KHI computed results using *Cflow* for HiLiftPW-2

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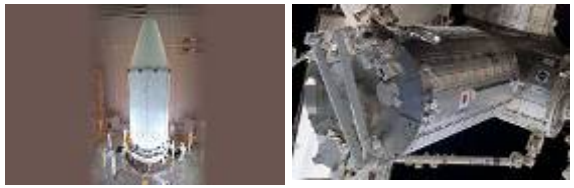
Presentation Outline

- Introduction
- KHI in-house CFD tool, "***Cflow***"
- KHI independently-generated grid by "***Cflow***"
- Results
  - Comparison between Cflow grid and committee provided grid
- Conclusion

About Us

- Kawasaki Heavy Industries, LTD. (***KHI***) is Japanese manufacture of a variety of transportation equipment (ships, rolling stock, ***aircraft***, motorcycle) , plant, and general machinery

Main Products of Kawasaki Group

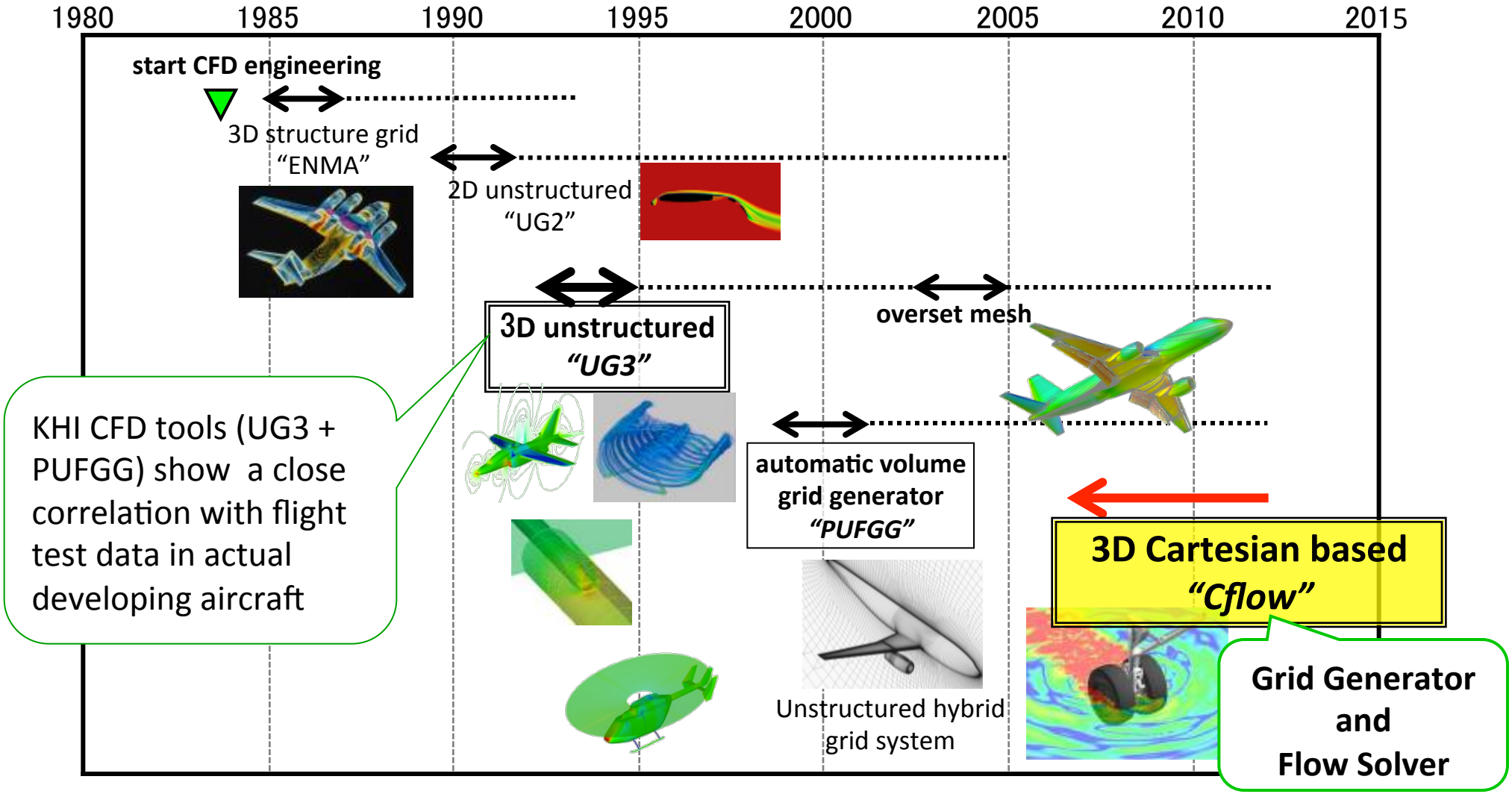
Airplanes	
Helicopters	
Space-related	

Main Products of Aerospace Company

quote from http://www.khi.co.jp/

History of CFD Engineering in KHI

- Since 1980s KHI has developed in-house CFD tools and used them for aircraft design

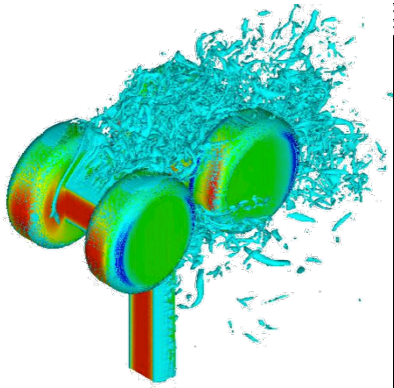


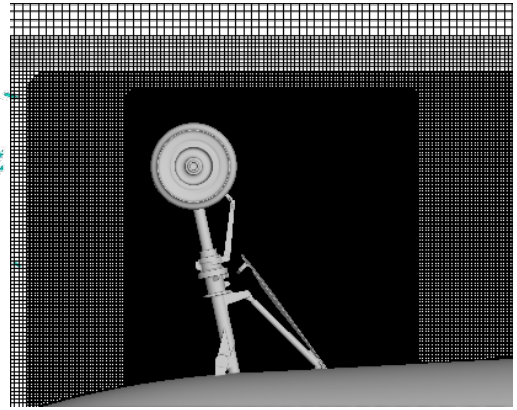
Early studies of Cflow

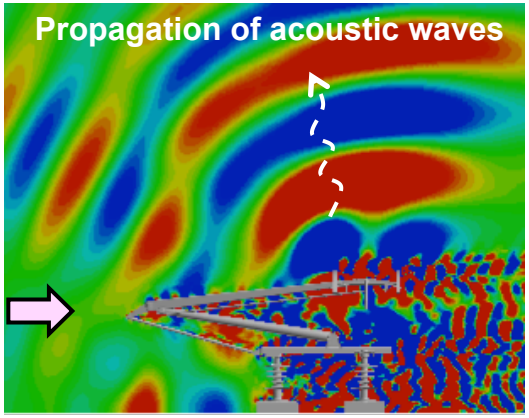
- KHI developed Cflow to meet growing needs for computation of ***highly complicated configuration*** or ***unsteady analysis*** about ***aeroacoustic problem***, wake interaction, etc.
  - Landing gear of aircraft
  - Pantograph of high speed train

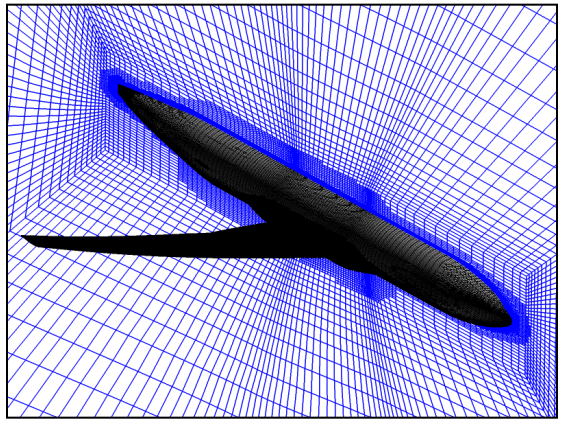
Cartesian base grid achieved promising result

- Next target is to steady/unsteady computation about aircraft configuration (***high aspect ratio*** wing, ***sweptback*** and ***dihedral*** angle)









Motivation and KHI computed cases

- Validation and verification of KHI in-house CFD code
- **Benchmark new CFD tool "Cflow" for a 3D high lift configuration and clarify the issues**

Case1		Grid	
		Cflow	C_uns_mix
Flow Solver	Cflow	***will be submitted***	submitted
	UG3	N/A	submitted

Case2a,2b		Grid	
		Cflow	C_uns_mix
Flow Solver	Cflow	not completed	*will be submitted*
	UG3	N/A	*will be submitted*

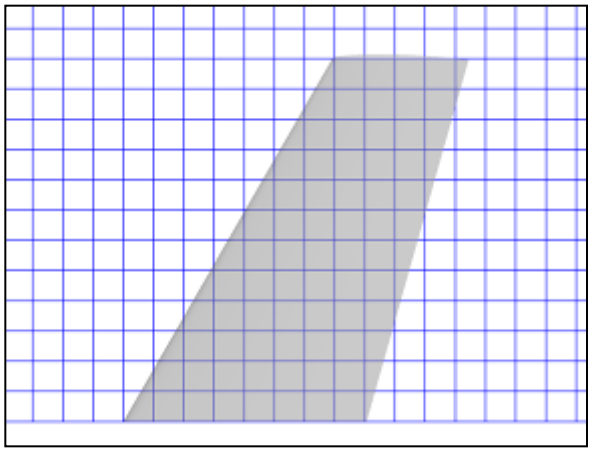
Case4		Grid
		3D unstructured Quad
Flow Solver	Cflow	submitted*
	UG3	submitted*

*Submitted data were inappropriate in outflow boundary condition. Revised data will be submitted

Distinctive point of Cflow Grid

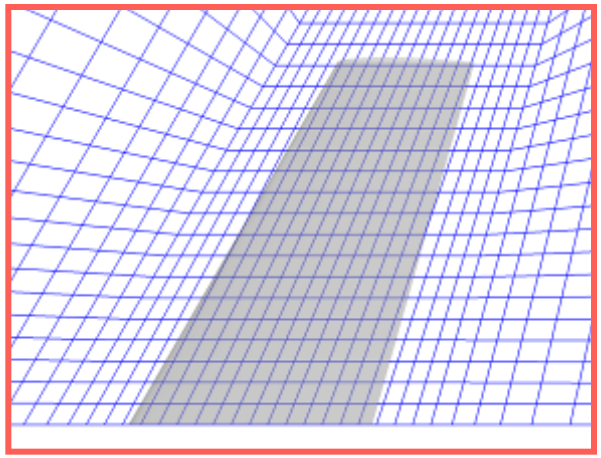
- Cflow conducts automatic Cartesian based grid generation
  - with octree Adaptive Mesh Refinement (AMR)
  - with Layered grid near surface for boundary layer
- In addition, ***"Non-Orthogonal Initial Grid"*** was developed to increase flexibility for high aspect ratio and sweptback configuration

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



Cartesian Initial Grid

conventional



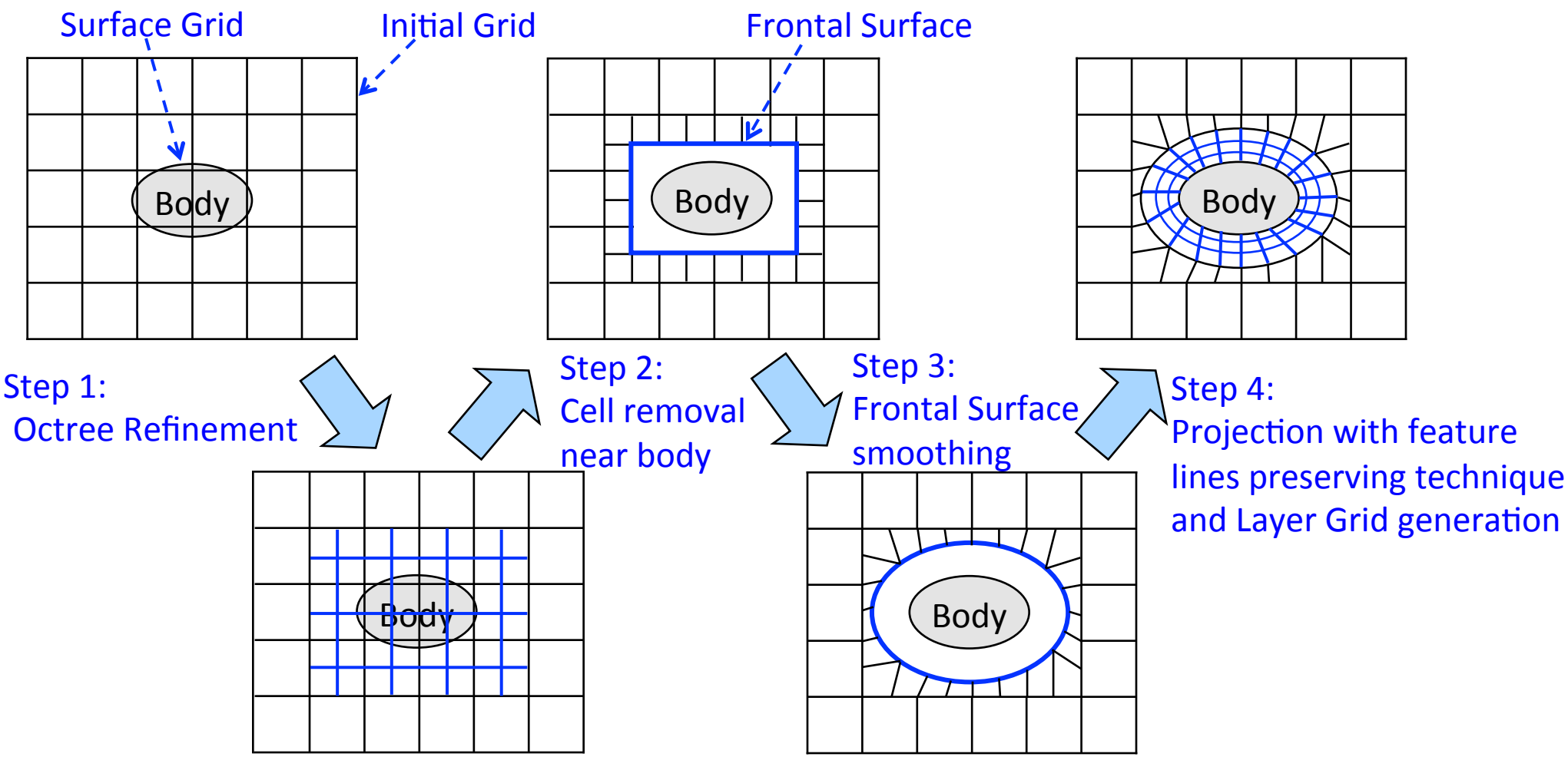
Non-Orthogonal Initial Grid

Cflow's unique point

- NOBLU Grid concept has been applied to NASA-CRM configuration (AIAA-2012-1259)

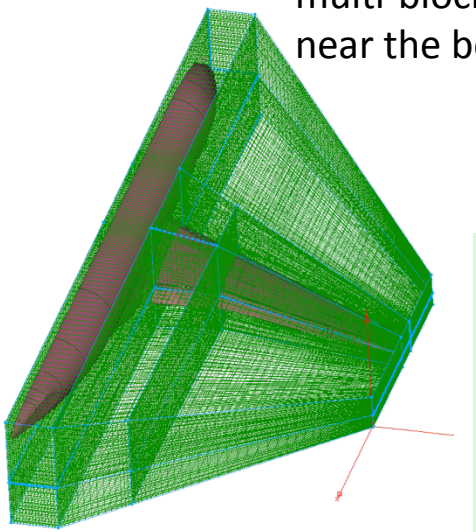
Cflow Grid Generation Procedure

- User prepare surface grid (STL) and initial grid (Cartesian or arbitrary non-orthogonal)
- Cflow automatically generate AMR with layer grid and surface mesh

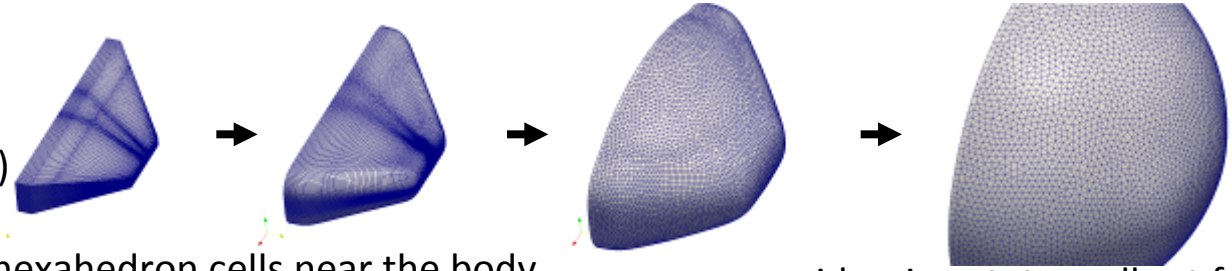


Initial Grid for High Lift Configuration

- a multi-block hexahedral structured grid generated by PointwiseV17
  - cuboidal block near the fuselage, oblique block along sweptback and dihedral angle around the wing
  - Control grid density and aspect ratio
- pile-up forming volume grid generated from structured grid boundary surface to far-field boundary

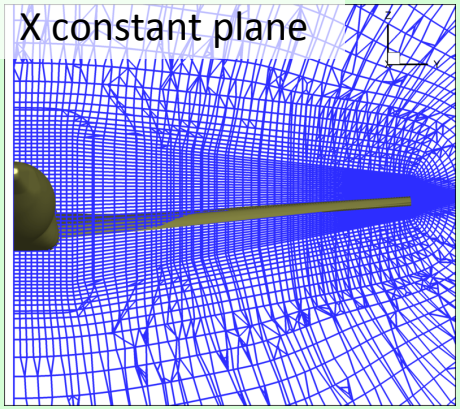


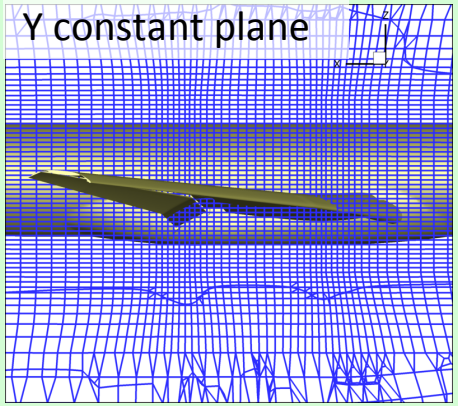
multi-block structured grid near the body (hexahedron)

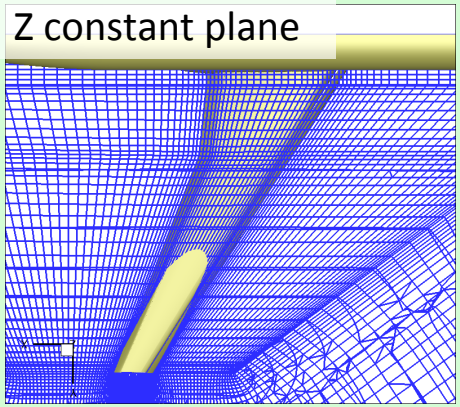


keep hexahedron cells near the body to allow adaptive mesh refinement

use pyramid, prism, tetra cells at far from the body







arbitrary shaped Initial Grid

Cflow Grid Information

- Case1 – Config 2
  - Cflow generated Coarse and Medium level grid. Fine level grid was not completed

Grid Level	Number of Total Nodes	Number of Total Cells	Wall Boundary Nodes	Wall Boundary Faces	Number of BL Layers
Coarse	23 million	23 million	0.6 million	0.6 million	32
Medium	74 million	74 million	1.3 million	1.3 million	52
Fine	will be about 200 million		-	-	-

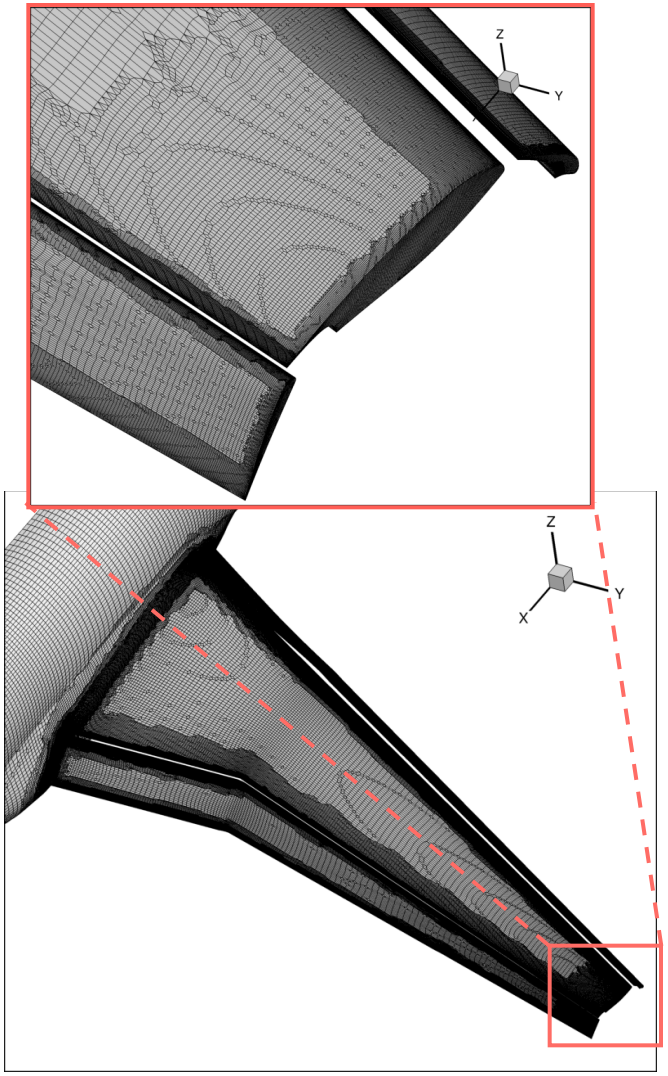
- Case2 – Config 4 (Config2 + FTF/STF)
  - Gridding was not completed

Need to improve grid generation algorithm / technique / Initial Grid

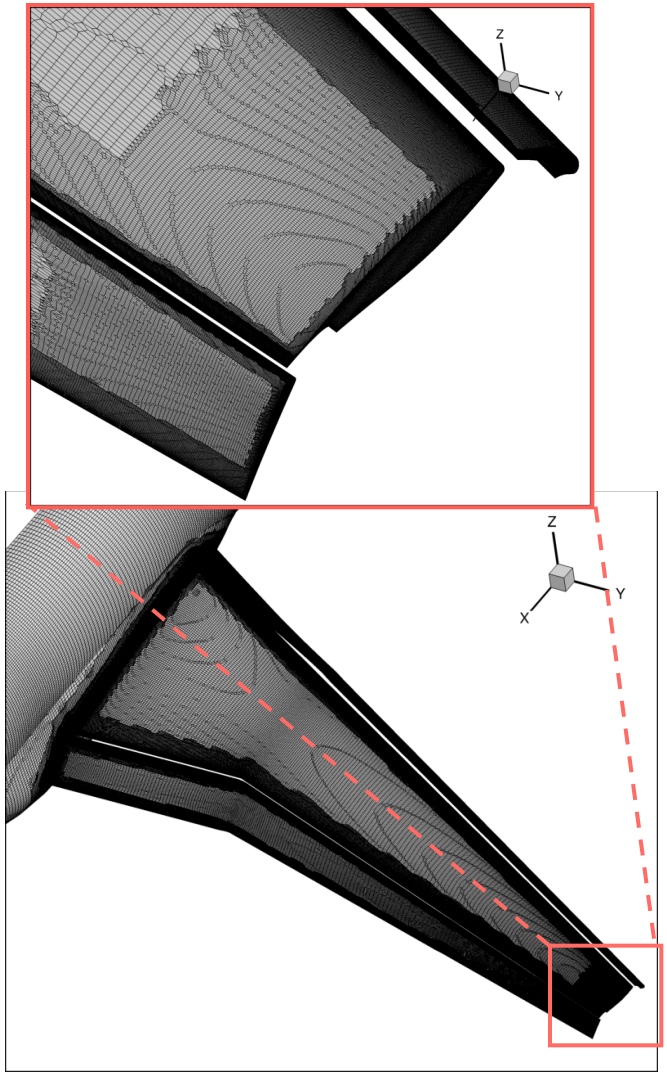
FYI: Config2_C_uns_mix_medium grid; the number of total cells is 130 million

Grid detail, Wing

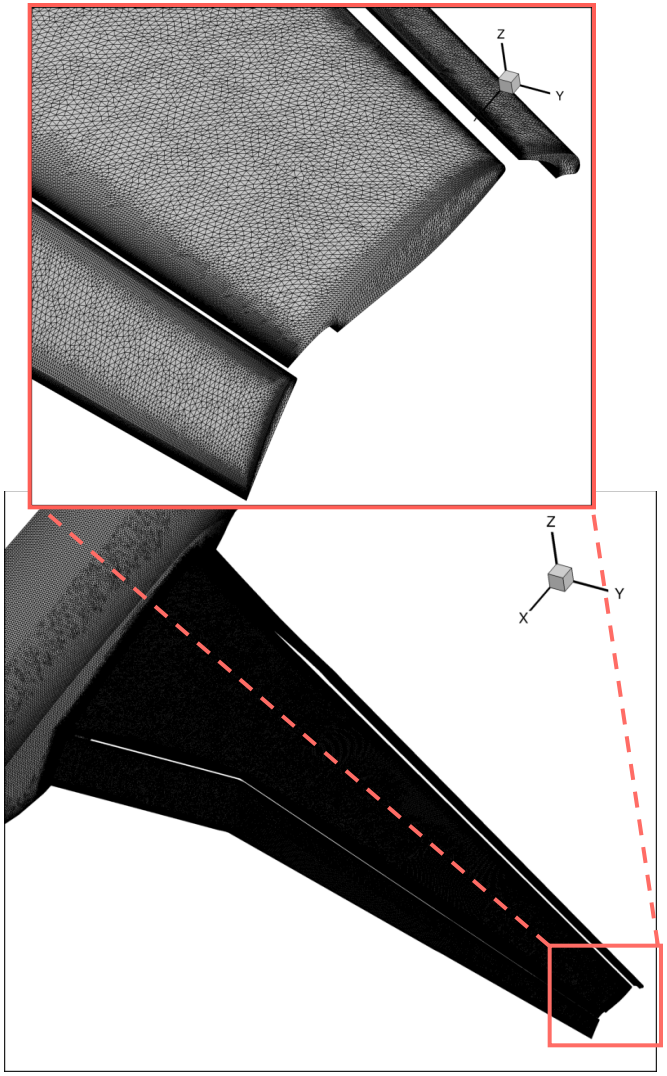
Cflow Grid - Coarse



Cflow Grid - Medium

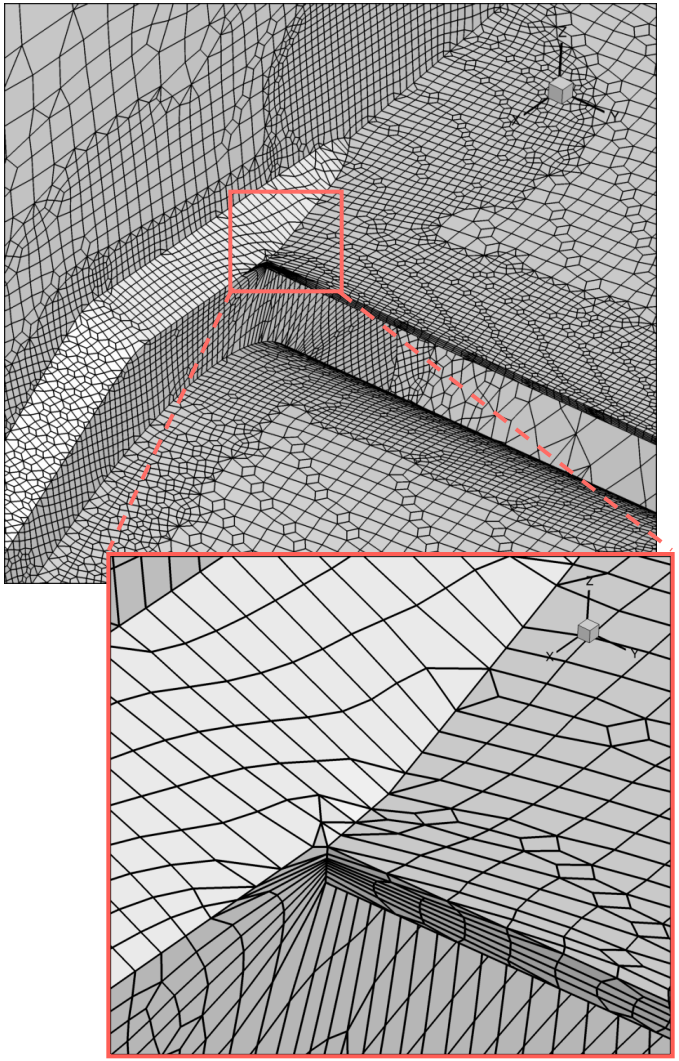


C_uns_mix Grid - Medium

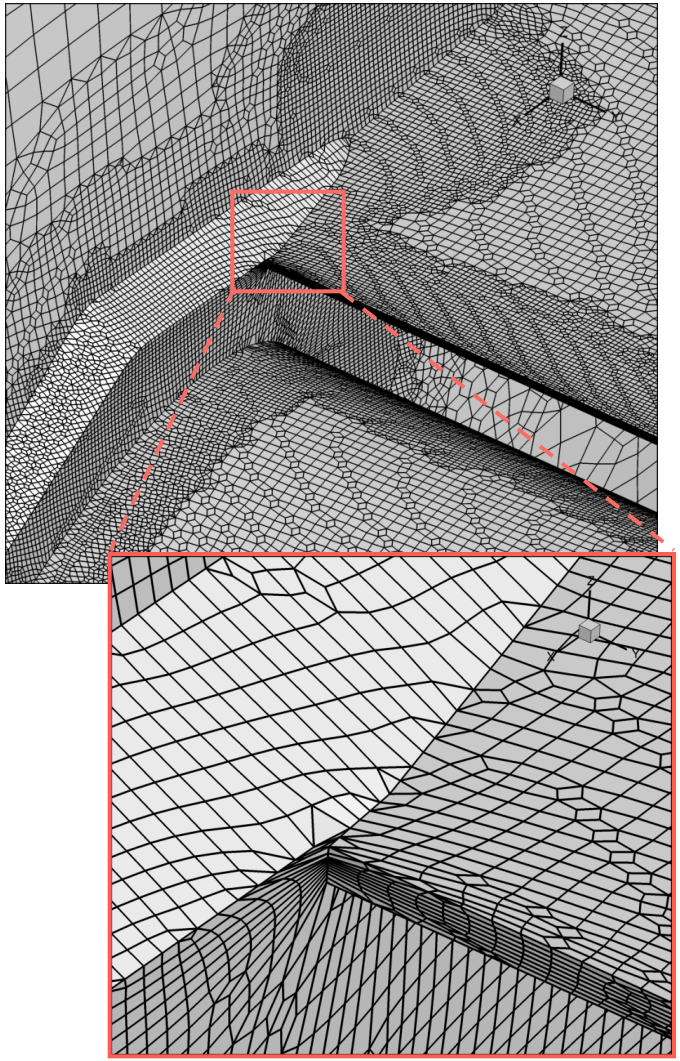


Grid detail, flap-seal

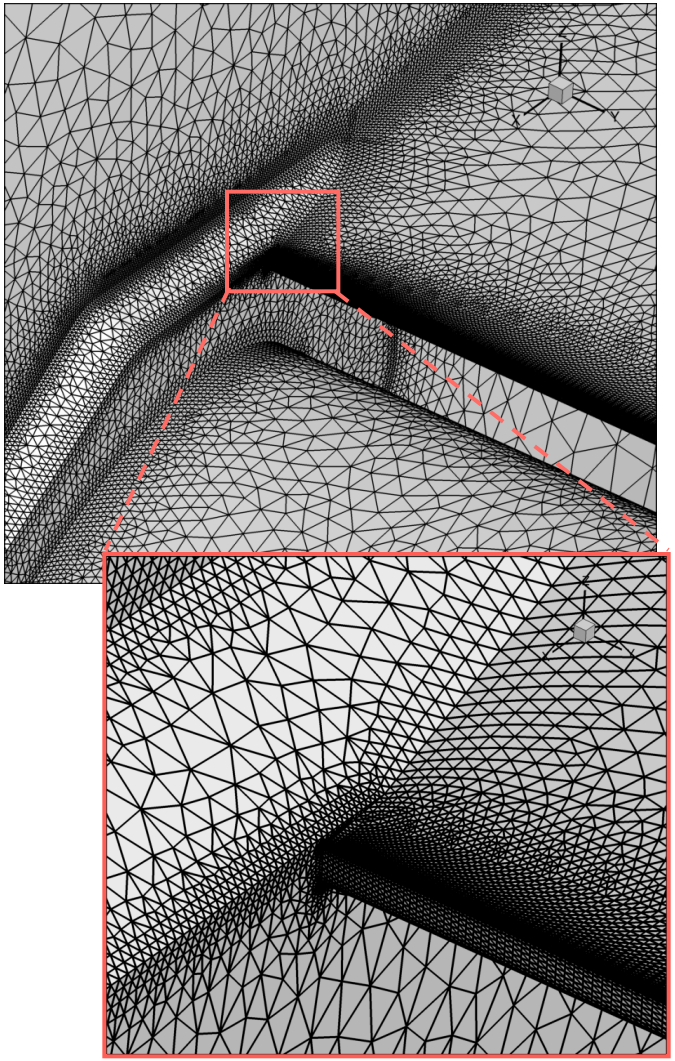
Cflow Grid - Coarse



Cflow Grid - Medium



C_uns_mix Grid - Medium



Grid detail, η=0.288 (PS 02)

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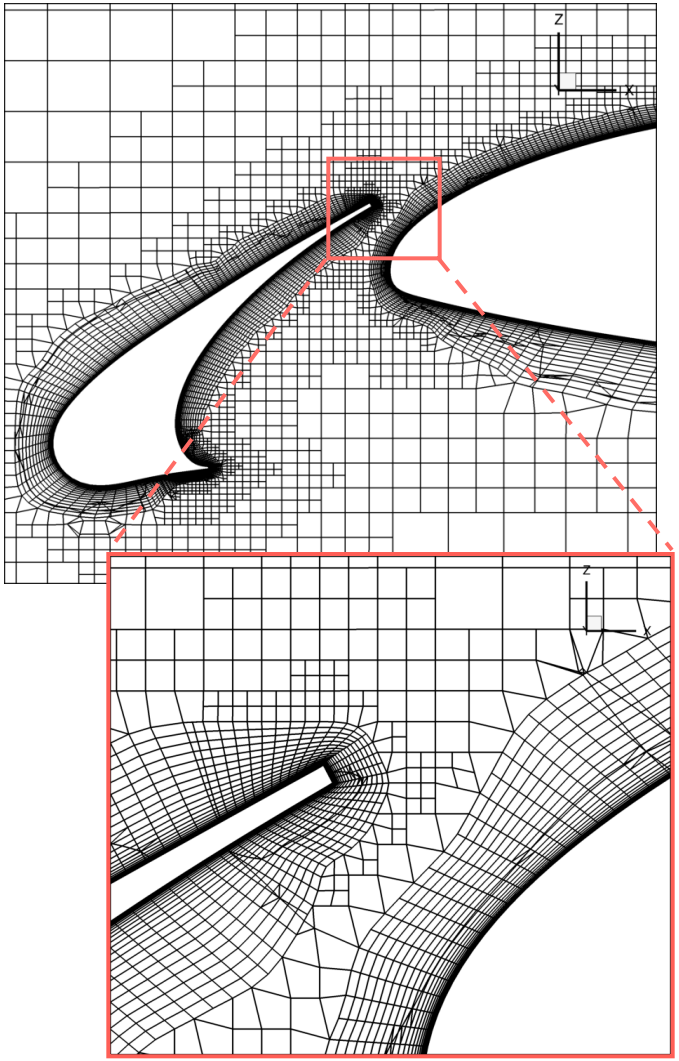
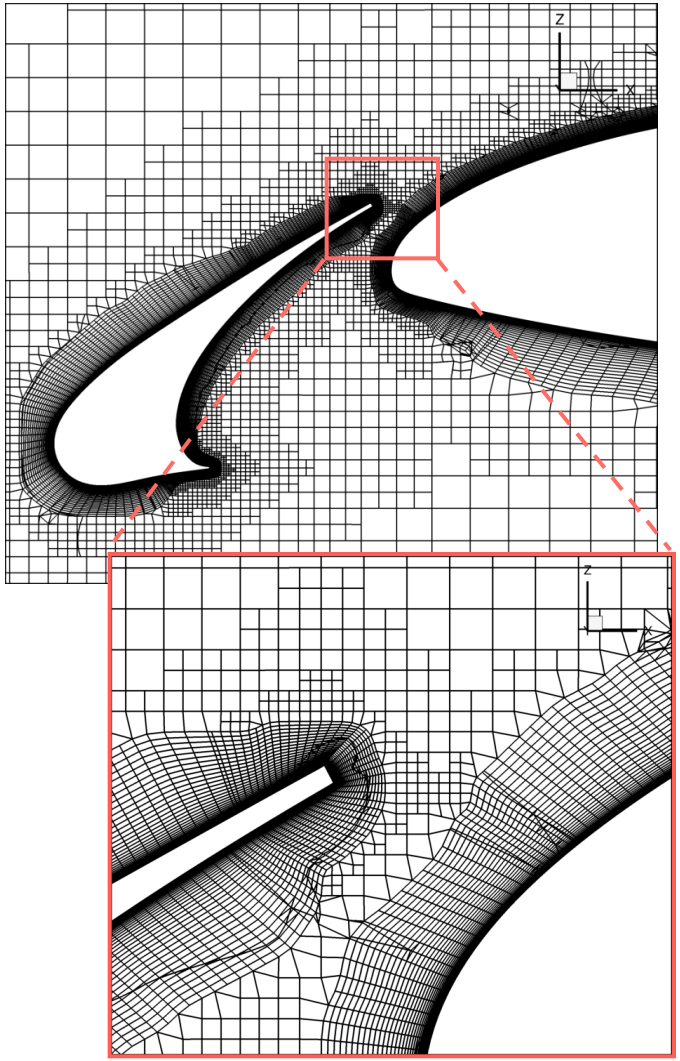
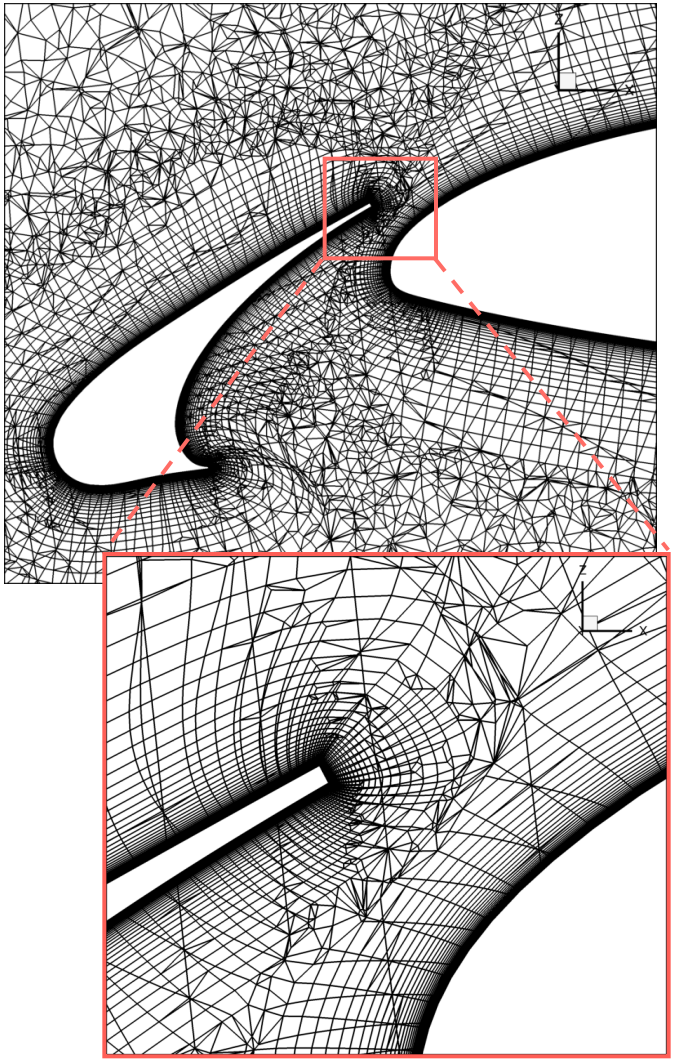
Cflow Grid - Coarse



Cflow Grid - Medium



C_uns_mix Grid - Medium



Grid detail, η=0.681 (PS 06)

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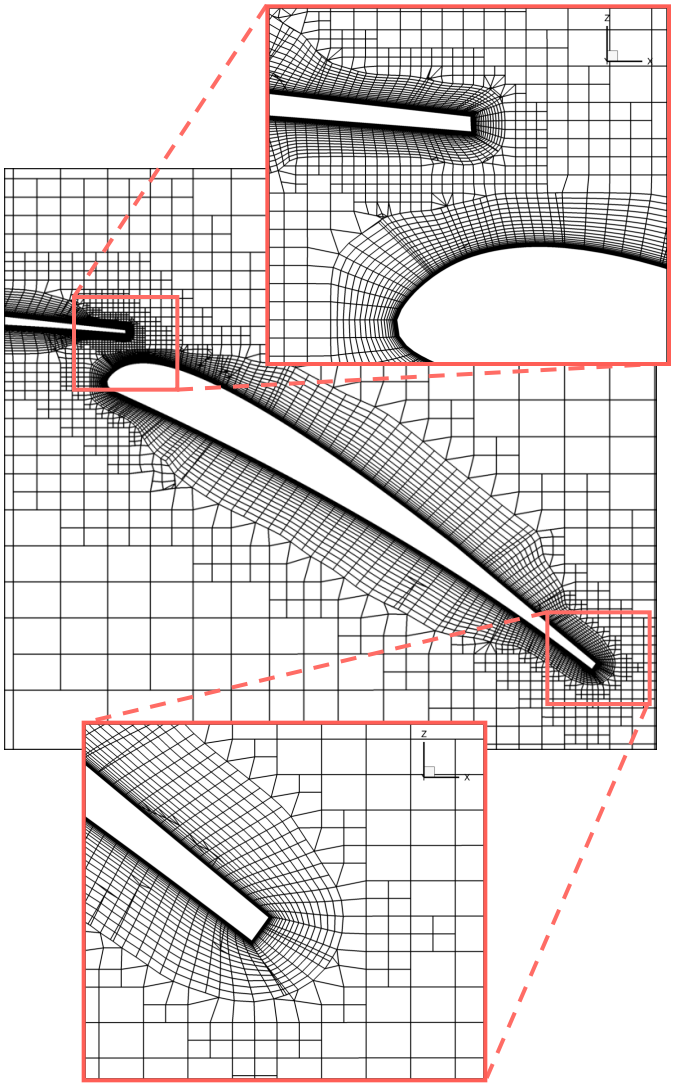
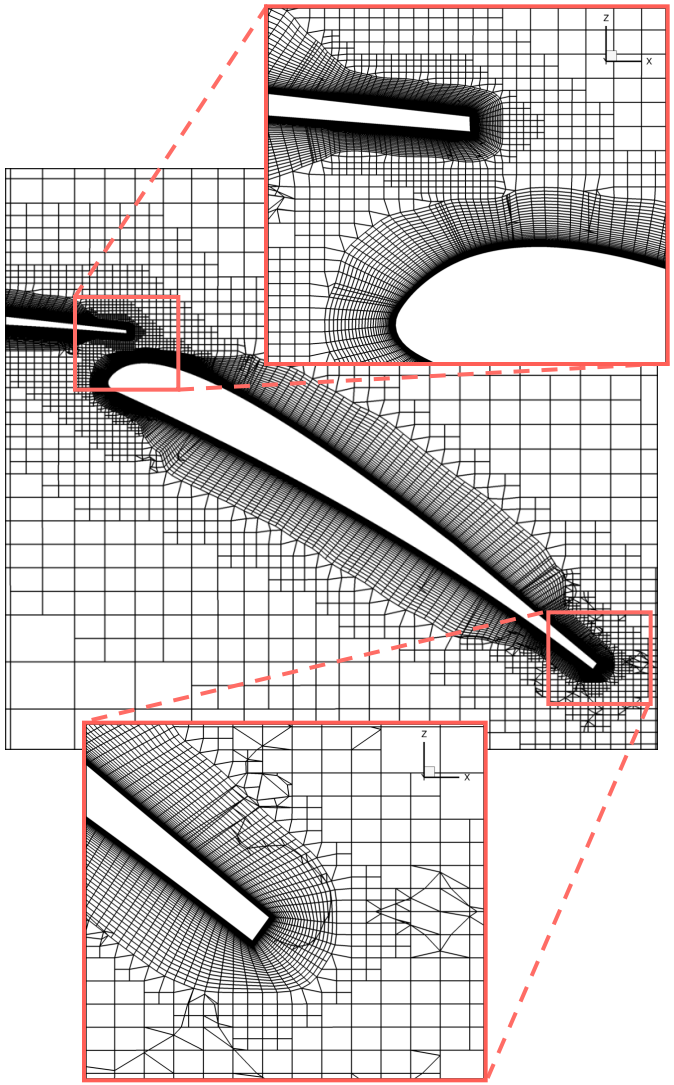
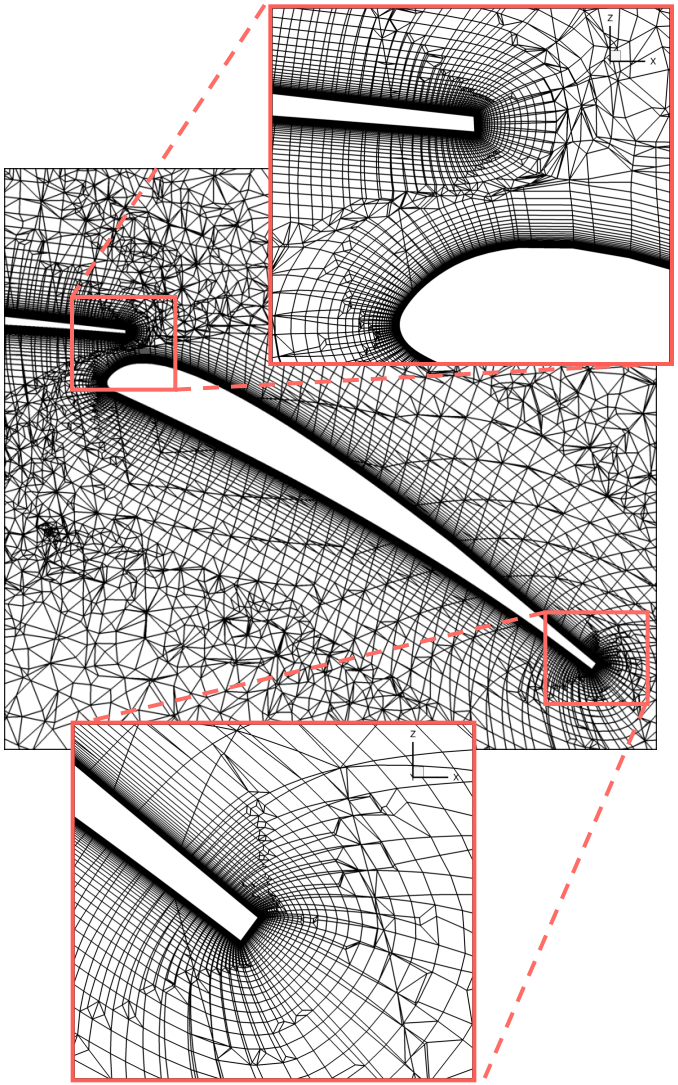
Cflow Grid - Coarse



Cflow Grid - Medium



C_uns_mix Grid - Medium

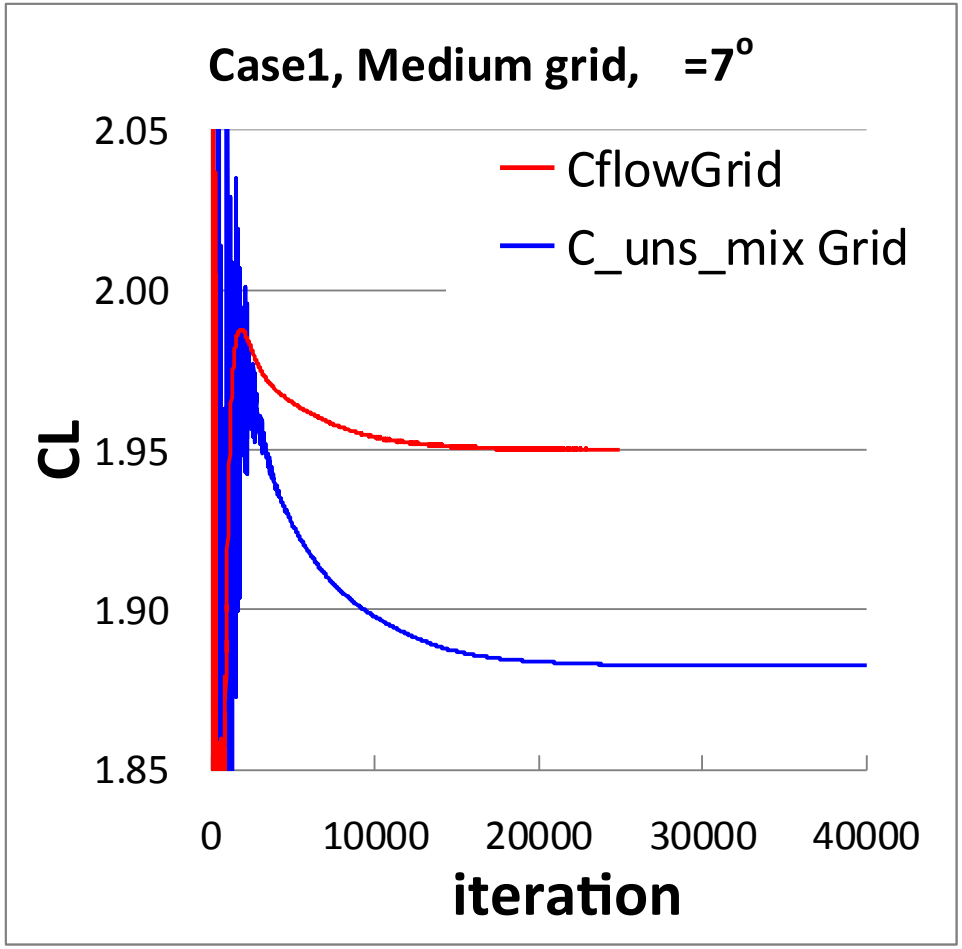


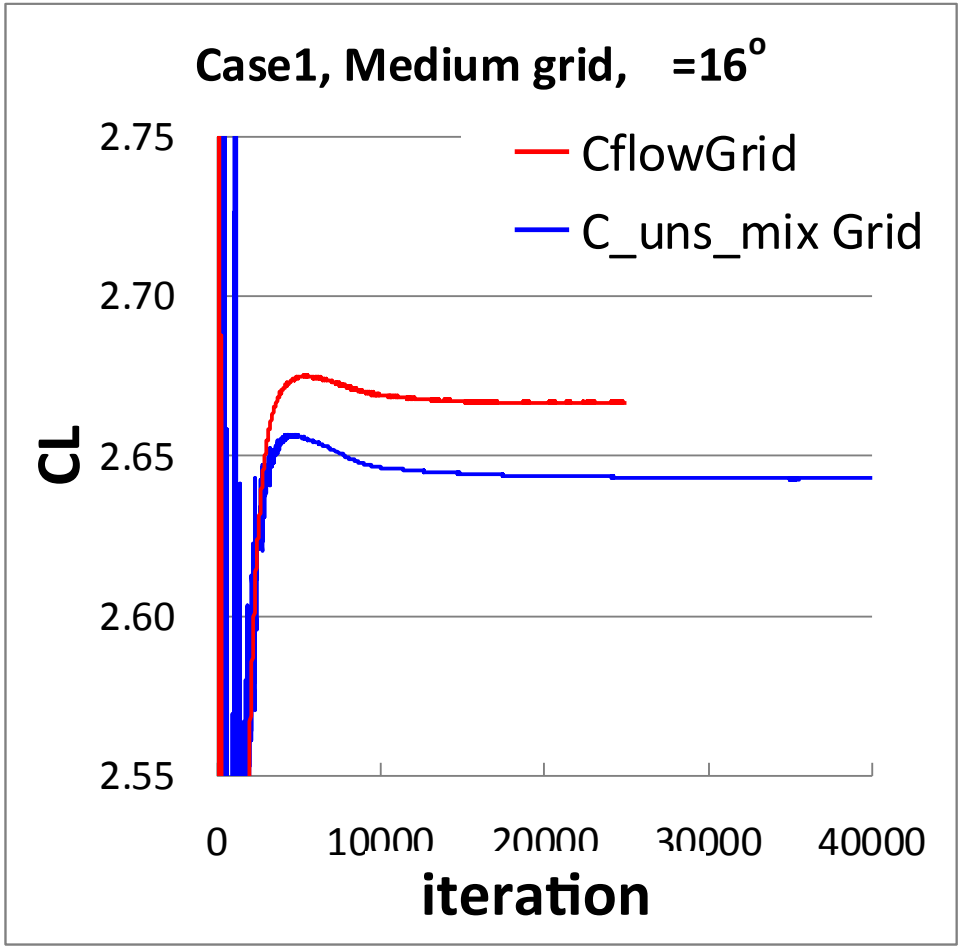
Numerical schemes of flow solver (used in this study)

- Grid System
  - Unstructured hybrid grid (polyhedral cells) with ***layered grid***
  - Octree Adaptive Mesh Refinement (***AMR***)
- Governing equation
  - Reynolds-Averaged Navier-Stokes equation (***RANS***)
- Time integration
  - Matrix Free Gauss-Seidel (MFGS) implicit method
- Spatial discretization
  - Cell-centered finite volume method
  - Simple Low-dissipation AUSM scheme (***SLAU***)
  - 2nd-order accurate MUSCL with modified Green-Gauss method
- Turbulence model
  - Spalart-Allmaras one equation model (***S-A***)
- Parallel computation
  - domain decomposition method with ***MPI***

Results: Case1, Iterative

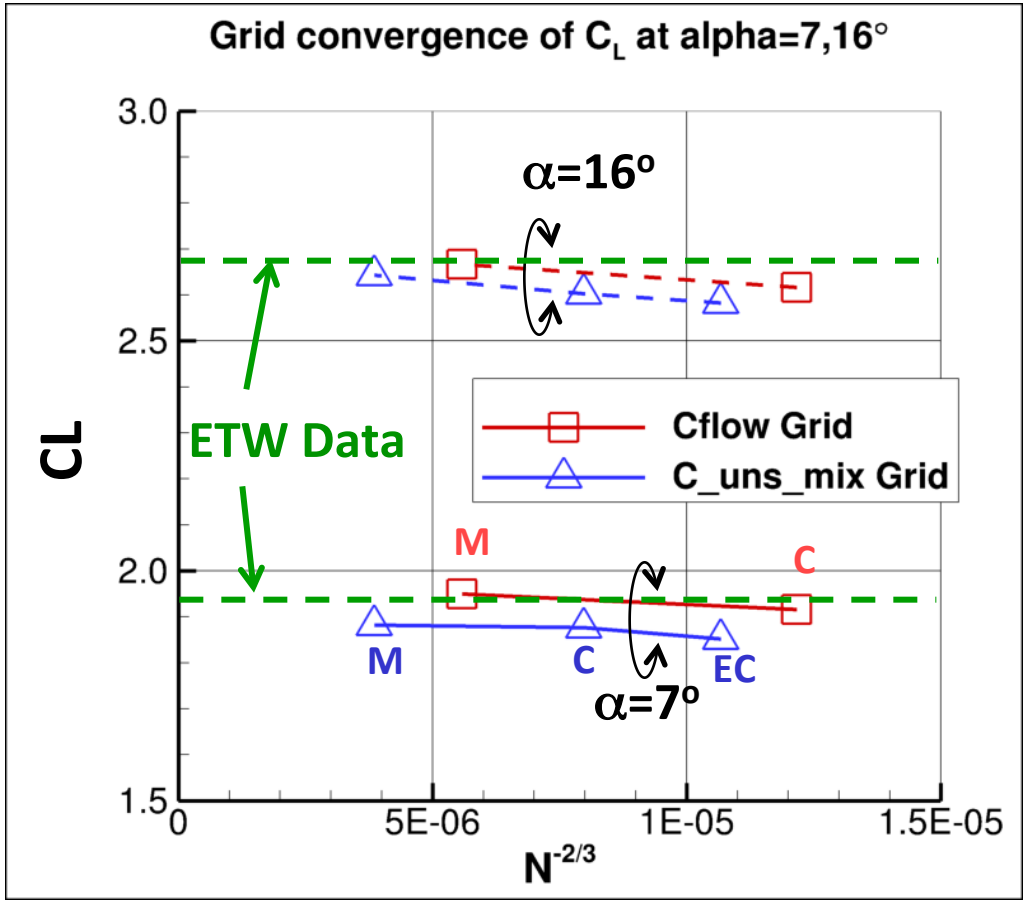
- Cflow grid got to steady state faster than C_uns_mix grid

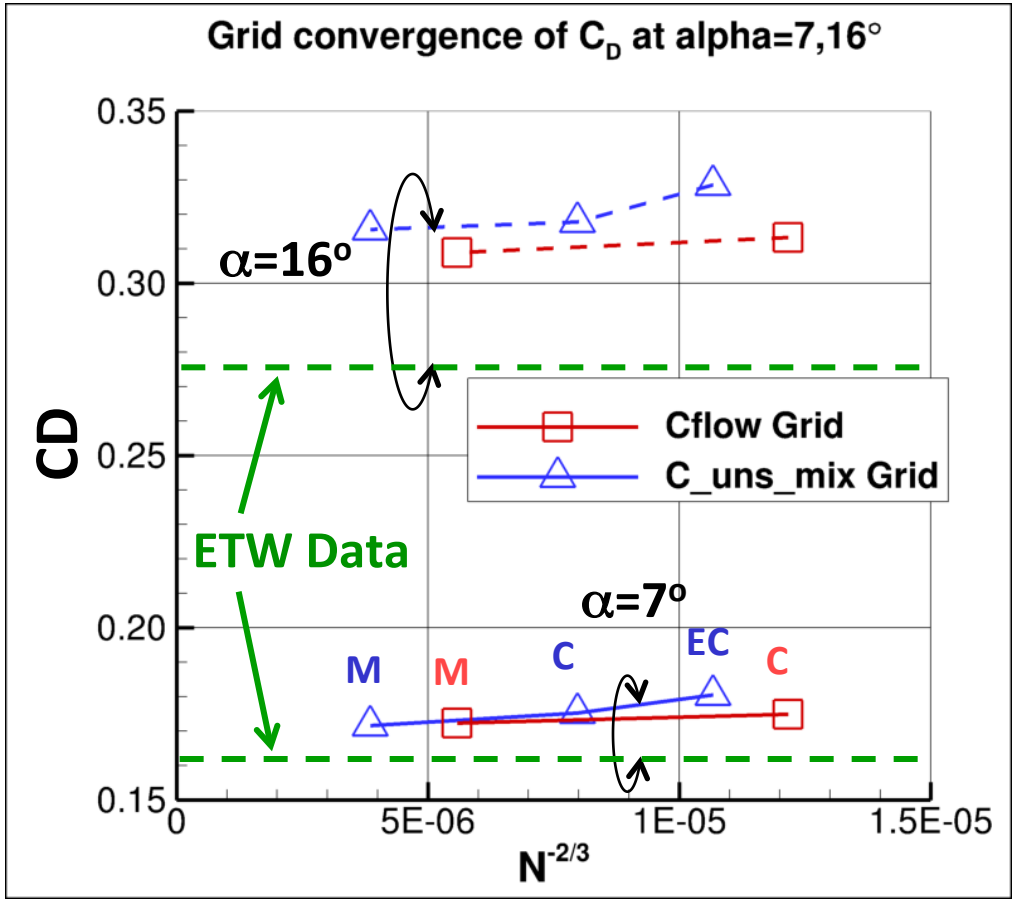




Results: Case1, Grid Convergence

- Cflow grid shows higher lift and lower drag than that of C_uns_mix grid
- Cflow grid can estimate experimental data with smaller grid size

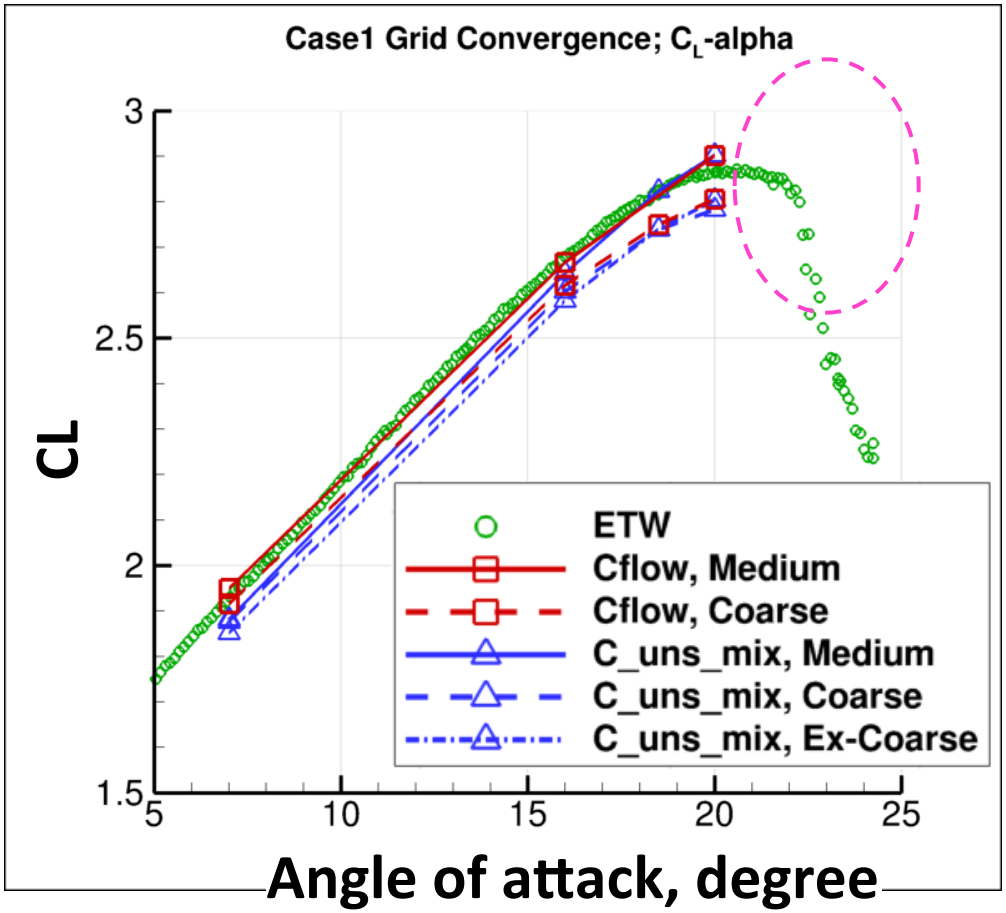


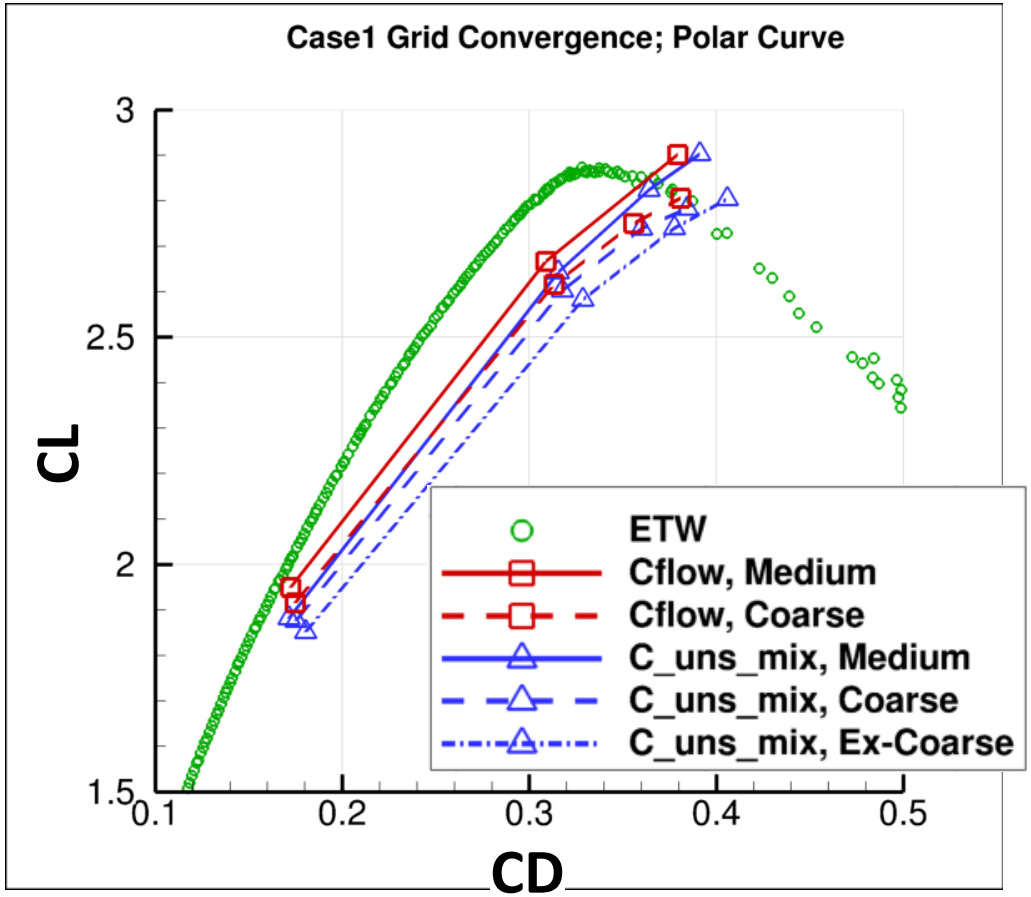


finer grid ← finer grid ←

Results: Case1, force & moment (1/2)

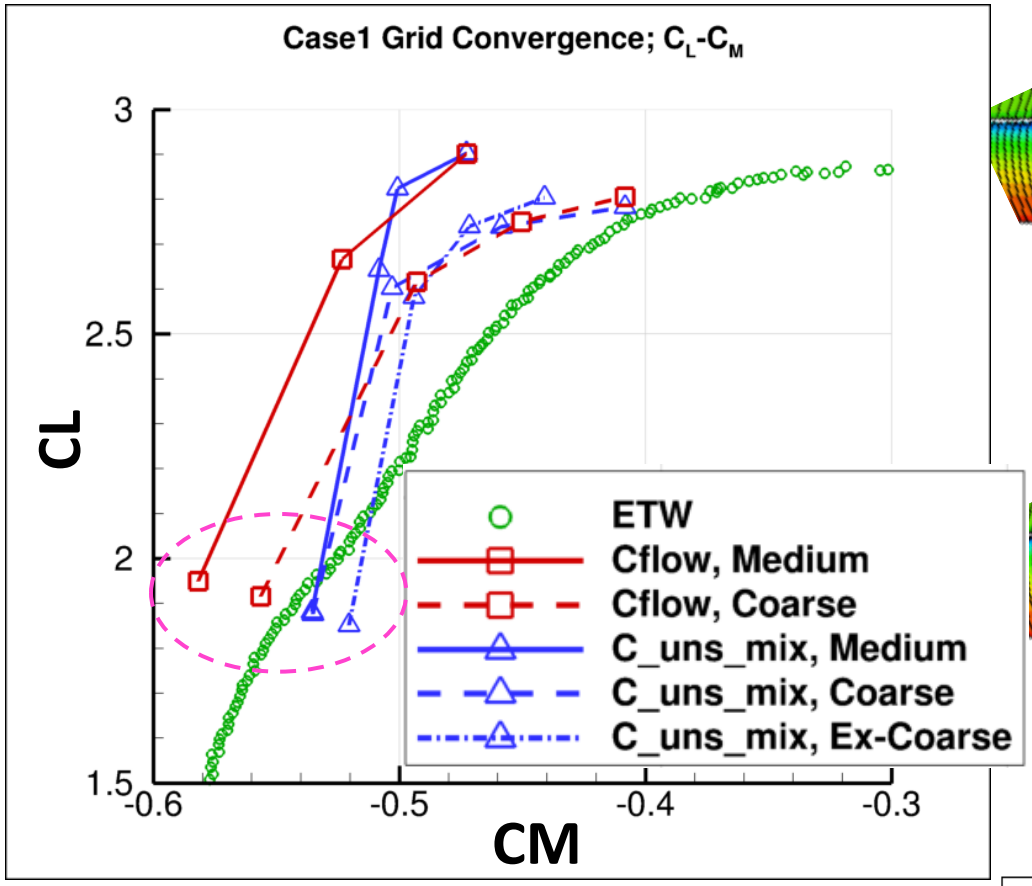
- most of the CFD results show lower lift than that of ETW data
- C_L of Cflow-Medium grid is in good agreement with ETW data
- high angle of attack cases will be computed

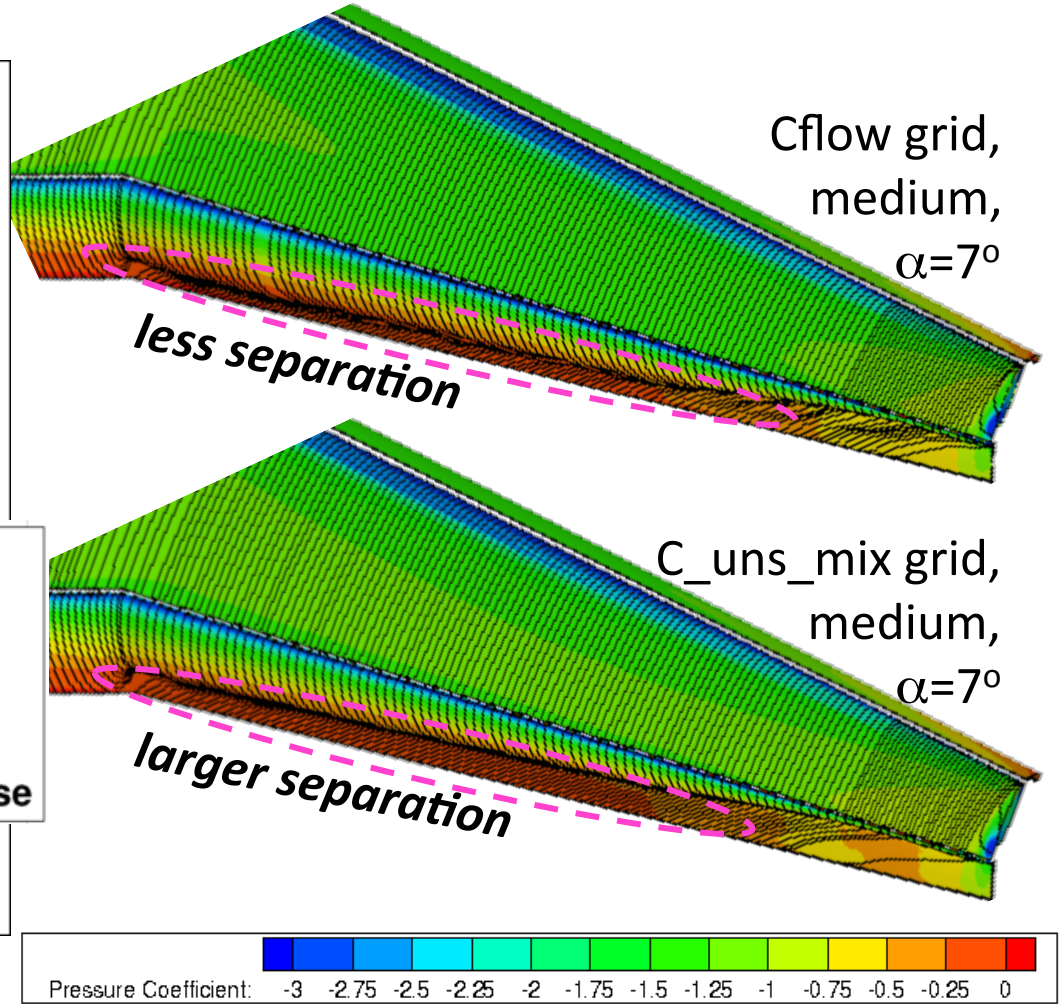




Results: Case1, force & moment (2/2)

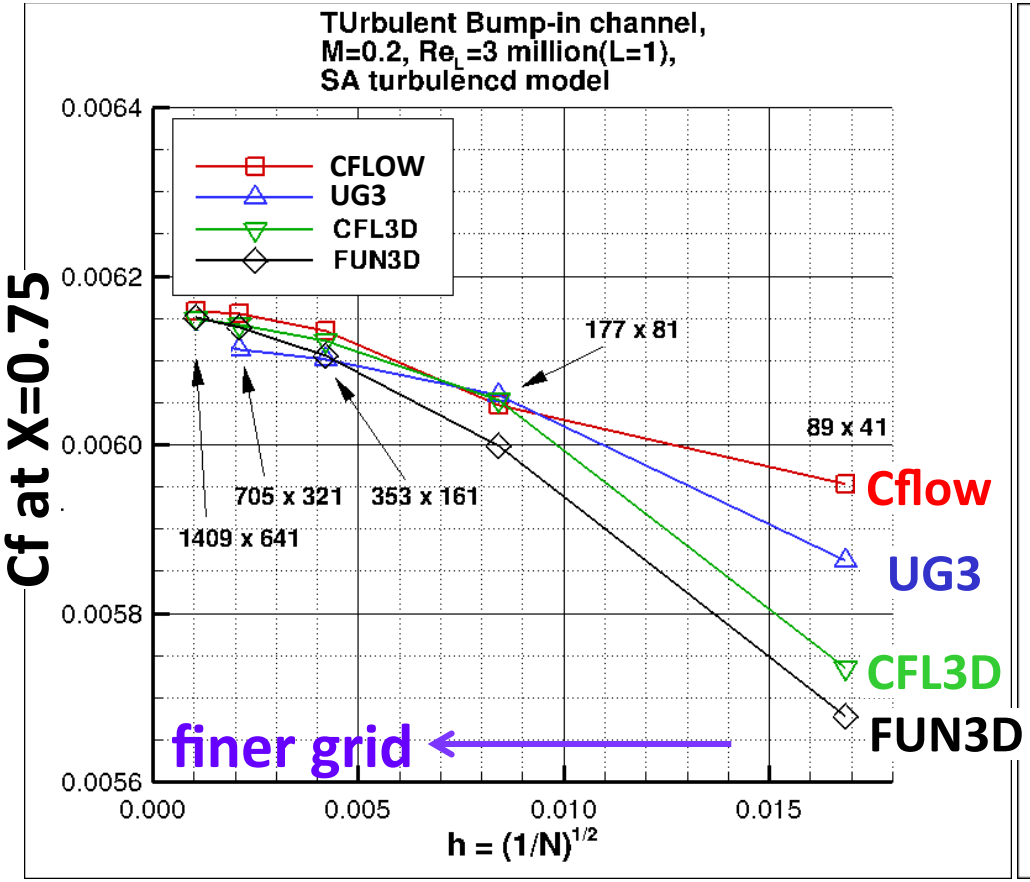
- C_L-C_M curve shapes vary widely at lower angle of attack
- Cflow grid has less separation area on the outboard flap than that of C_uns_mix grid

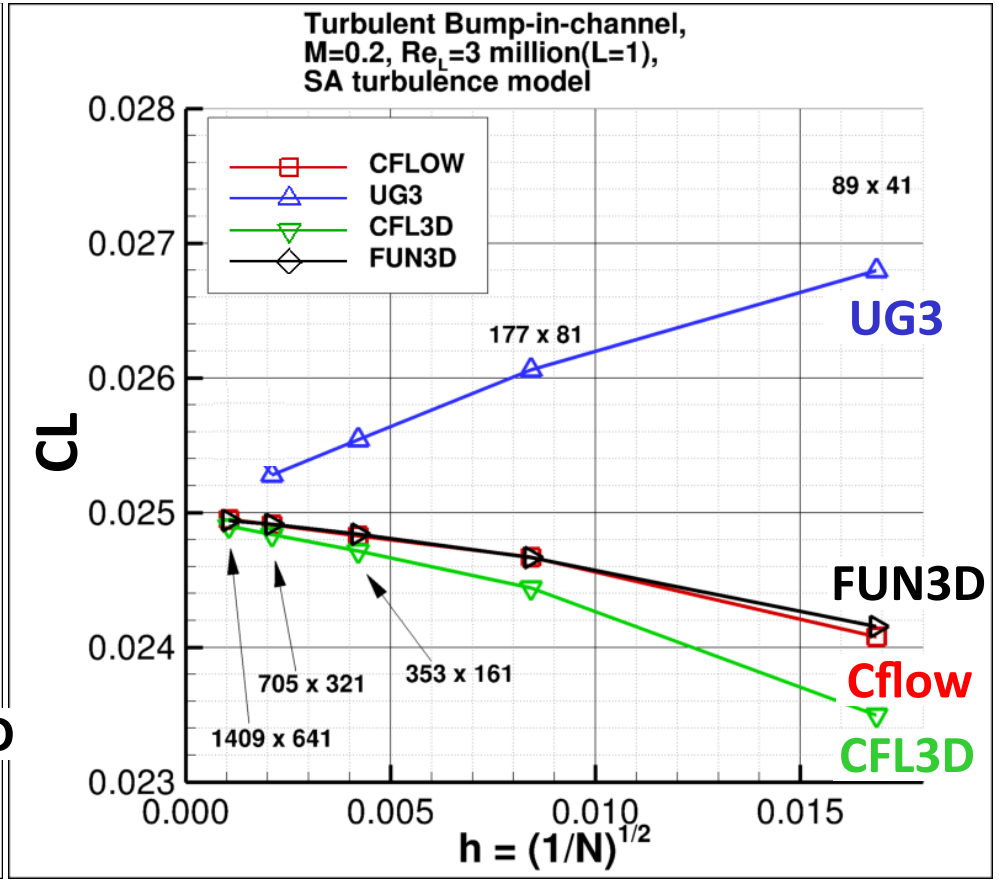




Results: Case4, Grid Convergence

- Submitted data were inappropriate outflow boundary condition (used free-stream condition)
- Revised computed data (used pressure outflow condition) shows good agreement with NASA codes in converged data.





Conclusion

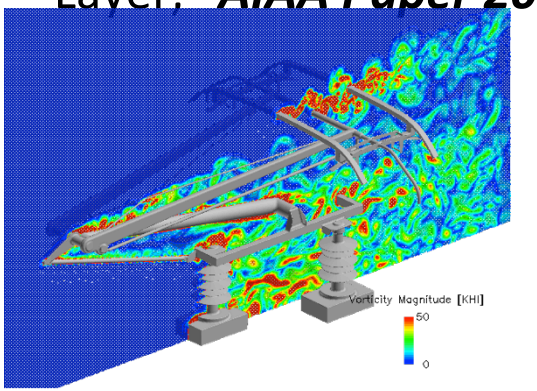
- KHI has been developing a new CFD tool "Cflow"
  - consists of Cartesian based grid generator and flow solver
  - "Non-Orthogonal Initial Grid" was developed to increase flexibility such as high aspect ratio and sweptback cells
- Benchmark Cflow for 3D high lift configuration
  - Cflow generated Coarse and Medium level grid. Fine grid was not completed
    - Cflow grid can reduce grid point by controlling initial grid shape and grid density
    - Cflow grid generation algorithm needs more robustness
  - Compared between "Cflow grid" and "C_uns_mix grid" calculated by "Cflow solver"
    - Cflow grid (i.e. NOBLU grid) shows a capability of application to an aircraft with high lift configuration.

- Cflow Grid (CGNS format) and computed results will be submitted

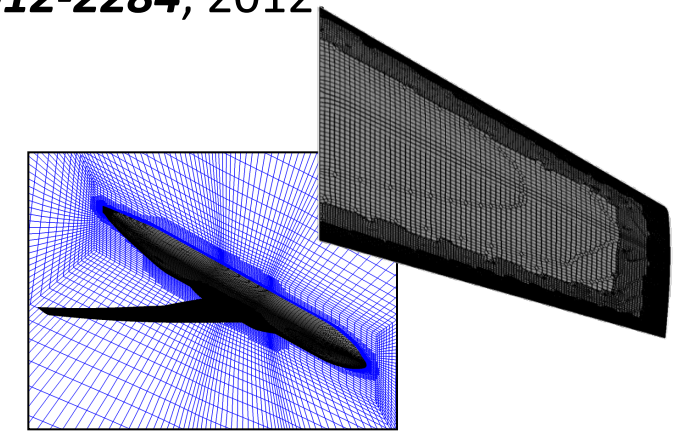
Thank you for your attention.

If you become interested in “Cflow”, you can find more detail information in the bellow papers.

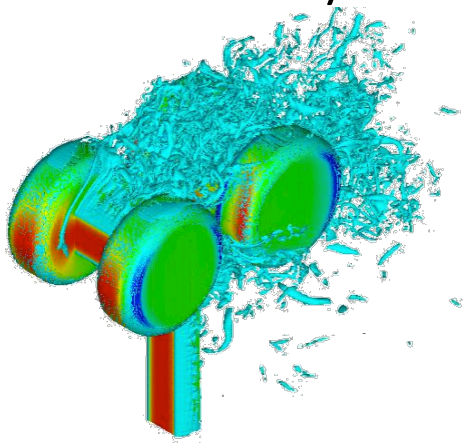
1. Ueno, Y., Ochi, A., Hayama, K., and Sasaki, T., “Prediction of Aeroacoustic Noise around High-speed Train using Unsteady CFD Analysis,” Inter-Noise, Osaka, 2011.
2. Nagata, T., Ueno, Y., and Ochi, A., “Validation of new CFD tool using Non-orthogonal Octree with Boundary-fitted Layer Unstructured Grid,” ***AIAA Paper 2012-1259***, 2012.
3. Ueno, Y., Nagata, T., Ochi, A., and Hayama, K., “Aeroacoustic Analysis of the Rudimentary Landing Gear Using Octree Unstructured Grid with Boundary-fitted Layer,” ***AIAA Paper 2012-2284***, 2012



1. Inter-noise, Pantograph



2. AIAA-2012-1259, NASA-CRM configuration



3. AIAA-2012-2284, Landing Gear

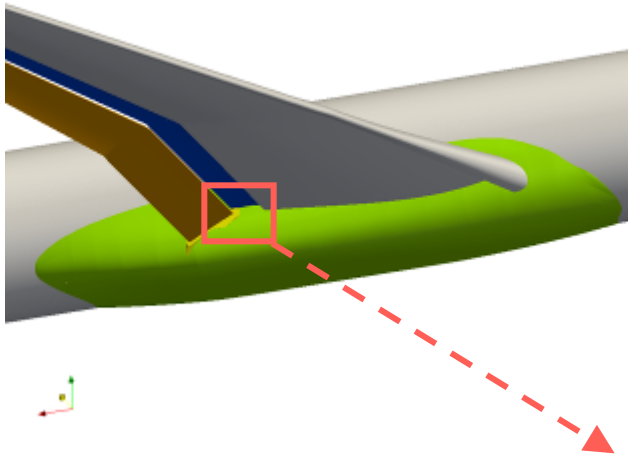
Computed time

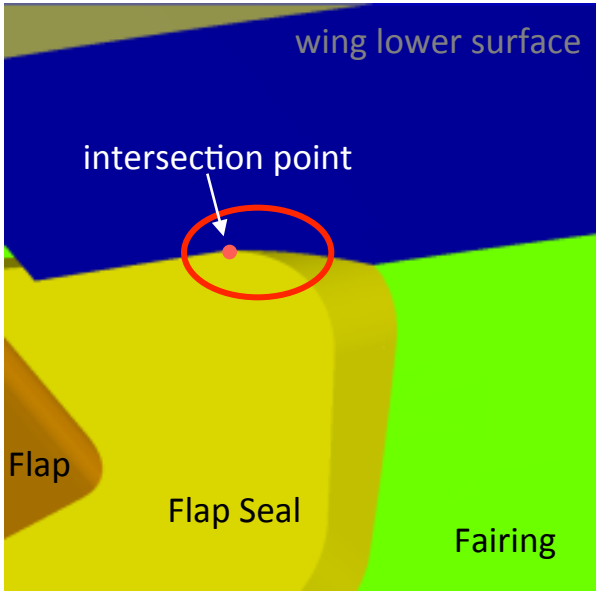
- Cflow Grid
  - Medium grid
  - 128CPU parallel
  - about 4days
  - CPU: Xeon X5660, 2.8GHz, 2CPU/6cores

- C_uns_mix Grid
  - Medium grid
  - use 256CPU
  - about 3 days
  - Xeon E5-2670, 2.6GHz, 2CPU/8cores

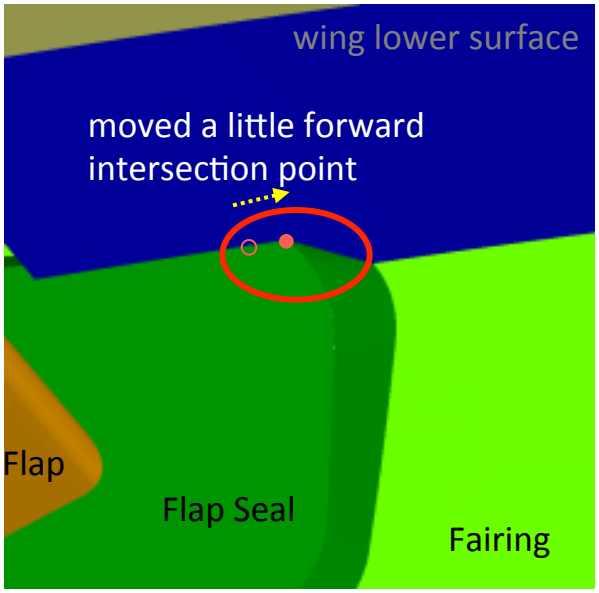
CAD modification

- intersection point of flap-seal and wing lower surface was moved a little forward for easier grid generation





original CAD data



modified CAD data

Numerical schemes of flow solver

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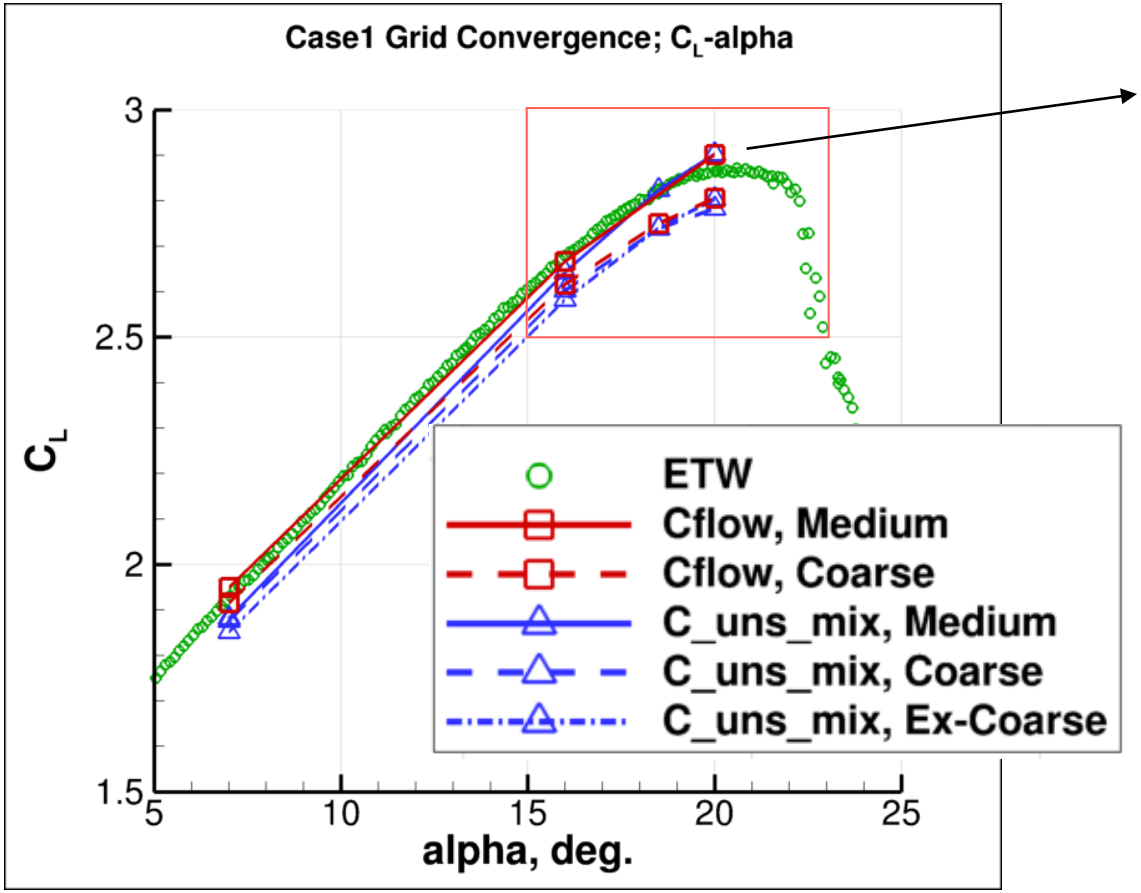
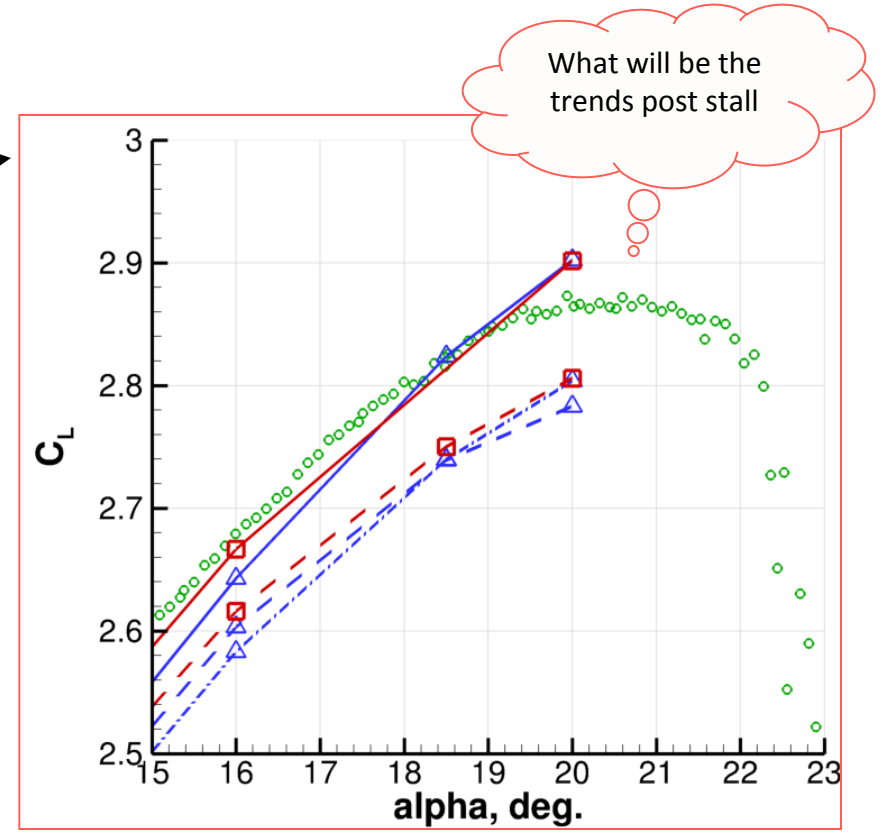
- Cflow basically implemented proven methods in UG3, furthermore some new schemes

	Cflow	***UG3***
Grid Systems	Unstructured hybrid (**polyhedral cells**) **Octree Adaptive Mesh Refinement**	Unstructured hybrid (hexahedron, prism, pyramid, tetrahedron cells) Overset Grid
Governing Equations	Three-dimensional, compressible Euler/Navier-Stokes	
Data Structure	face based	cell based
Spatial Discretization	Cell-centered finite volume method	
Reconstruction		
Interpolation to face value	MUSCL with modified Green-Gauss	MUSCL
Approximate Riemann Solver	SHUS, **SLAU**	SHUS, **LSHUS**, Roe, etc.
Viscous Term	2nd-order central difference	
Turbulence Models	Spalart-Allmaras (S-A)	***S-A***, Baldwin-Barth(B-B), Baldwin-Lomax (B-L), etc.
Unsteady Turbulence Models	DES, DDES	DES, DDES, LES
Time Integration	MFGS implicit method Runge-Kutta explicit method	
Parallelization	domain decomposition method with MPI *The number of parallel processing can be determined at the time of execution*	domain decomposition method with PVM, MPI, and Open MP

Results: Case1, force & moment (1/2)

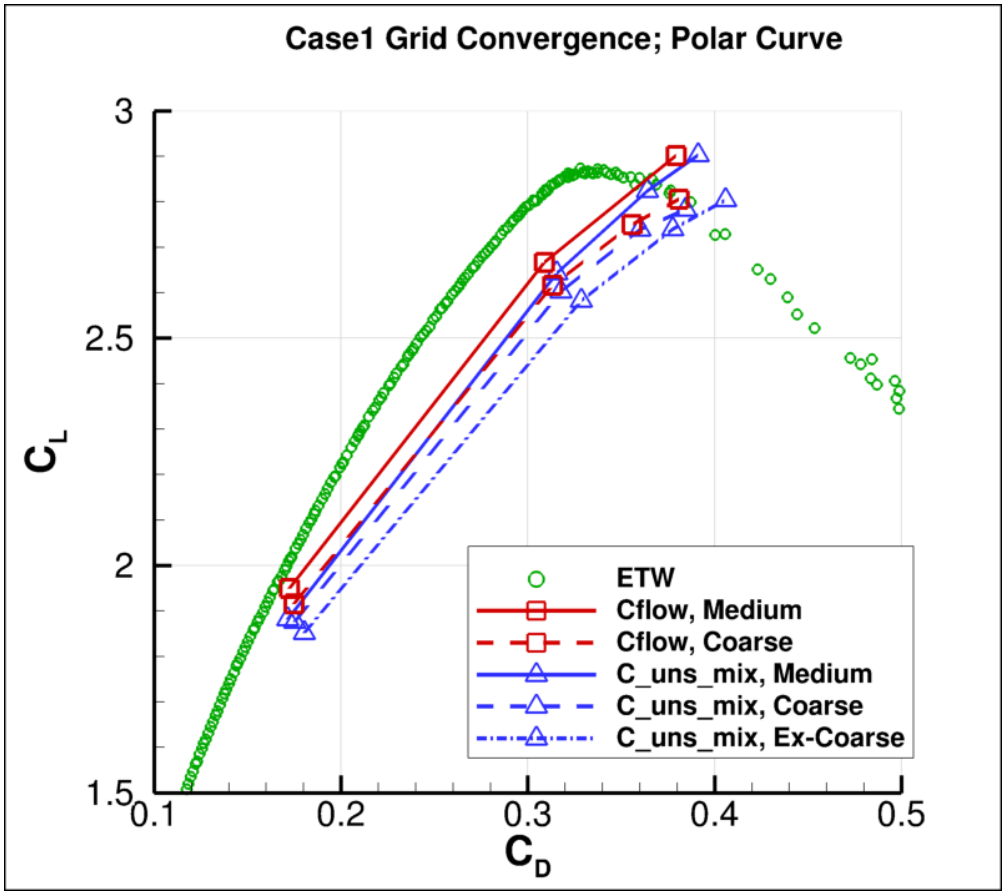
- most of the CFD results shows lower lift than that of ETW data
- C_L of Cflow-Medium grid is in good agreement with ETW data
- C_L- α slope is less than that of ETW data

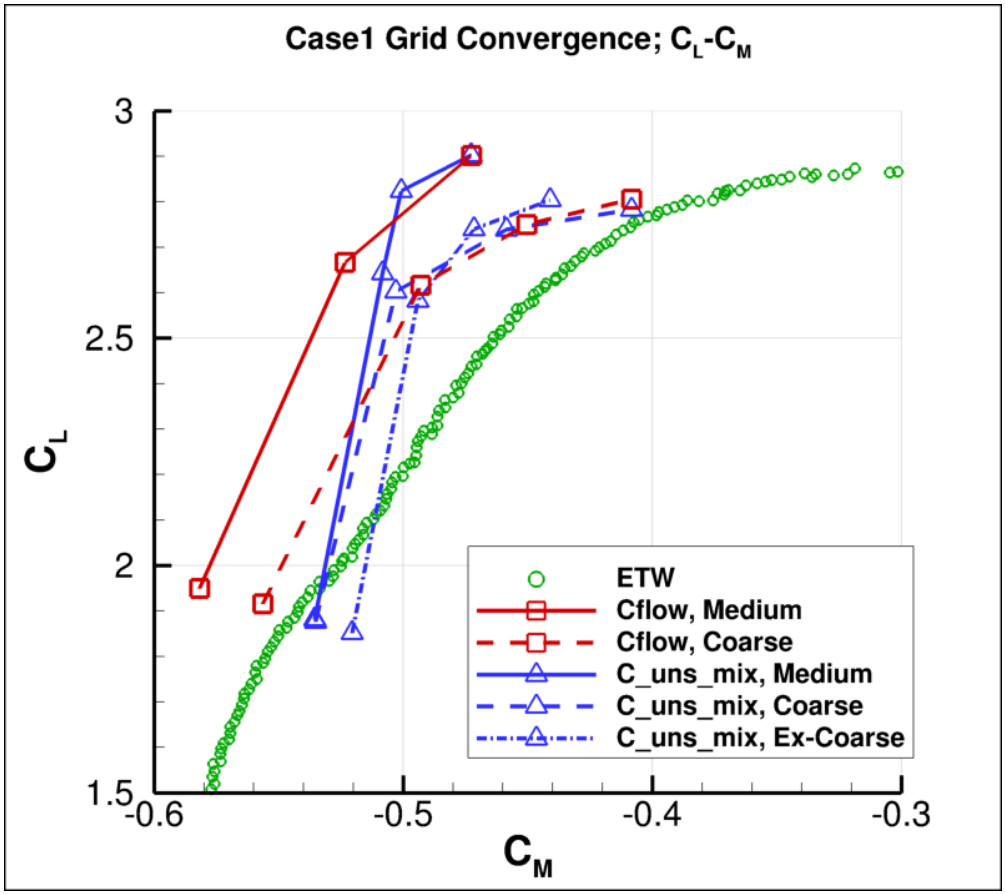




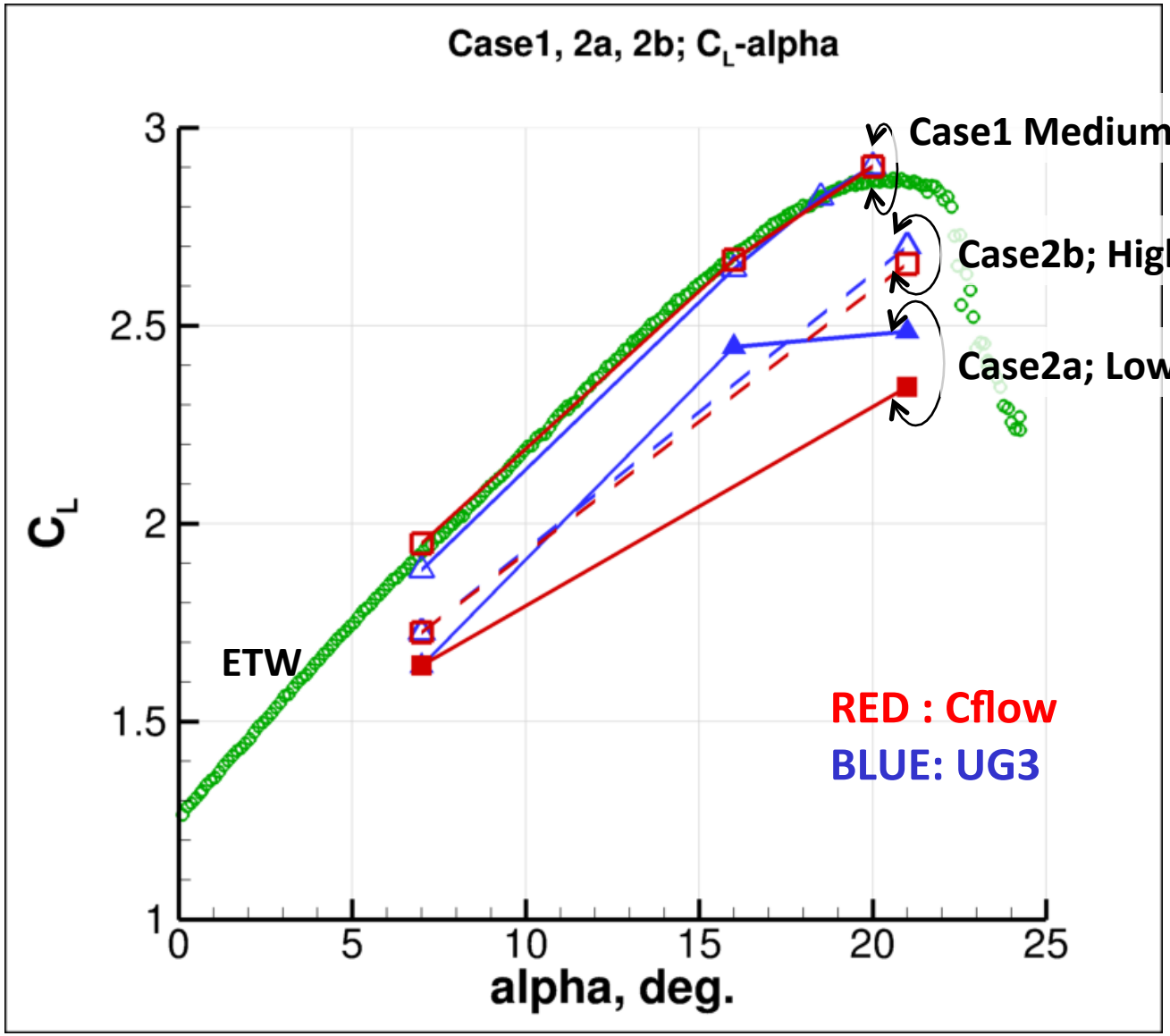
Results: Case1, force & moment (2/2)

- finer grid overestimate negative pitching moment





Results: Case2 CL-α, C_uns_mix Grid, Medium



- Case 2a and 2b are computed using thin layer approximated NS eq.