CFD Drag Prediction Workshop

OVERFLOW Analysis of the NASA CRM WB and WBNP Aero-Elastic Configurations

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Outline

- Flow Solver and Computing Platform
- Overset Grid Summary and Cases Analyzed
- Convergence History
- Results
  - Case 1: Verification
  - Case 2: Nacelle/Pylon Drag Increment
  - Case 3: Wing/Body Drag Polar
  - Case 4: Grid Adaption
- Conclusions

Flow Solver and Computing Platform

OVERFLOW Version 2.2k

- Setup used for past workshops
  - 2^{nd} order central differencing
  - SA-RC turbulence model (SA-noft2 with rotation/curvature corrections)
  - full N-S, exact wall distance calculation
  - free stream initial conditions
  - fully turbulent boundary layer
  - linear vs. nonlinear stress model via QCR

Pleiades Supercomputer

- SGI ICE cluster with >200,000 cores of mixed processor type
- Utilized Ivy Bridge nodes with 2 ten-core processor per node

case	grid	points	cores	sec/it	sec/it/grid	iterations	wall clock
WB	medium	24.7M	20	3.1	12.5×10^{-8}	10000	9 hrs
WB	ultrafine	82.7M	60	6.2	7.5×10^{-8}	25000	43 hrs
WBNP	medium	39.5M	40	2.5	6.3×10^{-8}	10000	7 hrs
WBNP	ultrafine	132.4M	80	4.1	3.1×10^{-8}	25000	28 hrs

Overset Grid Summary and Cases Analyzed

Wing/Body (WB) and Wing/Body/Nacelle/Pylon (WBNP) Grid Family

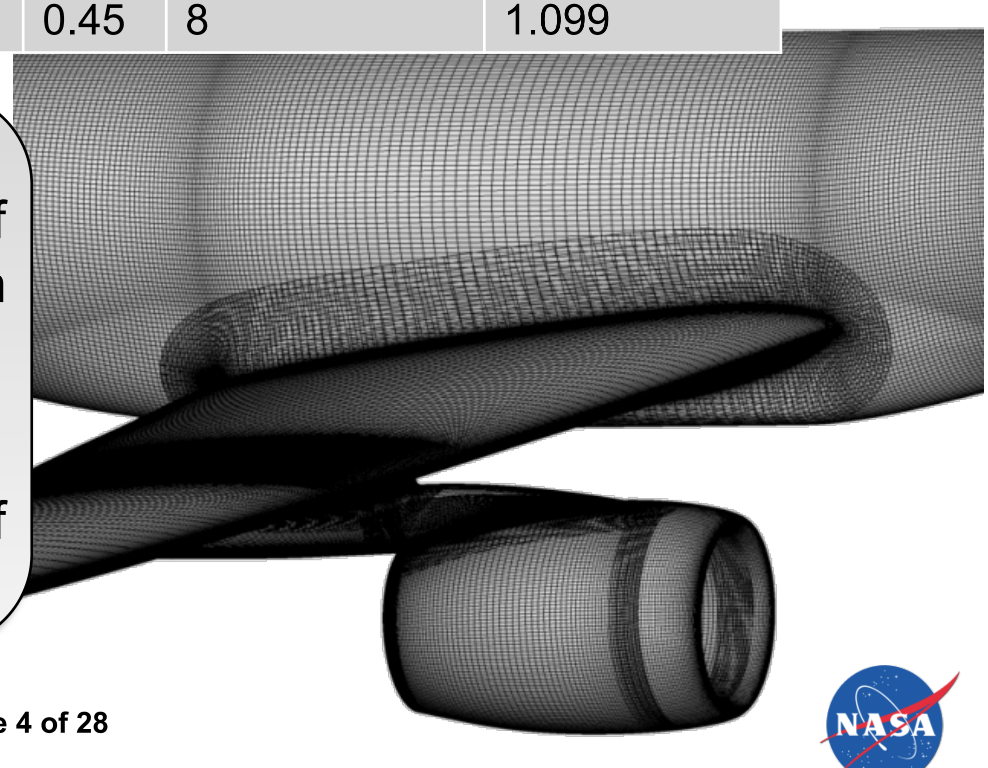
Grid Level	Points (million)		Viscous Spacing	~y+	Const Cells at Wall	Max Stretching
	WB	WBNP				
Tiny	7.4	11.9	0.001478”	1.02	4	1.235
Coarse	14.4	23.0	0.001182”	0.80	5	1.186
Medium	24.7	39.5	0.000985”	0.67	5	1.149
Fine	39.1	62.6	0.000845”	0.58	6	1.128
X-fine	58.2	93.2	0.000739”	0.50	7	1.112
U-fine	82.8	132.4	0.000657”	0.45	8	1.099

Case 1
SA, QCR-off
SA-RC, QCR-off
SA-RC, QCR-on

Case 2
SA-RC, QCR-off
SA-RC, QCR-on
WB and WBNP

Case 3
SA-RC, QCR-on
WB medium grid

Case 4
SA-RC, QCR-off
WB coarse grid



Convergence History

Residuals for Mach 0.85, C_L = 0.5

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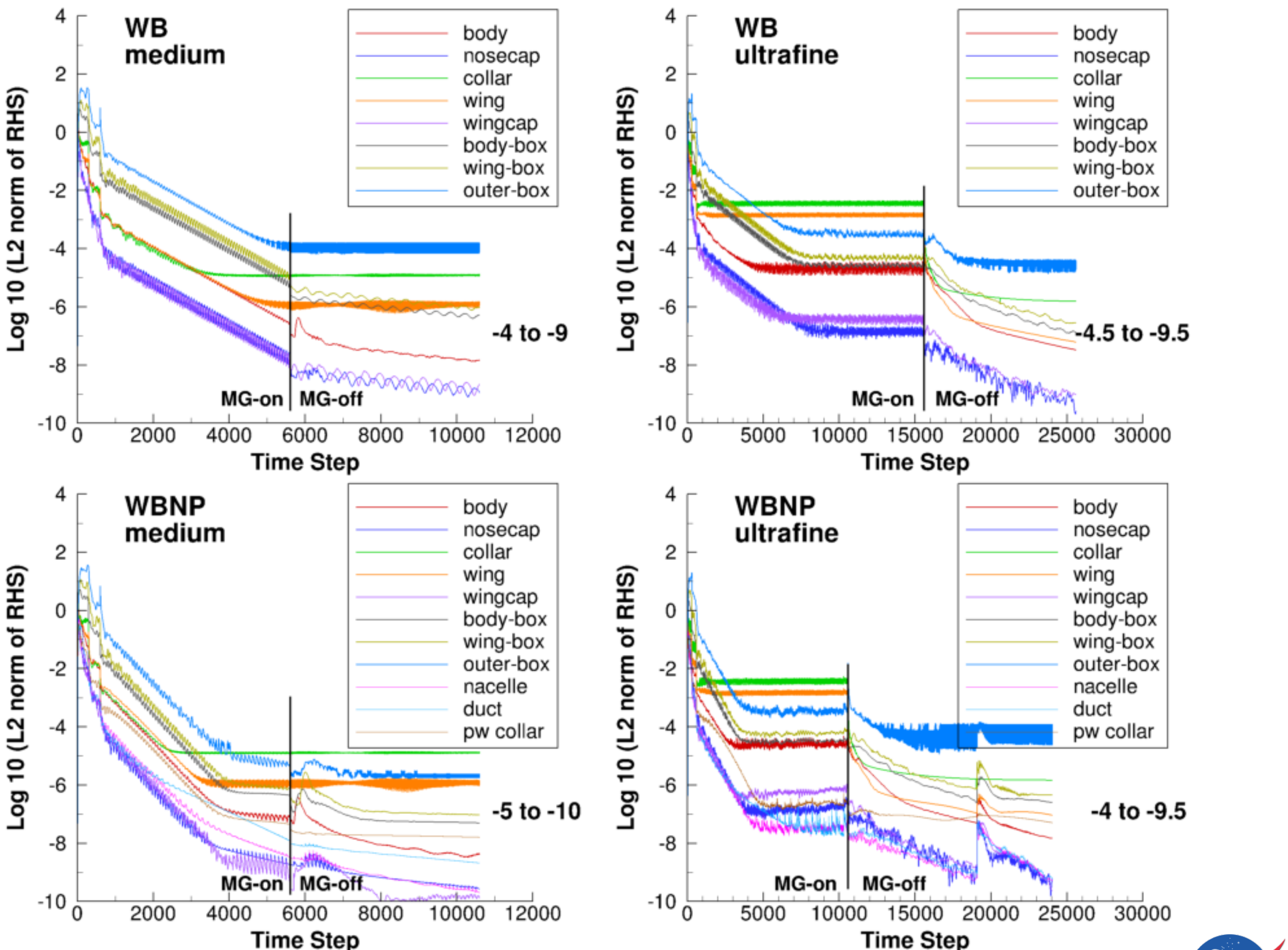
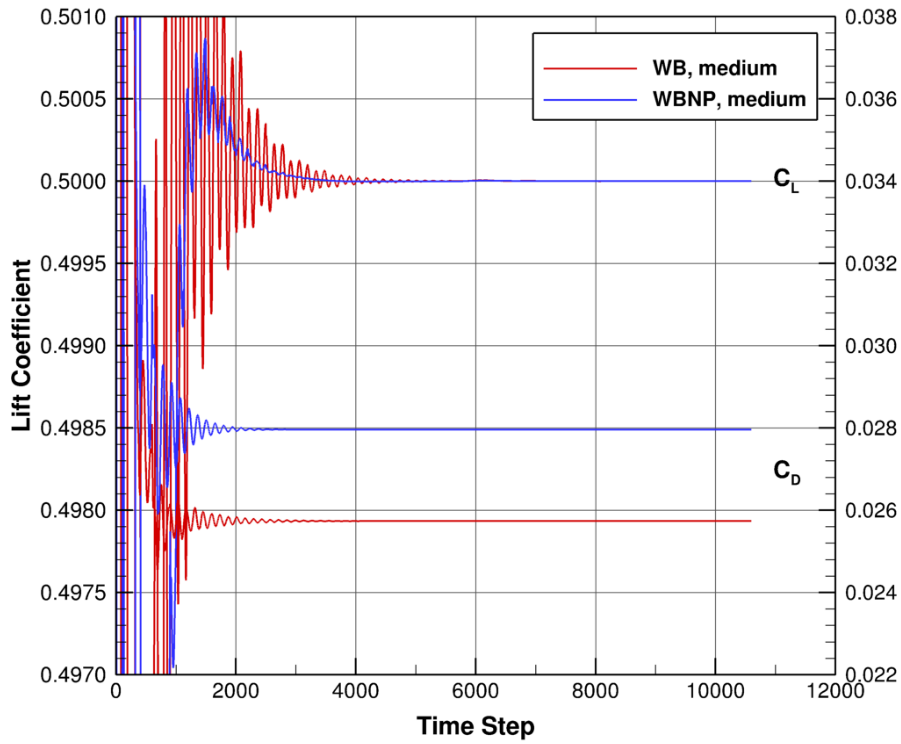
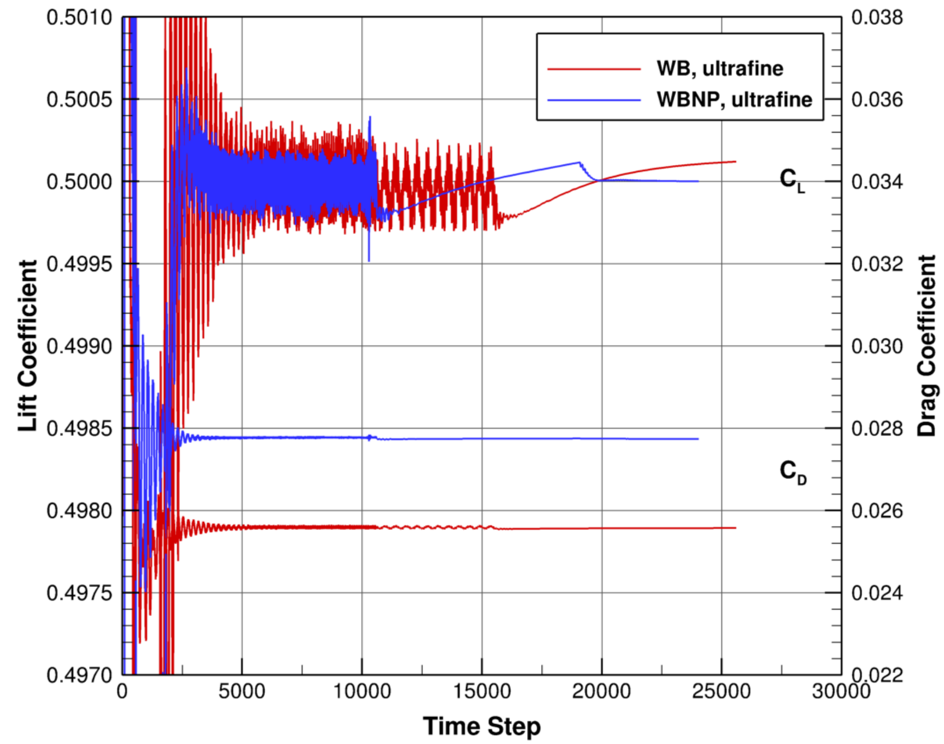


Convergence History

Lift and Drag for Mach 0.85, C_L = 0.5





- Shutting multi-grid off improved convergence for ultrafine grid and shifted force levels.

Test Case 1

Verification Study

Case 1: Verification Study
Drag Convergence

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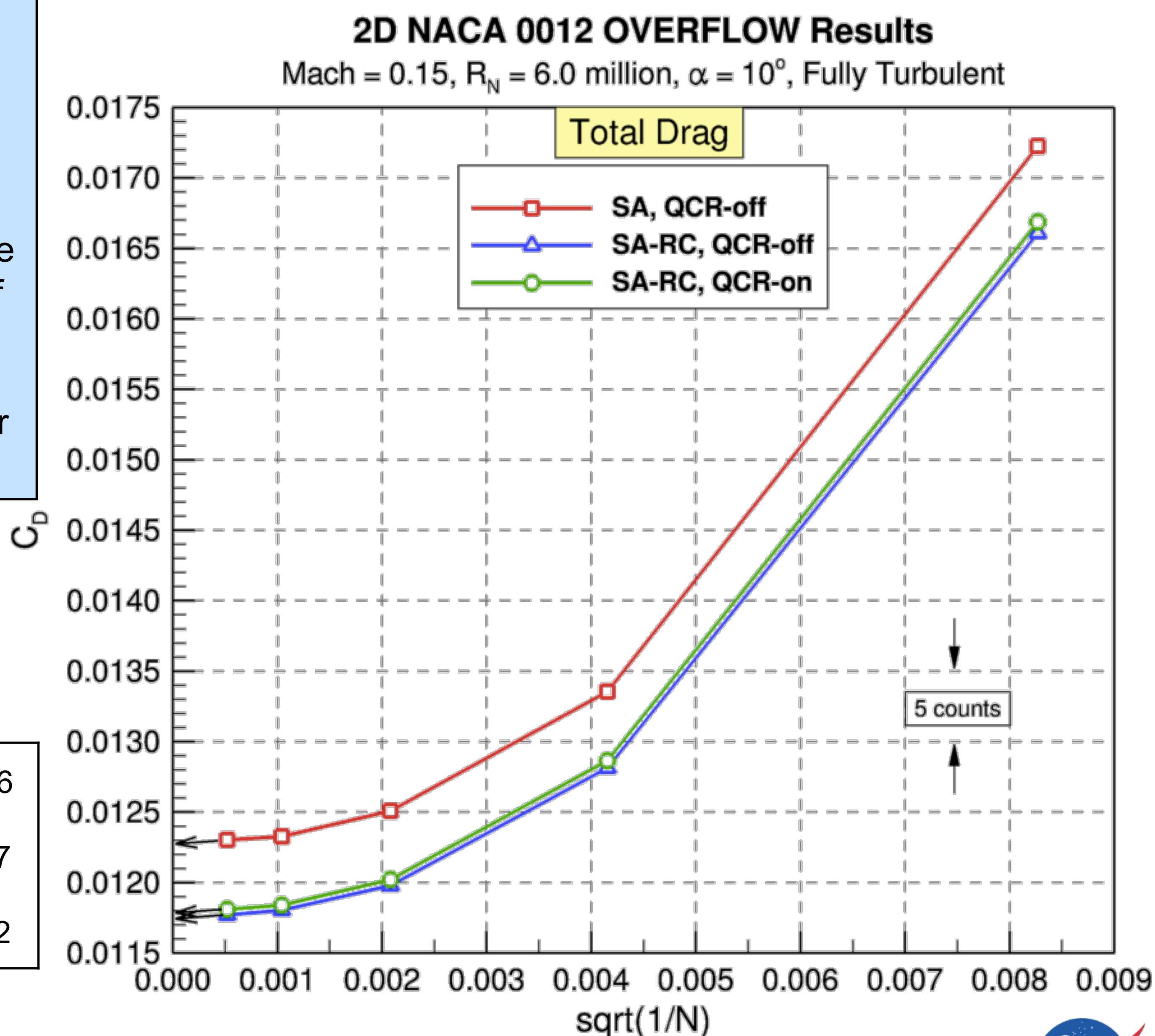
OVERFLOW v2.2k

- Central differencing
- Matrix dissipation
- SA turbulence model
- Rotation and Curvature (RC) corrections on/off
- QCR on/off
- Multi-grid on except for finest grid level



Continuum Drag

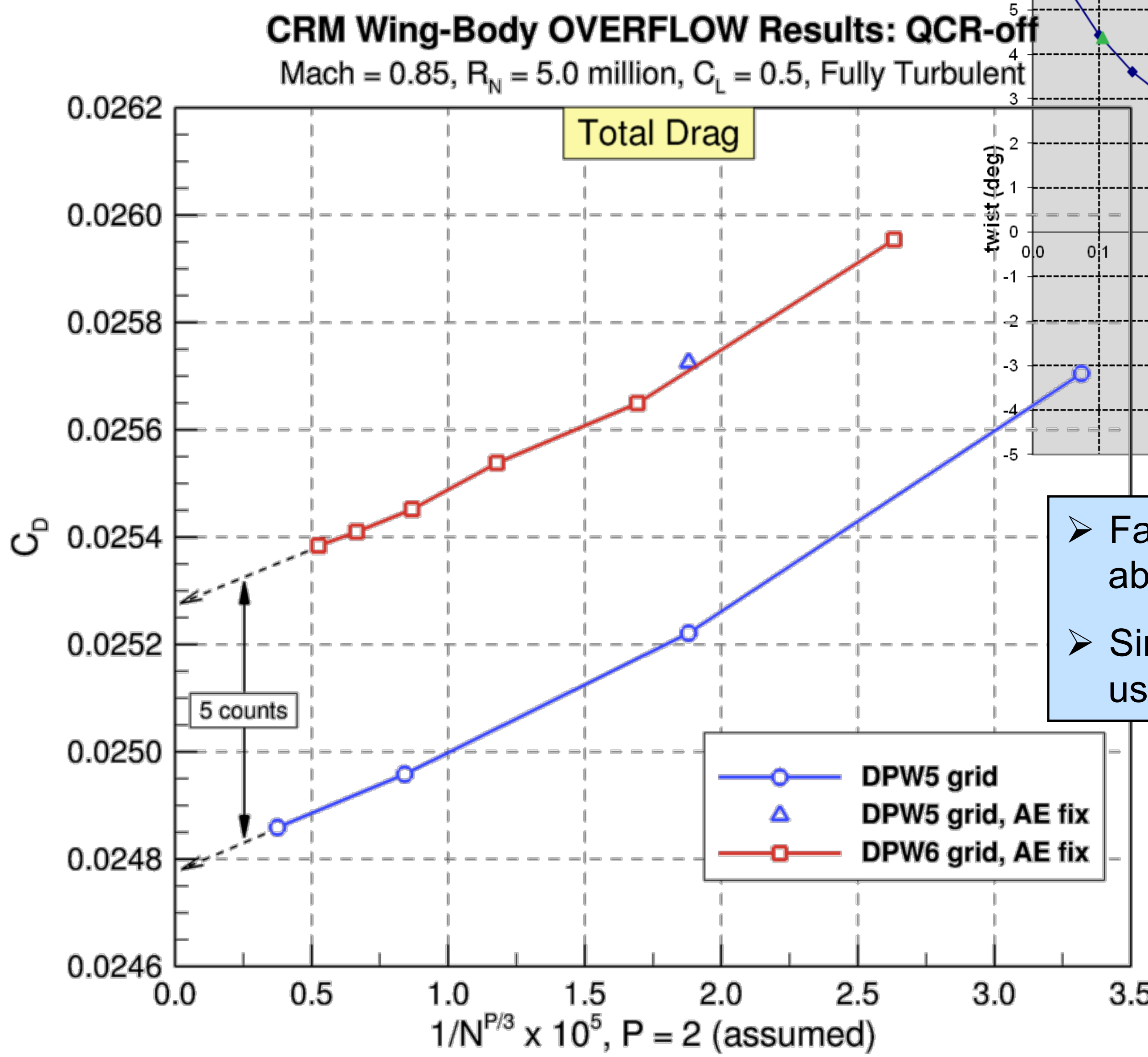
SA, QCR-off	0.012276
SA-RC, QCR-off	0.011737
SA-RC, QCR-on	0.011782

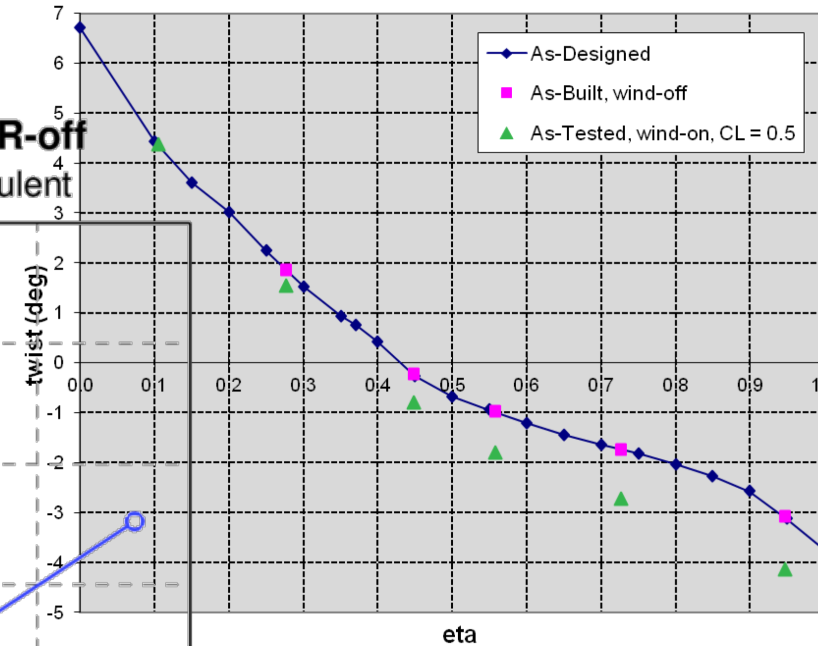
Test Case 2

Nacelle/Pylon Drag Increment

Case 2: Nacelle/Pylon Drag Increment

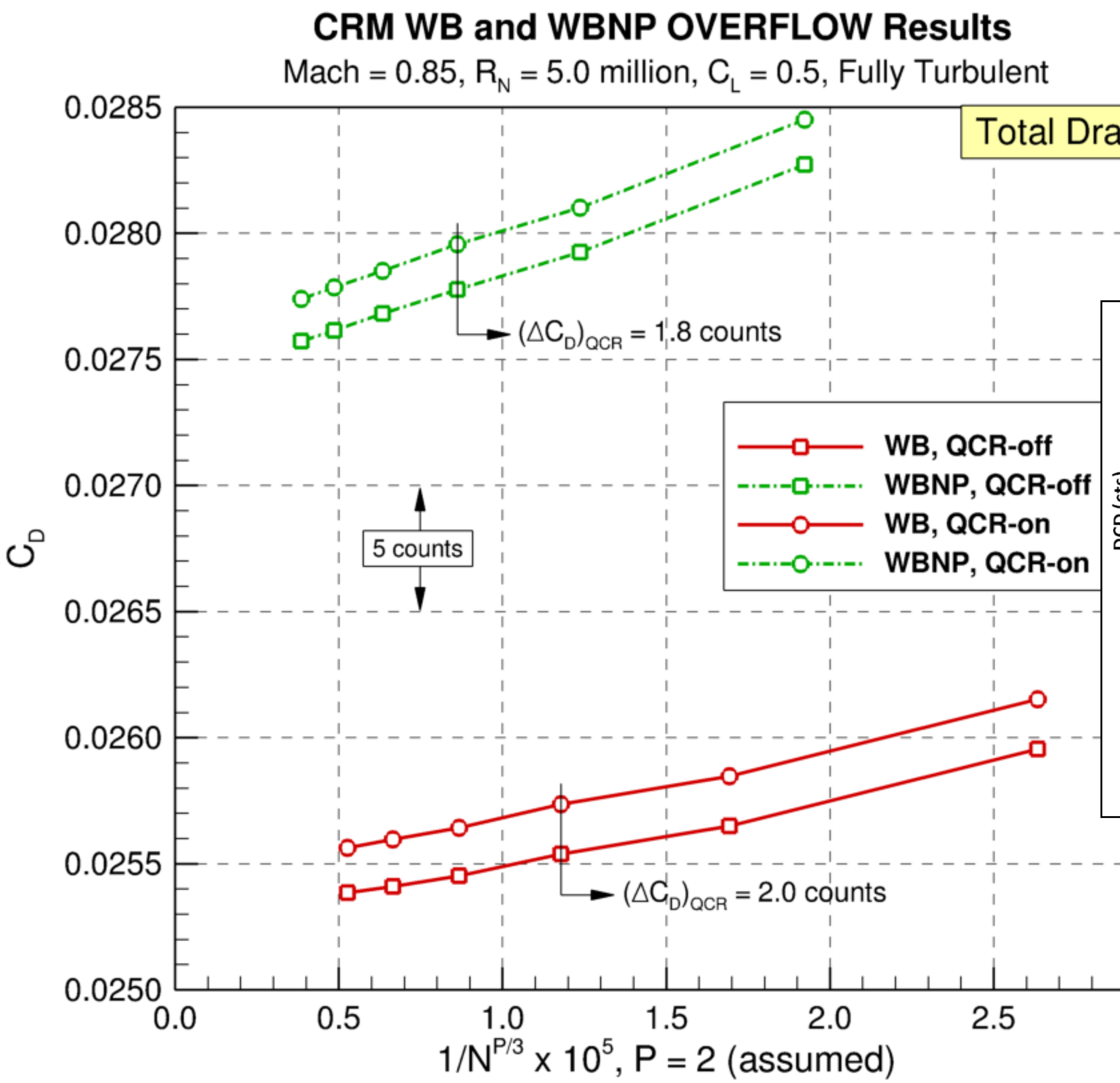
Effect of Wing Twist on WB Drag Level



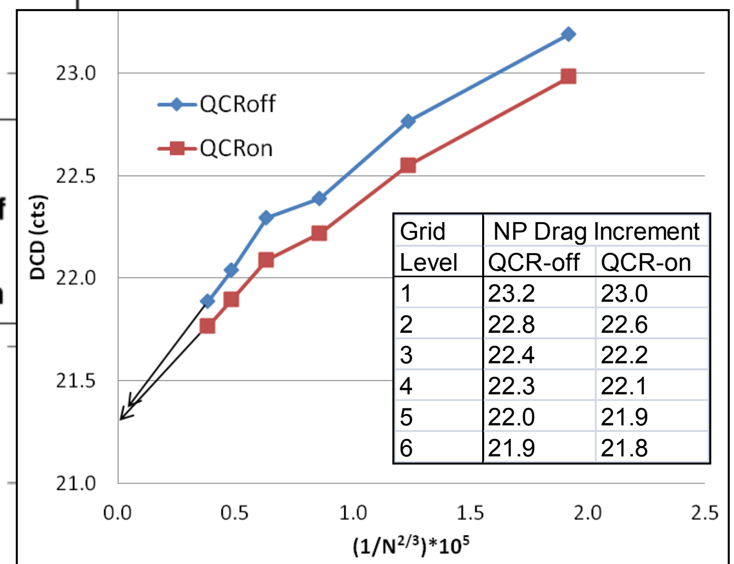


- Fairly constant drag shift of about 5 cts due to wing washout
- Similar WB drag level computed using different grid topologies

Case 2: Nacelle/Pylon Drag Increment
Effect of Grid Resolution and QCR



- QCR increases drag by ~2 cts due to AoA increase of ~0.04°



Grid	NP Drag Increment	
Level	QCR-off	QCR-on
1	23.2	23.0
2	22.8	22.6
3	22.4	22.2
4	22.3	22.1
5	22.0	21.9
6	21.9	21.8

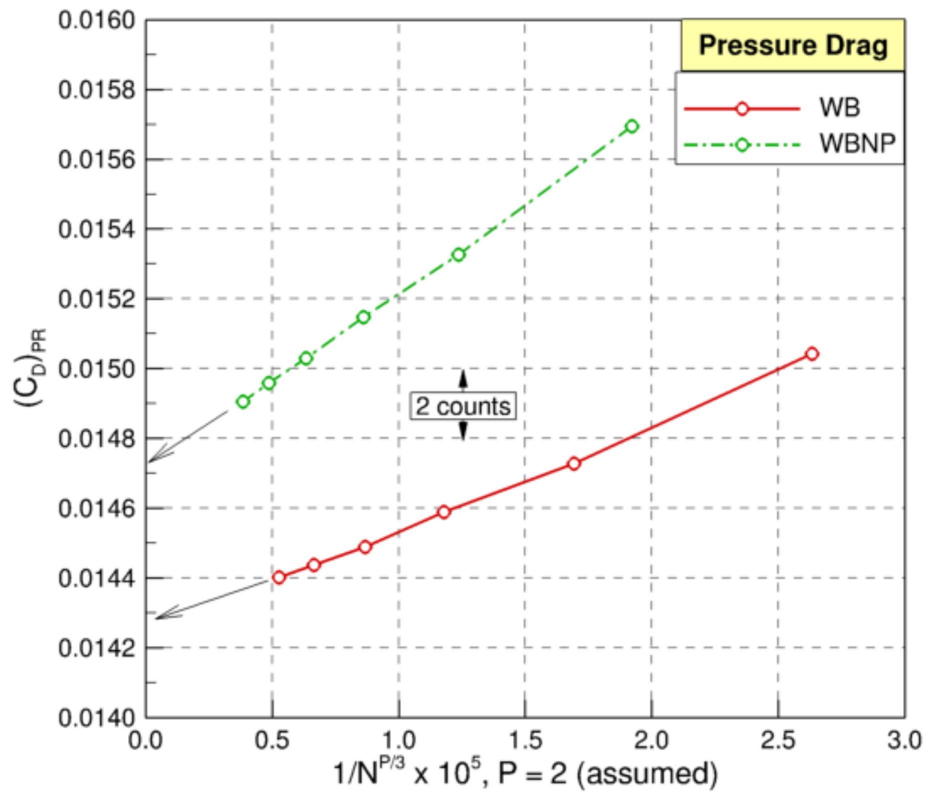
- NP drag increment predicted to be 22 to 23 cts at the design condition depending on grid level.

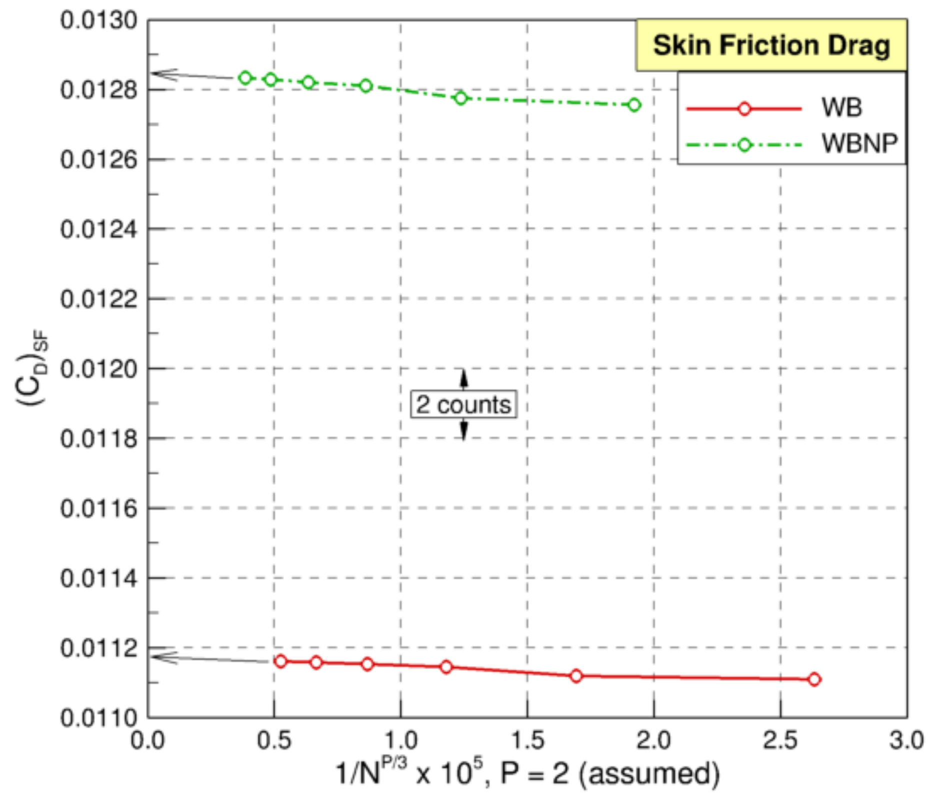
Case 2: Nacelle/Pylon Drag Increment

Pressure and Skin Friction Drag Comparison

CRM OVERFLOW Results: QCR-on

Mach = 0.85, R_N = 5.0 million, C_L = 0.5, Fully Turbulent





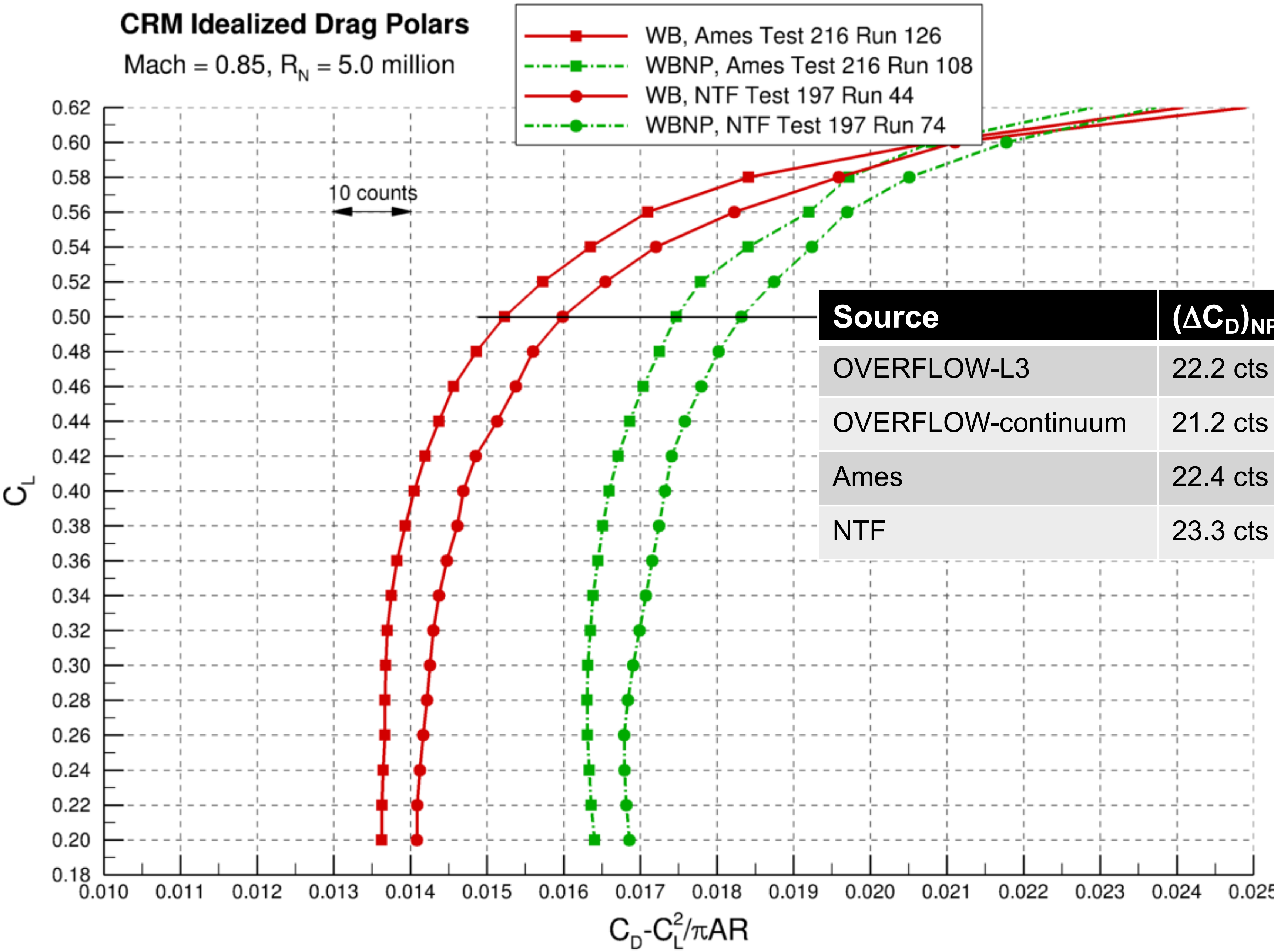
- Pressure drag at the continuum:
  - WB = .01427, WBNP = .01471

$(\Delta C_D)_{PR}$ = 4.4 cts

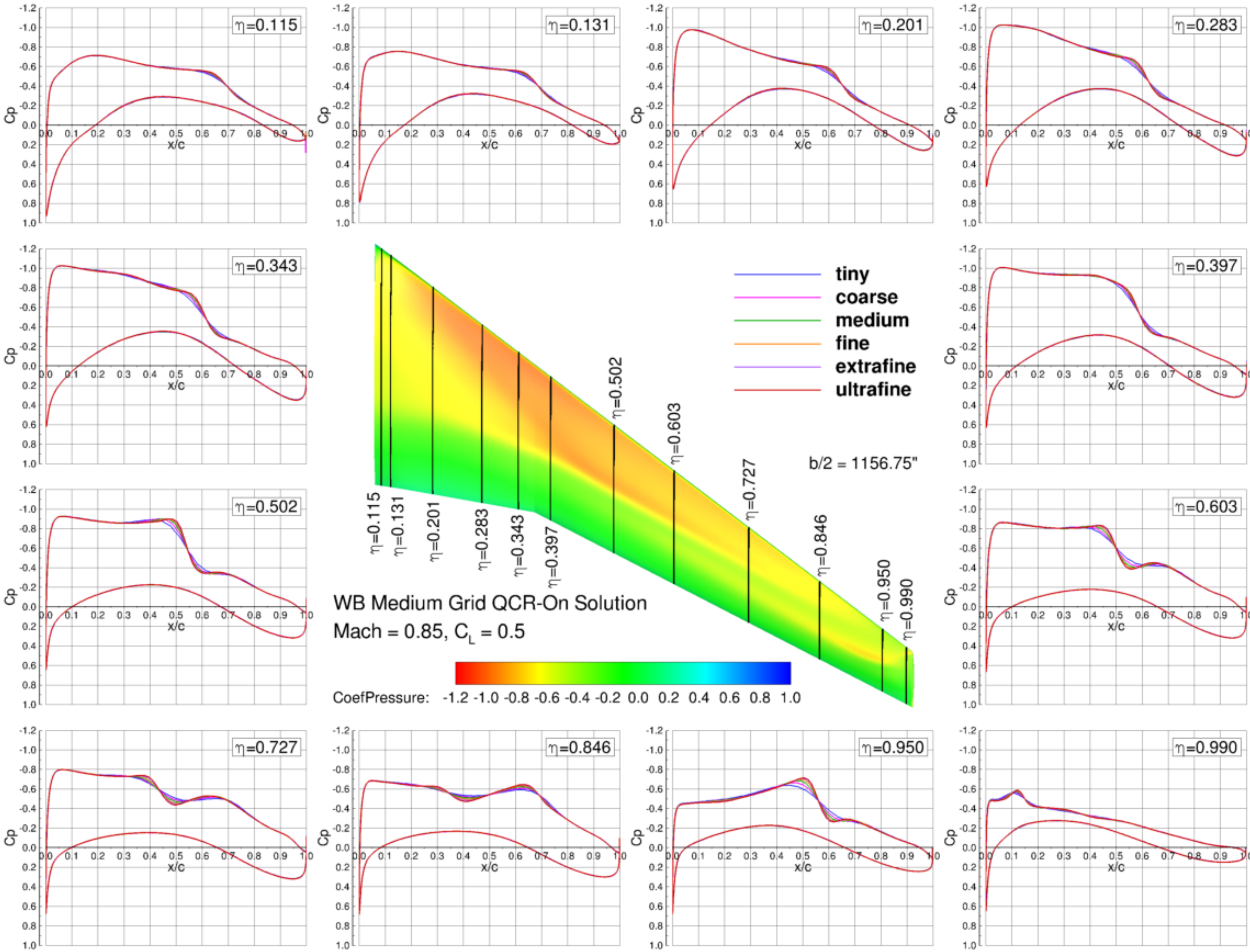
- Skin friction drag at the continuum:
  - WB = 0.01117, WBNP = 0.01285

$(\Delta C_D)_{SF}$ = 16.8 cts

Case 2: Nacelle/Pylon Drag Increment
Test Data vs. OVERFLOW



Source	$(\Delta C_D)_{NP}$
OVERFLOW-L3	22.2 cts
OVERFLOW-continuum	21.2 cts
Ames	22.4 cts
NTF	23.3 cts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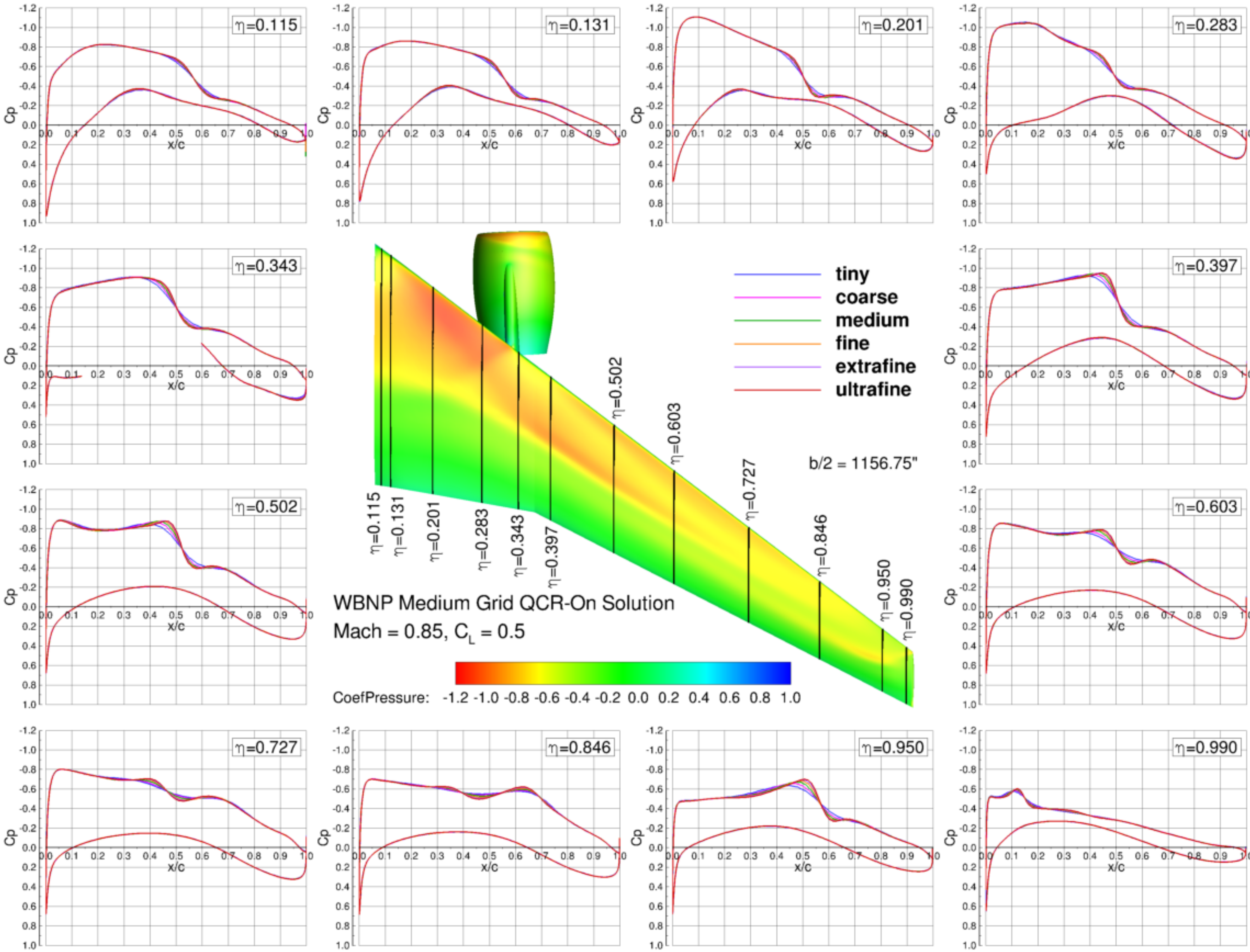
η=0.502
η=0.603
η=0.727
η=0.846
η=0.950
η=0.990
Cp
x/c
tiny
coarse
medium
fine
extrafine
ultrafine
b/2 = 1156.75"
WB Medium Grid QCR-On Solution
Mach = 0.85, C_L = 0.5
CoefPressure: -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0

BOEING

NASA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Mach = 0.85, C_L = 0.5
CoefPressure: -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0

Test Case 3

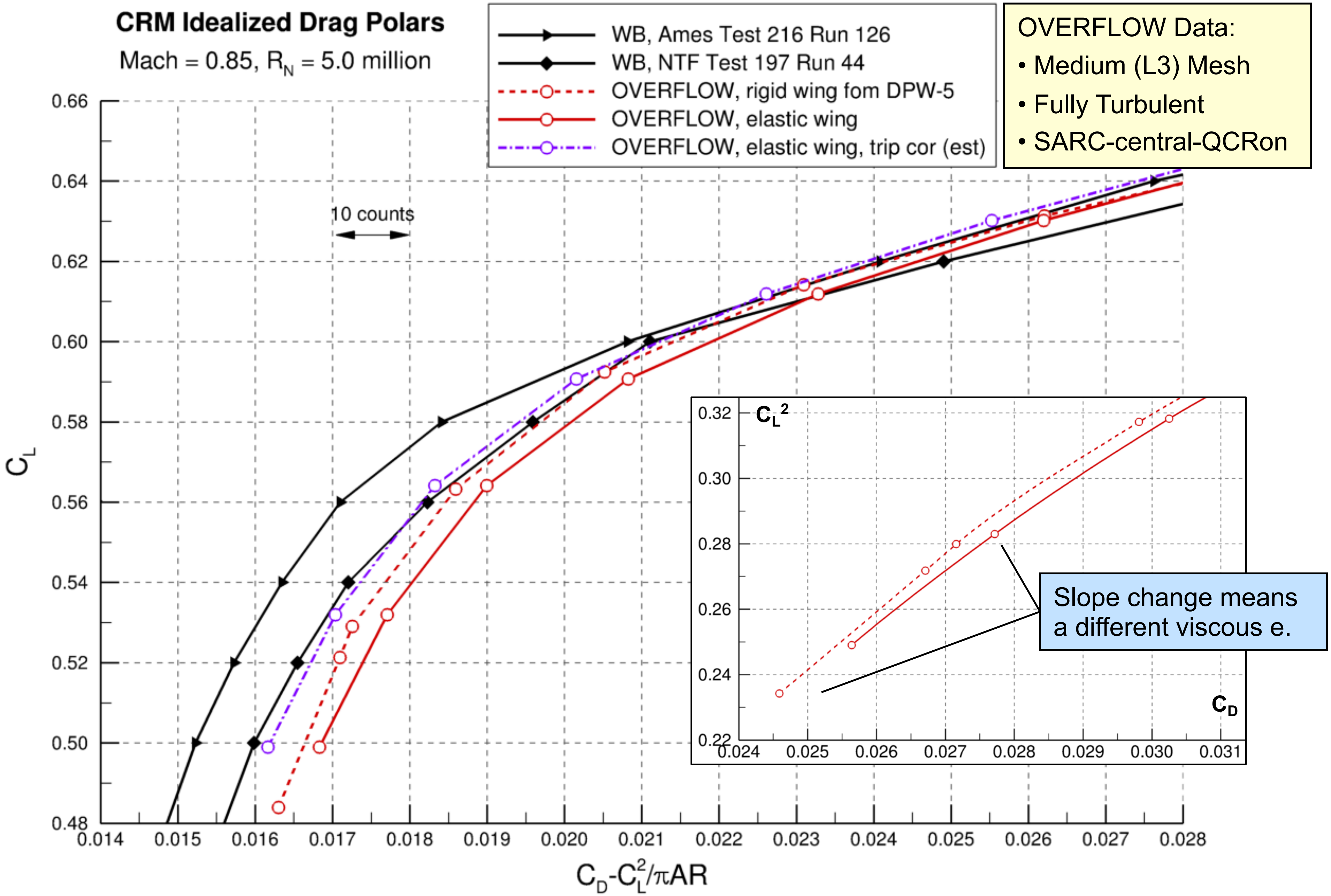
Wing/Body Drag Polar

Case 3: WB Drag Polar
Idealized Drag Polar Comparison

AIAA 2012-0707, Rivers/Hunter, "*Support System Effects on the NASA Common Research Model*"

Adding the model support system to the CFD model changes wing, tail and aft body pressures and decreases drag by ~25 counts at C_L = 0.5 for the Wing-Body-Tail configuration

OVERFLOW Data:
- Medium (L3) Mesh
- Fully Turbulent
- SARC-central-QCRon



Case 3: WB Drag Polar
Pitching Moment Comparison

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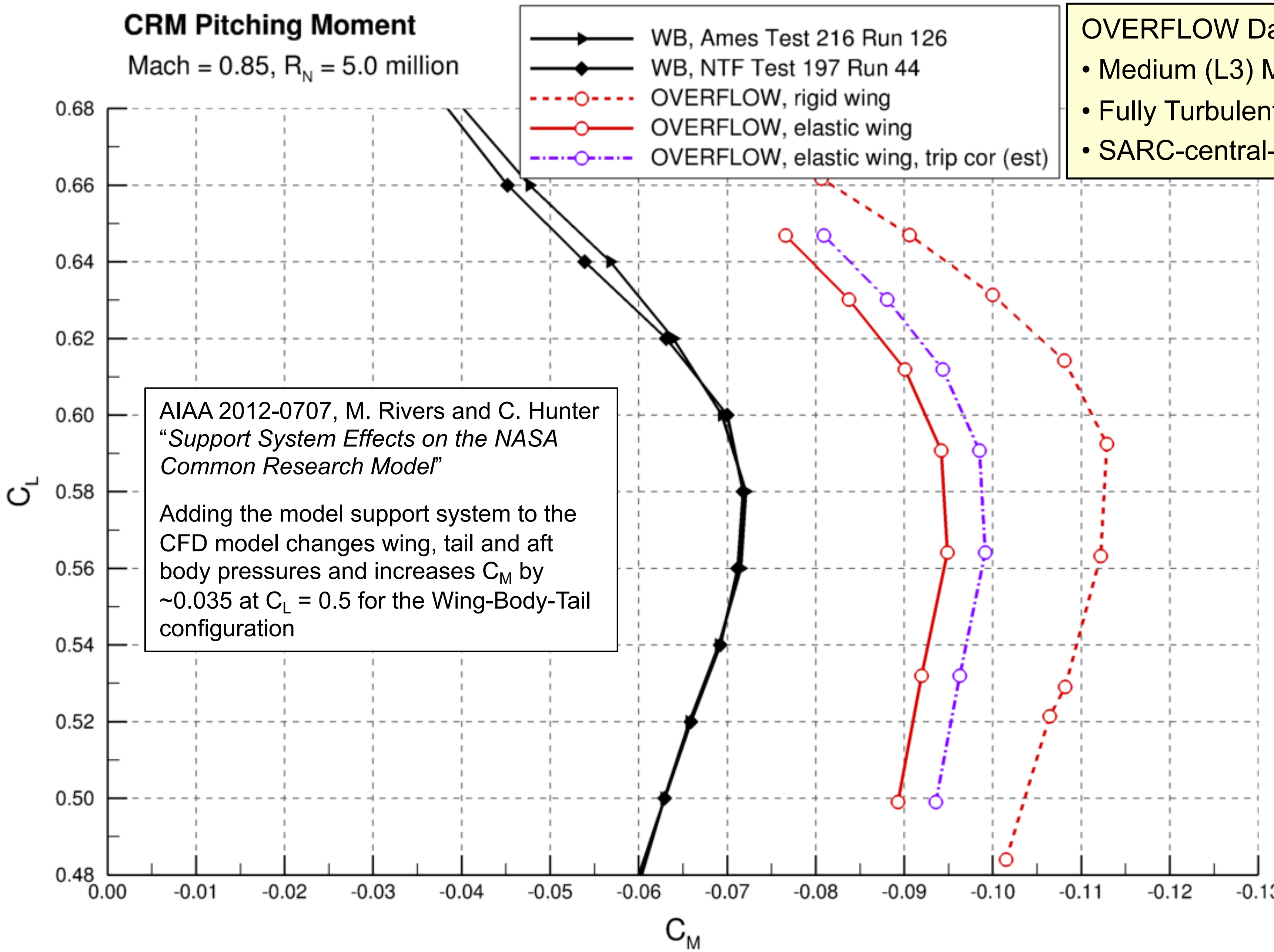

OVERFLOW Data:
- Medium (L3) Mesh
- Fully Turbulent
- SARC-central-QCRon

AIAA 2012-0707, M. Rivers and C. Hunter "*Support System Effects on the NASA Common Research Model*"

Adding the model support system to the CFD model changes wing, tail and aft body pressures and increases C_M by ~0.035 at C_L = 0.5 for the Wing-Body-Tail configuration

Test Case 4

Wing/Body Grid Adaption

Case 4: WB Grid Adaption

Background Information on Overset Grid Adaption

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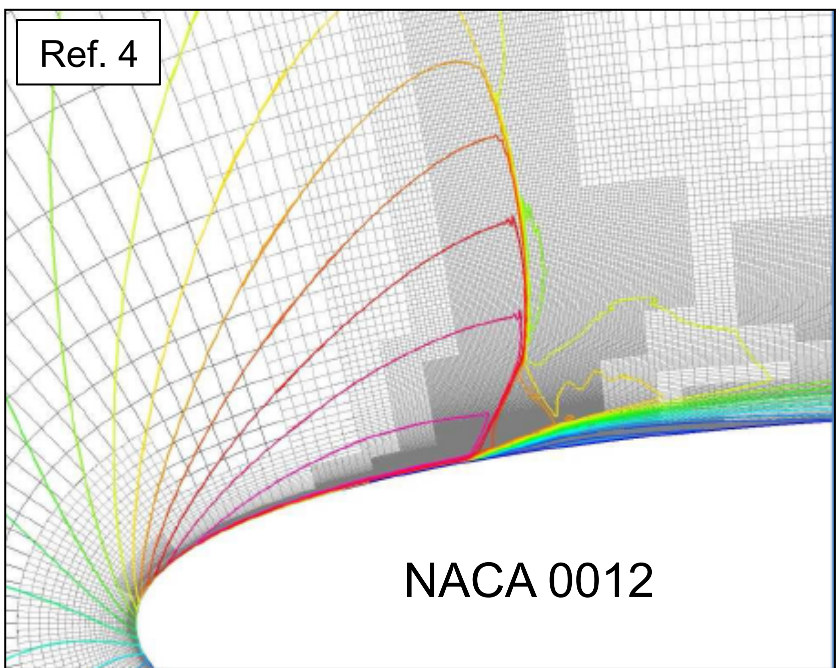
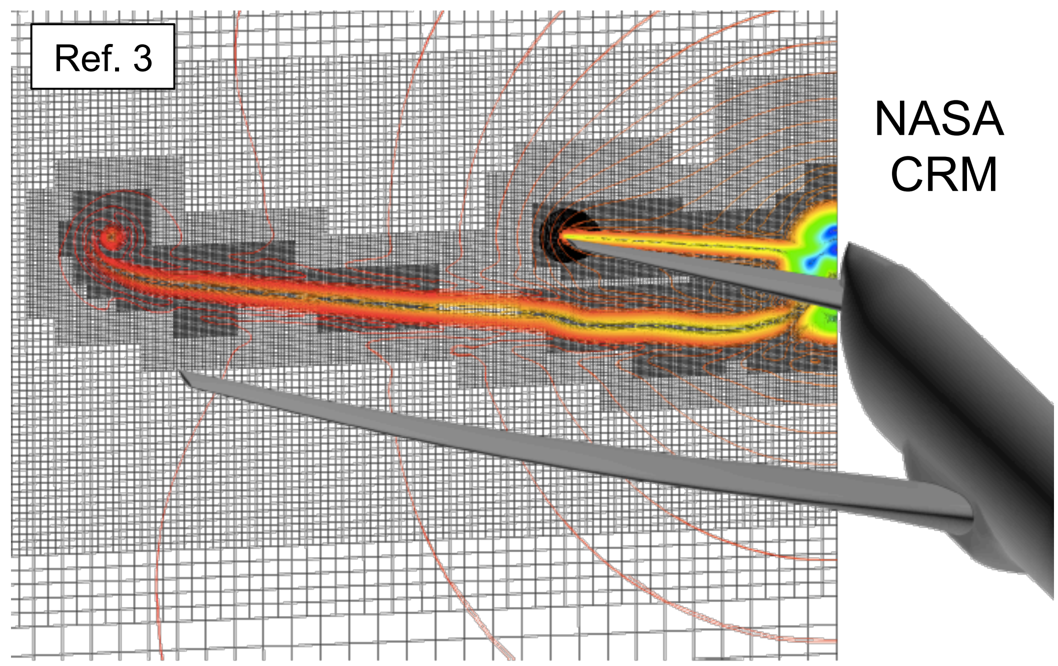
References

1. Buning, P. G., Pulliam, T. H., "Near-Body Grid Adaption for Overset Grids," June 2016.
2. Buning, P. G., Pulliam, T. H., "Cartesian Off-Body Grid Adaption for Viscous Time-Accurate Flow Simulation," AIAA 2011-3693, June 2011.
3. Lee, H. C., Pulliam, T. H., "Effect of Using Near and Off-body Grids with Grid Adaption to Simulate Airplane Geometries," AIAA 2011-3985, June 2011.
4. Buning, P. G., "A New Solution Adaption Capability for the OVERFLOW CFD Code," Overset Grid Symposium, September 2010.

- **Feature-based adaption – not driving integrated forces such as drag**
- **Sensor function is the undivided 2nd difference of flow variables (truncation error in flow gradient regions)**
- **Isotropic grid refinement (all 3 directions) where neighboring grids differ by 2x**
- **Parametric cubic interpolation of original near-body grid**





Case 4: WB Grid Adaption
Approach and Drag Results

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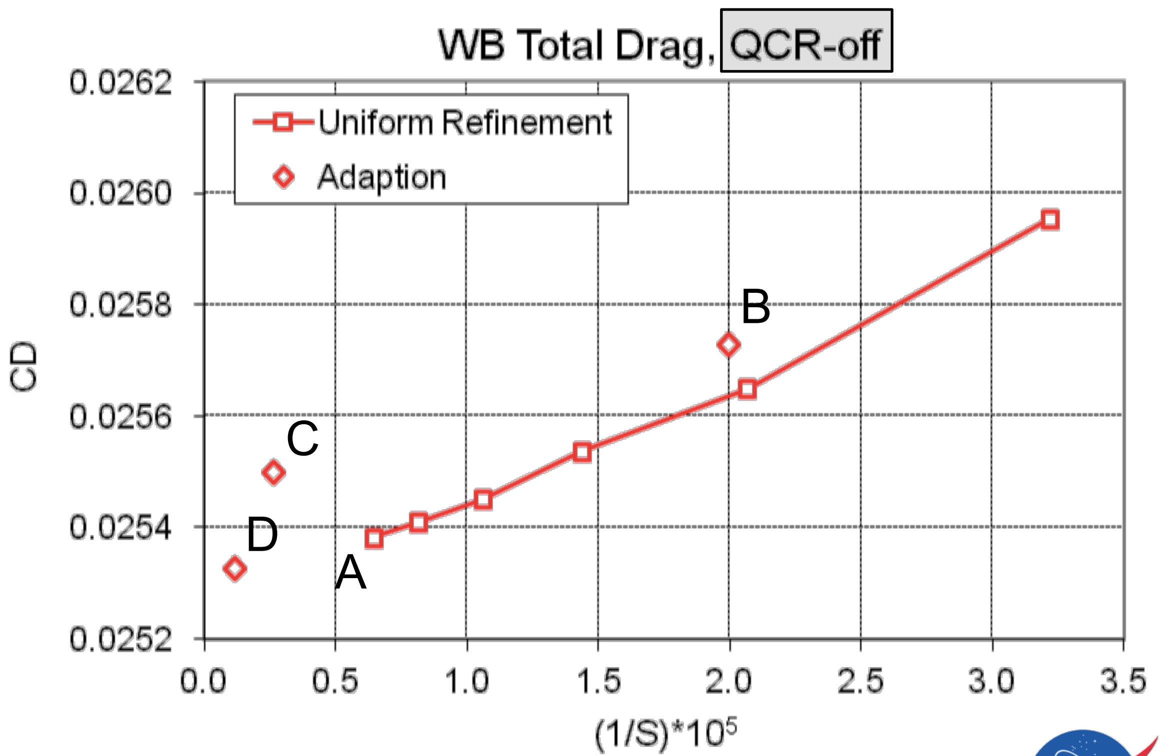
		Adaption Parameters						Total		WingSrf	
Case	Initial Grid	Phase	Type	Region	Limit	NB Levels	OB Levels	Points	Increase	Points	Increase
A	L6, ufine	n/a	none	n/a	n/a	n/a	n/a	82.8M		156.3K	
B	L2, coarse	n/a	none	n/a	n/a	n/a	n/a	14.4M		50.3K	
C	L2, coarse	1	gradient	wing, wake	100M	3	2 (wake)	98.3M	6.8x	387.6K	7.7x
D	L2, coarse	1	uniform	all zones	n/a	1	1				
		2	uniform	wing	n/a	2	0				
		3	gradient	wing, body	400M	3	2	388.9M	27x	895.1K	17.8x

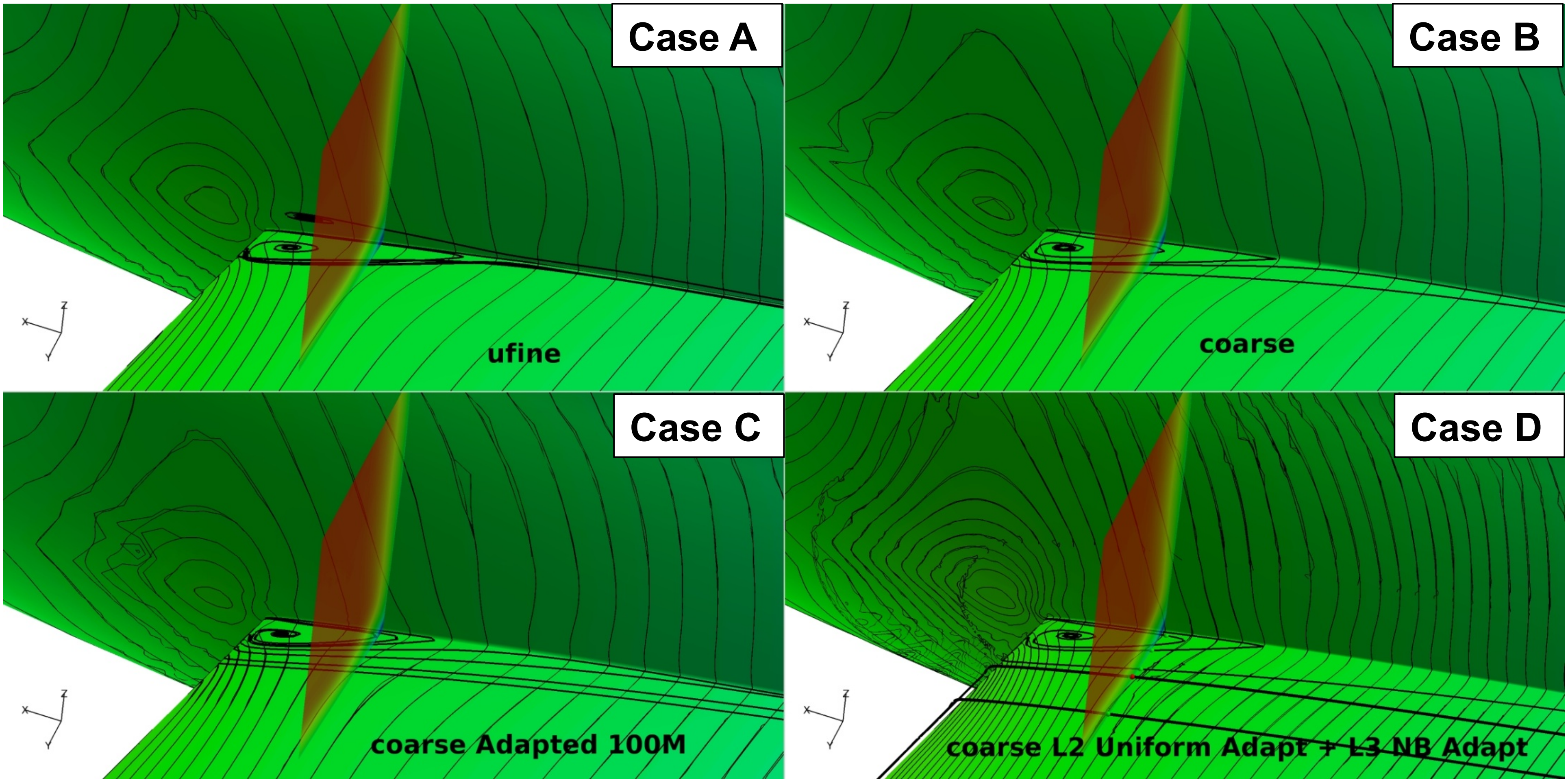
Notes:
> existing near-field and far-field box grids were used
> gradient-based adaption used undivided 2nd difference for sensor function
> NB = near-body, OB = off-body

Modified grid topology to satisfy boundary condition limitations → coarse grid point count and drag level changed.

Tracked number of surface grid points on the wing (S) instead of total number of points (N).



Case 4: WB Grid Adaption
SOB Separation Bubble Comparison



- SOB separation is insensitive to grid refinement at the design condition even with QCR-off.

Case 4: WB Grid Adaption

Wing Pressure Contours

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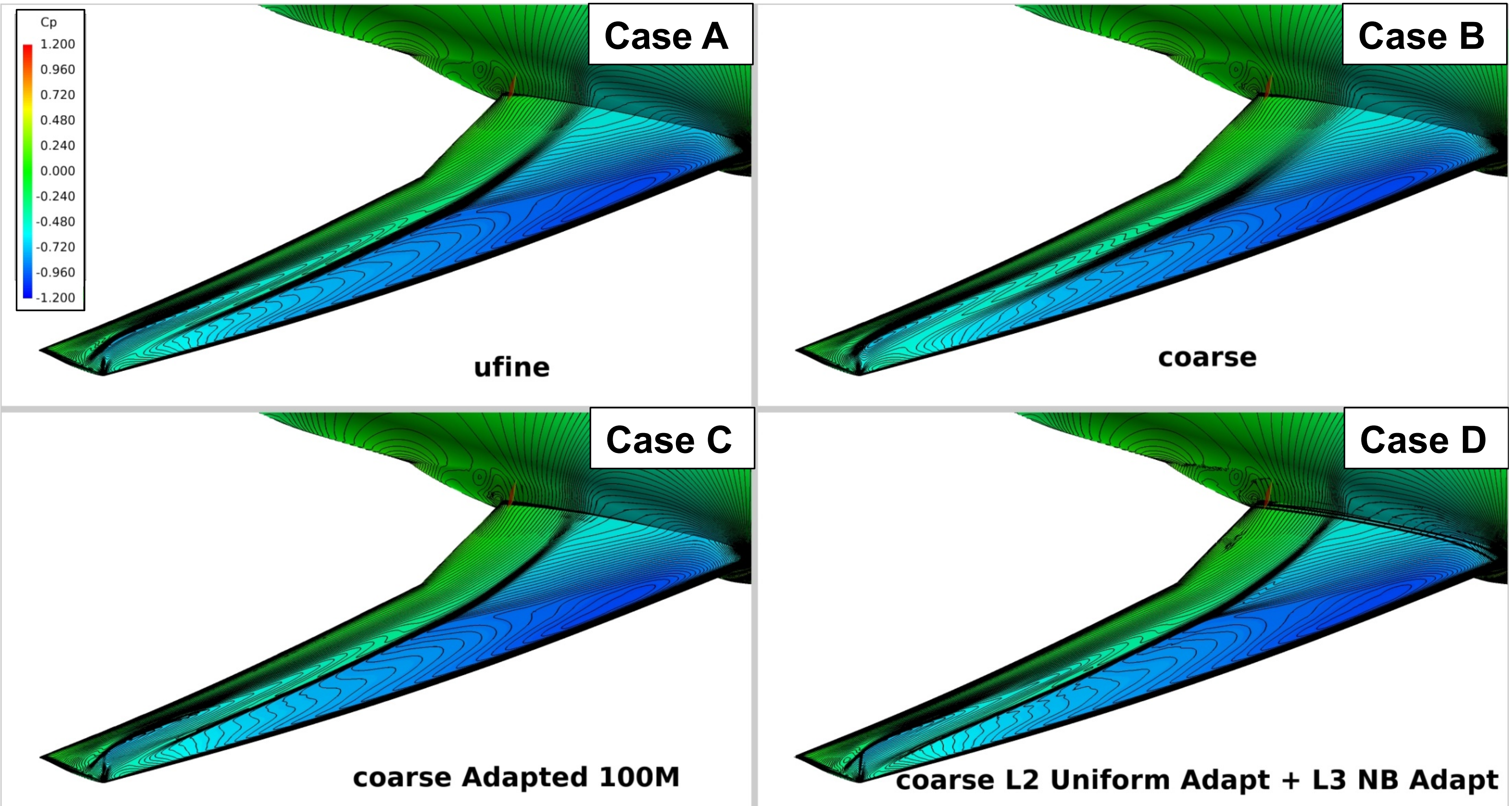
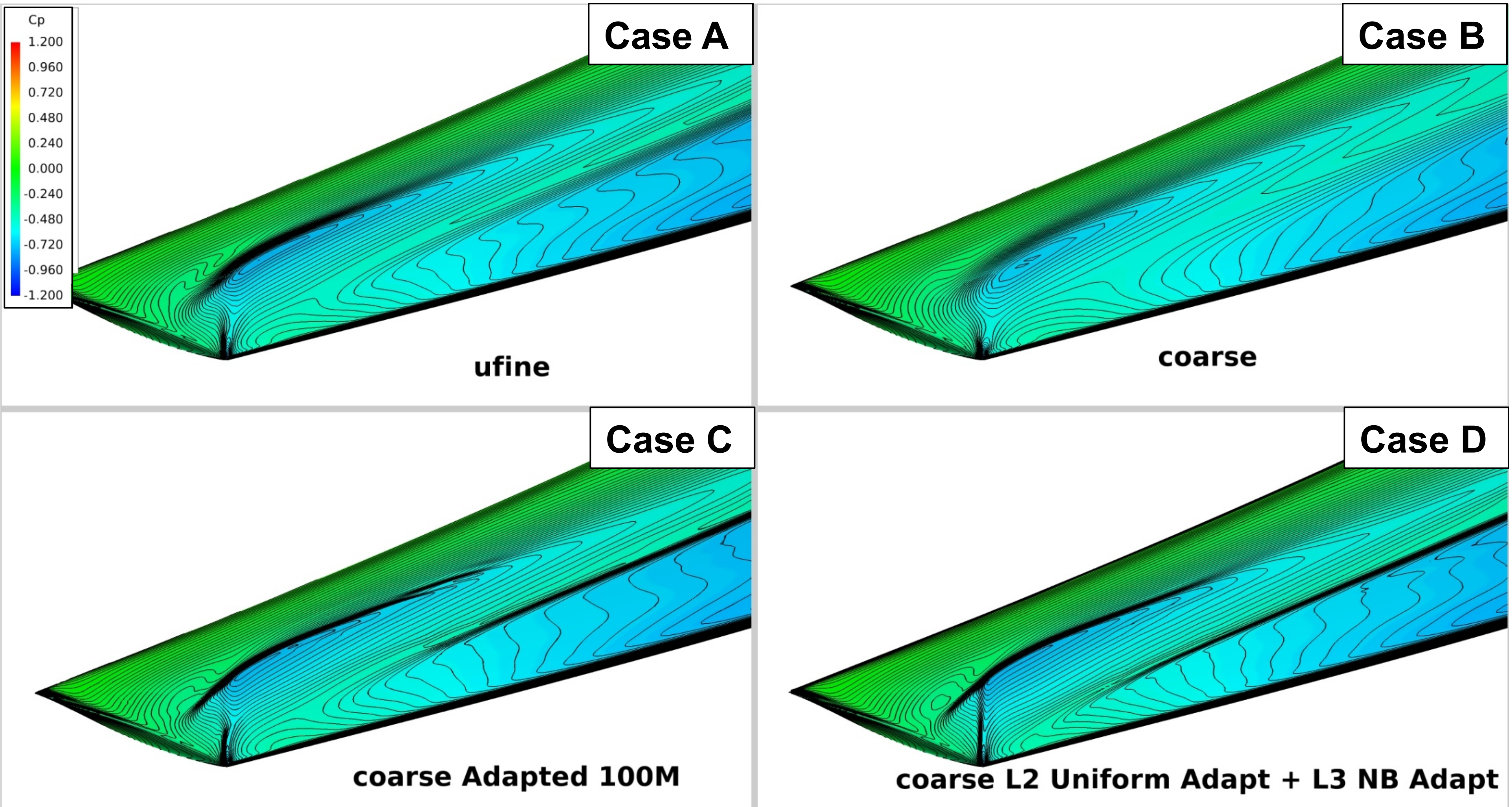


- Wing shock structure is better defined in adapted solutions (C & D).

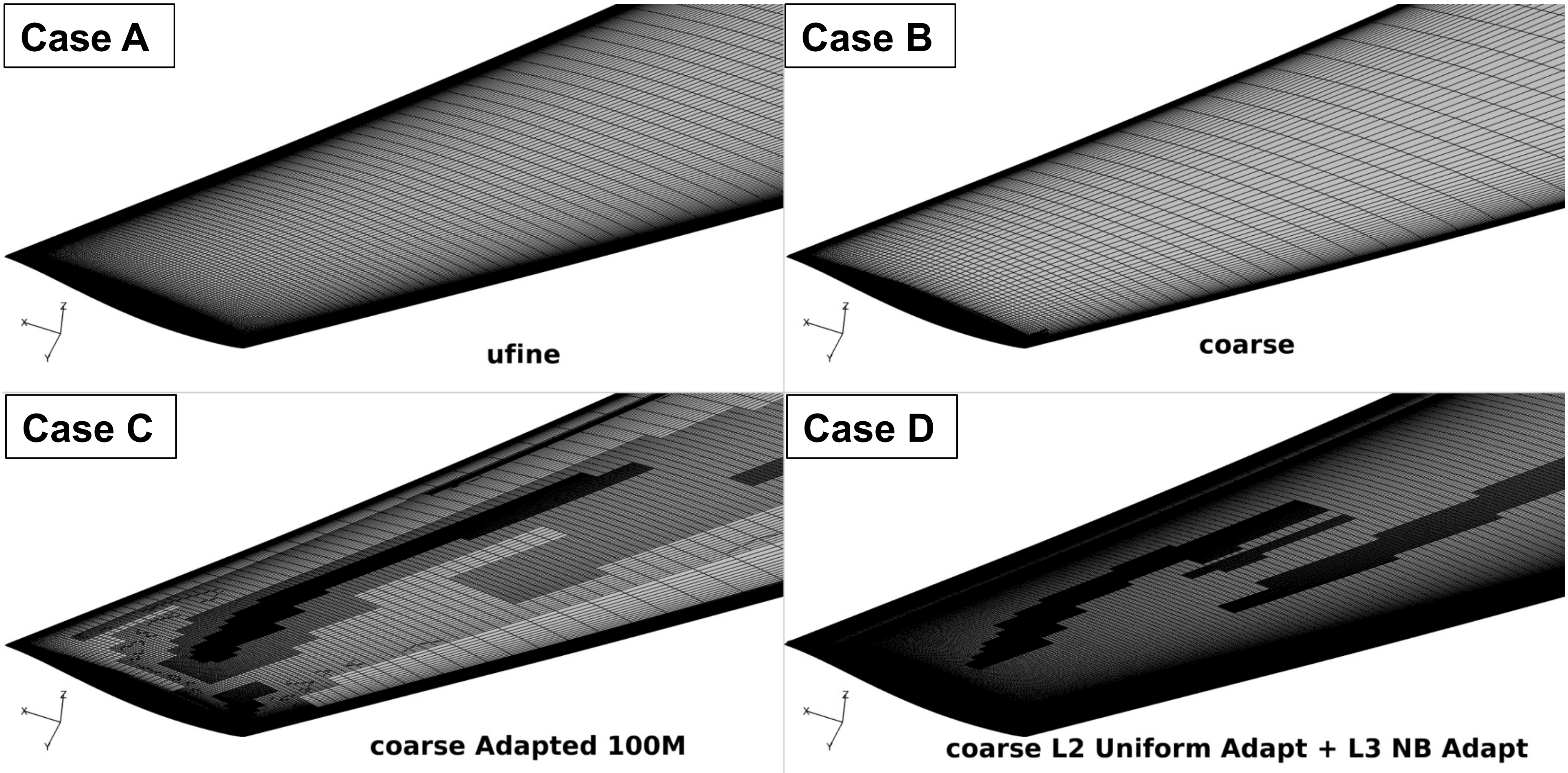
Case 4: WB Grid Adaption
Wing Pressure Contours – Tip Region



- Wing tip shock structure characterized by a forward-swept lambda shape.
- This feature is not captured well by the ultra-fine grid suggesting uniform grid family refinement can fail to resolve some areas of the flow field.

Case 4: WB Grid Adaption

Wing Surface Grid Comparison



- This surface grid comparison illustrates how feature-based adaption refines in high gradient regions as opposed to the uniform refinement done in Case A.

Case 4: WB Grid Adaption

Wing Pressure Cut Comparison

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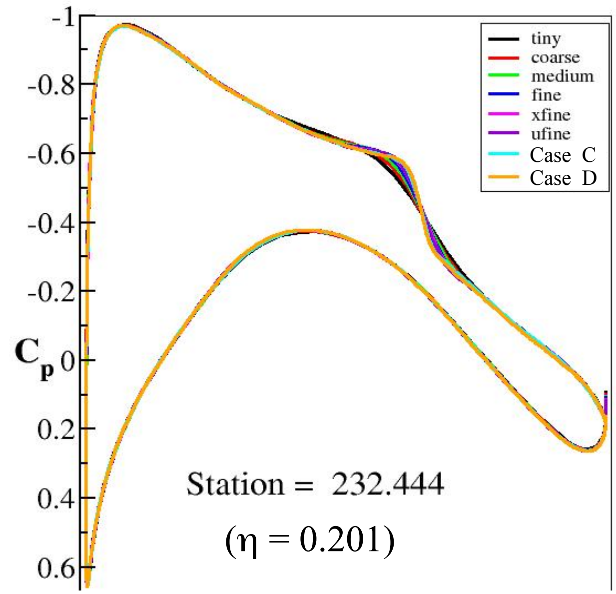
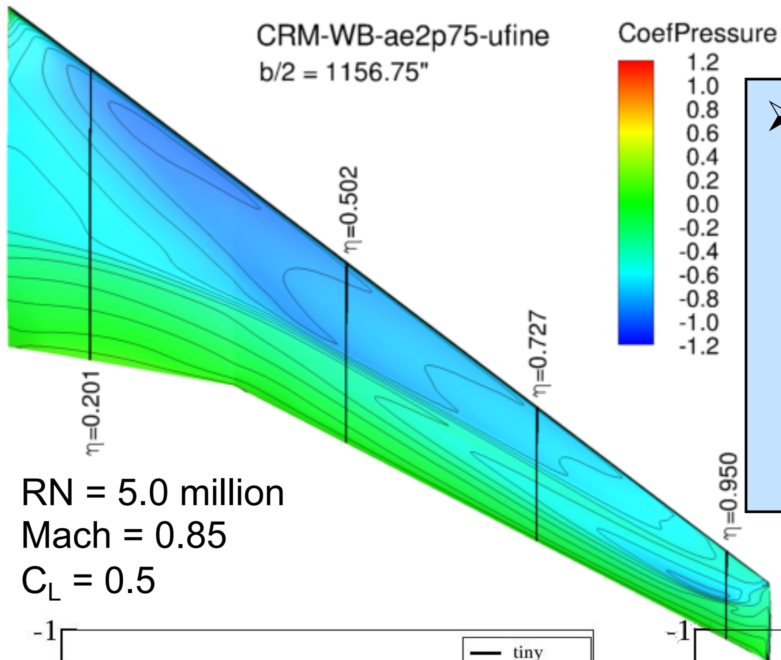
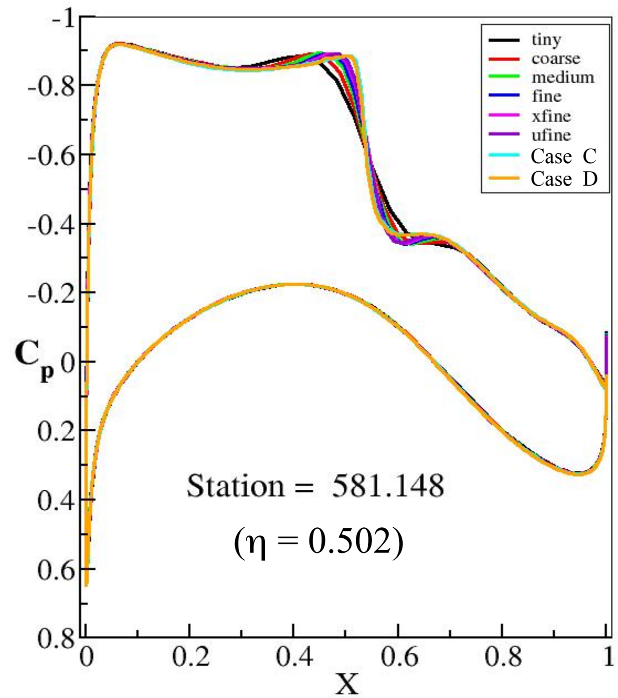
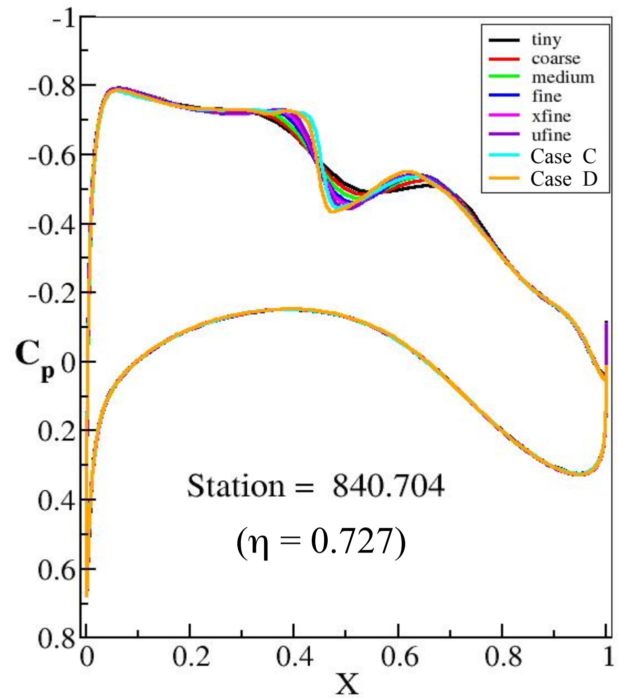


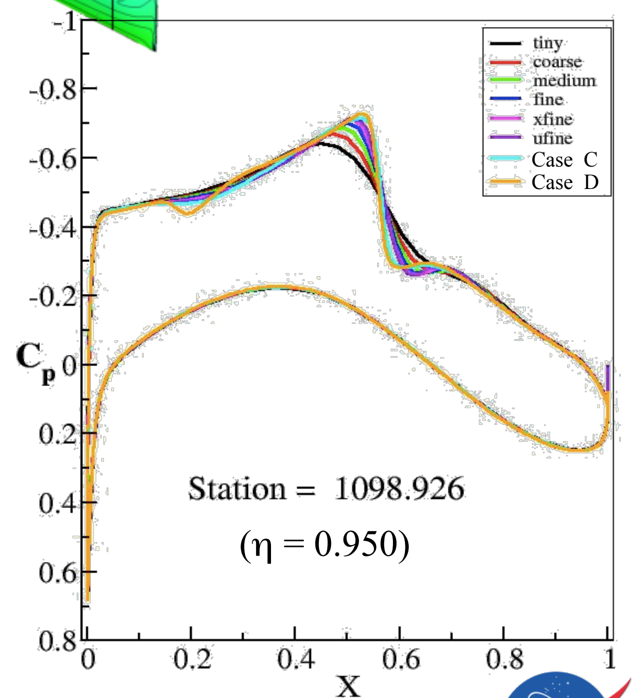


RN = 5.0 million
Mach = 0.85
C_L = 0.5

- Adapted solutions yield similar trends at the shock as the uniform grid family except at the tip where a lambda shock system is predicted in Case D.







Case 4: WB Grid Adaption
Wing Pressure Cut Comparison

RN = 5.0 million
Mach = 0.85
C_L = 0.5

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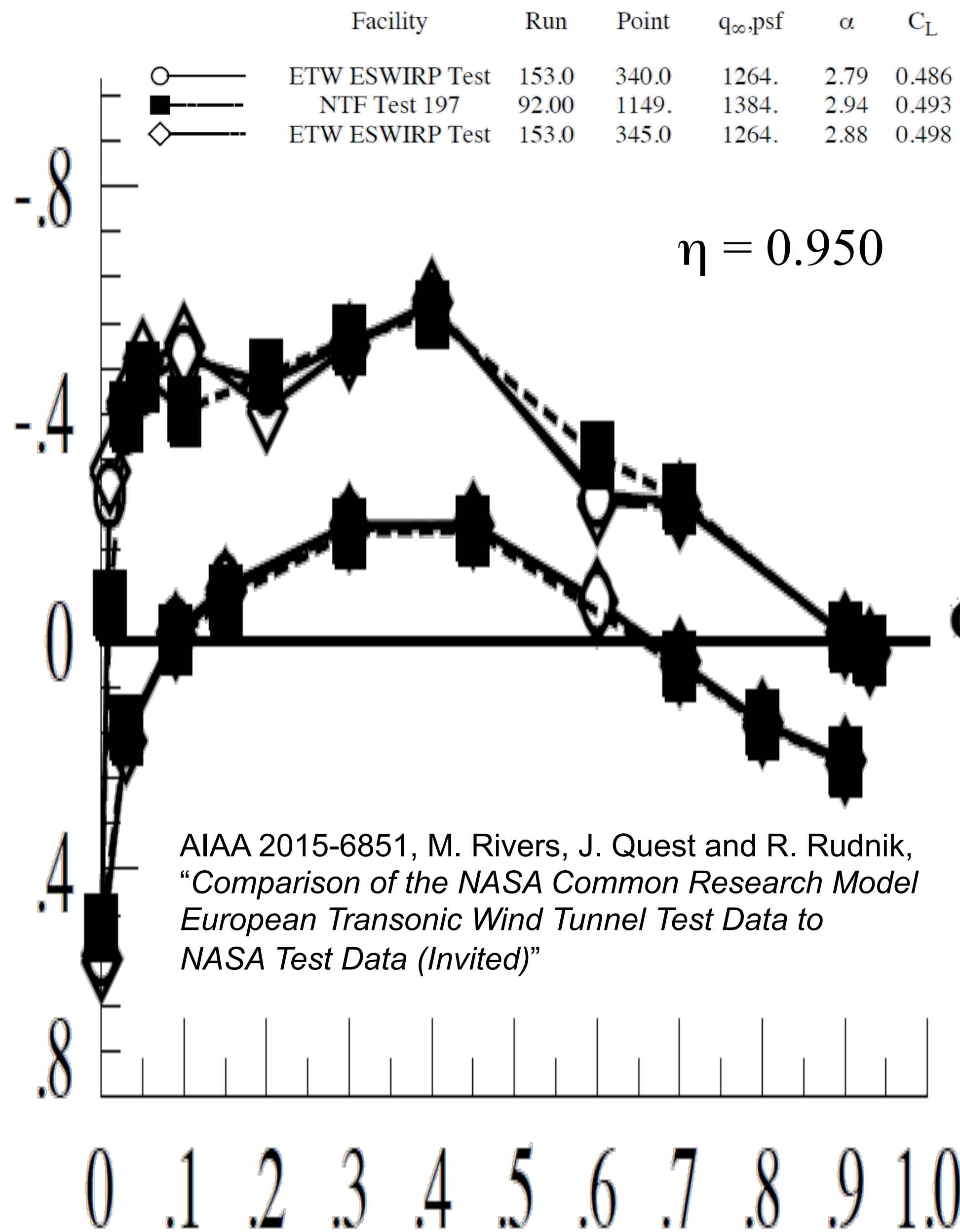
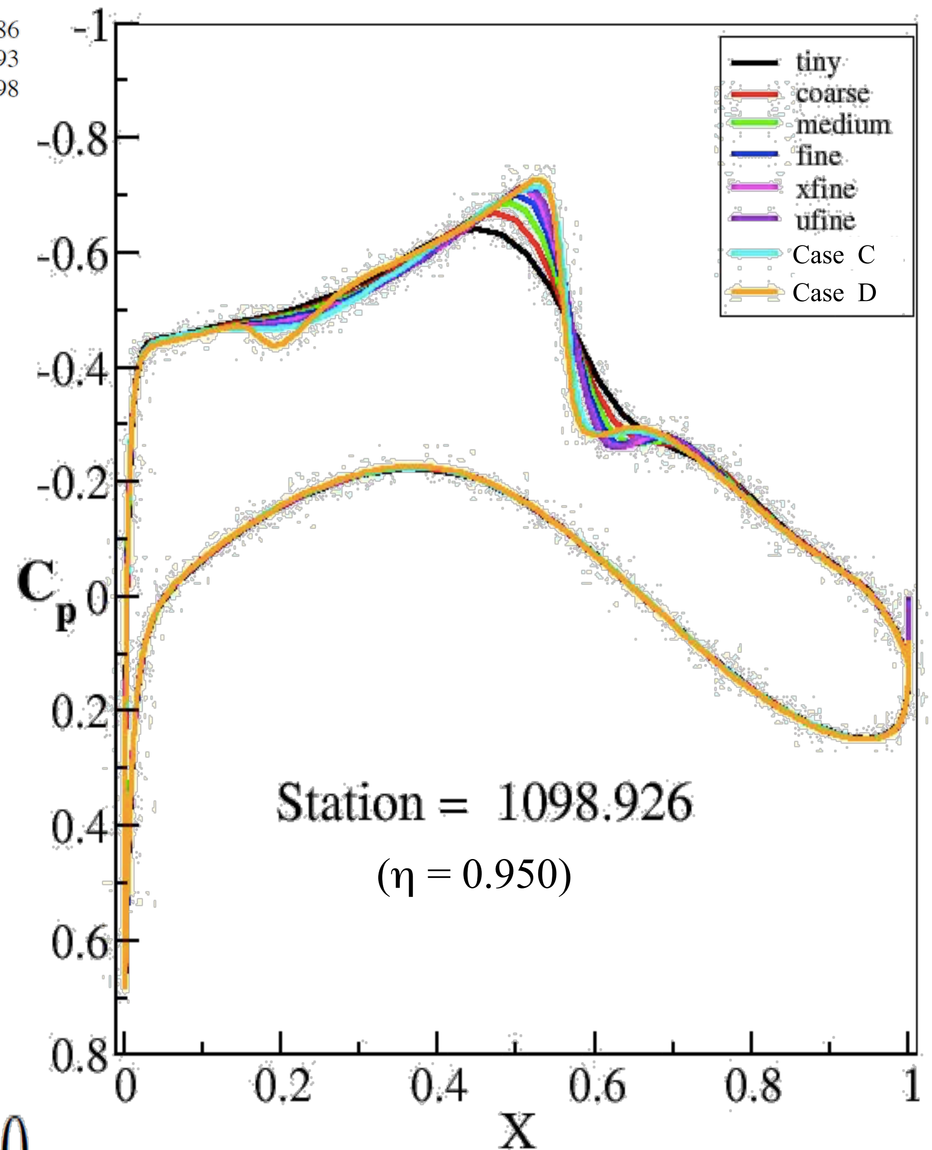


AIAA 2015-6851, M. Rivers, J. Quest and R. Rudnik, "*Comparison of the NASA Common Research Model European Transonic Wind Tunnel Test Data to NASA Test Data (Invited)*"



DLR F11 OVERFLOW Analysis

Conclusions

Verification Study

- Rotation and curvature corrections reduced continuum drag level by 5.4 counts (4.4%).

Nacelle/Pylon Drag Increment

- The 1° of wing washout between the designed and tested wings is predicted to increase drag by 5 counts at the design condition.
- OVERFLOW predicts a 21.2 count drag increase at the continuum due to the addition of the NP.
  - roughly 80% of this increment is skin friction drag
  - good agreement with Ames and NTF data

Wing/Body Drag Polar

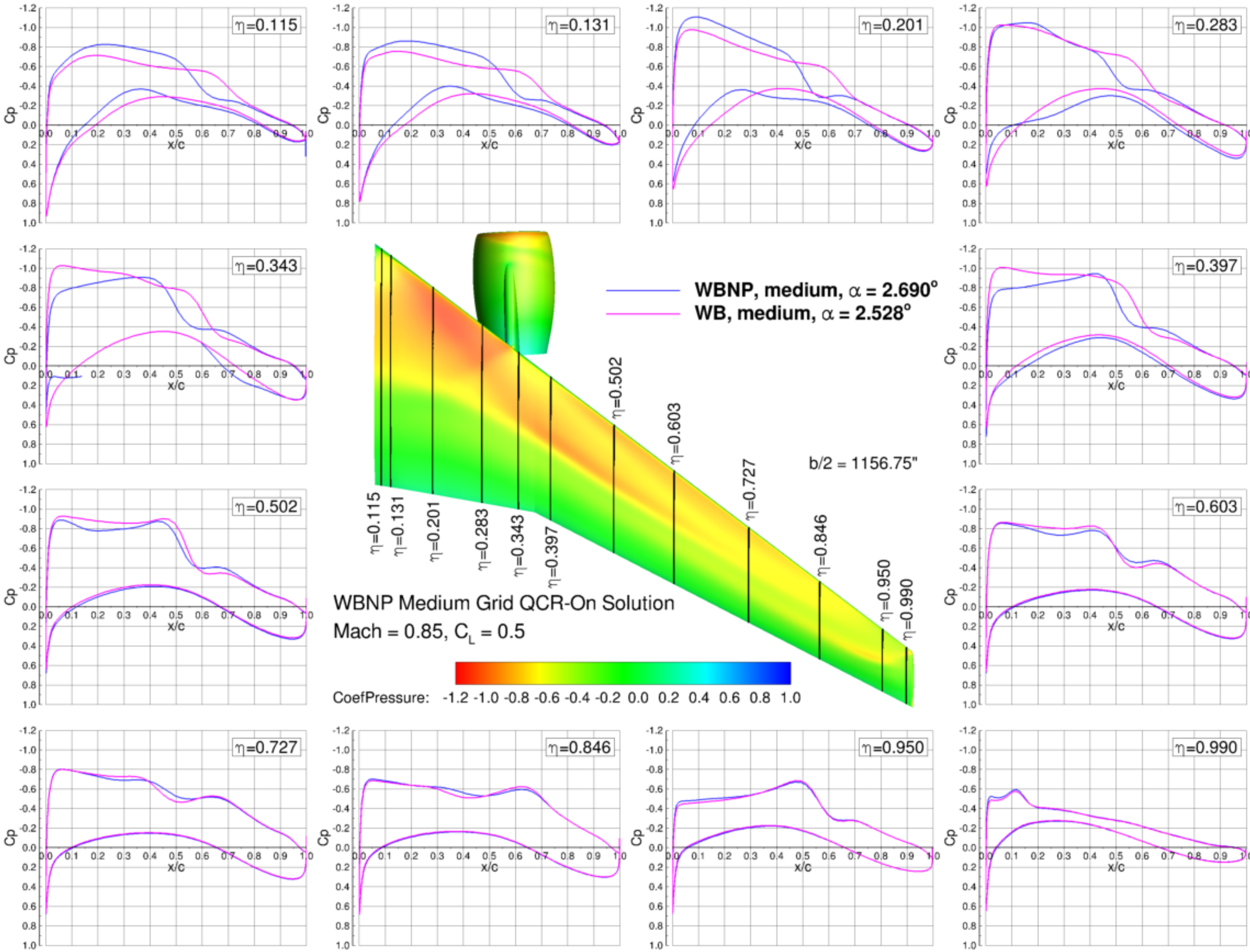
- Modeling the as-tested wing twist pushes the computed data closer to experiment.

Wing/Body Grid Adaption

- Feature-based adaption can be better than uniform grid refinement in terms of resolving all shock features.

Thank You!

Back-Up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η=0.727
η=0.846
η=0.950
η=0.990
Cp
x/c
WBNP, medium, α = 2.690°
WB, medium, α = 2.528°
b/2 = 1156.75"
WBNP Medium Grid QCR-On Solution
Mach = 0.85, C_L = 0.5
CoefPressure: -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0

Case 4: WB Grid Adaption
Pressure Contours

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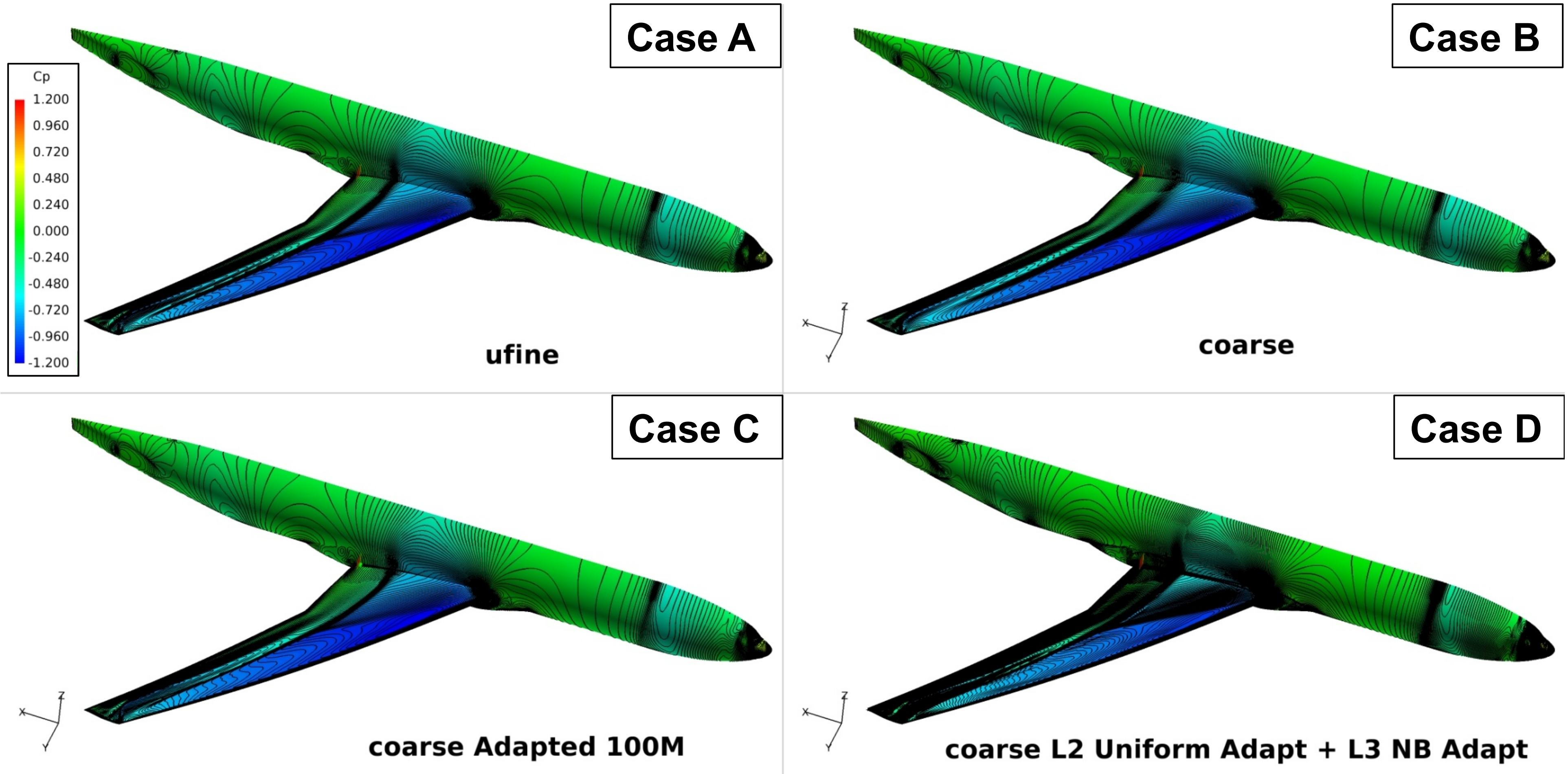

Case 4: WB Grid Adaption

Wing Pressure Contours – OB Region

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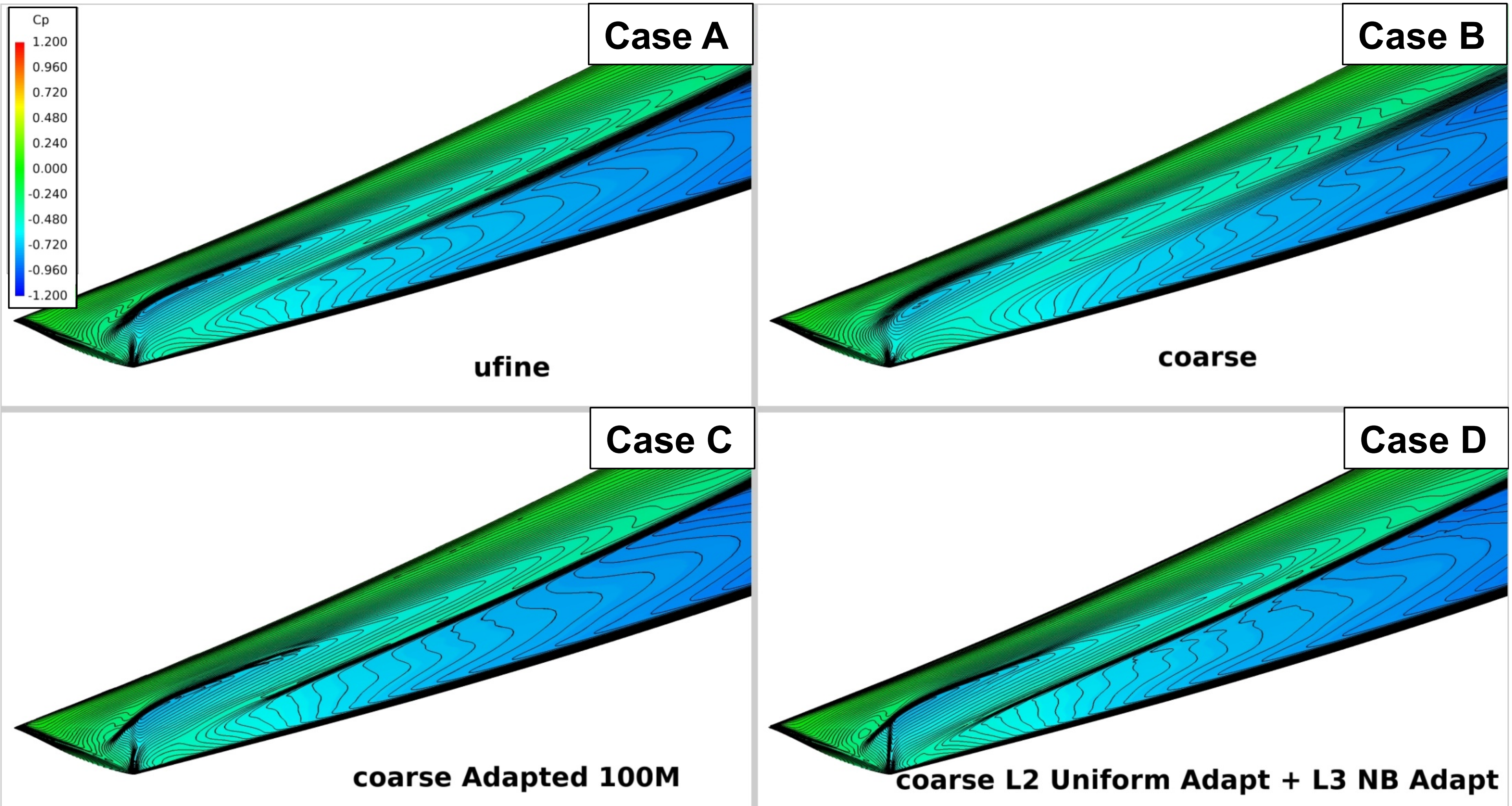

- Complex OB wing shock structure more evident with extreme grid resolution in Case D.