



6th AIAA CFD Drag Prediction Workshop
June 16-17, 2016 in Washington, D.C. USA

Validation Study of in-house CFD tool “*Cflow*”

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16KT008948



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Outline

■ Objectives

- to validate in-house CFD tool "Cflow" from viewpoints of industry application; how to set up grid, efficiency, accuracy etc.

■ Case1; Cflow Solver verification

- common grid (unstructured quad)
- SA turbulence model

■ Case2-3; Grid/Solver validation

Case 2A, 2B, 3		Turbulence model	
		<i>SA-noft2</i>	SA-noft2-QCR2000
Grid	Baseline Grid (Boeing.Babcock.Unstructured)	X	X
	<i>Original grid (Cflow.NOBLU.grid)</i>	X	X

Backgrounds and Motivation

Kawasaki originally developed

$$\textbf{\textit{Cflow}} = \boxed{\text{Grid Generator}} + \boxed{\text{Flow Solver}}$$

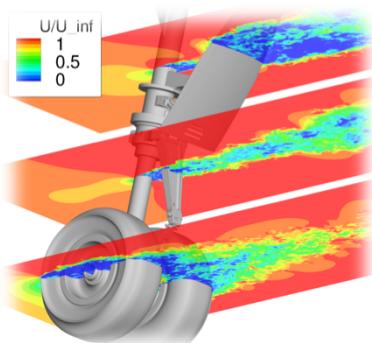
Cartesian Octree AMR
+ layered grid

highly complicated

unsteady

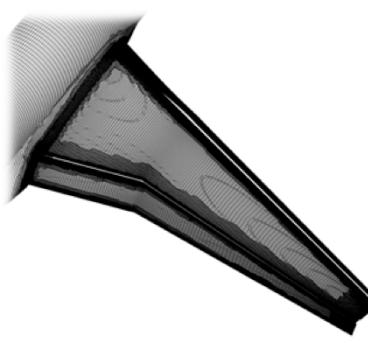
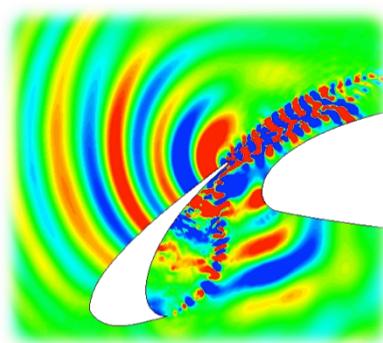
large-scale

- Participating AIAA workshop becomes a driving force for development and validation of CFD tools.

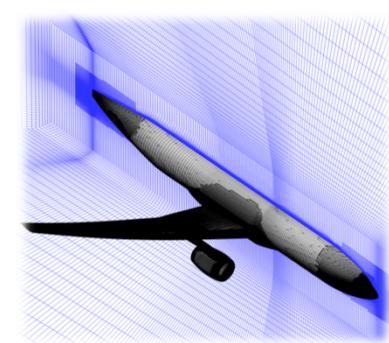


2010-2016
BANC I-IV

Aeroacoustic analysis



2013
HiLift-PW2



2016
DPW6 (present)

Aerodynamic analysis

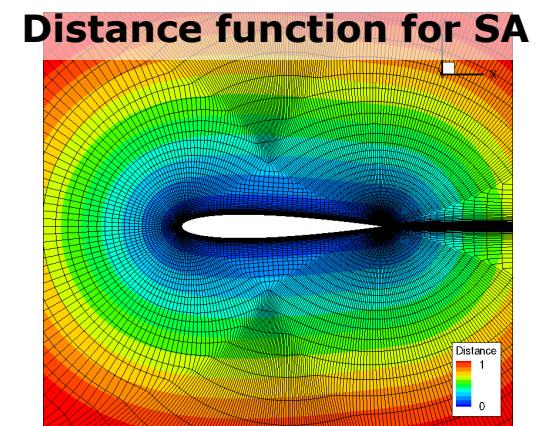
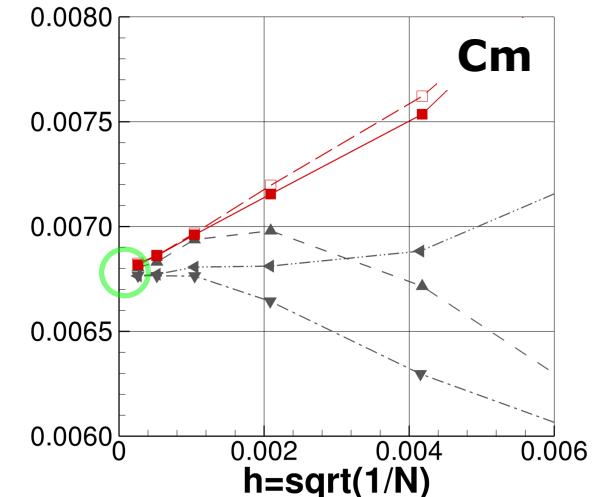
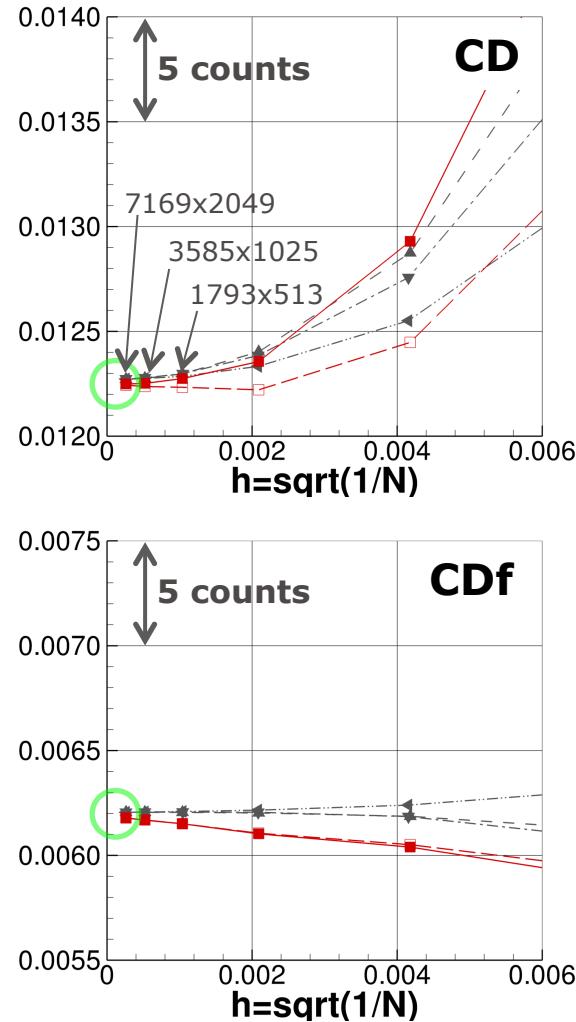
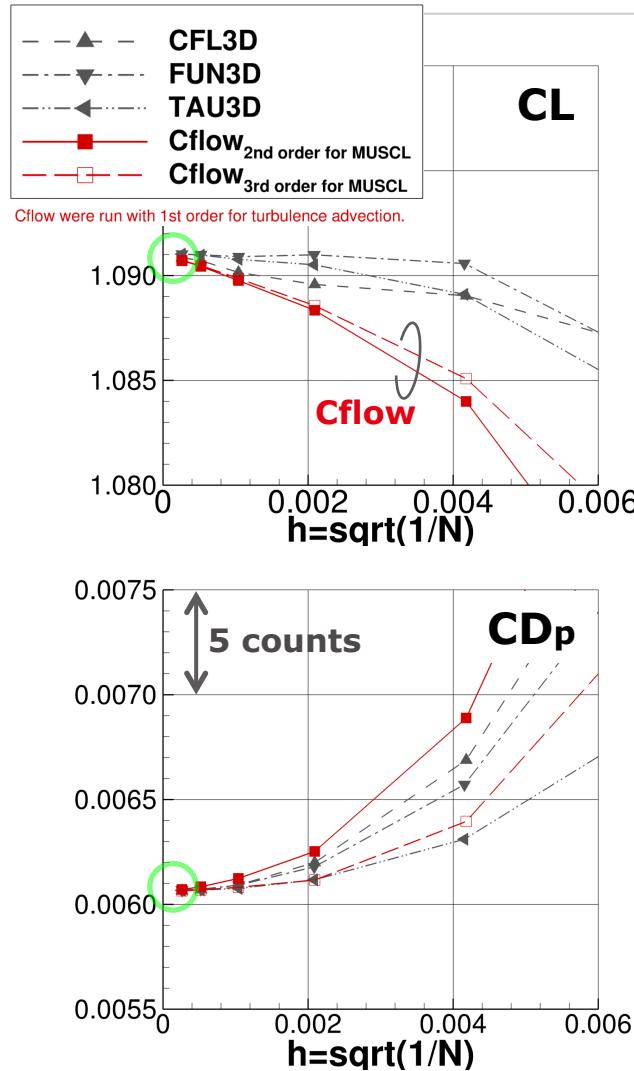
Numerical schemes of flow solver “Cflow”

Cflow = Grid Generator + **Flow Solver**

- Grid System
 - Unstructured hybrid grid (polyhedral cells)
- Governing equation
 - Compressible Navier-Stokes equations (**RANS**)
- Time integration
 - 2nd-order Matrix Free Gauss-Seidel (**MFGS**) implicit method
- Spatial discretization
 - **Cell-centered** finite volume method
 - Simple Low-dissipation AUSM scheme (**SLAU**)
 - 2nd-order accurate unstructured-MUSCL based reconstruction
- Turbulence modeling
 - Spalart-Allmaras (**SA-noft2**, SA-noft2-QCR2000)
- Parallel computation
 - MPI

Case1 : Verification Study

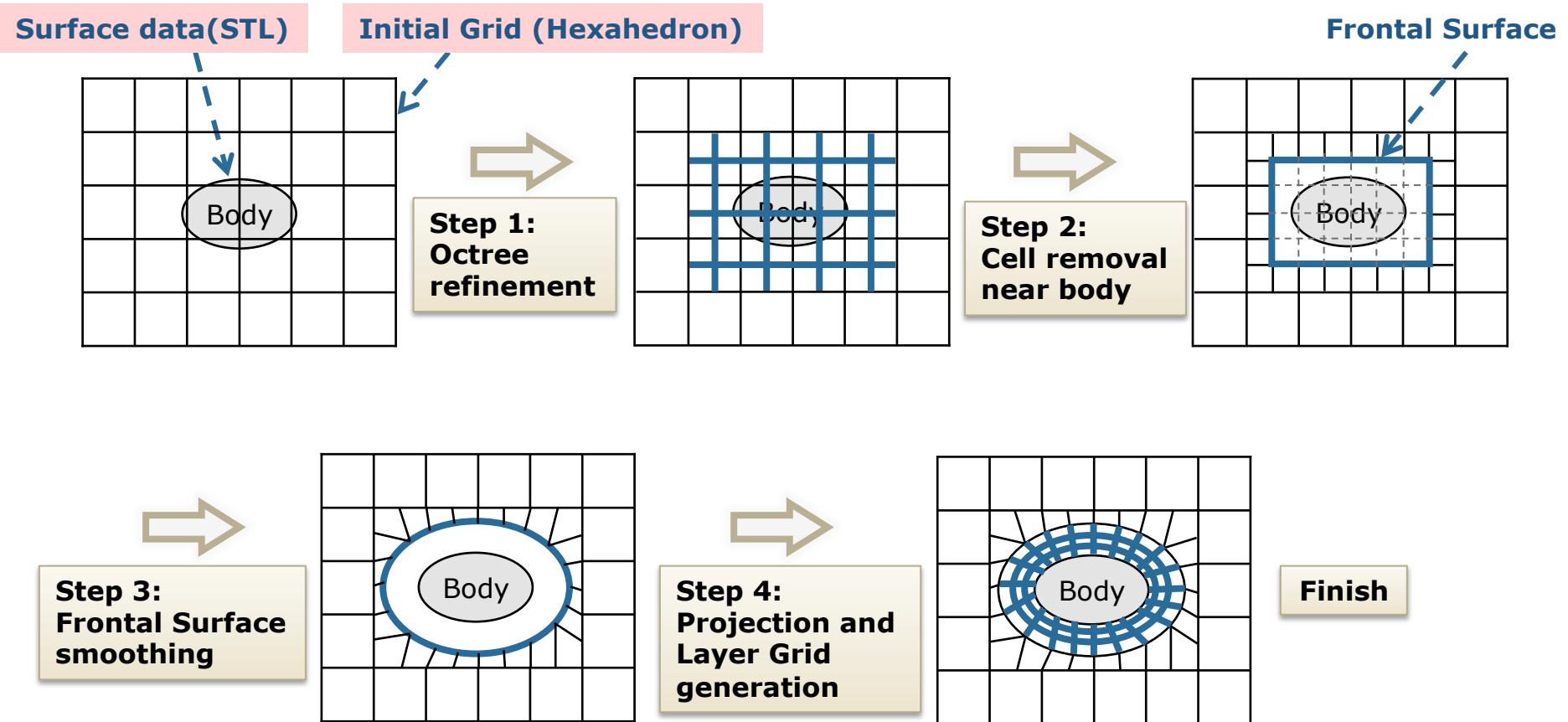
FAMILY II UNSTRUCTURED QUAD VERSIONS OF GRIDS



Cflow achieved equivalent convergence with other codes.

"Cflow" Grid Generation Procedure

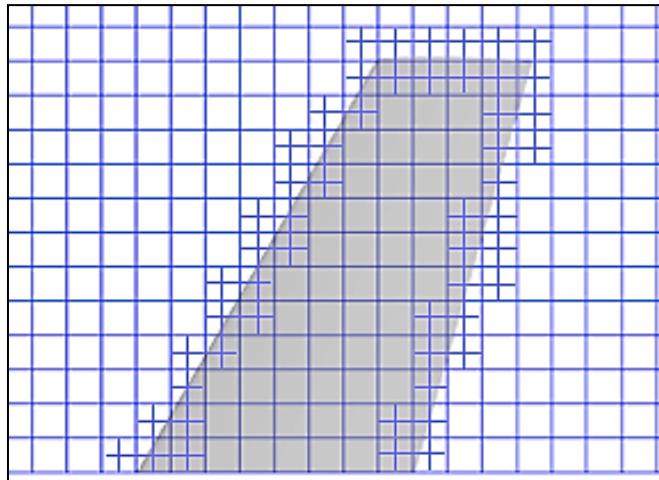
Cflow = **Grid Generator** + Flow Solver



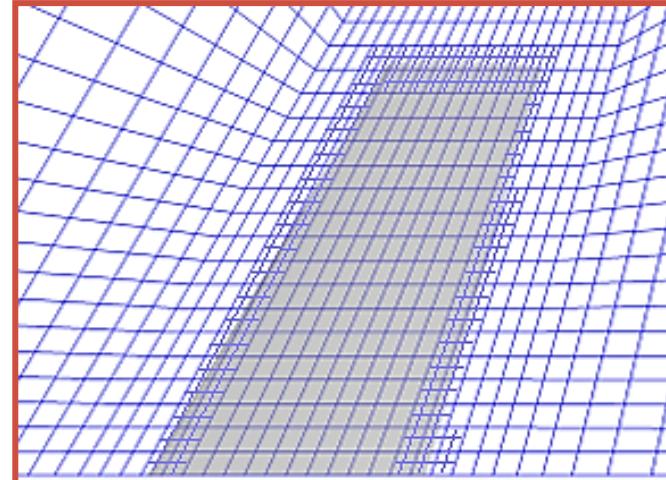
Cflow conducts automatic Cartesian based grid generation with octree Adaptive Mesh Refinement, and with Layered grid near surface for boundary layer.

Characteristics of Cflow Grid

NOBLU (Non-orthogonal Octree Boundary-fitted Layer Unstructured) Grid



Conventional Cartesian

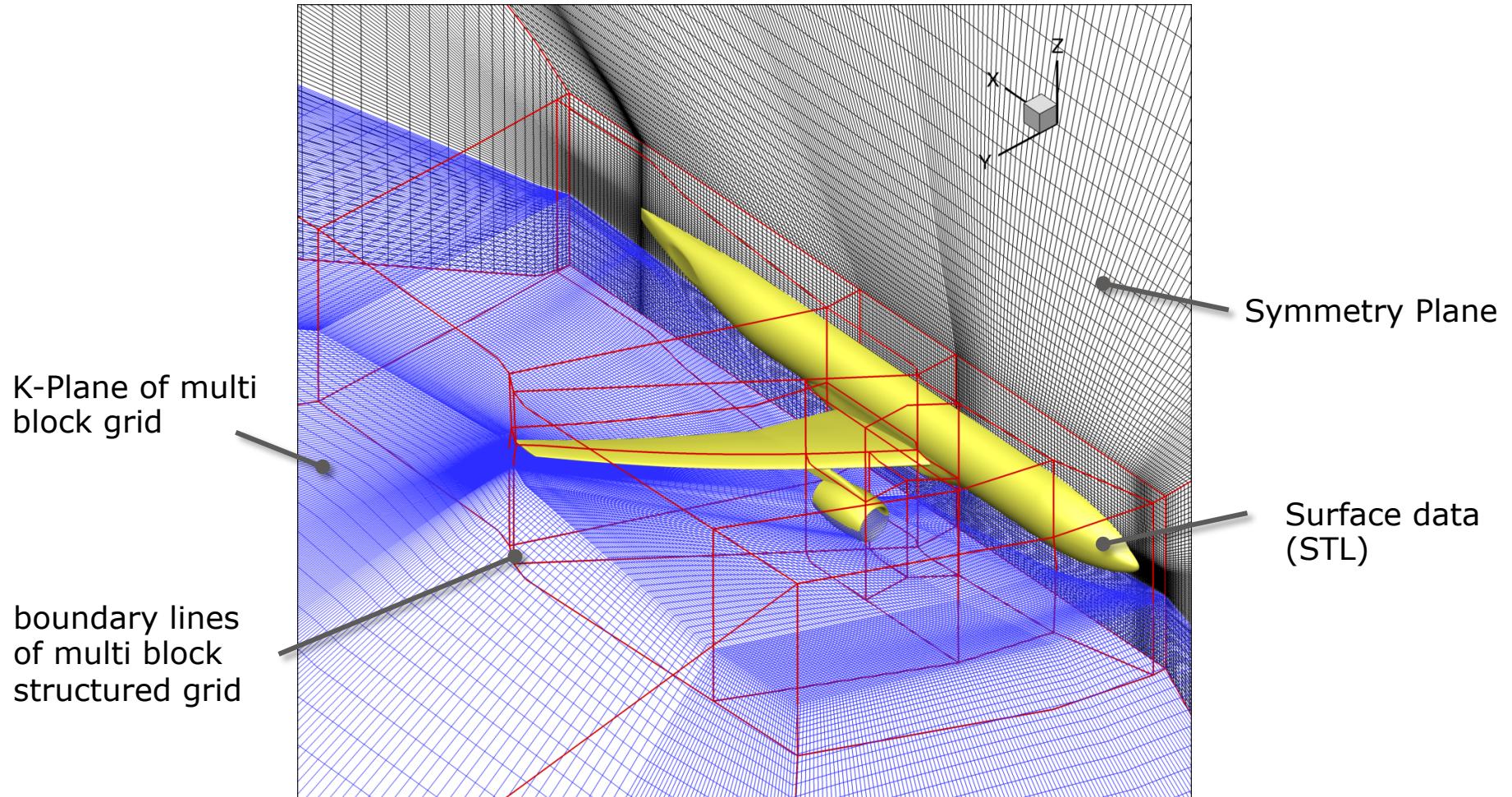


Non-Orthogonal Initial Grid

Efficient

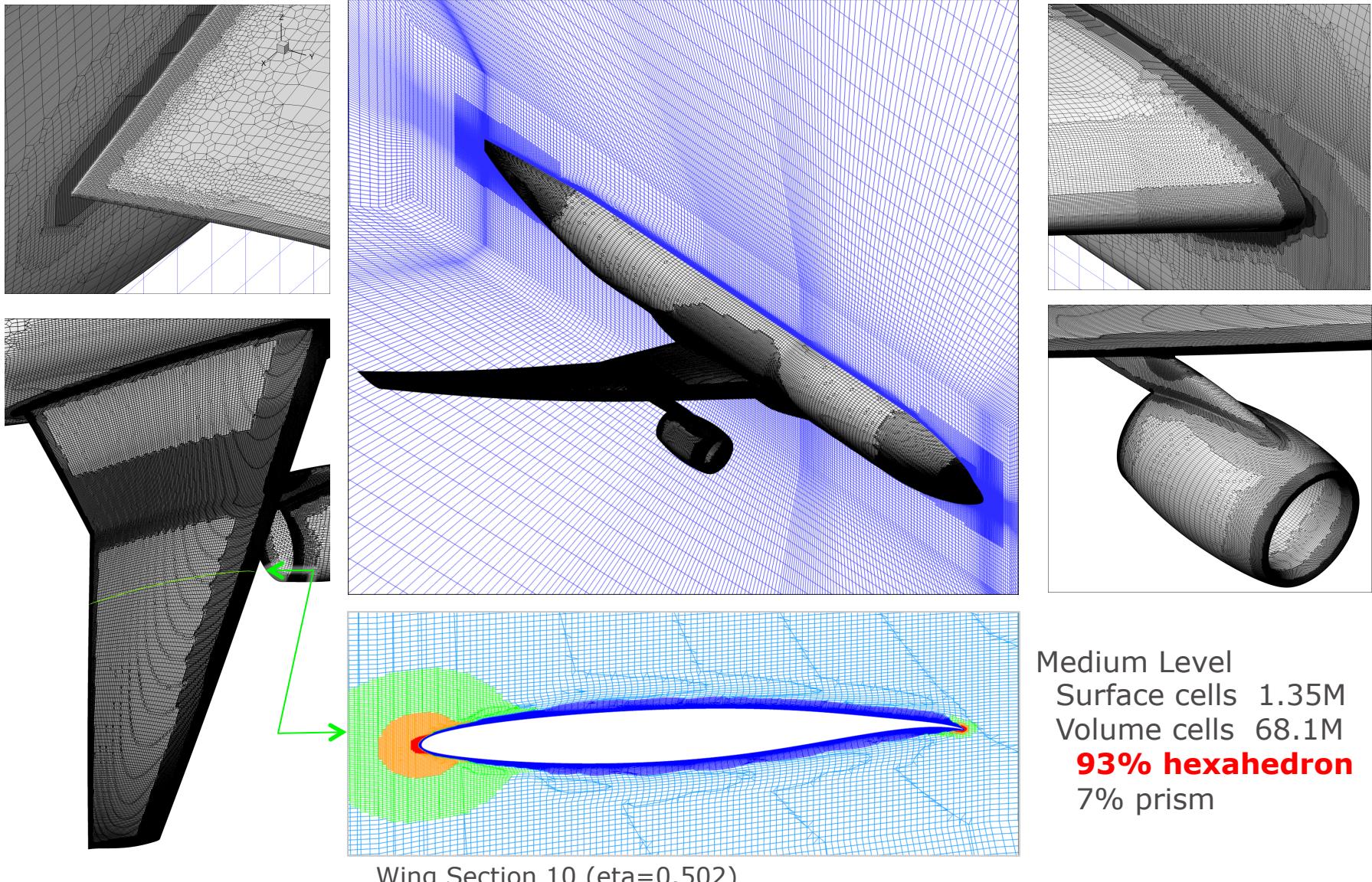
- Cflow adopts “**Non-Orthogonal Initial Grid**” to increase flexibility for high aspect ratio and sweptback configuration
- Controlling the grid spacing and aspect ratio of “Initial Grid” can achieve higher resolution around leading and trailing edge and can reduce the number of grid points.

Case2&3; CRM WB/WBNP Configuration Non-orthogonal Initial Grid Setup

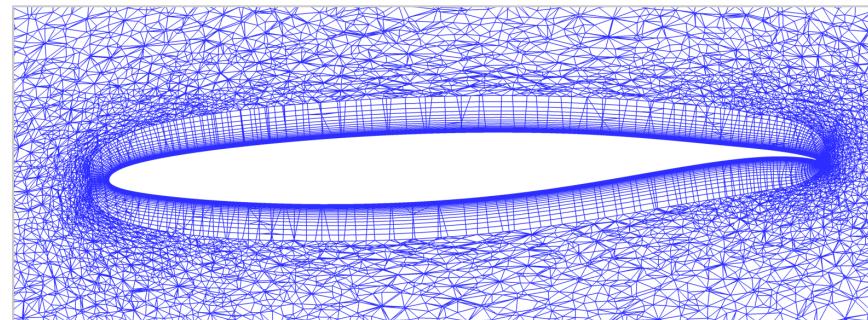
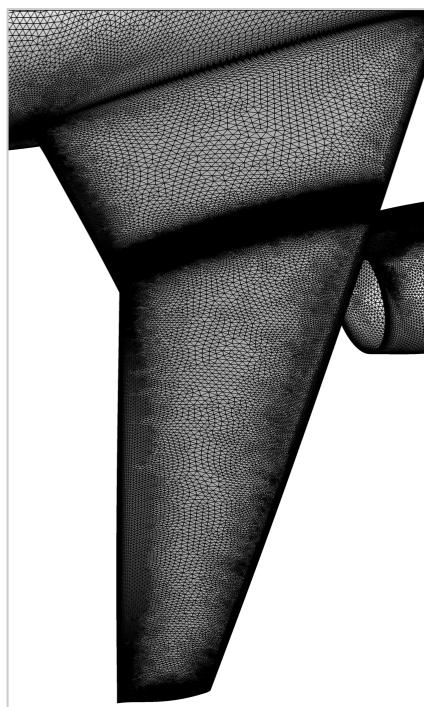
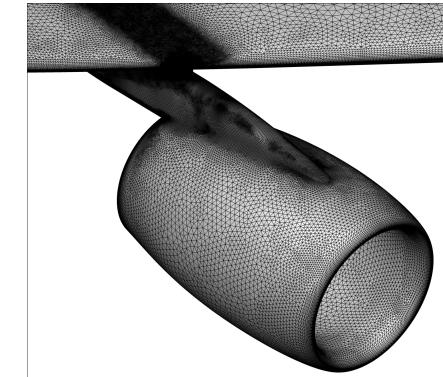
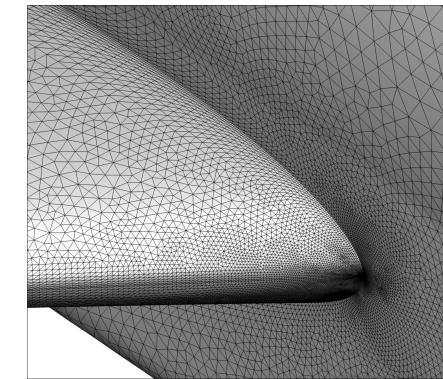
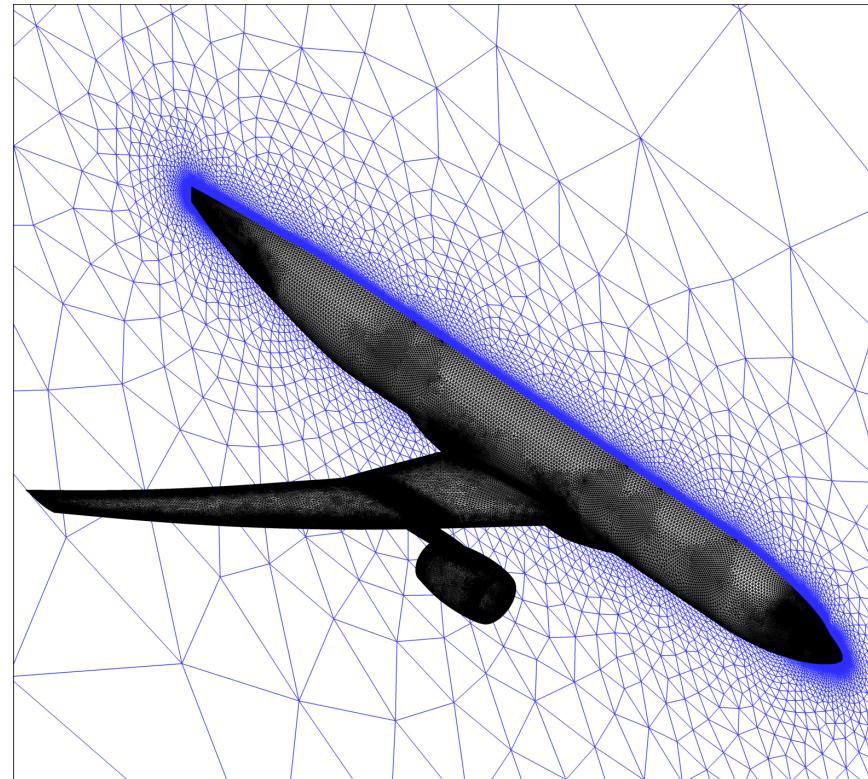
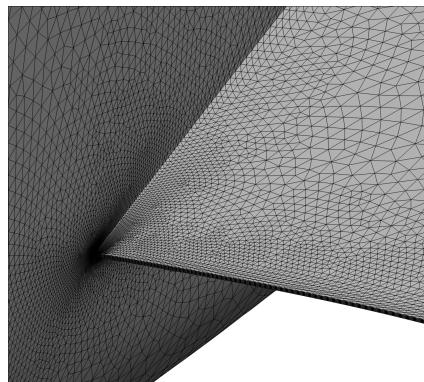


One Initial grid is compatible with WB/WBNP, aeroelastic shape change.

Case2&3; Cflow.NOBLU Grid



Case2&3; Baseline Grid (Boeing.Babcock.Unstructured.CC.REV00)

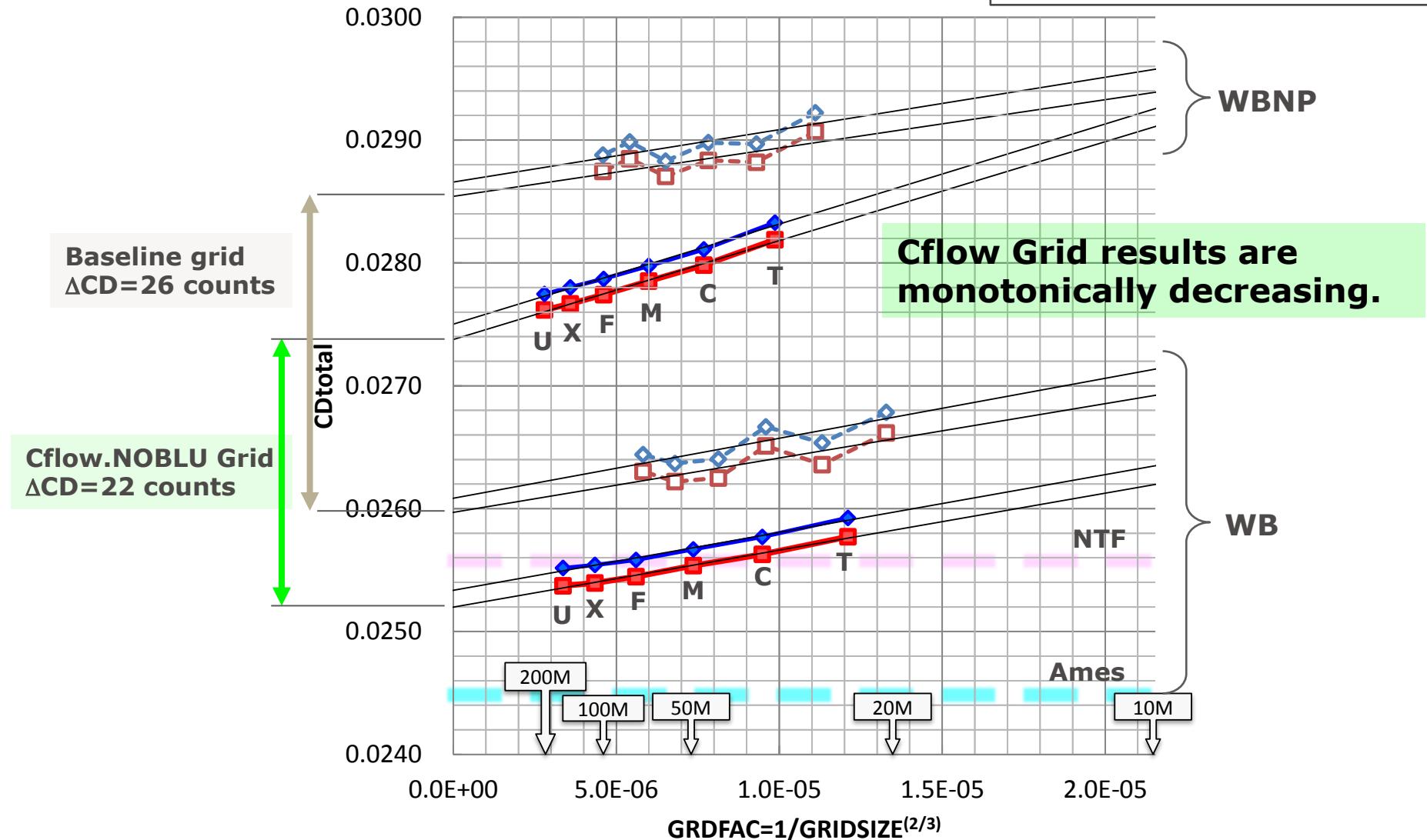


Wing Section 10 ($\eta = 0.502$)

Medium Level
Surface cells 0.75M
Volume cells 45.7M
35% Tetra
65% Prism
0.1% Pyramid

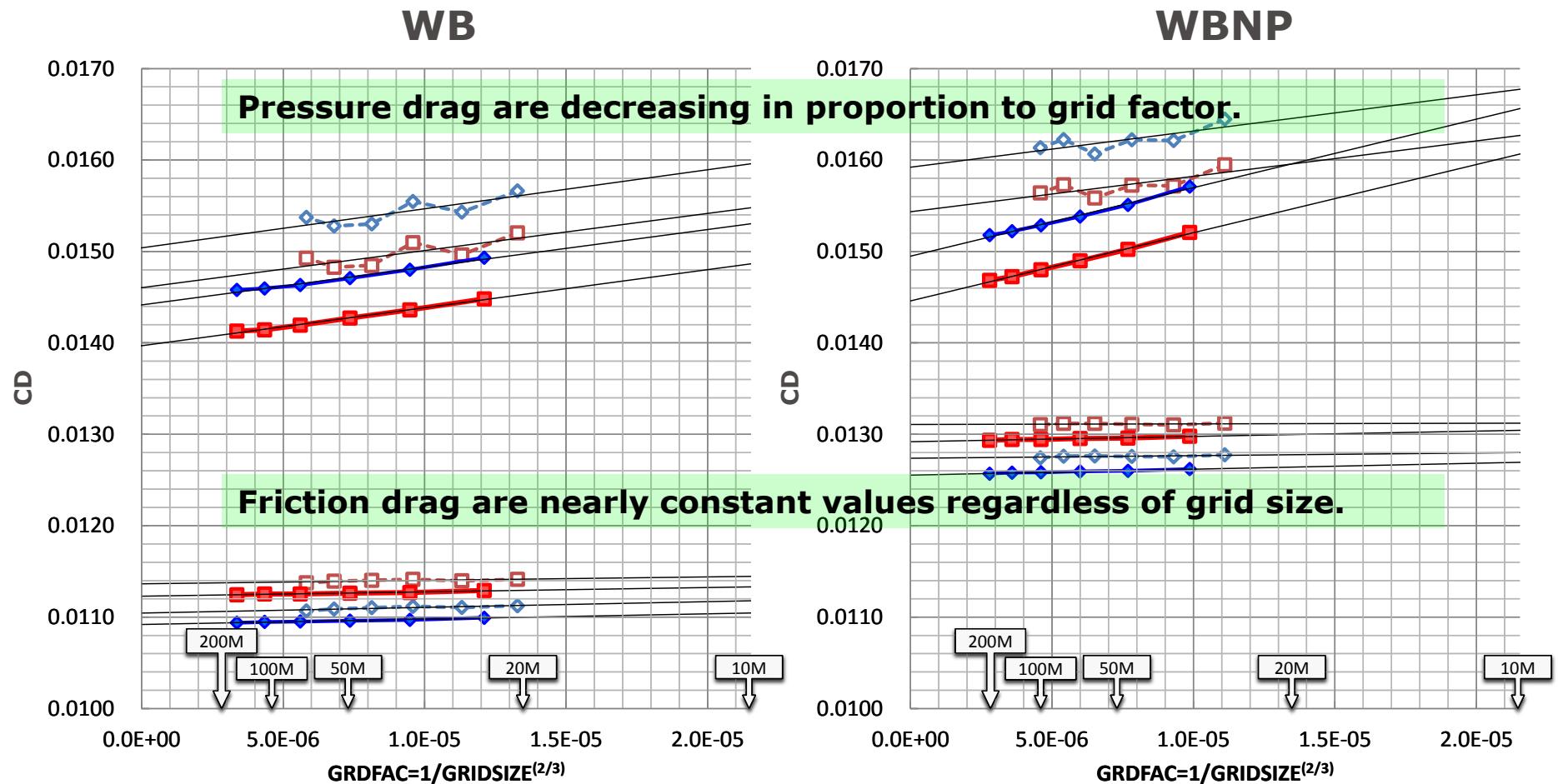
Case2 : Grid Convergence CD_total, WB/WBNP

- Cflow Grid, SA-noft2
- ◆ Cflow Grid, SA-noft2-QCR2000
- Baseline Grid, SA-noft2
- ◇ Baseline Grid, SA-noft2-QCR2000



Case2 : Grid Convergence Drag breakdown, WB/WBNP

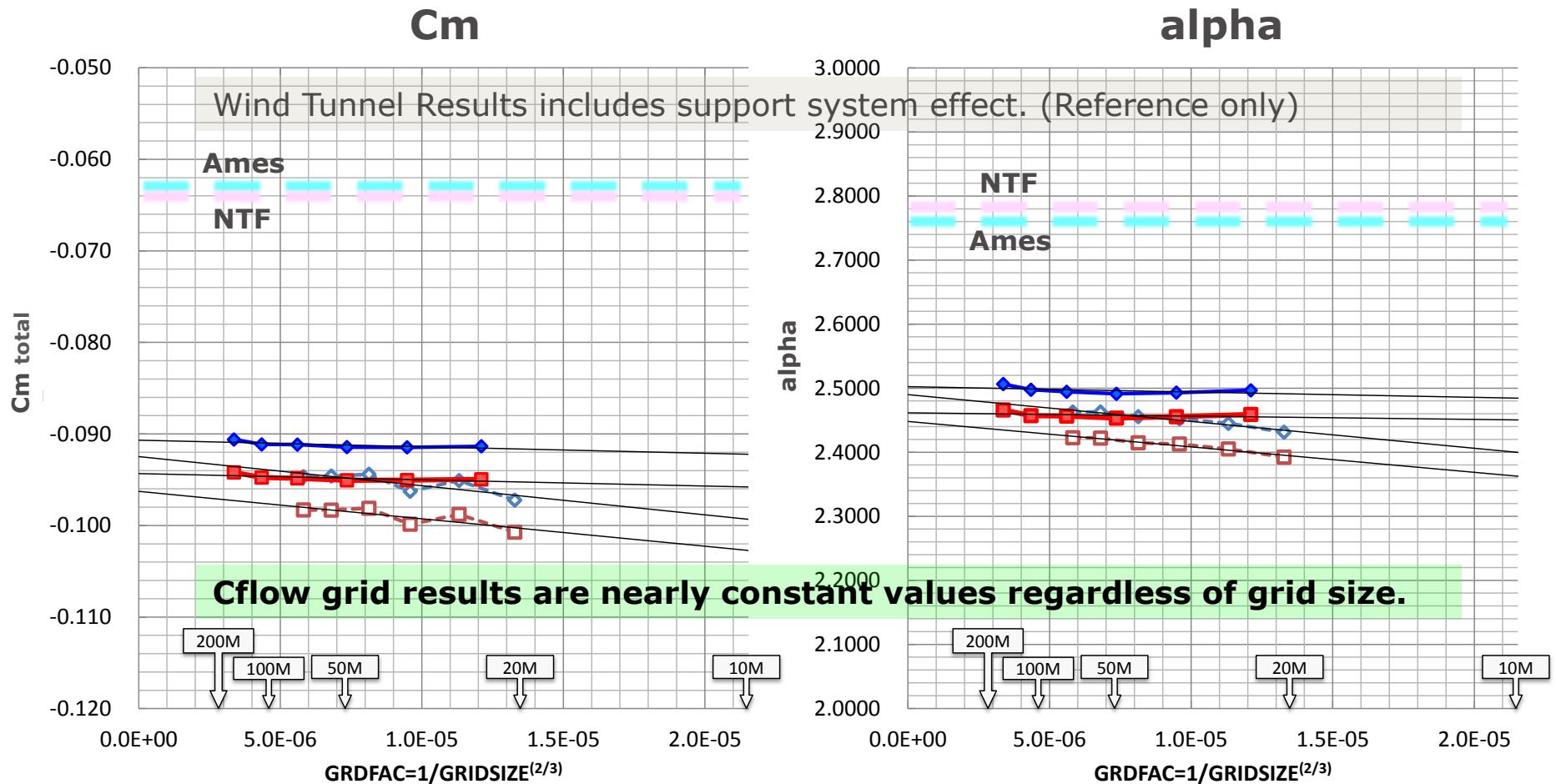
- Cflow Grid, SA-noft2
- ◆ Cflow Grid, SA-noft2-QCR2000
- Baseline Grid, SA-noft2
- ◇ Baseline Grid, SA-noft2-QCR2000



Case2 : Grid Convergence

Cm and alpha, WB

- Cflow Grid, SA-noft2
- ◆ Cflow Grid, SA-noft2-QCR2000
- Baseline Grid, SA-noft2
- ◇ Baseline Grid, SA-noft2-QCR2000

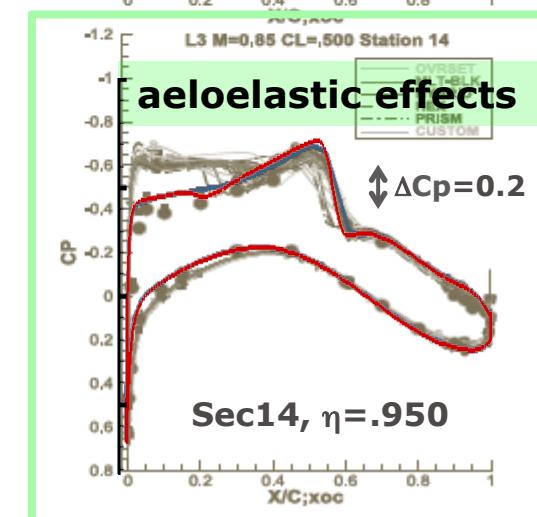
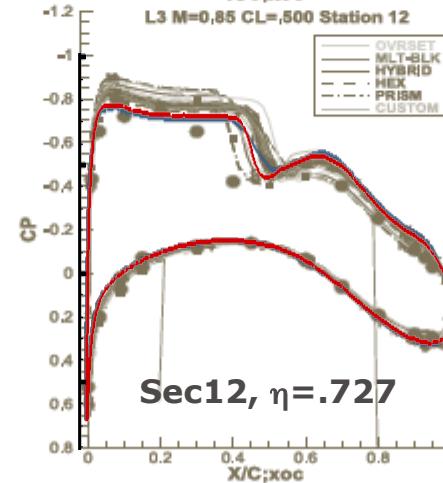
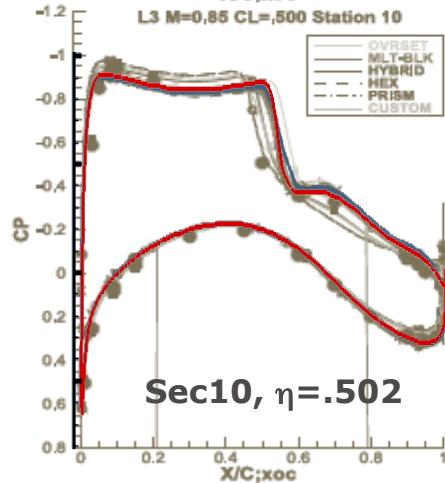
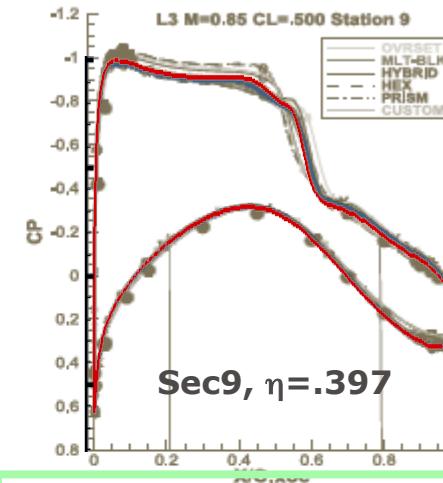
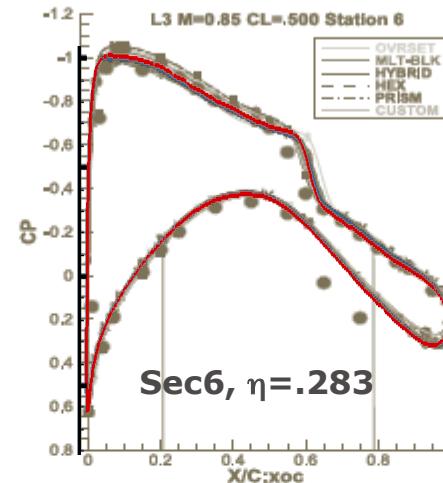
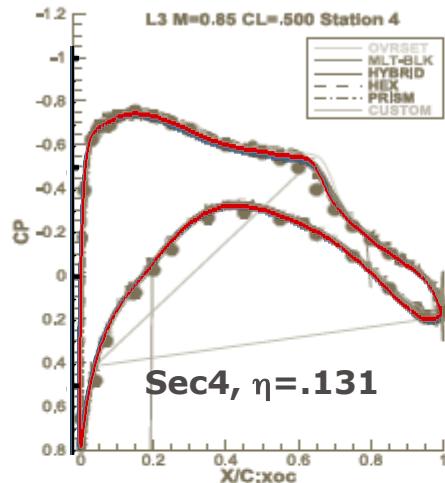


Case2 WB : spanwise Cp variation

Cflow Grid, SA-noft2
Baseline Grid, SA-noft2

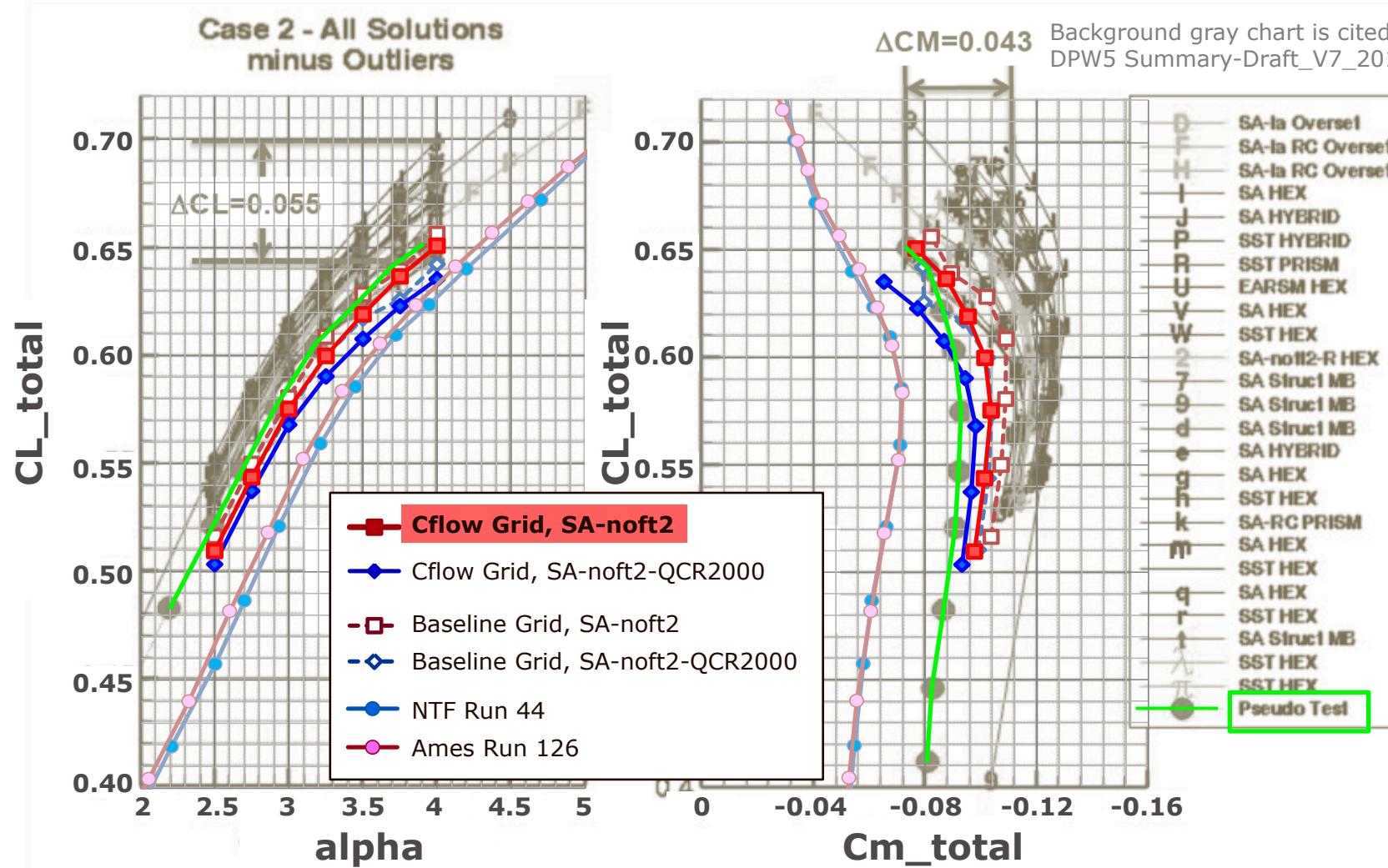
Background gray chart is cited from
DPW5 Summary-Draft_V7_2012.pdf, p.45

Case 1: Level 3 Grid, M=0.85, C_L=.50
Spanwise Variation



Case3 : CRM WB Static Aero-Elastic Effect CL-alpha, CL-Cm

DPW5 : Rigid shape
DPW6 : Aeroelastic shape

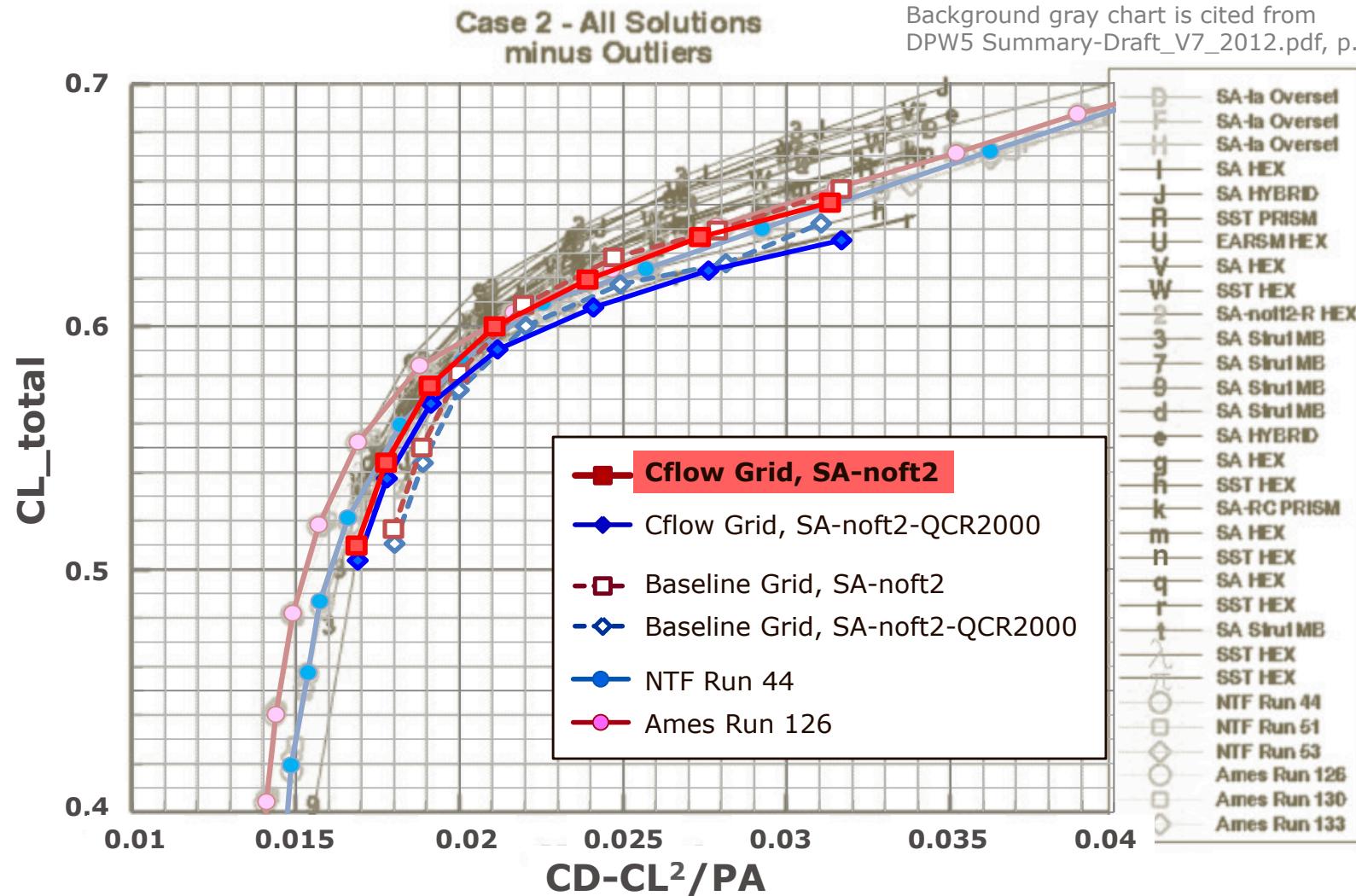


Pseudo Test data based on NTF test data modified by results from AIAA-2012-3209

"Cflow grid, SA-noft2" corresponds to Pseudo Test data.

Case3 : CRM WB Static Aero-Elastic Effect Drag Polar

DPW5 : Rigid shape
DPW6 : Aeroelastic shape

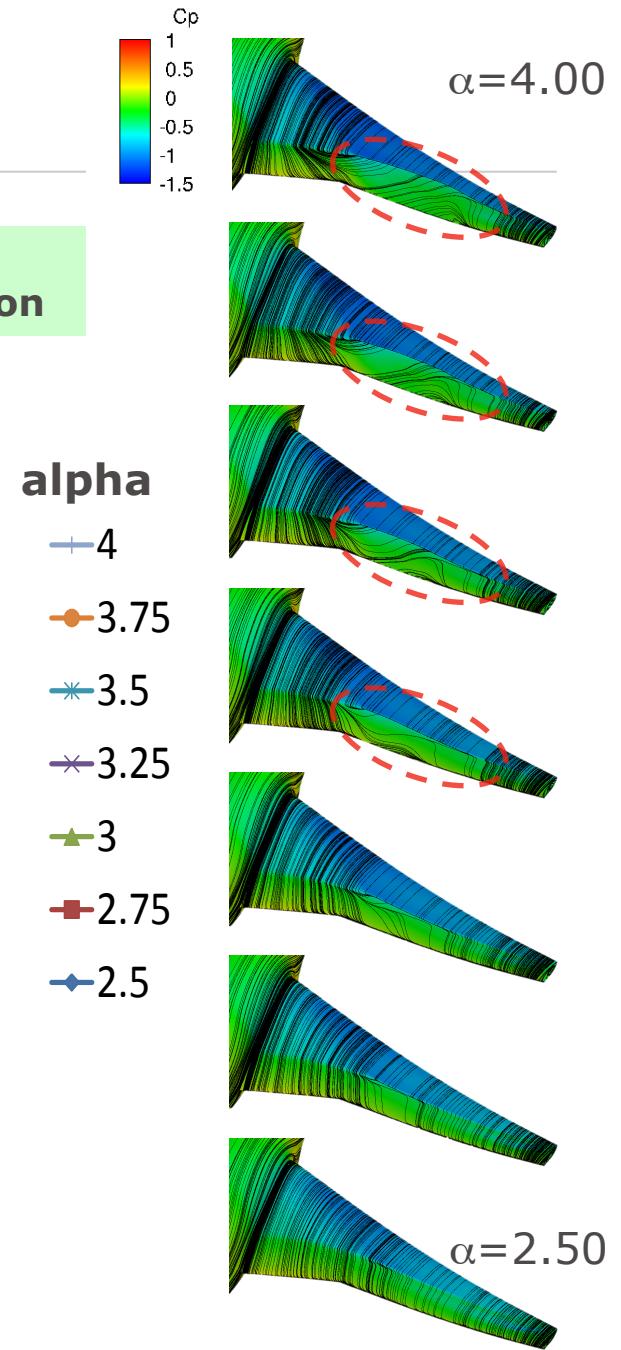
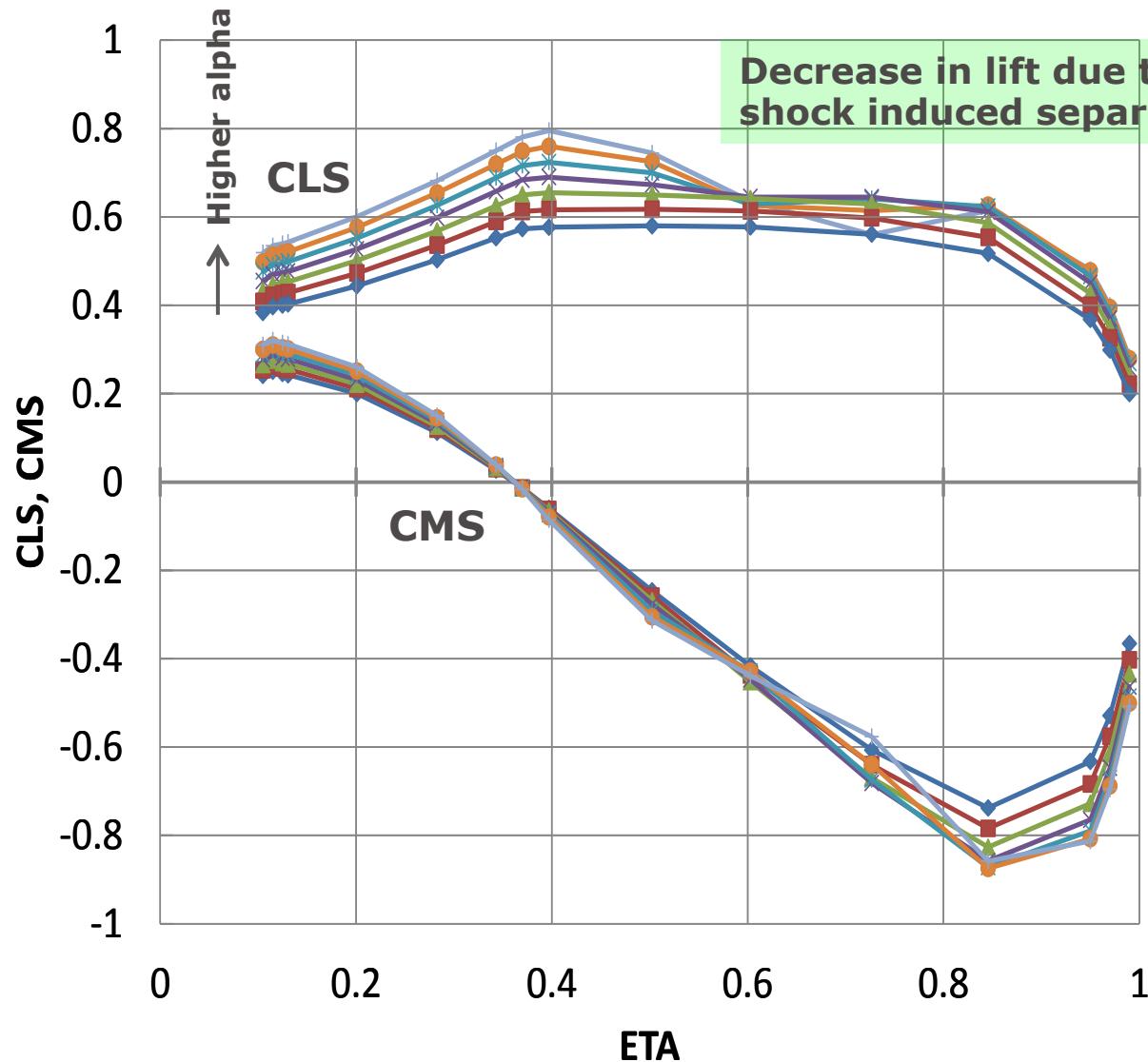


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"Cflow grid, SA-noft2" is good agreement with WT Test data.

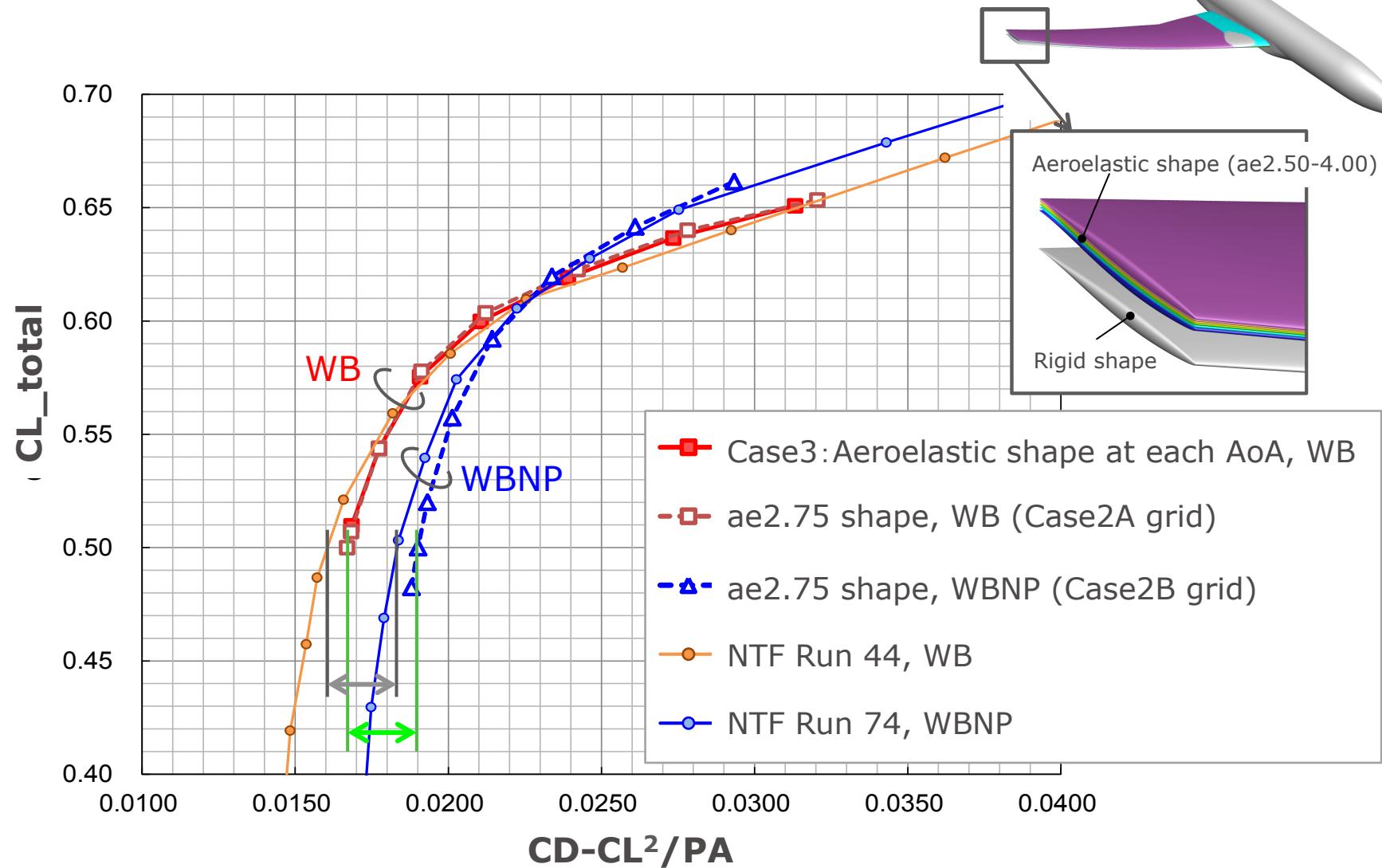
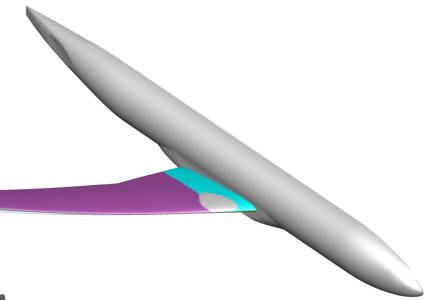
Case3 Sectional Lift & Moment

Cflow.NOBLU Grid, SA-noft2



CRM Nacelle/Pylon Drag Increment

Cflow.NOBLU Grid, SA-noft2



CFD Nacelle/Pylon drag increment is good agreement with WT Test data.

Summary

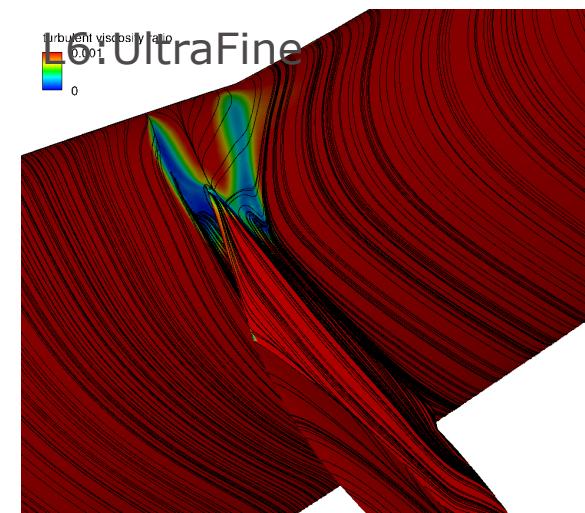
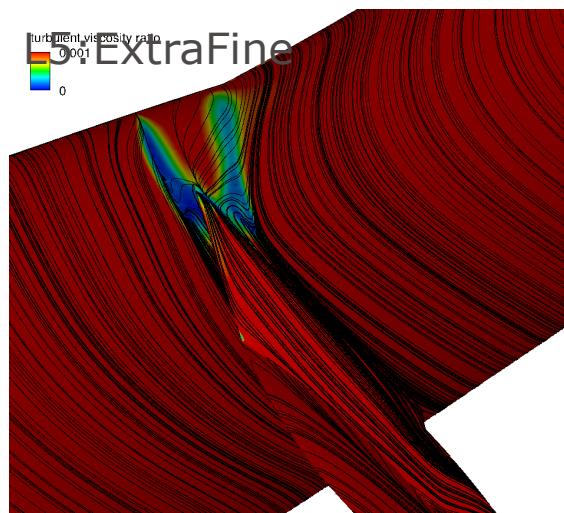
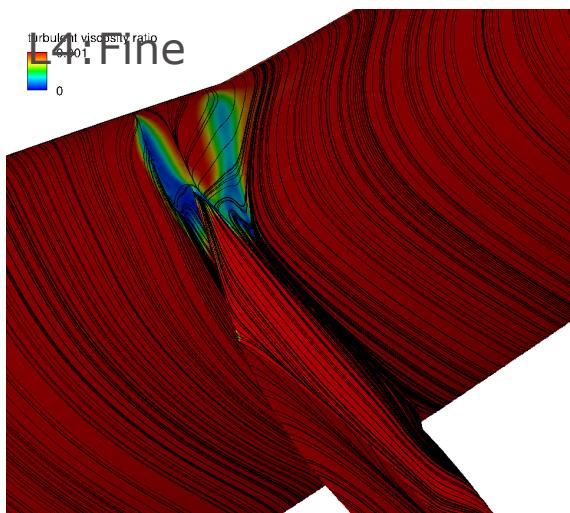
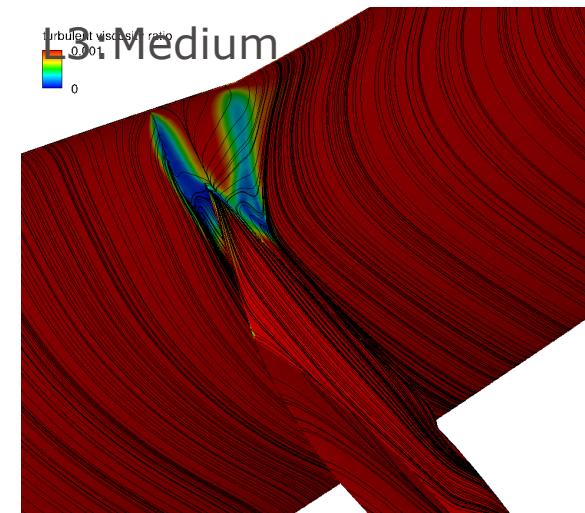
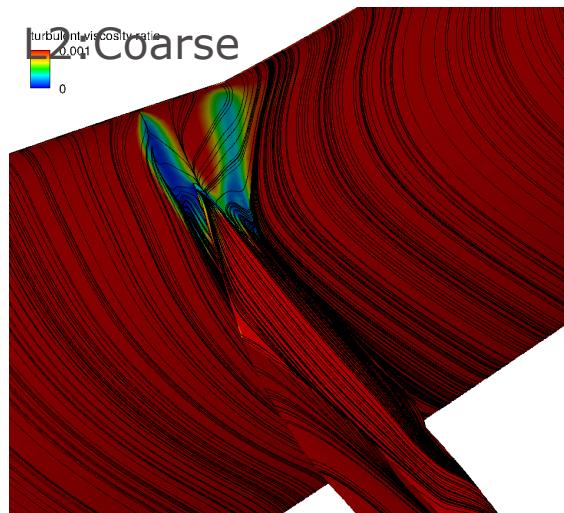
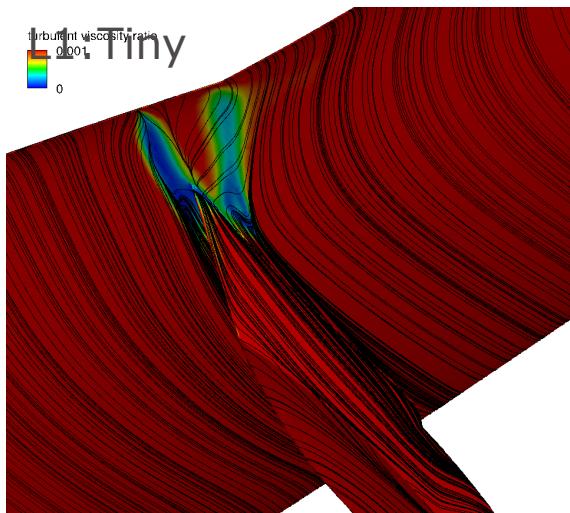
- Validation study of Kawasaki in-house CFD tool “Cflow” was conducted
 - Case1: Solver Verification
 - Cflow solver achieved equivalent convergence with other codes.
 - Case2: Grid convergence
 - Cflow original “NOBLU Grid” were applied to CRM WB/WBNP config.
 - CD_{total} and CD_p were monotonically decreasing
 - CL, CD_f, C_m, and α were nearly constant values regardless of grid size
 - Case3: Aeroelastic effect
 - Both aerodynamic characteristics and Nacelle/Pylon drag increment were good agreement with WT Test data.
- Future Work
 - further study on turbulence model effect, baseline grid, etc.
 - enhance grid generator function of feature preservation
 - participate in HiLift-PW3

Kawasaki, working as one for the good of the planet
“Global Kawasaki”

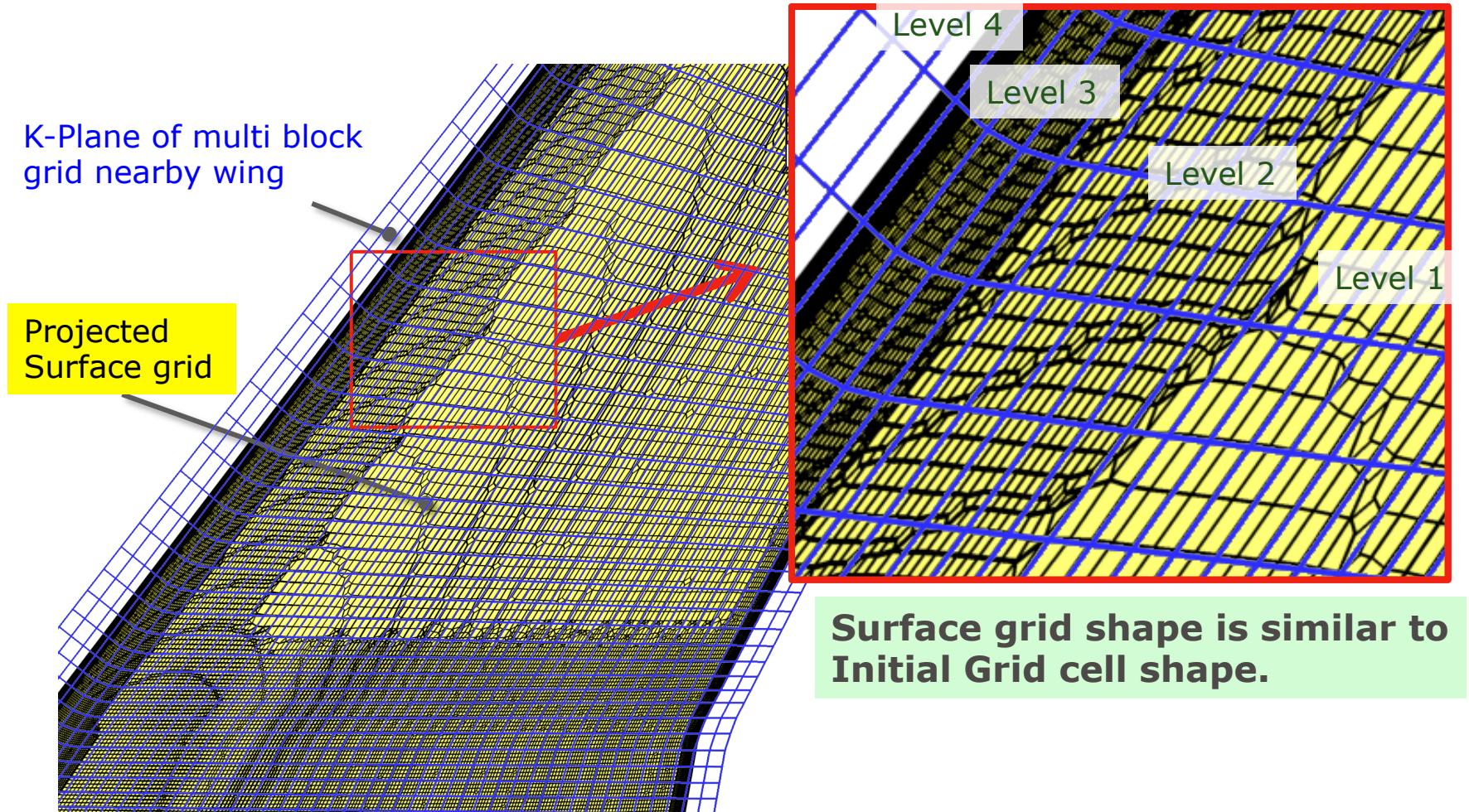
Case 2B

Cf, oilflow

WBNP, Cflow NOBLU Grid, SA-noft2

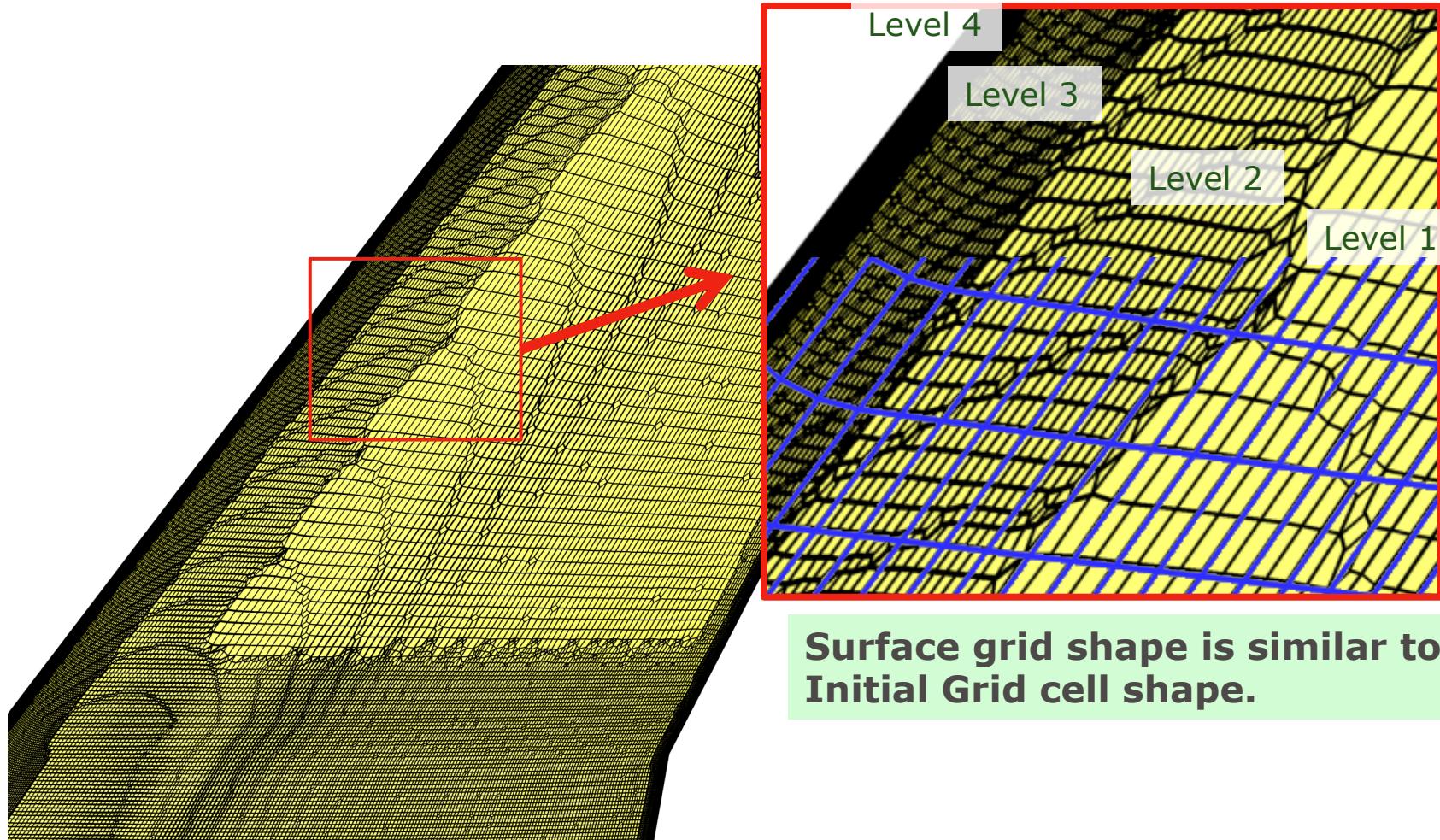


Case2&3; Cflow.NOBLU Grid



Controlling the grid spacing and aspect ratio of "Initial Grid" can achieve higher resolution around leading and trailing edge and can reduce the number of grid points.

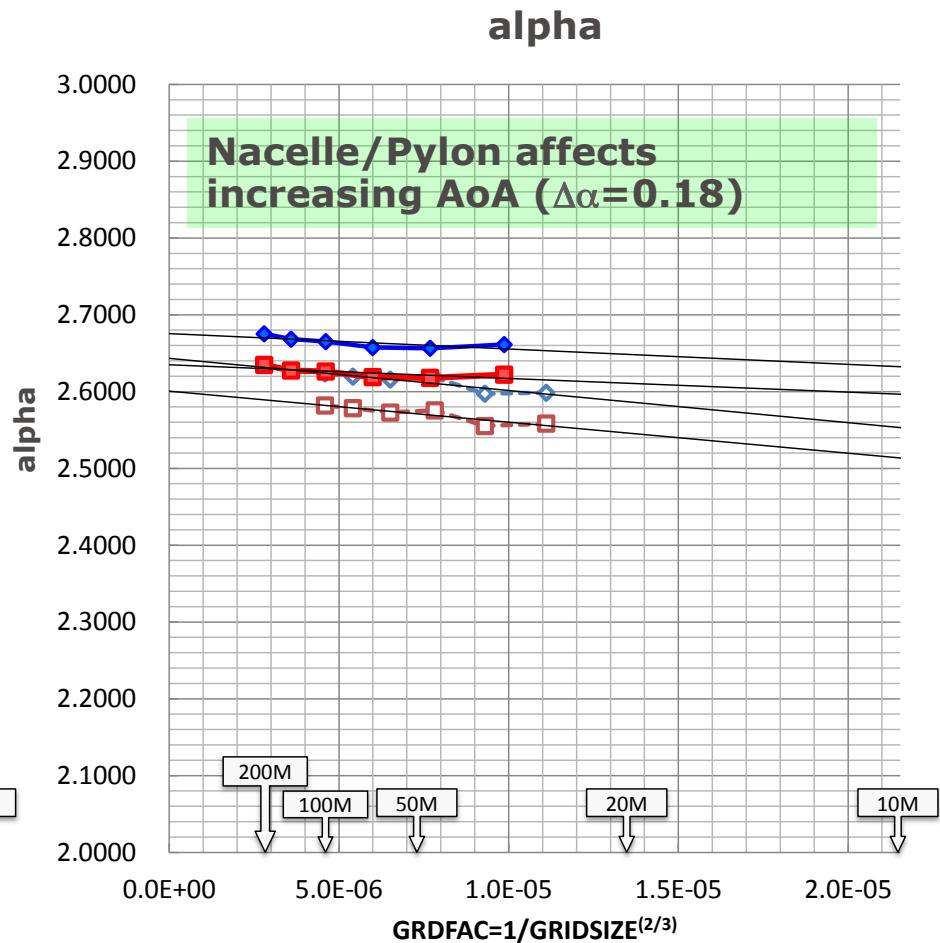
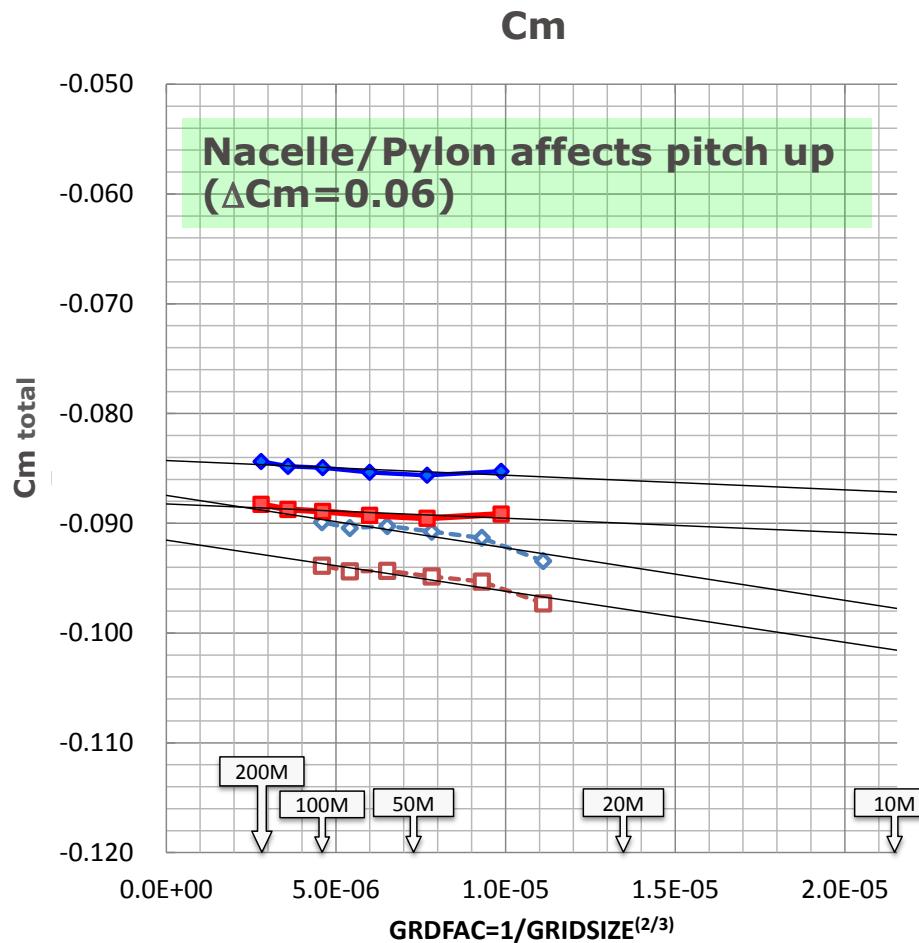
Case2&3; Cflow.NOBLU Grid



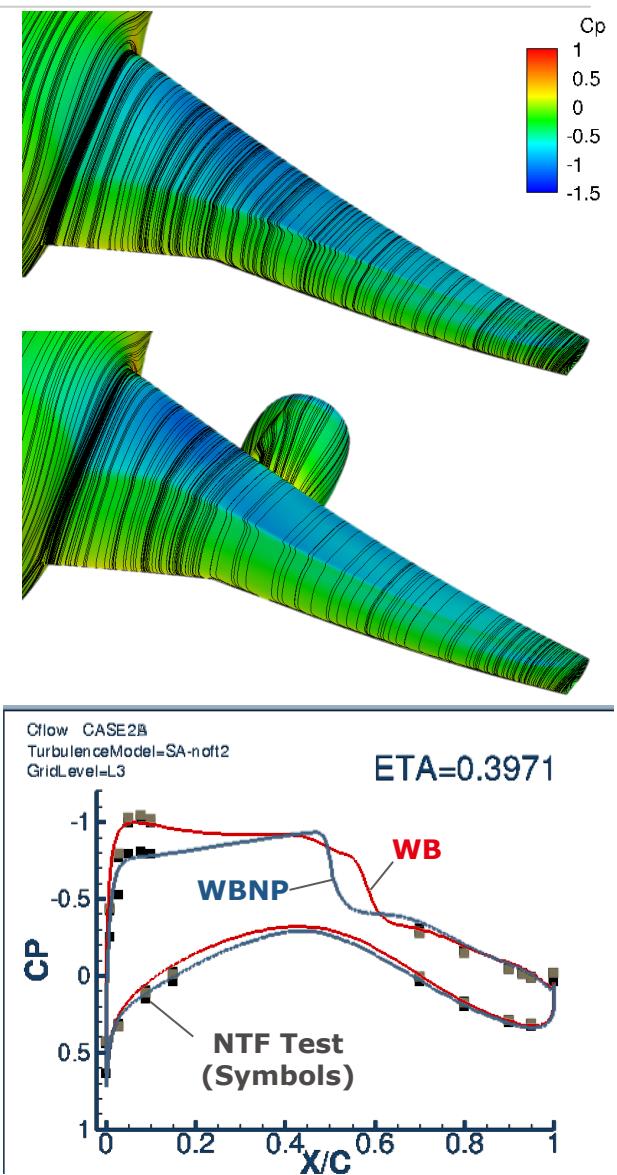
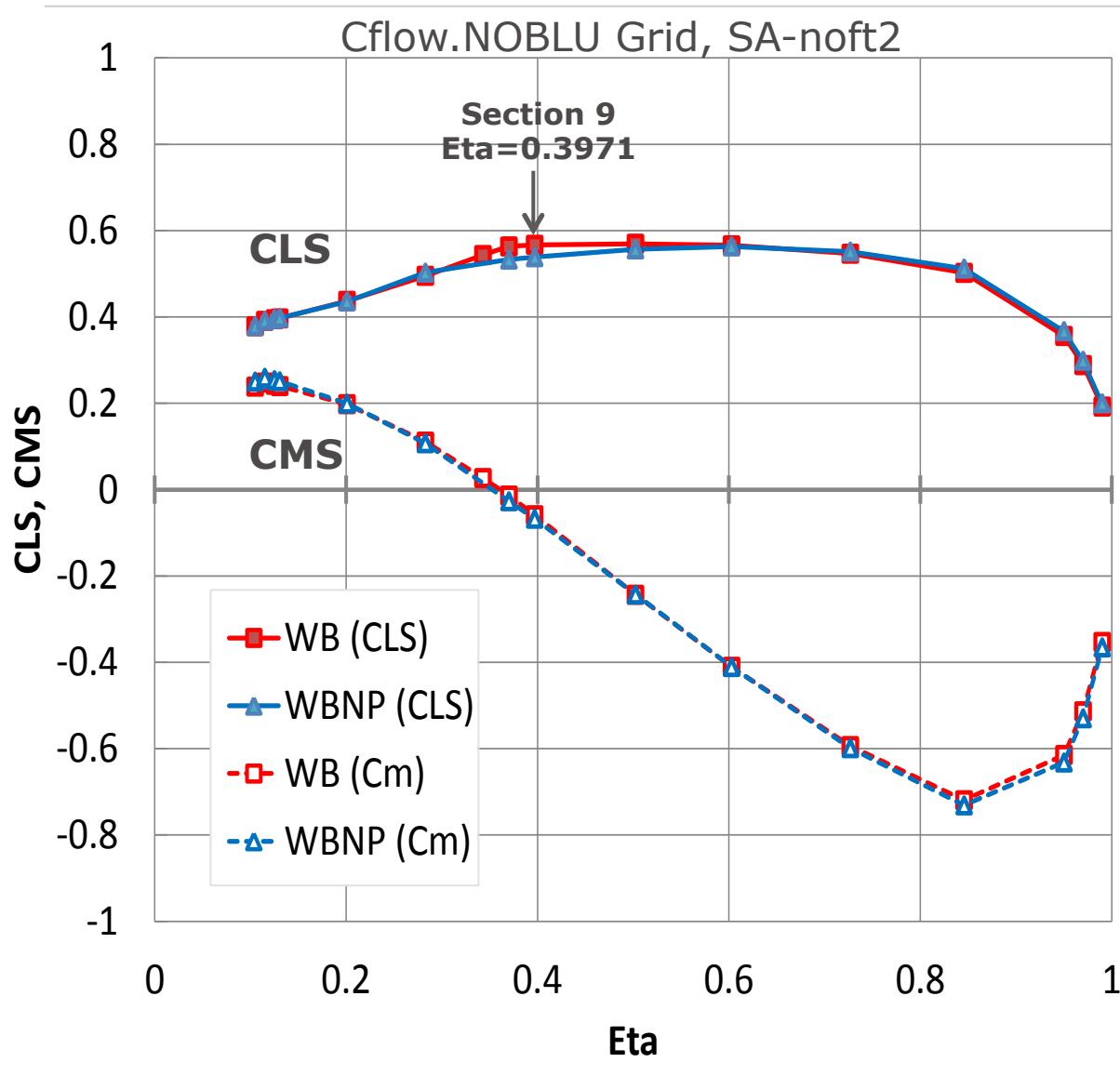
Controlling the grid spacing and aspect ratio of "Initial Grid" can achieve higher resolution around leading and trailing edge and can reduce the number of grid points.

Case2 : Grid Convergence Cm and alpha, WBNP

- Cflow Grid, SA-noft2
- ◆ Cflow Grid, SA-noft2-QCR2000
- Baseline Grid, SA-noft2
- ◇ Baseline Grid, SA-noft2-QCR2000

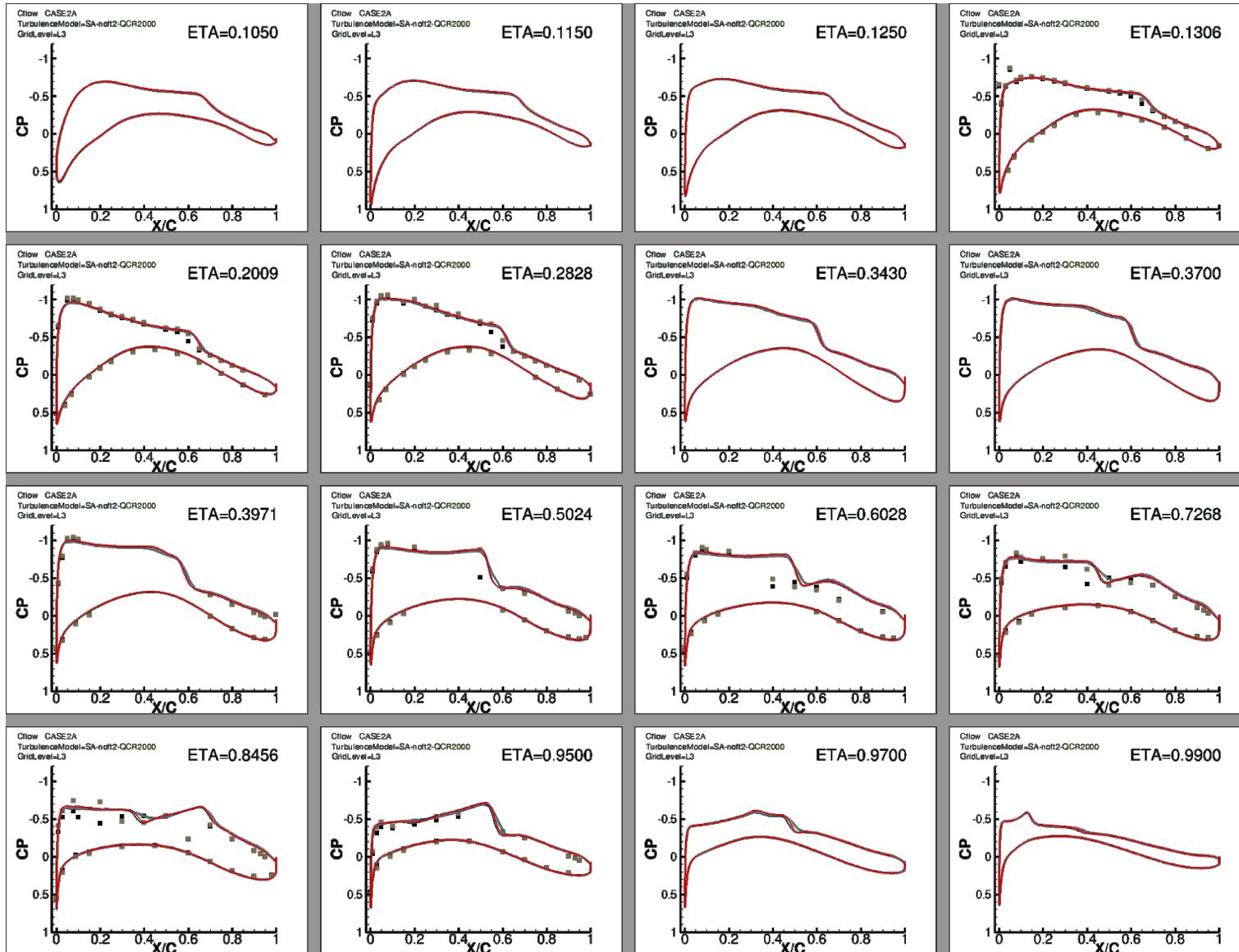


Case2 Sectional Lift & Moment WB/WBNP



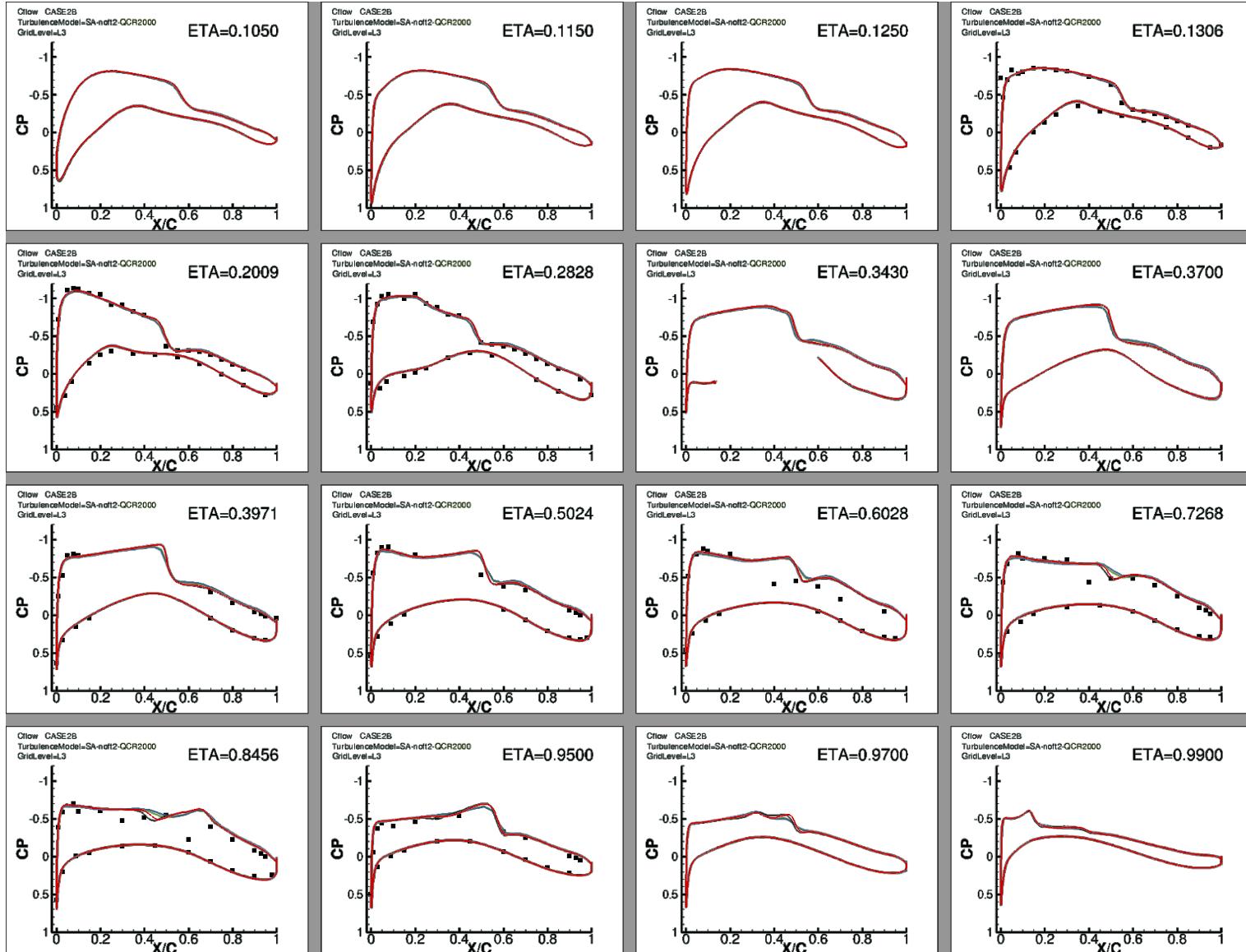
Case2A L3 Medium grid comparison

— Cflow Grid SA-noft2
— Cflow Grid SA-noft2-QCR2000
— Baseline Grid SA-noft2
— Baseline Grid SA-noft2-QCR2000
■ WT Data $\alpha=2.70$
■ WT Data $\alpha=2.93$



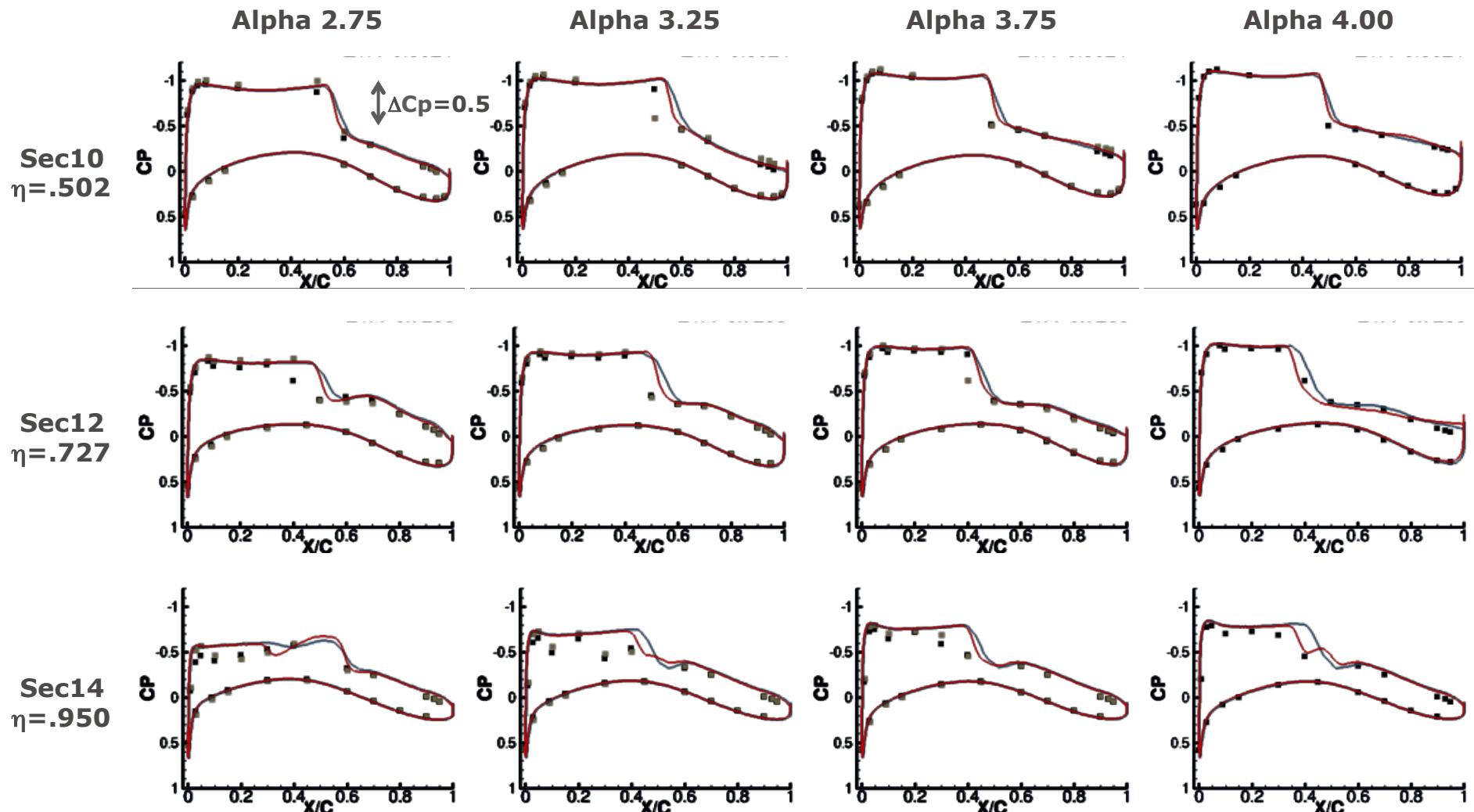
Case2B L3 Medium grid comparison

— Cflow Grid SA-noft2
— Cflow Grid SA-noft2-QCR2000
— Baseline Grid SA-noft2
— Baseline Grid SA-noft2-QCR2000
■ WT Data $\alpha=2.96$



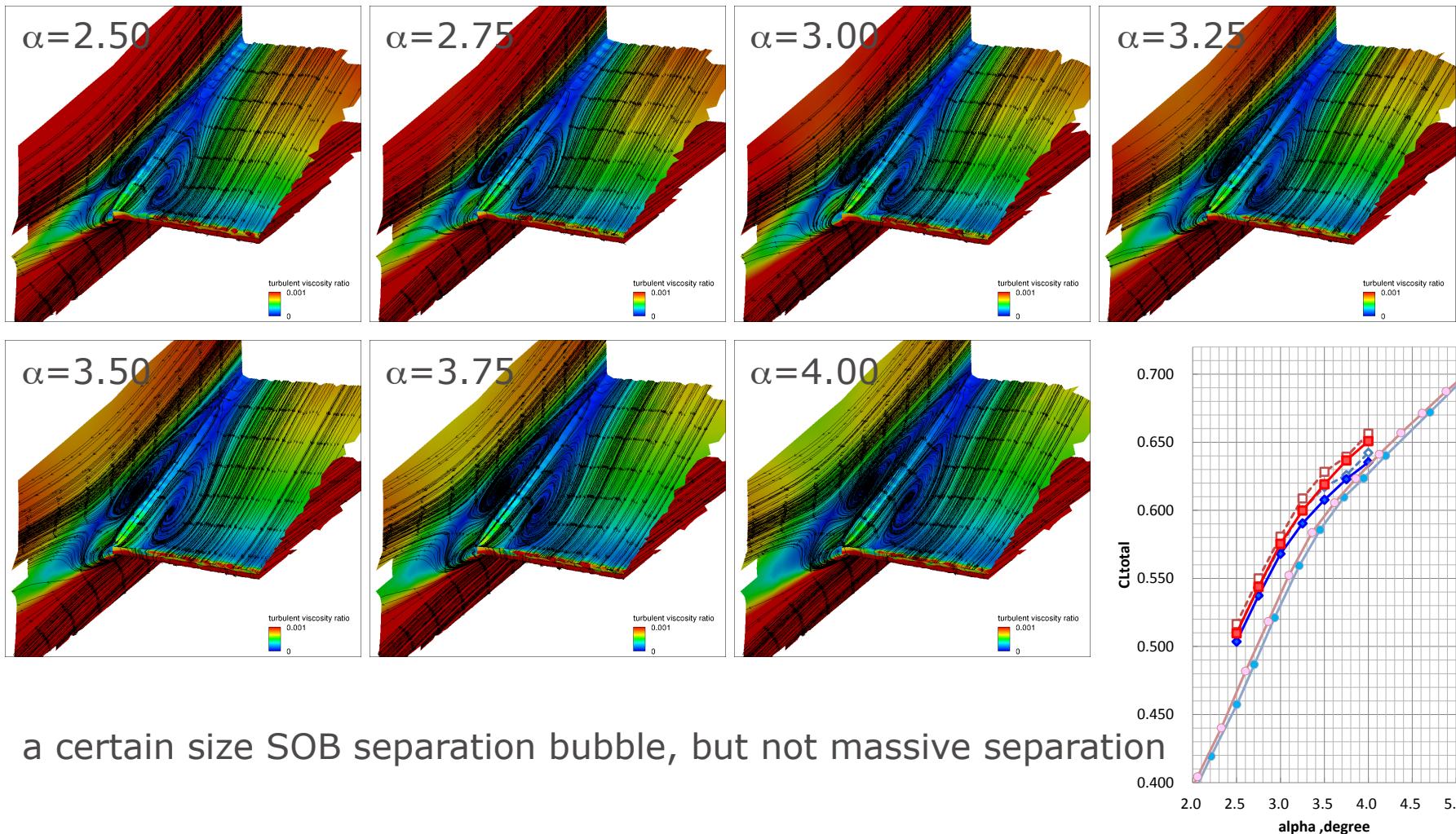
Case3 WB : Cp variation

- Cflow Grid, SA-noft2
- Baseline Grid, SA-noft2
- WT Data
- WT Data



Case 3 SOB Separation Bubble

WB, Cflow NOBLU Grid, SA-noft2



a certain size SOB separation bubble, but not massive separation