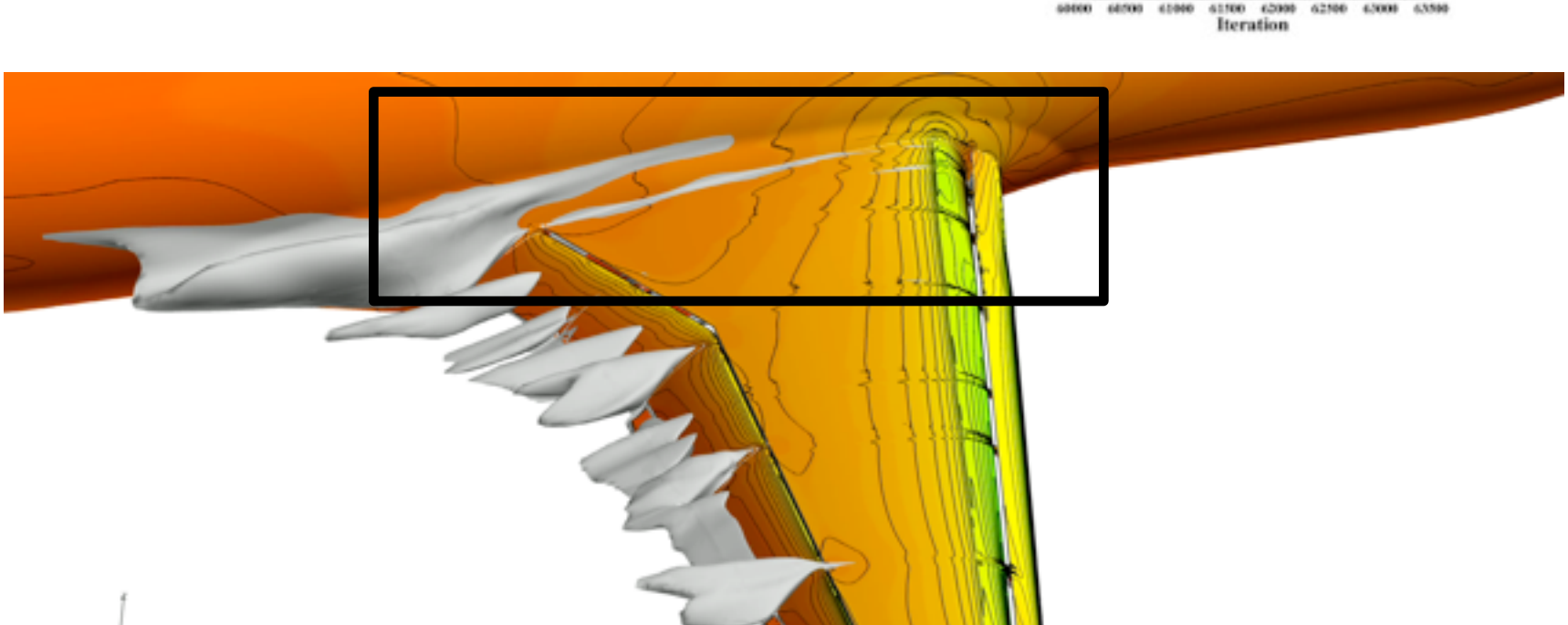
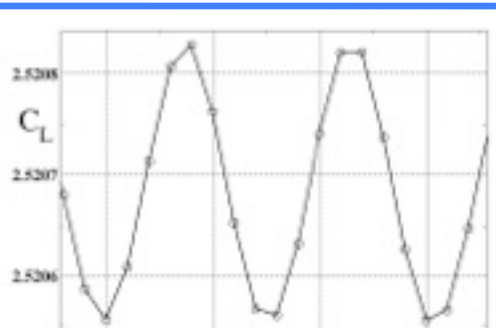
Flap Wake Region and Side-of-Body

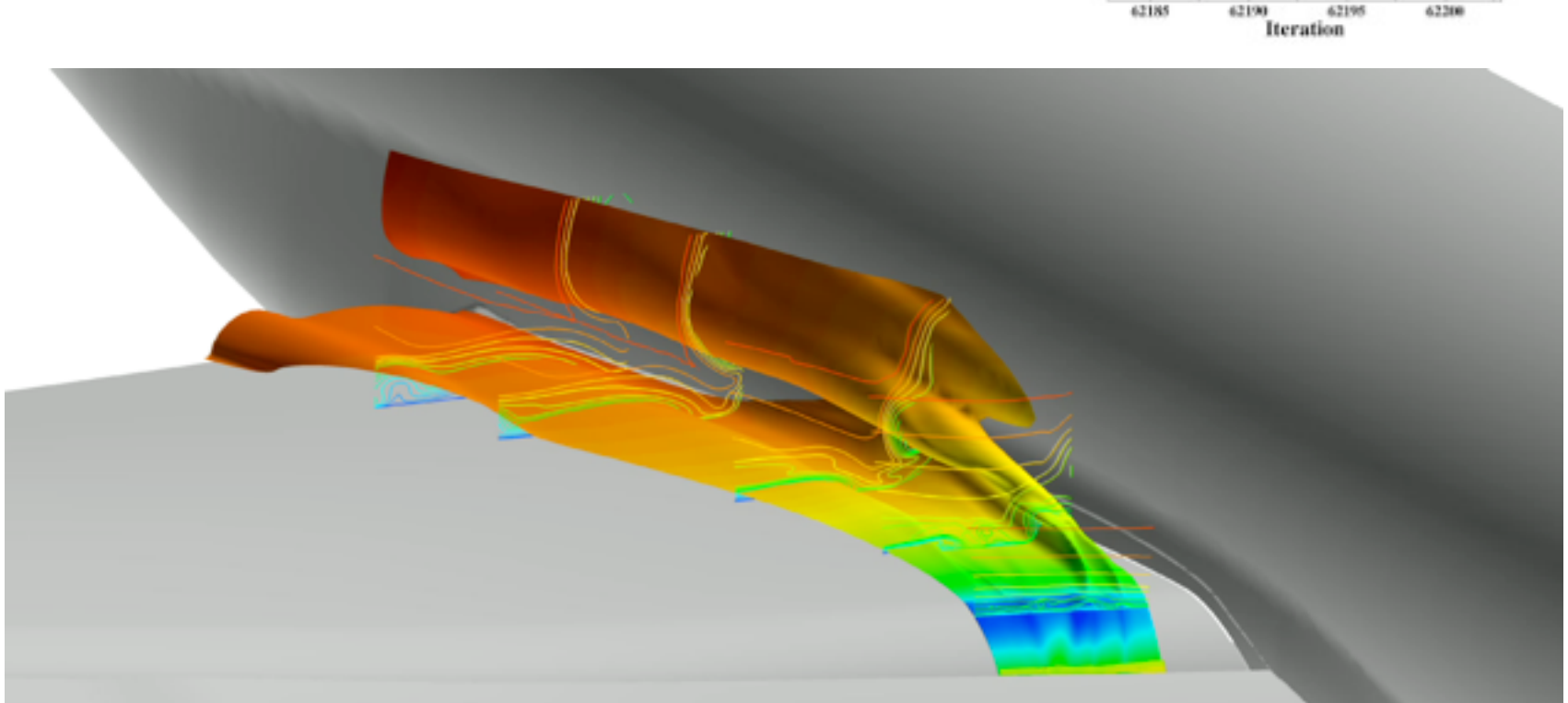




Alpha = 16° Case 3a – Time Accuracy Study

High-Frequency Oscillations In
Side-Of-Body Junction Flow Region





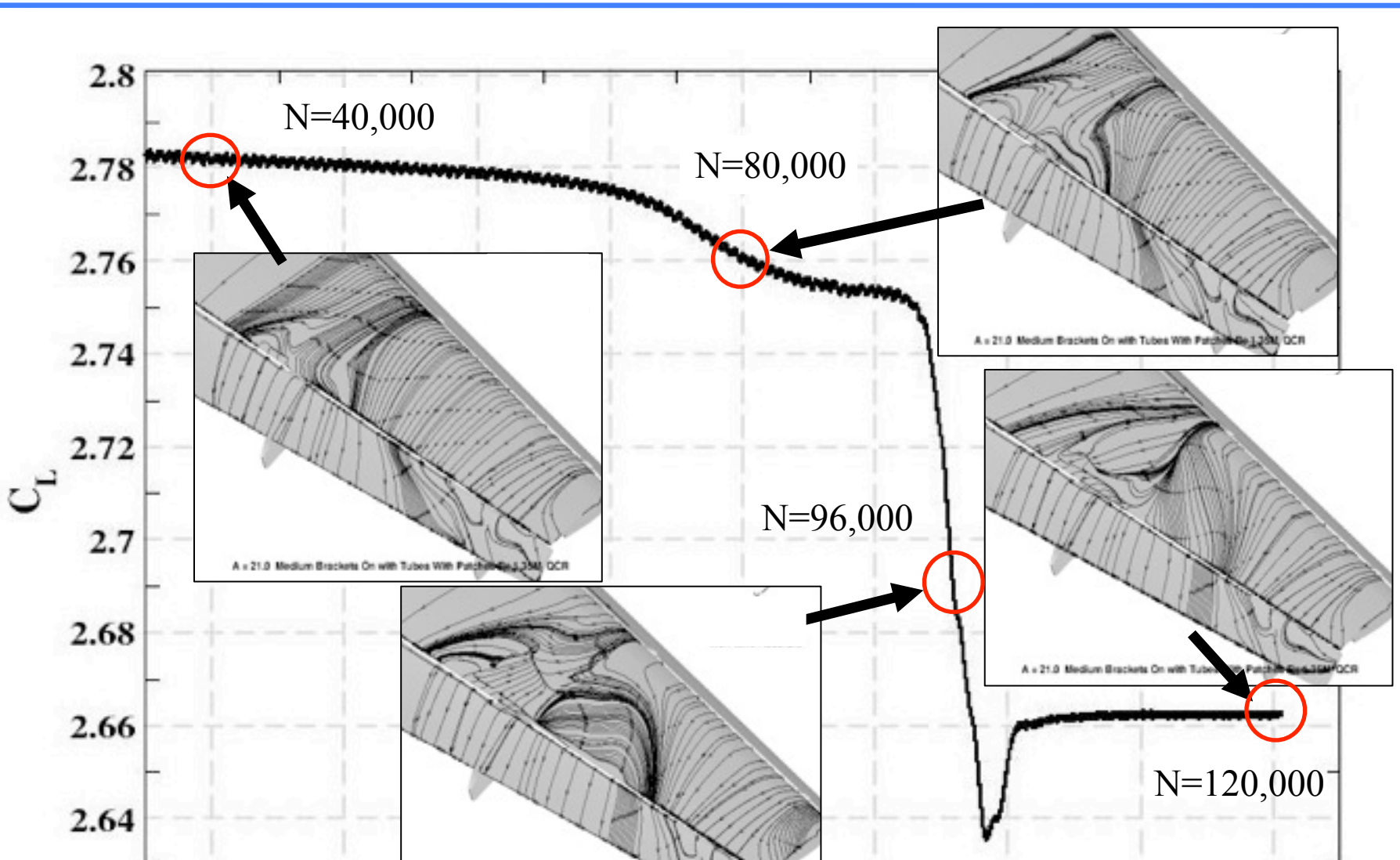
Time Accurate Solutions Show

- Low-Frequency Oscillations
  - Flap Wake
- High-Frequency Oscillations
  - Side-of-Body Separation

- Small Regions of Unsteadiness Reason
  - Non-Time-Accurate (NTA)
    - Convergence is So Difficult
    - Another Source of Uncertainty

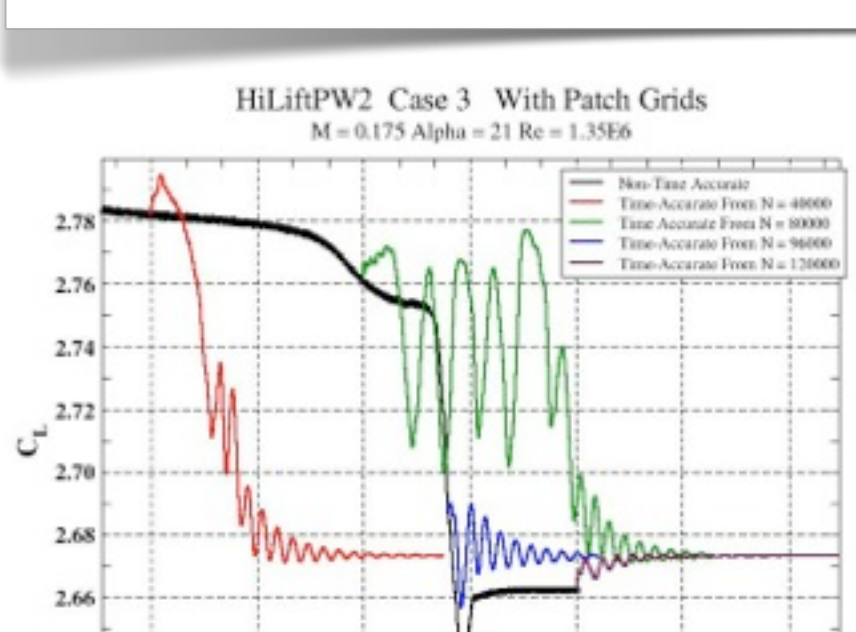
- Time-Accurate Integration
  - Necessary Check For
    - Solutions Poor Convergence
    - NTA Unsteadiness

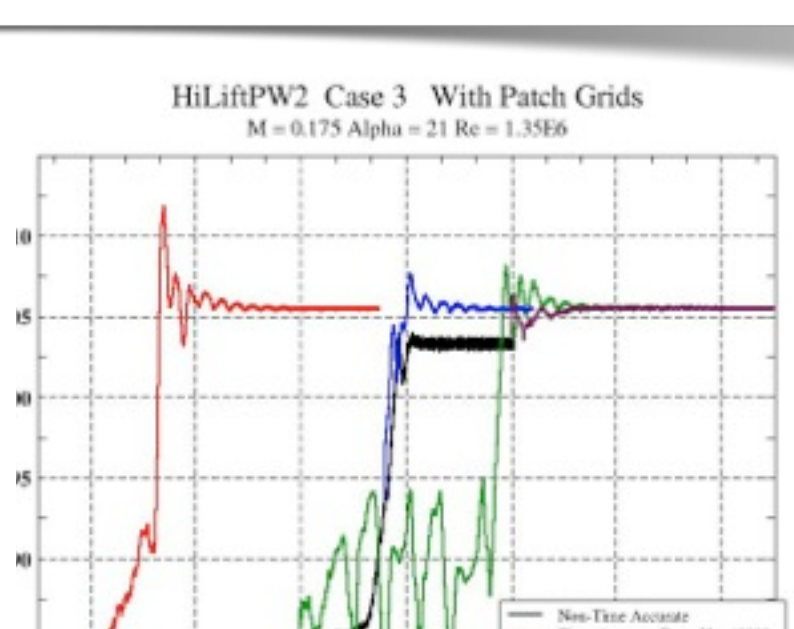
Alpha = 21° NTA Solutions At Various N



Alpha = 21° : Time Accurate Investigation

- Restart NTA solution TA at Key Spots Along Convergence History
  - All the TA Runs Converge to Consistent Result
  - NTA to TA: Increase ~ 0.4 % in C_L, ~0.6% in C_D (23 Counts)





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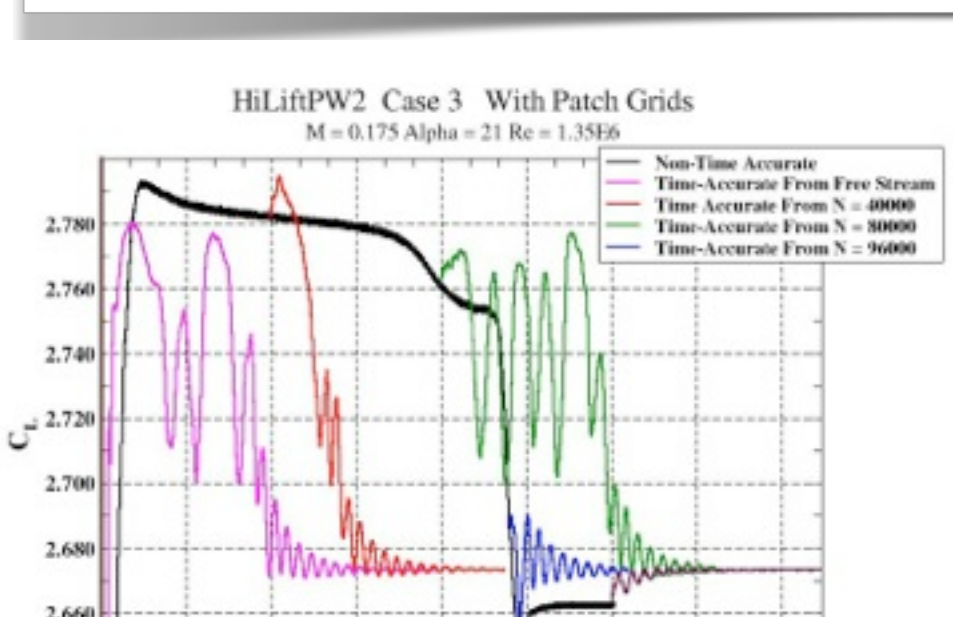
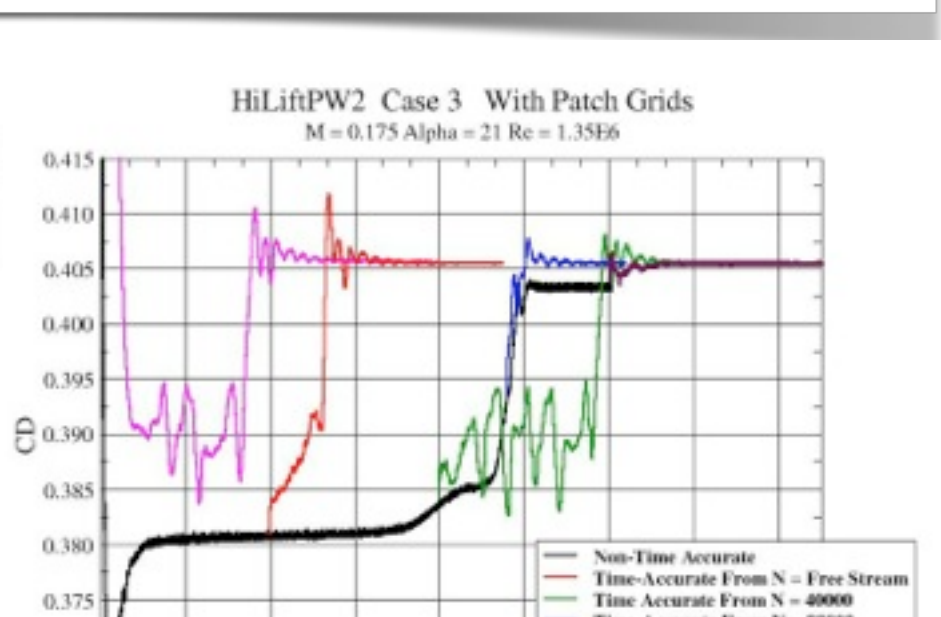
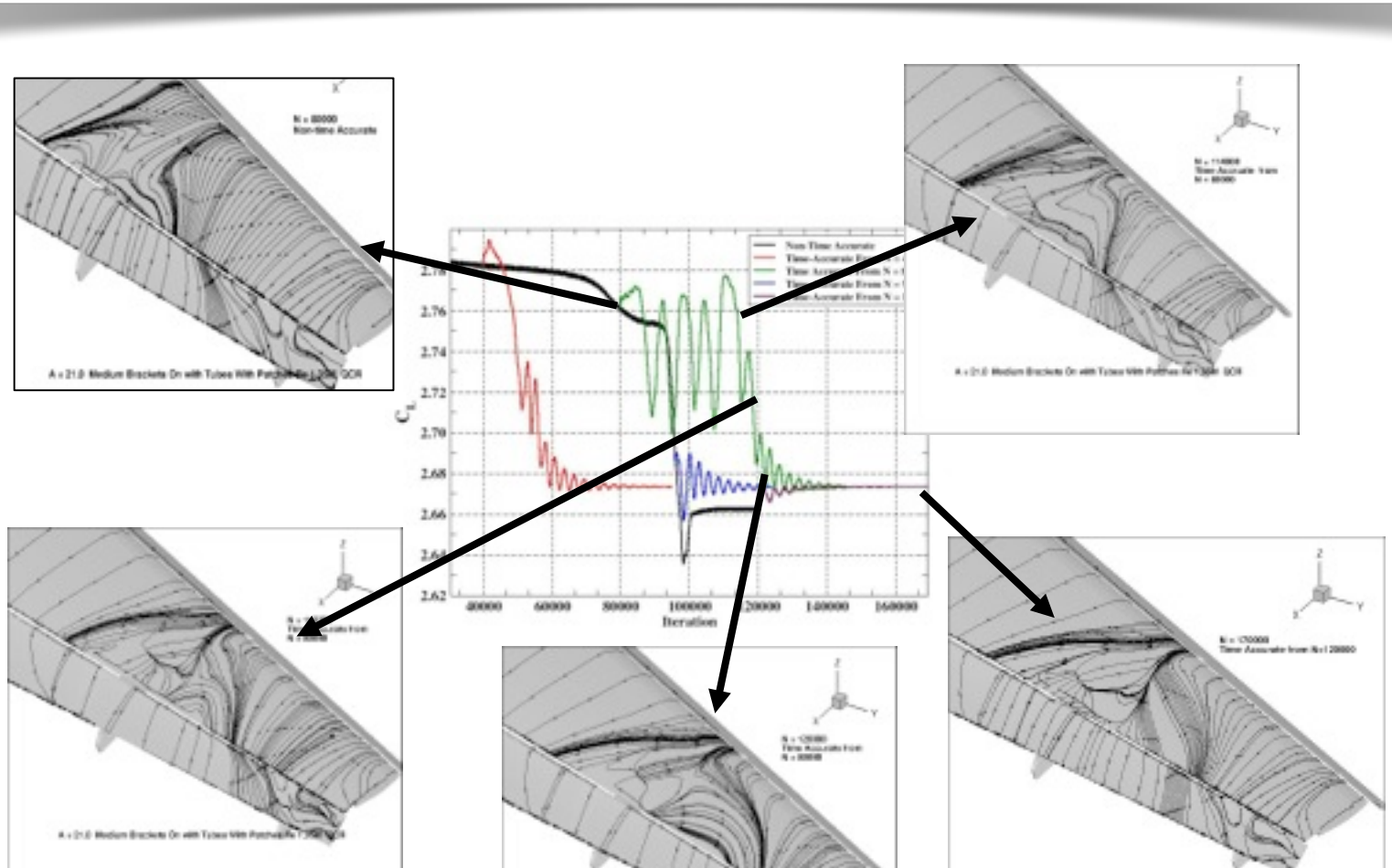




Alpha = 21° : Time Accurate Investigation

- Separation Bubble Grows In Size From N = 80,000 to TA Result



DLR F11 OVERFLOW Analysis

DLR F11 OVERFLOW Analysis

- Uniform Grid Refinement
  - Does Not Have a Big Effect on Pressures or Stall
- QCR: Significant Effect at Both Low and High Angles of Attack
  - Alters Off-body Flow Field at Side-of-body for 7º and 12º
  - Forces Stall to Occur at 22.4º for High RN, 20º for Low RN
- Trailing Edge Stall Occurs: Main Element Full-chord Separation
  - Experiment : ~50% Semi-span or Behind Slat Bracket #5
  - OVERFLOW : ~80% Semi-span or Behind Slat Bracket #6
- More Study is Needed
  - Determine Why We Missed the Critical Wing Station

DLR F11 OVERFLOW Analysis

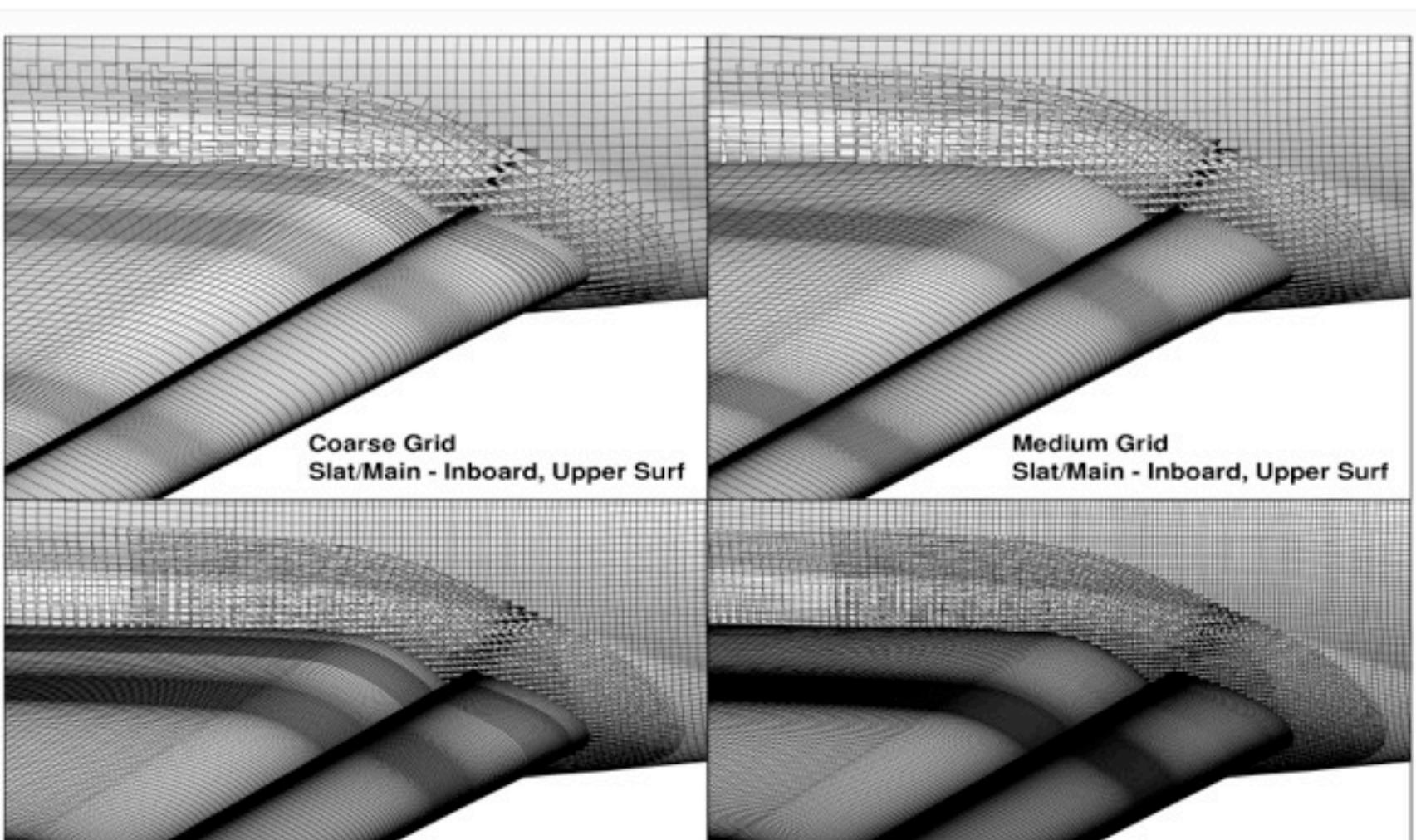
- Unsteady Analysis Required for the Pre-/Post- Stall Regions
  - Non-Time Accurate Results May Be
    - Misleading
    - Difficult to Converge
  - Time Accurate Results Produce Consistent Convergence
- Further Study is Required to
  - Develop Reasonable Resource Balances for TA Simulations
    - Convergence Criteria
    - Efficient Solvers
    - Error Control
  - Assess the Effect on Solution Unsteadiness on Increments

Thank You!

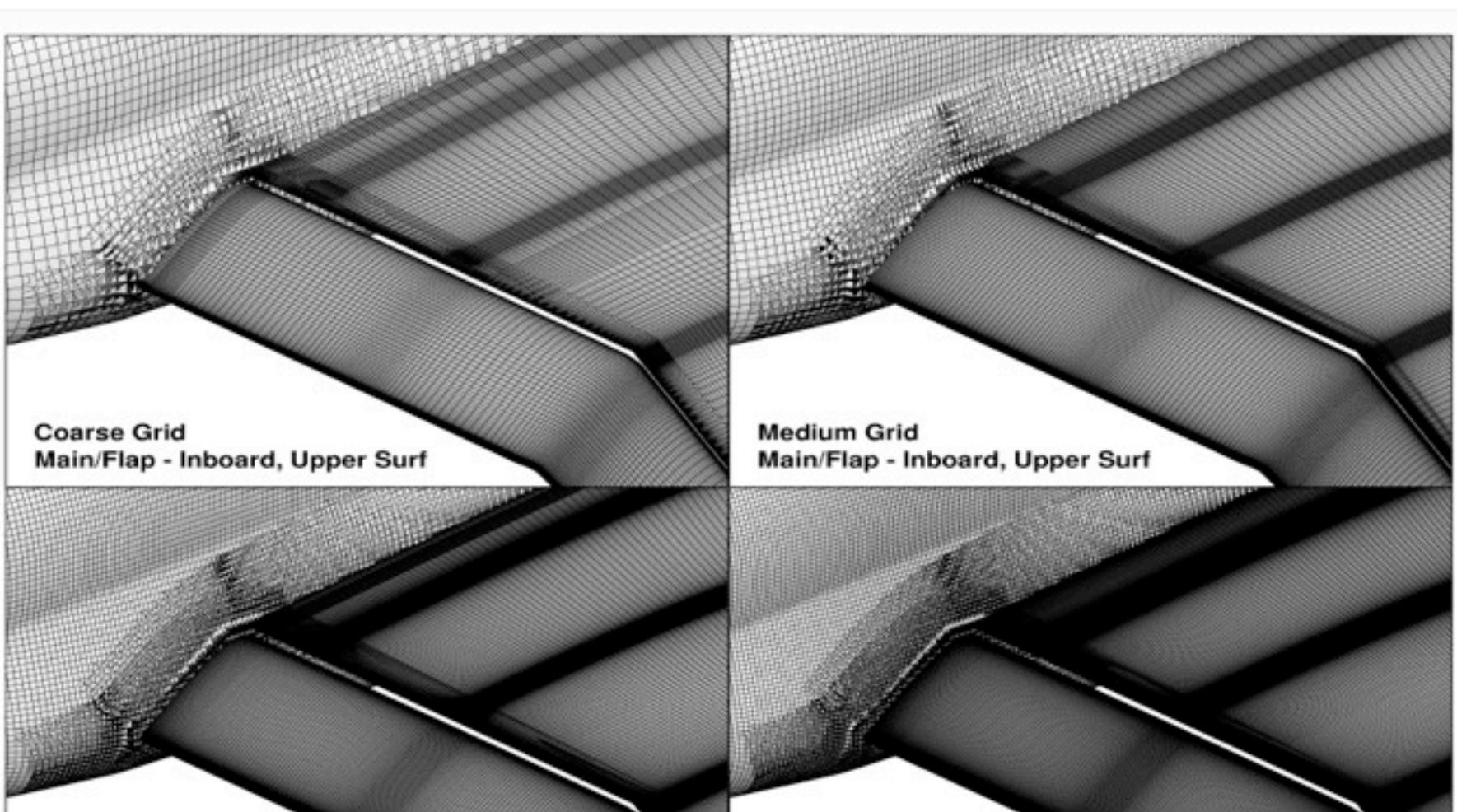
Questions?

Thank You!

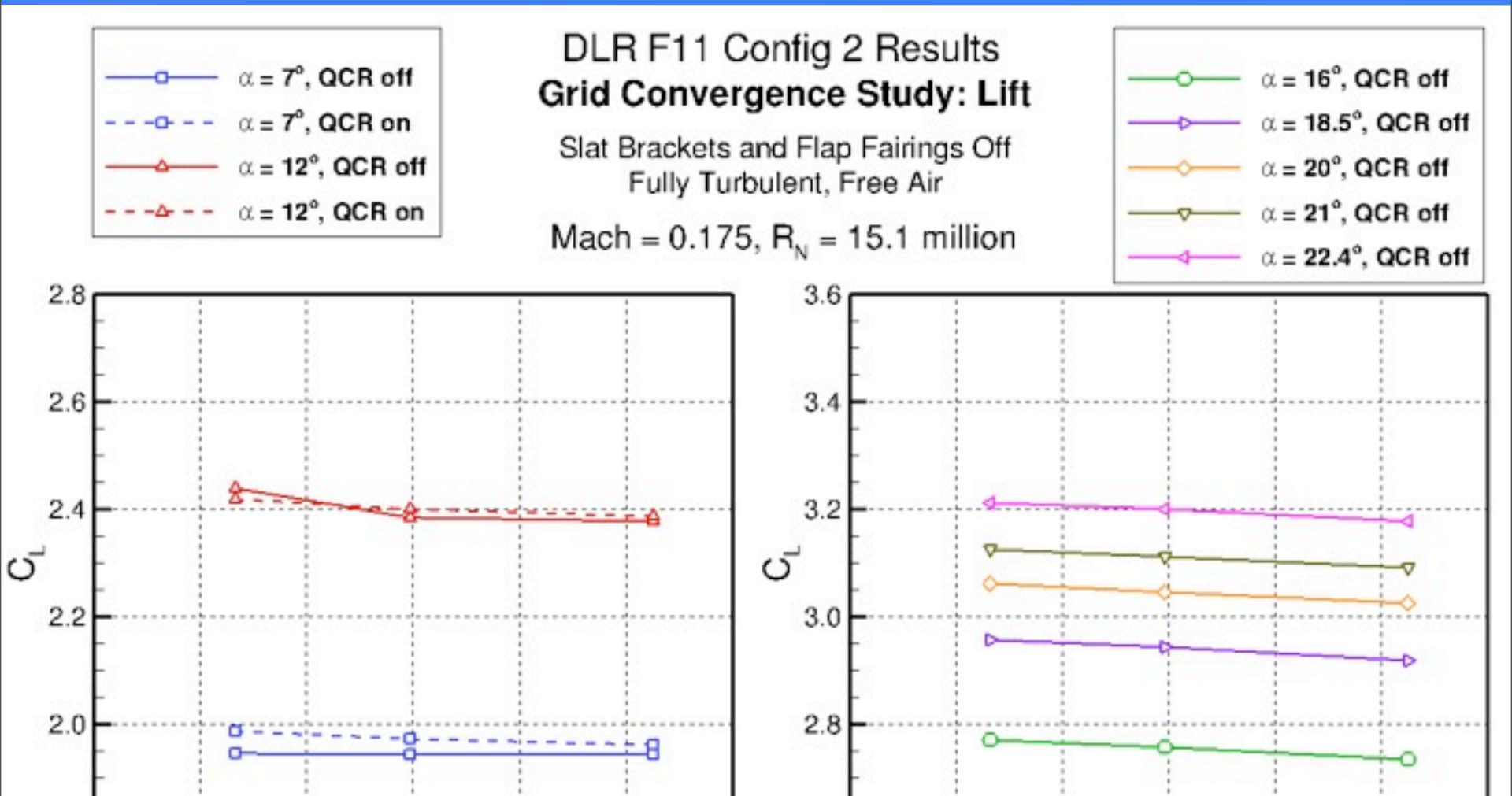
Grid Details



Grid Details

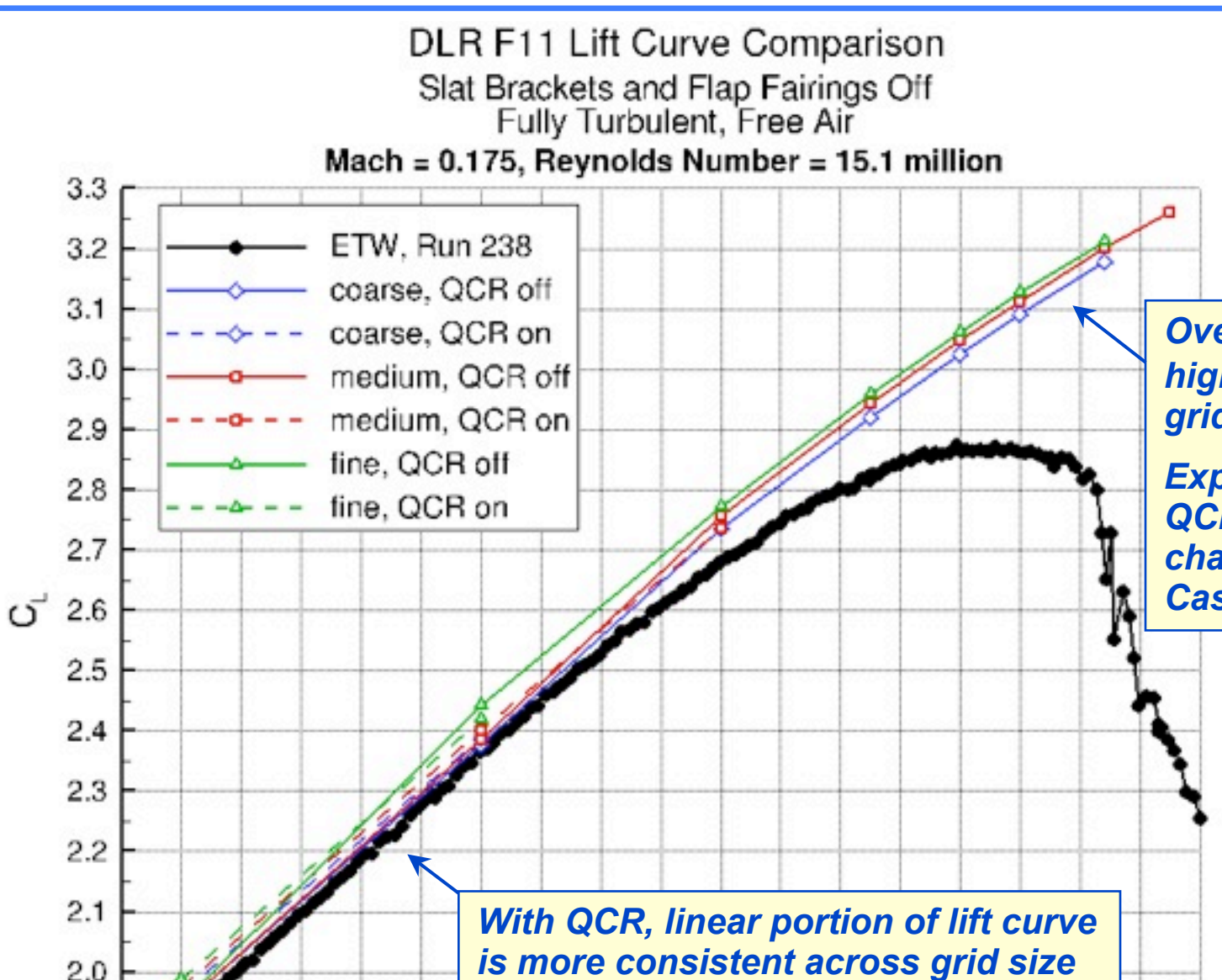


Test Case 1 – Grid Convergence Study



Using QCR for the lower angles, all lift trend lines are linear and relatively flat with grid refinement

Test Case 1 – Grid Convergence Study

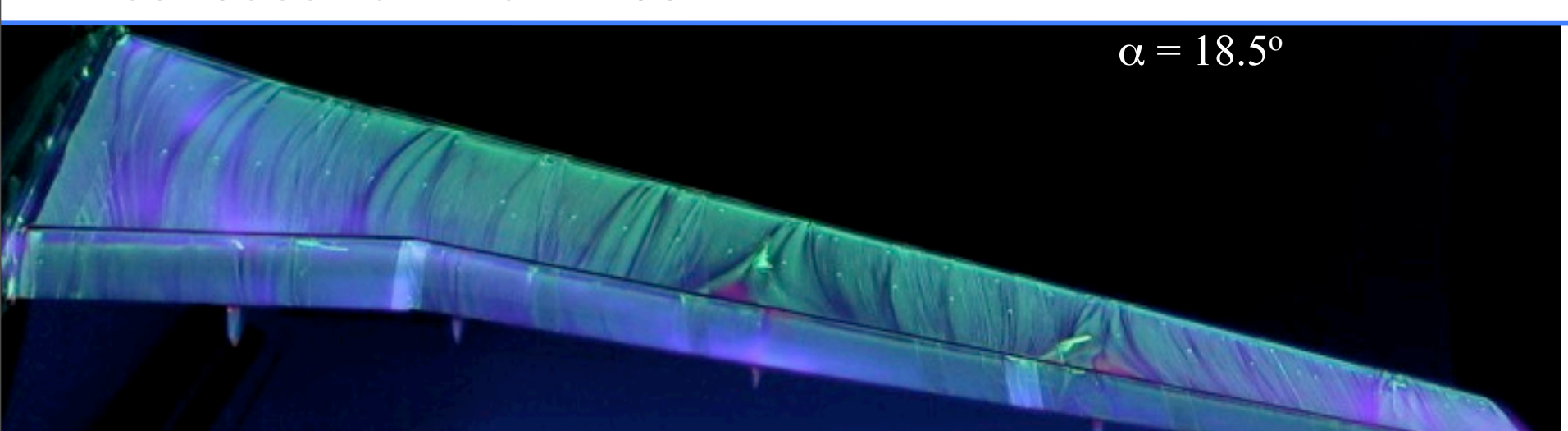


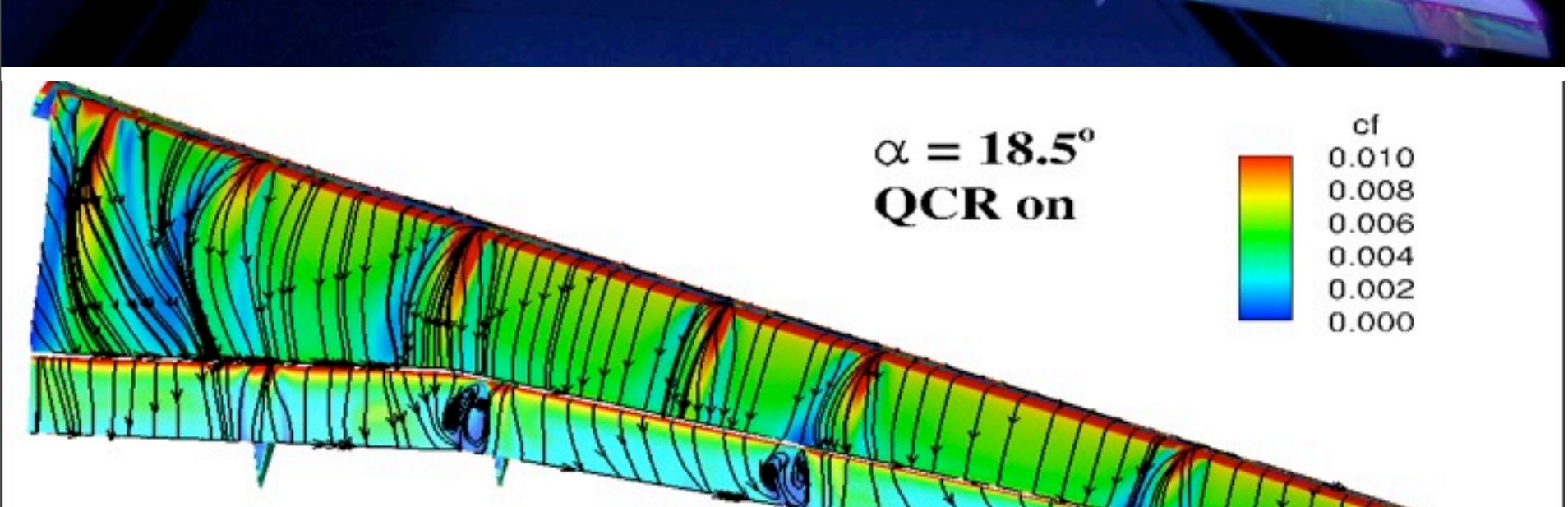
Over-predicting C_L at higher alphas for all grid densities analyzed

Explored the effect of QCR on stall characteristics for Test Case 2a/b

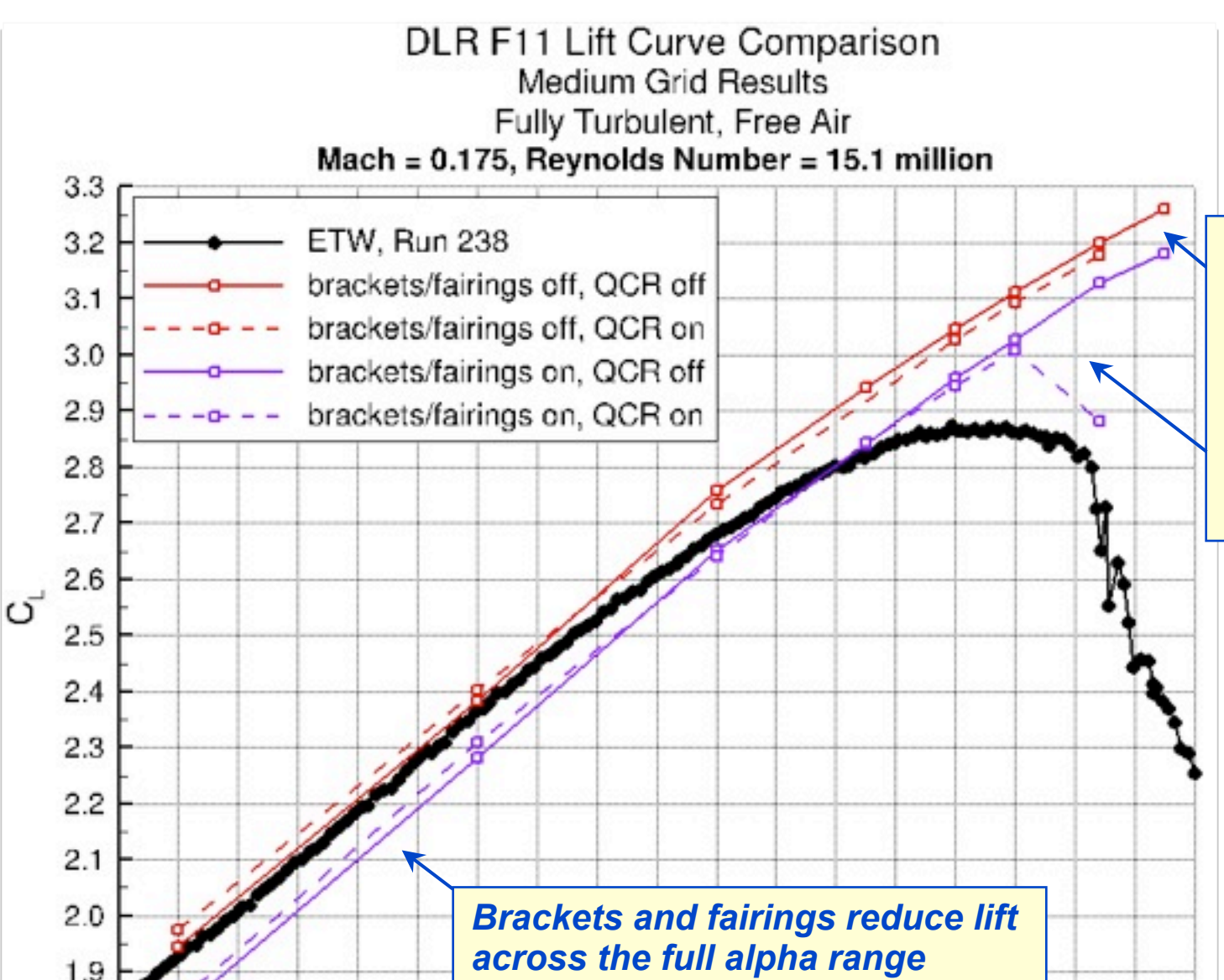
With QCR, linear portion of lift curve is more consistent across grid size

Test Case 2a – Re = 1.35M





Test Case 2b – Reynolds Number Study



QCR Off: brackets / fairings do not alter stall behavior

QCR On: brackets / fairings force stall at 22.4º

Brackets and fairings reduce lift across the full alpha range