008 - KHI Contribution to HiLiftPW-3

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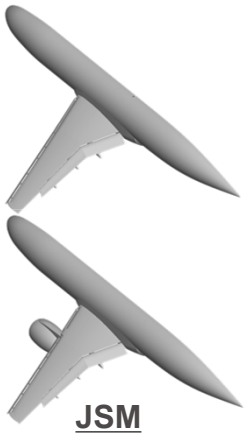
Outline

- Summary of cases completed
- Introduction of “Cflow”
- Overview of grid systems and numerical methods
- Results of HL-CRM
- Results of JSM
- Summary and future works

Summary of cases completed

HL-CRM



JSM

DSMA661 Airfoil

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study
1a (full gap)	yes	yes
1b (full gap w adaption)	yes	yes
1c (partial seal)	yes	yes
1d (partial seal w adaption)	yes	yes

Topics of this presentation

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction
2a (no nacelle)	yes	no	no
2b (no nacelle w adaption)	yes	no	no
2c (with nacelle)	yes	no	no
2d (with nacelle w adaption)	yes	no	no

Case	2D Verification study
3	yes

Introduction of "*Cflow*"

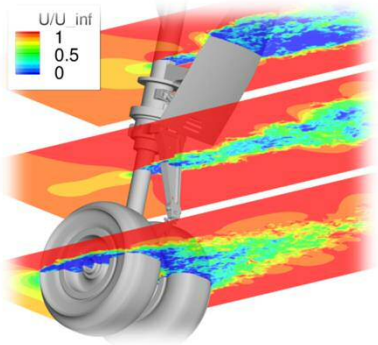
Kawasaki original CFD tool

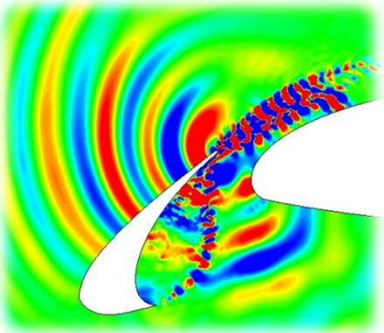
Cflow = Grid Generator + Flow Solver

Non-orthogonal Octree AMR
+layered grid

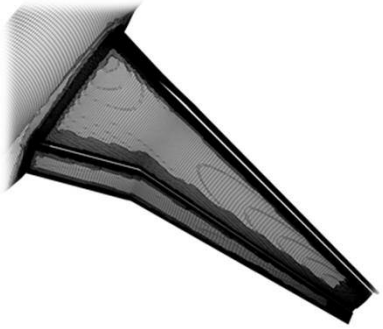
highly complicated | unsteady | large-scale

■ Cflow has been validated in various workshops.

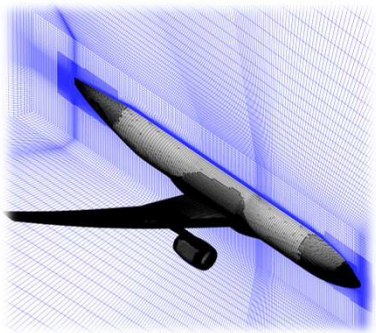




2010-2016
BANC I-IV



2013
HiLift-PW2



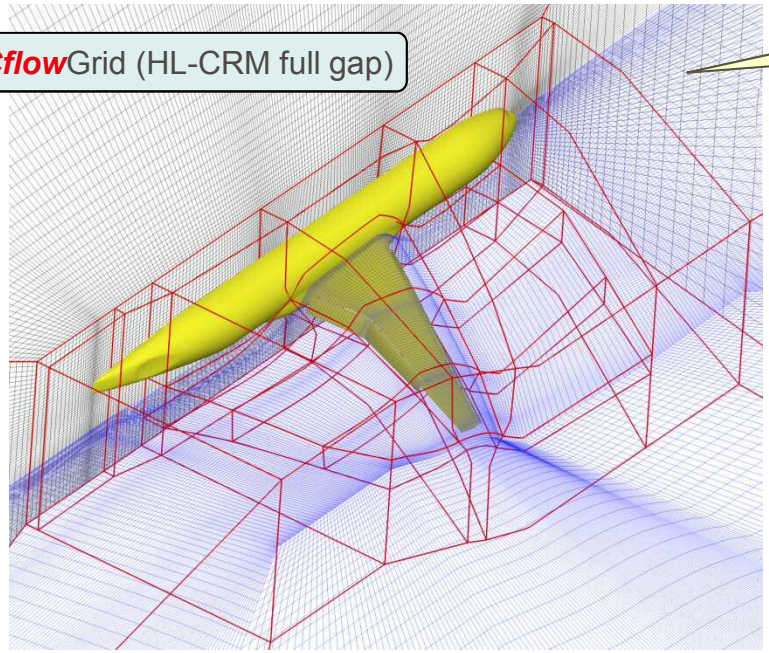
2016
DPW6

Unsteady flow

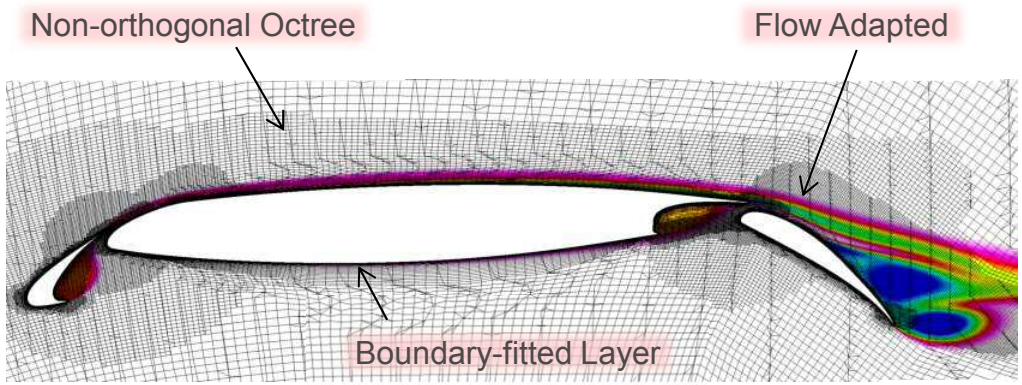
Steady flow

Overview of grid systems

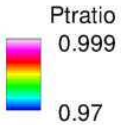
Case	Grid System	Solver	Comment
1a, 1c	**B3**-HLCRM_UnstrHexPrismPyrTet_PW	***Cflow*** Solver	
1b, 1d	***Cflow***Grid (Unstructured Hexahedra)		Single grid is applied to all AoA.
2a, 2c	**D**-JSM_UnstrMixed_JAXA		
2b, 2d	***Cflow***Grid (Unstructured Hexahedra)		Single grid is applied to all AoA.



Details about ***Cflow*** Grid were presented in **GMGW-1**.



Sectional Grid
HL-CRM full gap, eta=0.552, AoA=8[deg]



Summary of code and numerics used

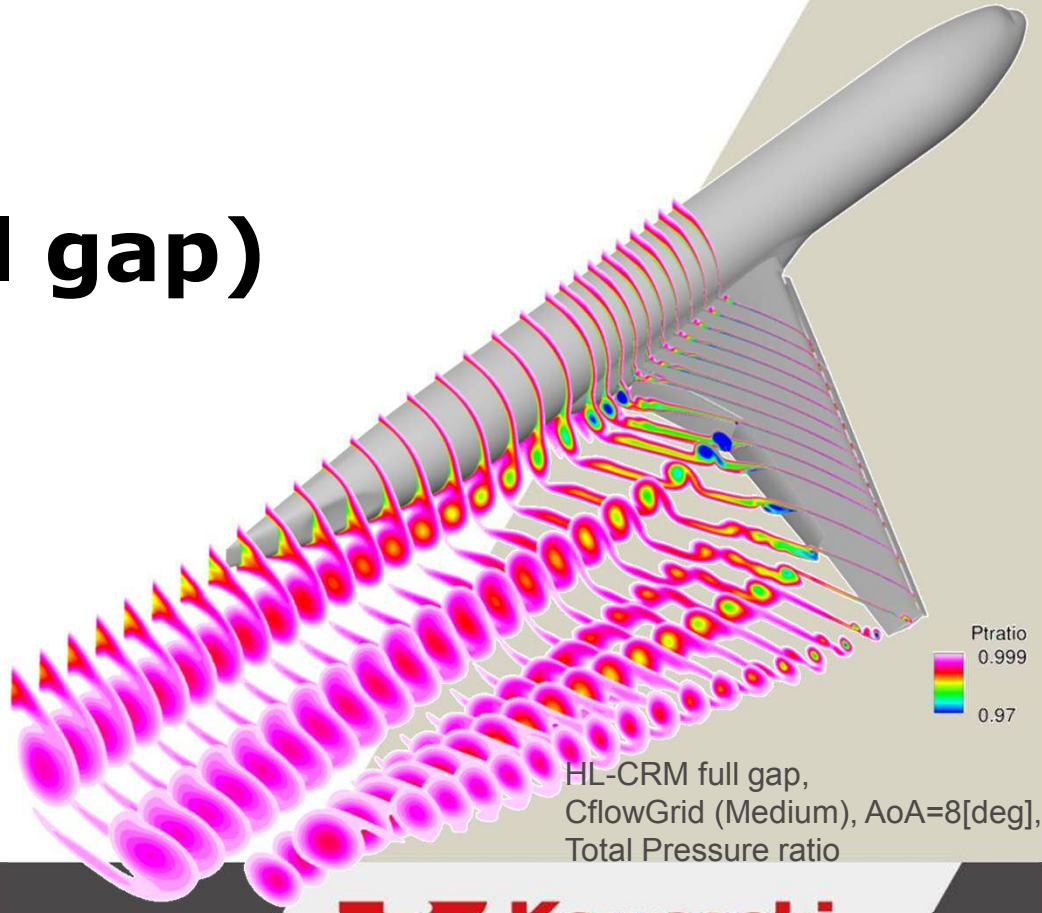
	Cflow **Solver methods**
Governing Equations	**RANS**
Spatial Discretization	Cell-centerd finite volume method with 2nd-order accurate reconstruction based on MUSCL
Inviscid Flux	**SLAU** (Simple Low-dissipation AUSM scheme)
Viscous Flux	2nd-order accurate central difference
Time Integration	MFGS implicit method with local time stepping
Turbulence Model	**SA-noft2**

■ Reference for ***Cflow*** details

1. Nagata, T., Ueno, Y., and Ochi, A., "*Validation of new CFD tool using Non-orthogonal Octree with Boundary-fitted Layer Unstructured Grid*," 50th AIAA Aerospace Sciences Meeting, (AIAA 2012-1259).
2. Ueno, Y., Nagata, T., and Ochi, A., "*Aeroacoustic Analysis of the Rudimentary Landing Gear Using Octree Unstructured Grid with Boundary-fitted Layer*," 18th AIAA/CEAS Aeroacoustics Conference, (AIAA 2012-2284).
3. Yasuhiro Ito, Mitsuhiro Murayama, Atsushi Hashimoto, Takashi Ishida, Kazuomi Yamamoto, Takashi Aoyama, Kentaro Tanaka, Kenji Hayashi, Keiji Ueshima, Taku Nagata and Akio Ochi, "*TAS Code, FaSTAR and Cflow Results for the Sixth Drag Prediction Workshop*," 55th AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2017-0959).
4. Atsushi Hashimoto, Takashi Aoyama, Yuichi Matsuo, Makoto Ueno, Kazuyuki Nakakita, Shigeru Hamamoto, Keisuke Sawada, Kisa Matsushima, Taro Imamura, Akio Ochi, and Minoru Yoshimoto. "*Summary of First Aerodynamics Prediction Challenge (APC-I)*", 54th AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2016-1780).

Case 1a, 1b
– HL-CRM (full gap)

Grid Convergence



HL-CRM full gap,
CflowGrid (Medium), AoA=8[deg],
Total Pressure ratio

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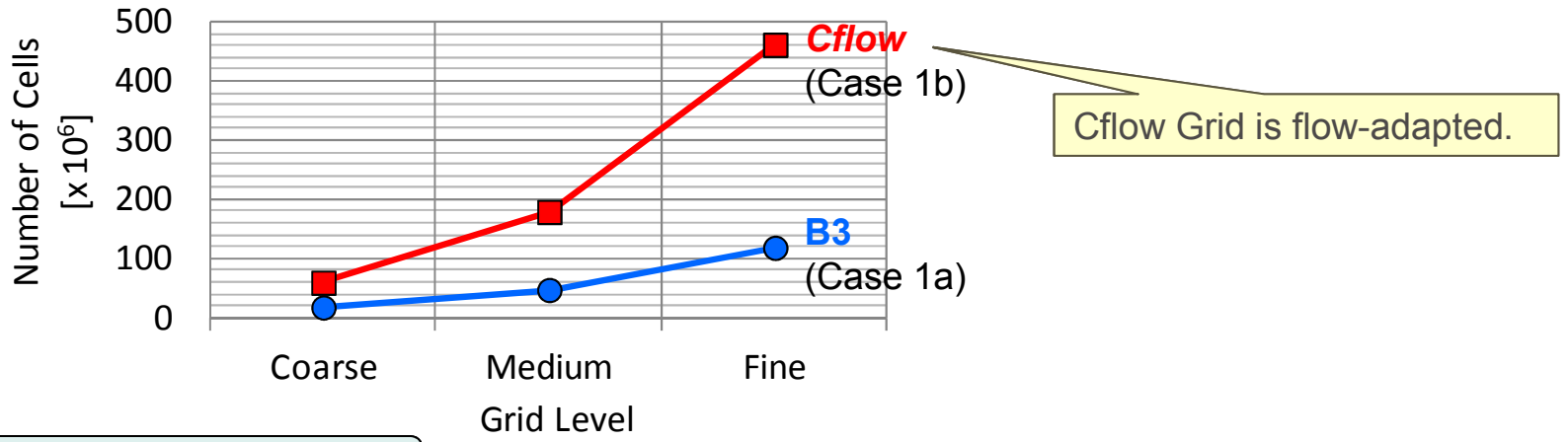
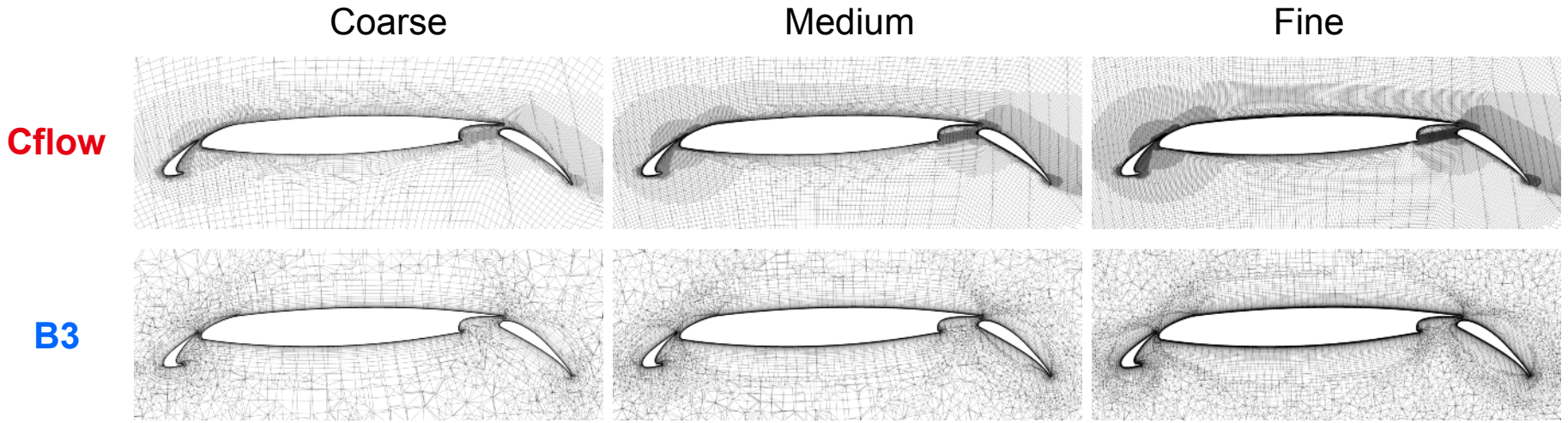
Grid size

HL-CRM
full gap

- 3 sizes of grid is computed for both B3 and *Cflow* Grid.



Sectional Grid @ η=0.552



Grid convergence – CD-CDi, CL

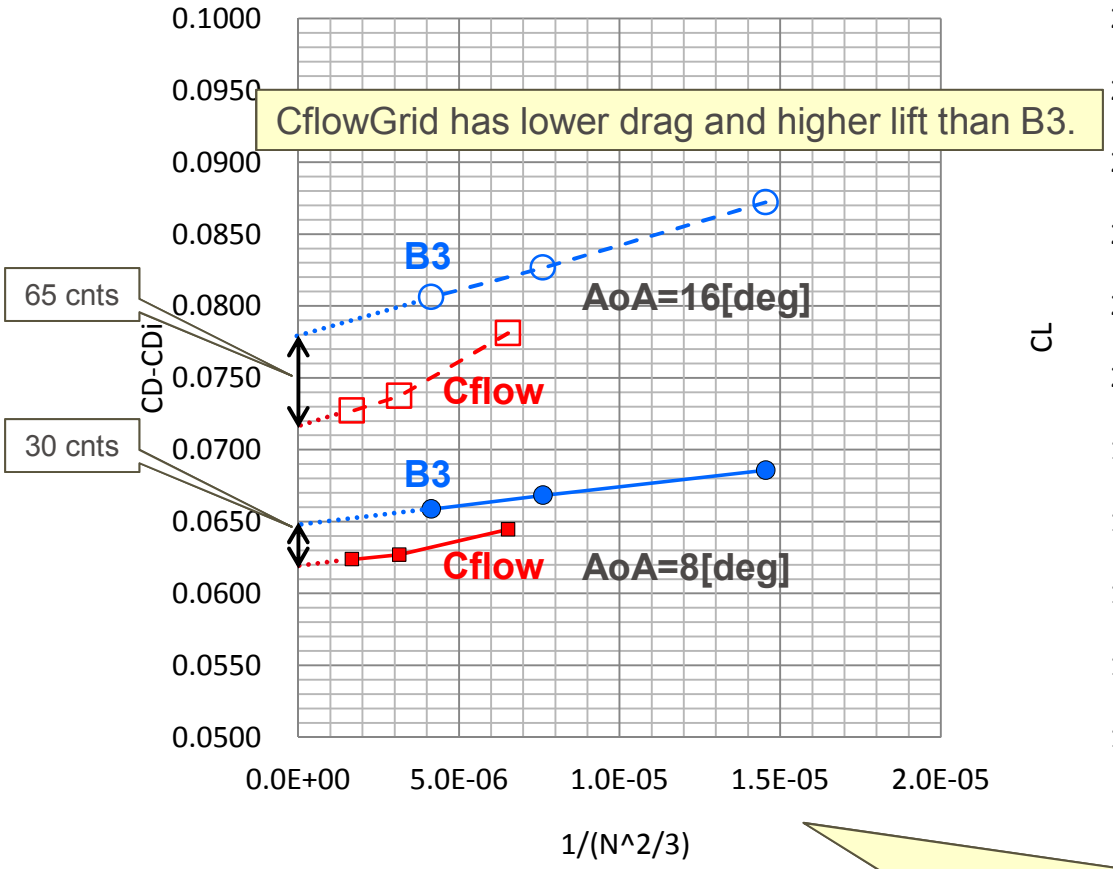
CD-CDi

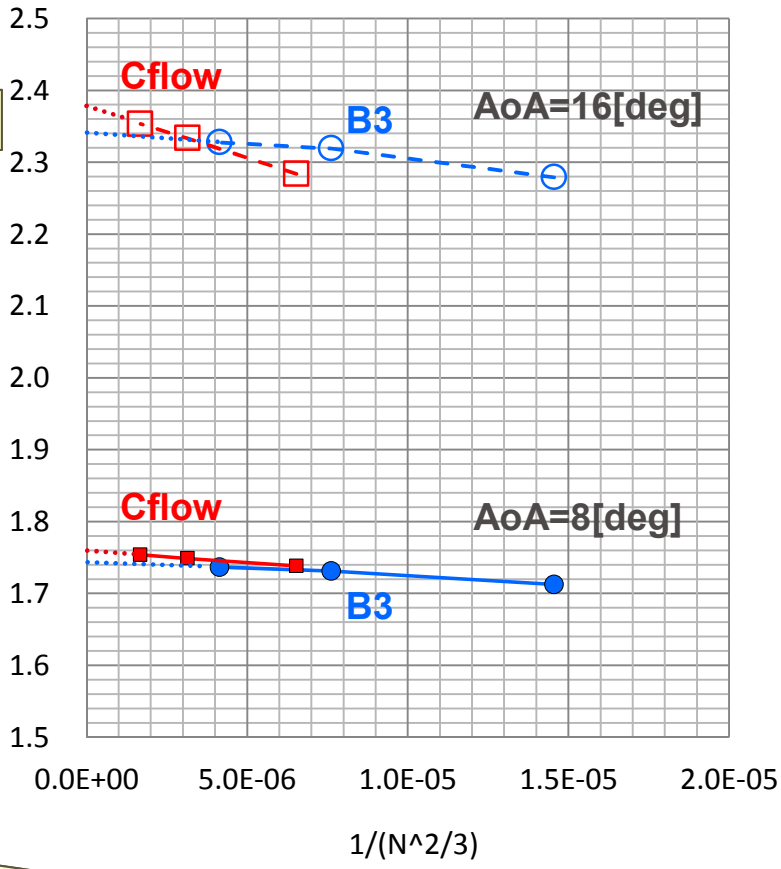
* CDi=CL2/(πAe), A=9.0, e=1

CL

Fine ⇦ Medium ⇦ Coarse

CflowGrid has lower drag and higher lift than B3.



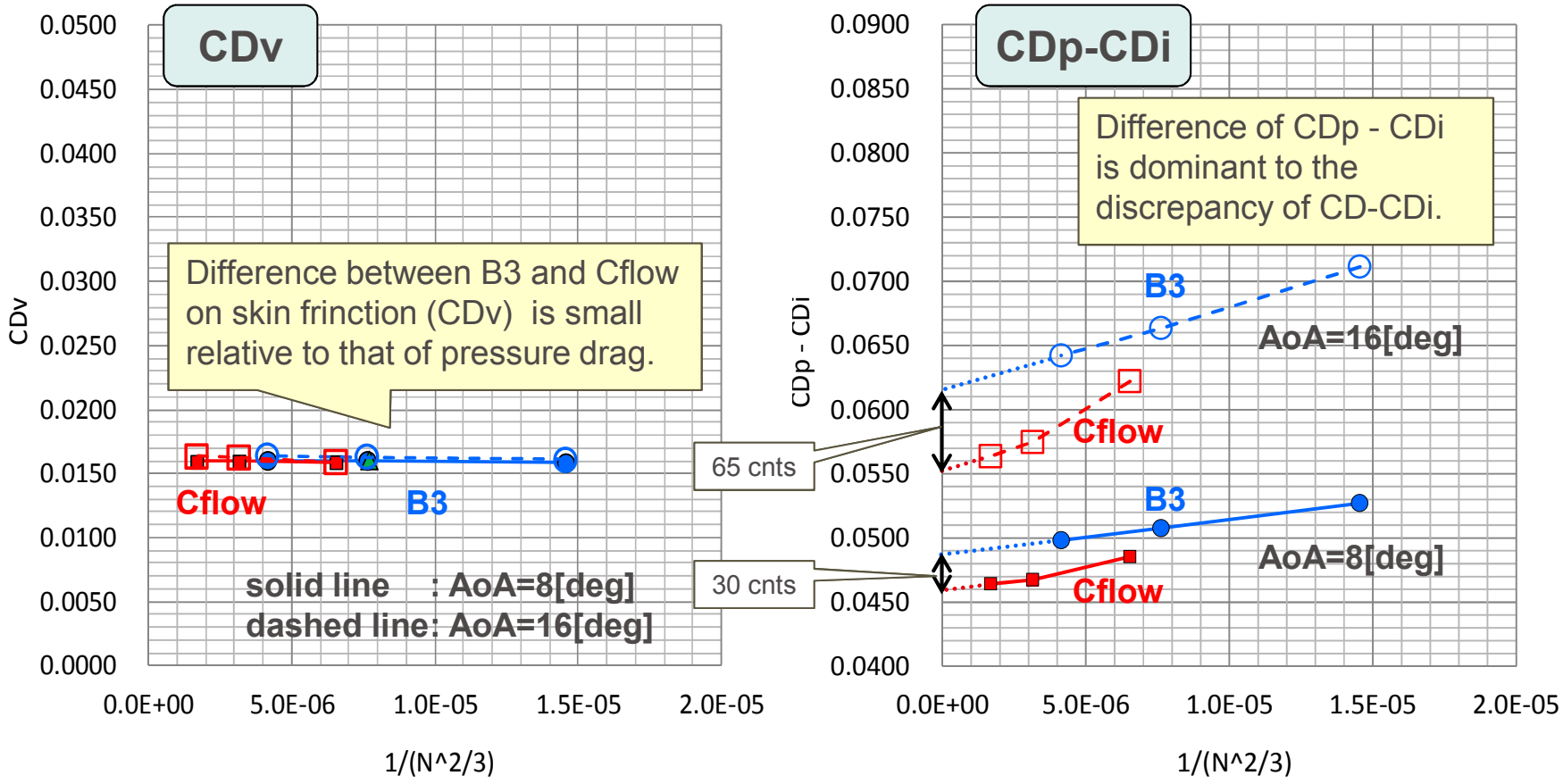


Discrepancy between B3 and Cflow seems to come from pressure drag (next page).

Grid convergence – CDv, CDp

HL-CRM
full gap

- Friction drag coefficient (CDv) and pressure drag coefficient (CDp).



Surface streamlines @ AoA=16[deg]

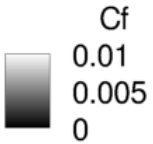
Surface : Cf

B3 (Fine)

Separation near flap gap and outer flap edge is larger than Cflow.

Cflow (Coarse)

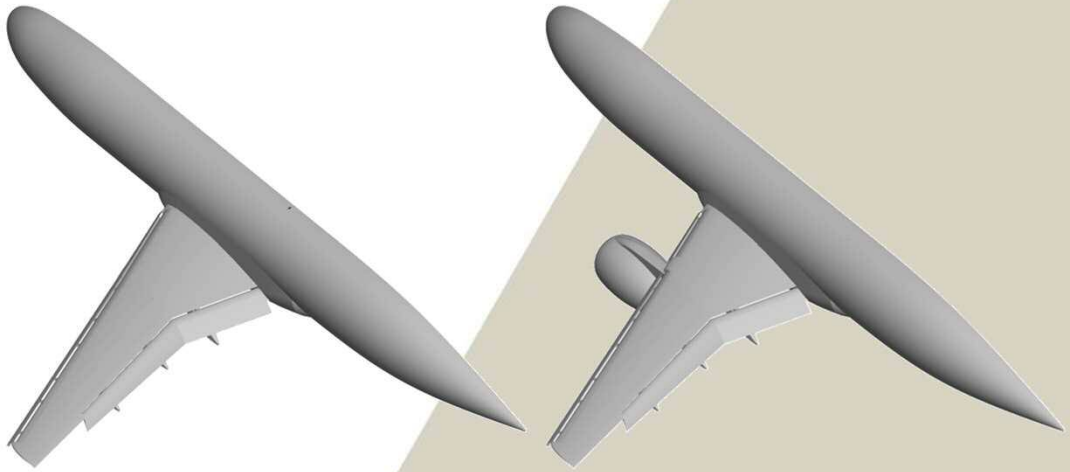
Wing surface mesh density is similar to each other.



Surface Grid

Grid around flap gap and outer flap edge is coarse.

Case 2a-2d
– JSM (Nacelle ON/OFF)



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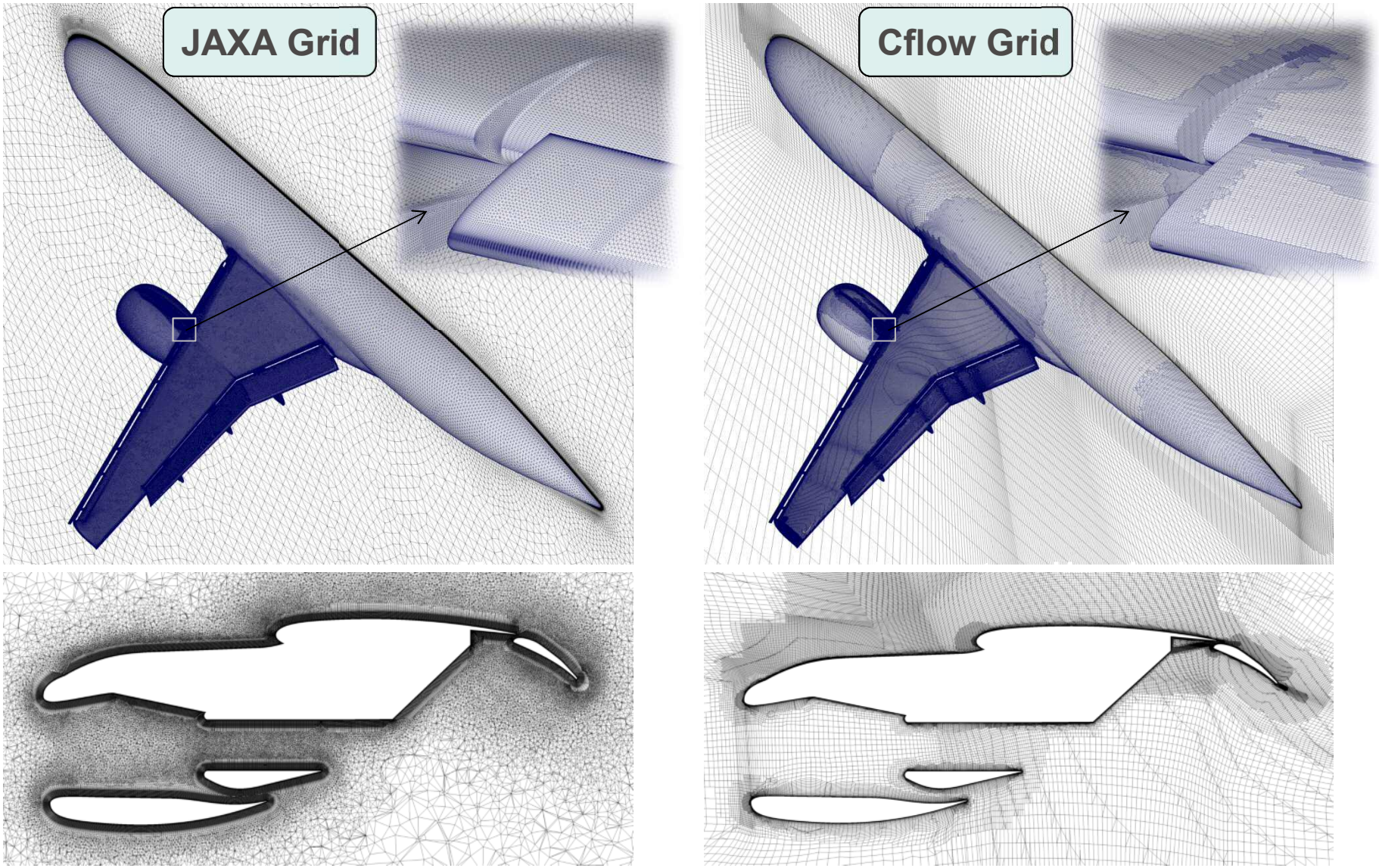
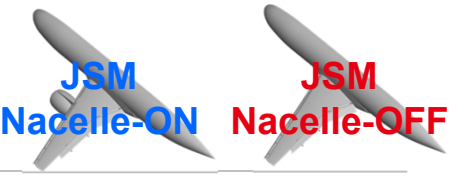
Computational mesh

JSM
Nacelle-ON



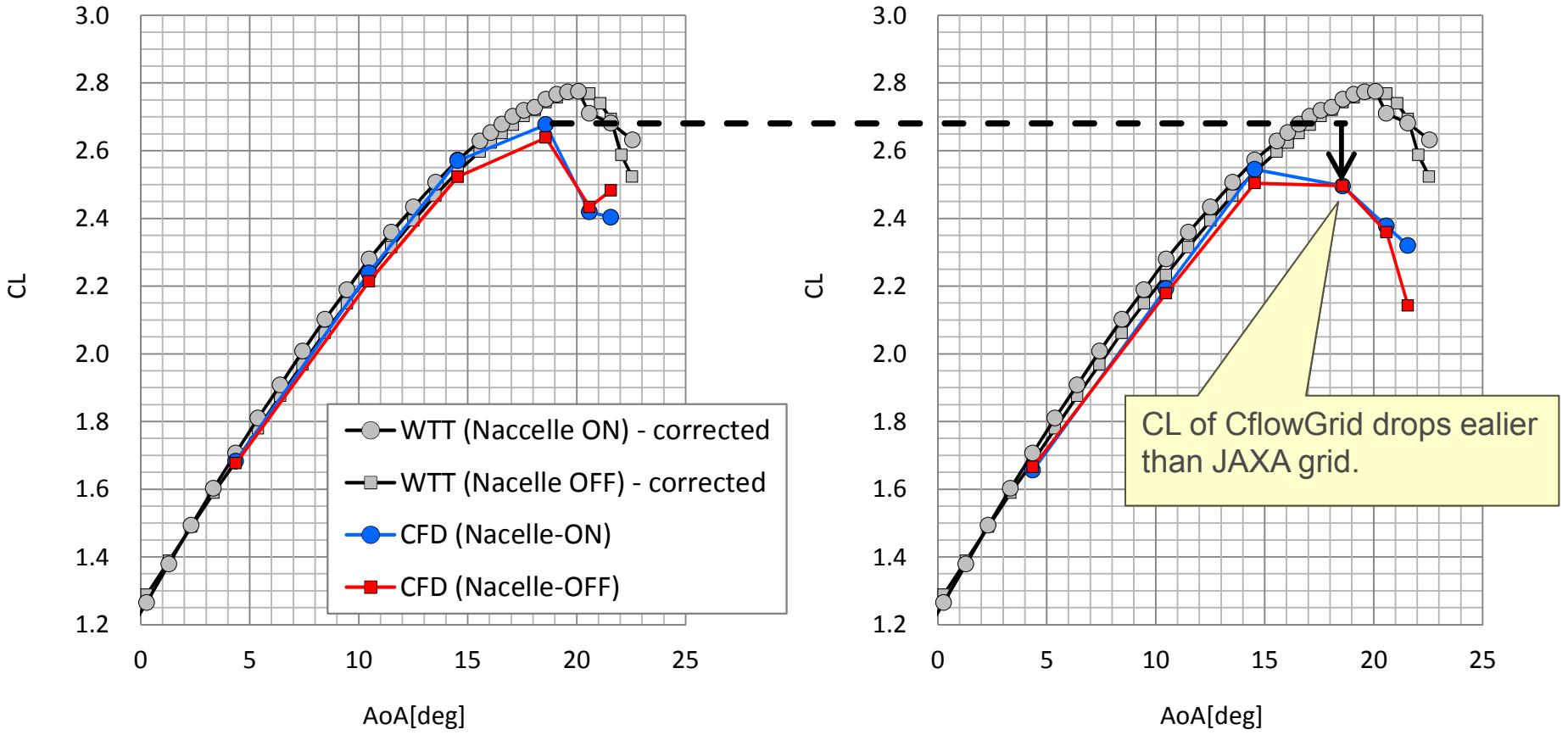
Lift curve

Mach	0.172
Re[-]	1.93 x 10^6

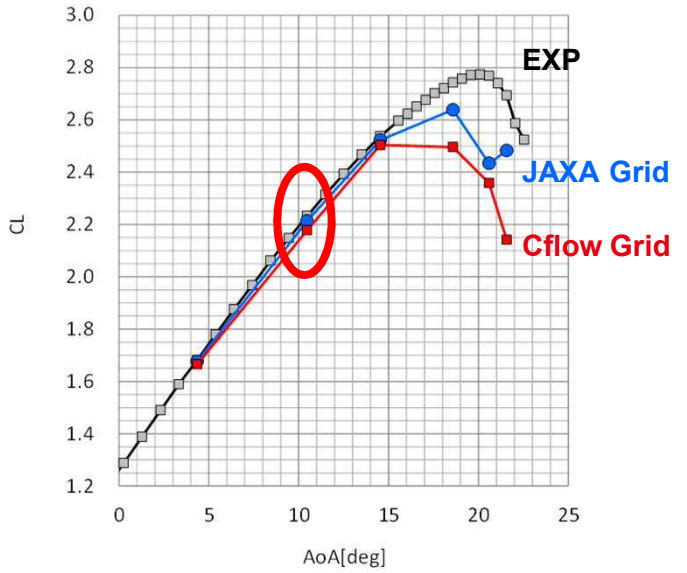


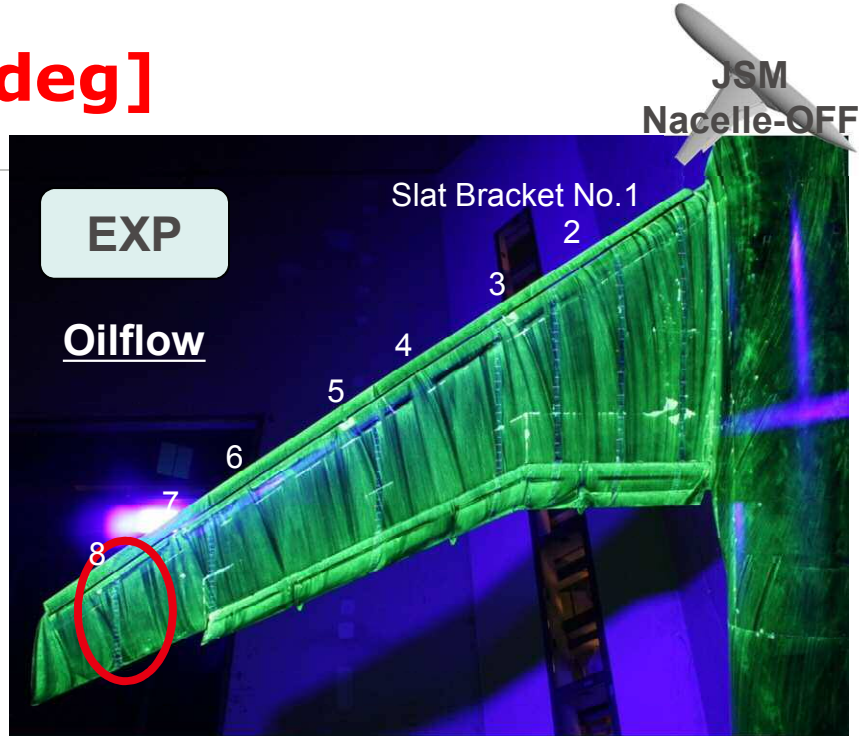
JAXA Grid

Cflow Grid

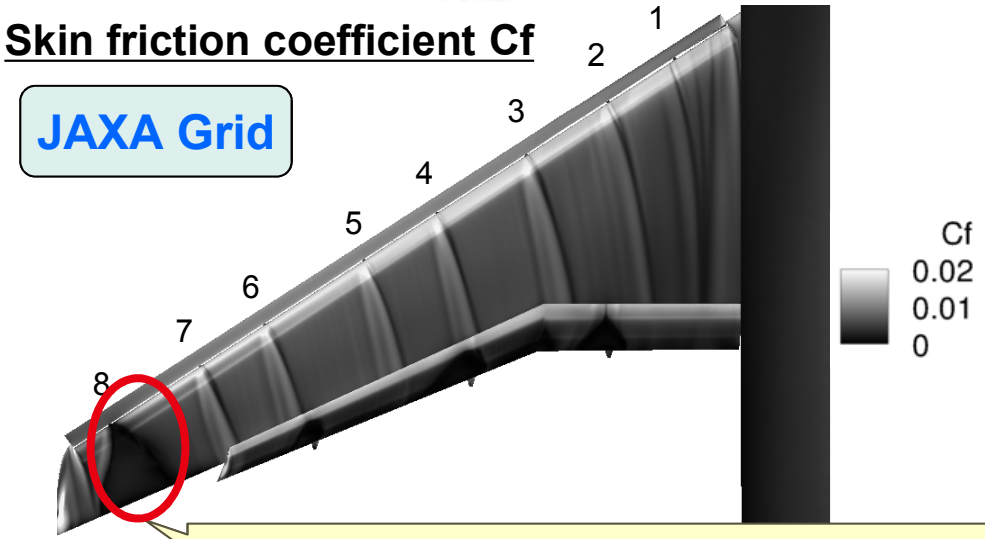


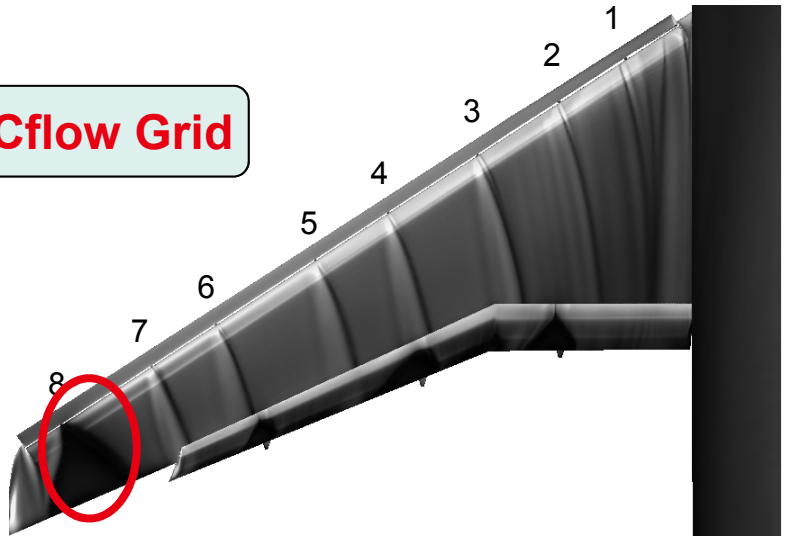
Surface flow AoA=10.47[deg]





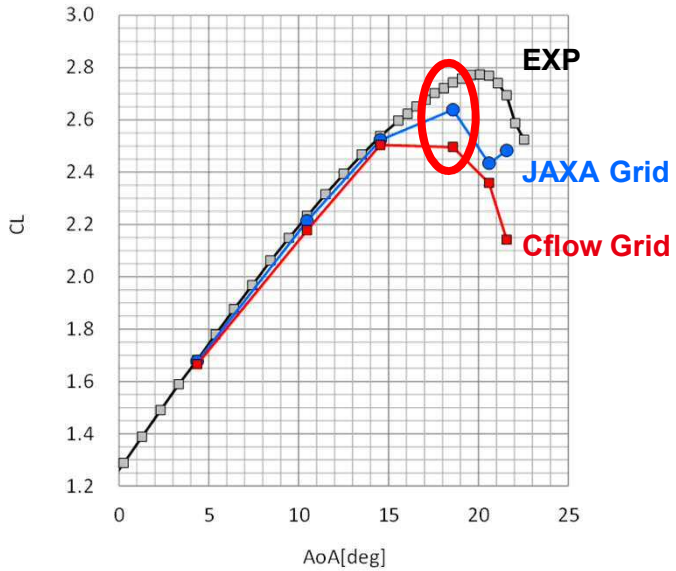
Skin friction coefficient Cf



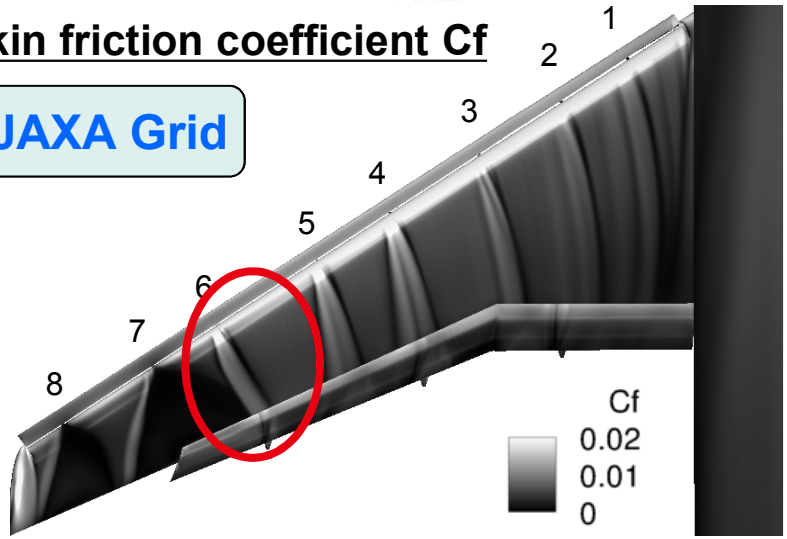


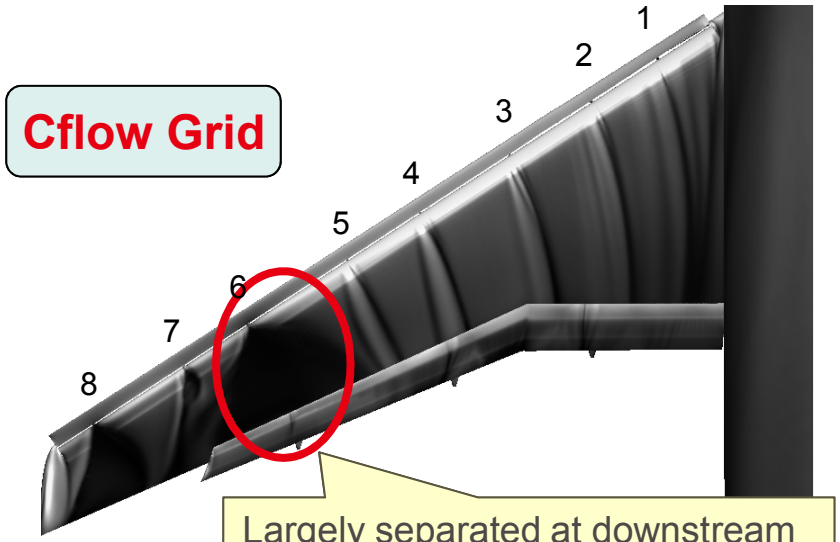
Separation at downstream side of #8 bracket.

Surface flow AoA=18.58[deg]



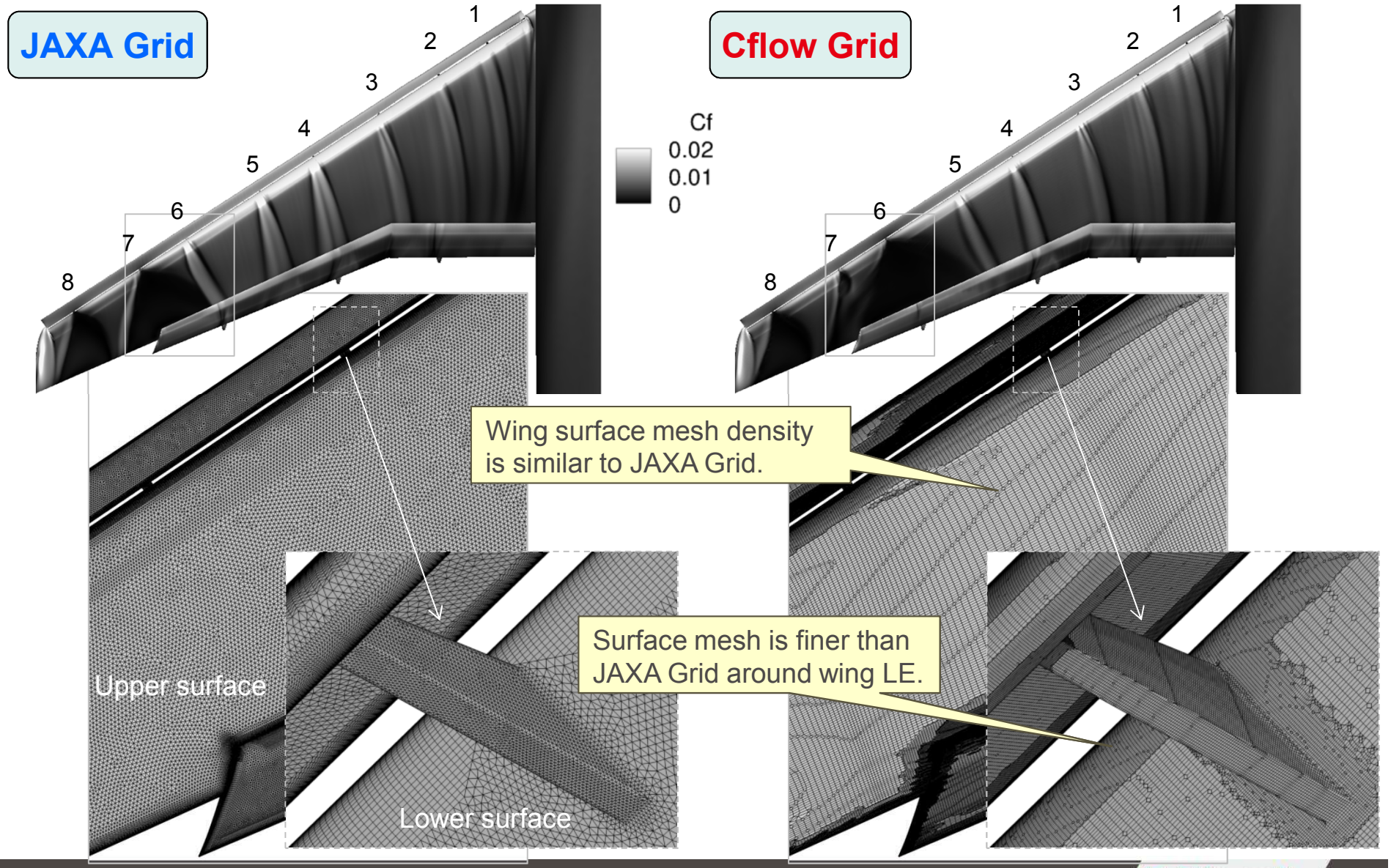
Skin friction coefficient Cf





Largely separated at downstream side of #6 bracket.

Wing surface mesh

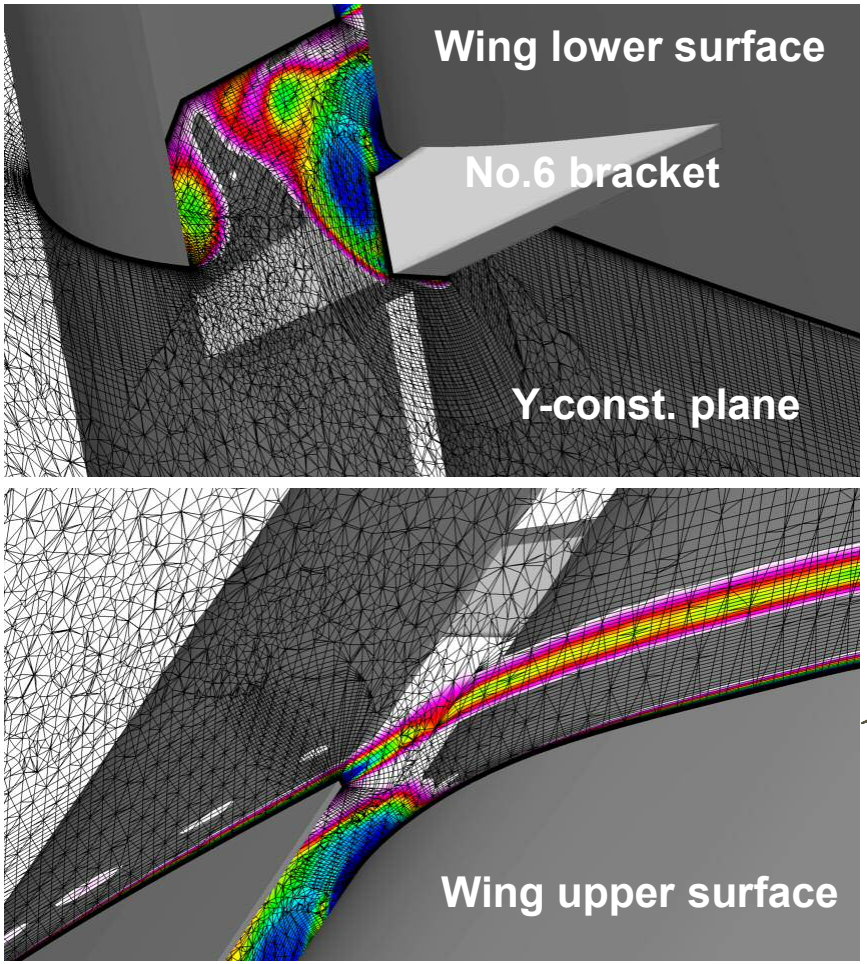


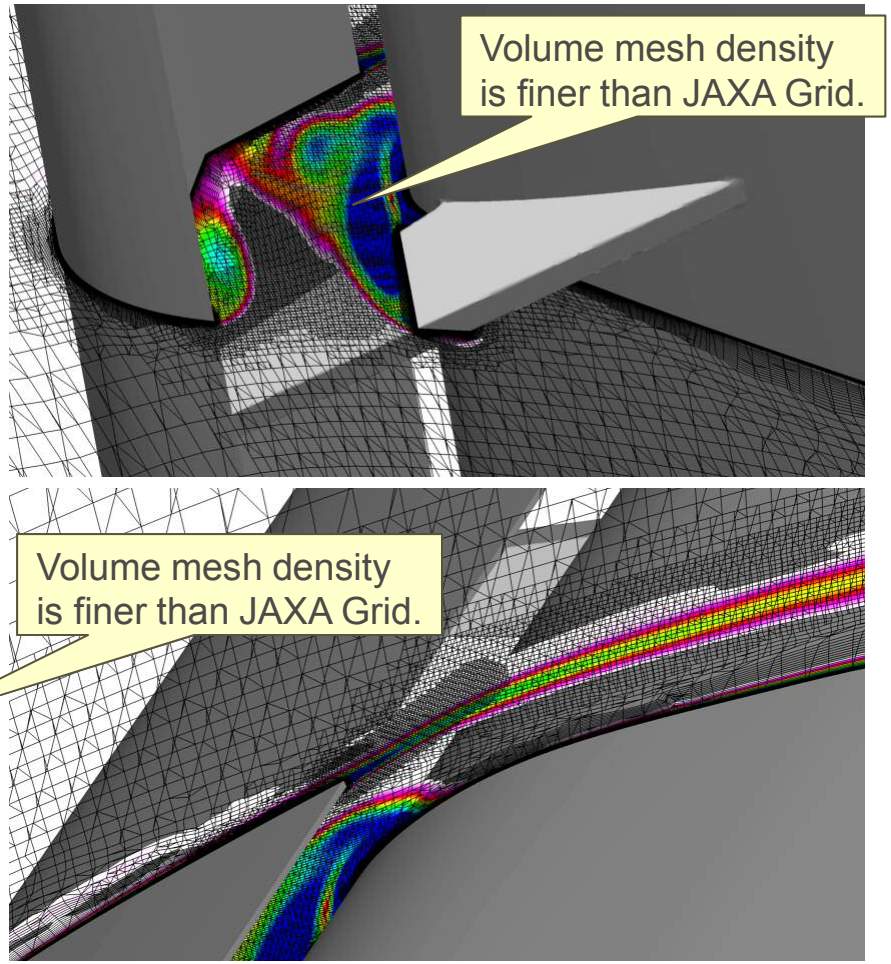
Total pressure ratio @ No.6 bracket

JAXA Grid

Total pressure ratio
0.999
0.97

Cflow Grid

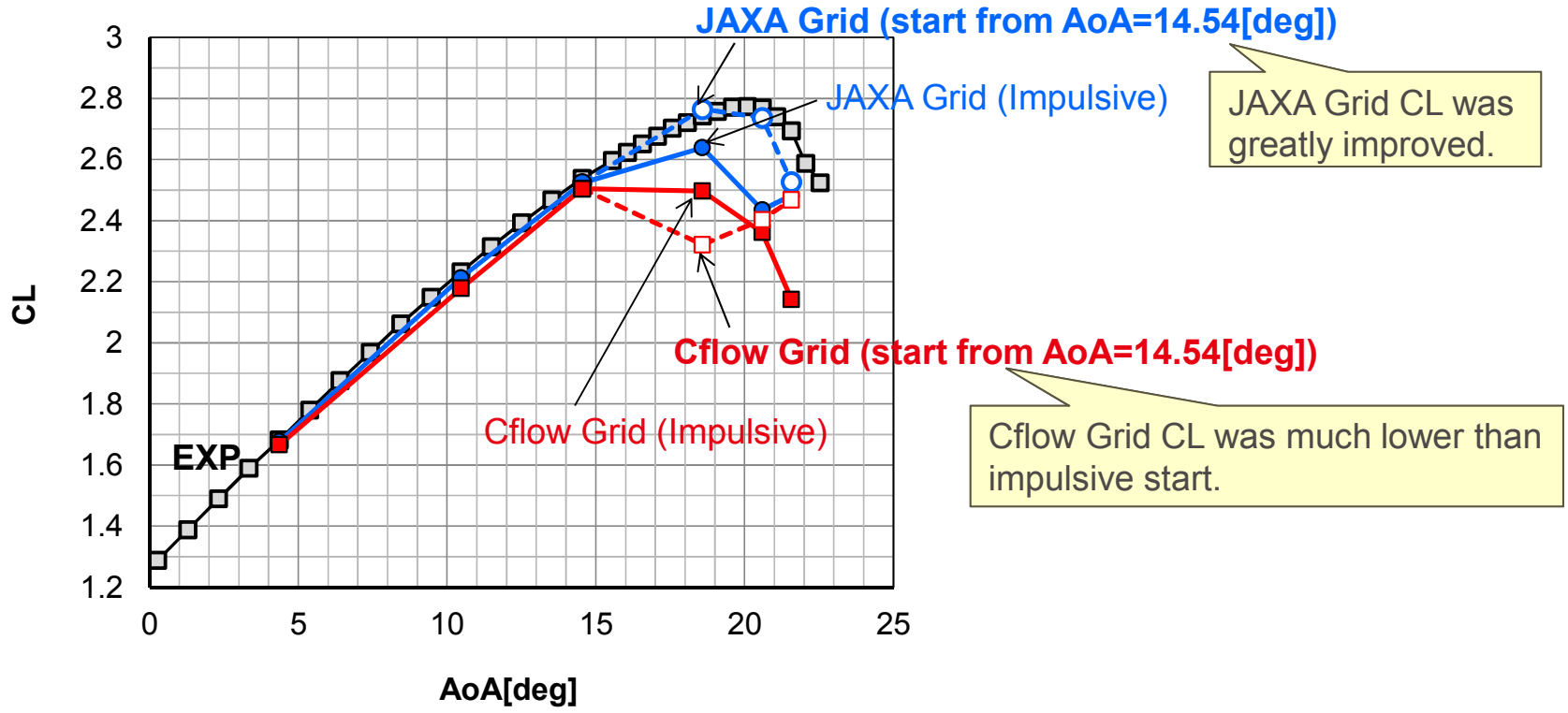




Effects of initial condition

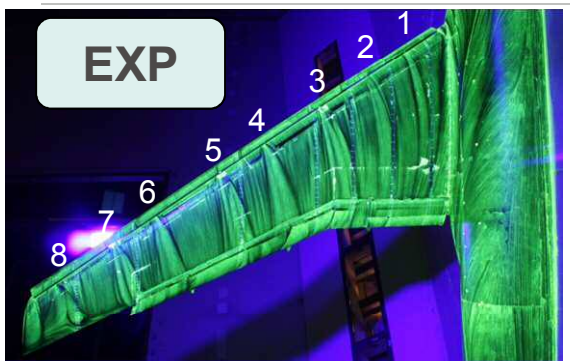
JSM
Nacelle-OFF

- Effects of initial condition were investigated at AoA greater than 18.54[deg].
  - Two results are compared.
    - Impulsive start
    - start from the results of AoA=14.54[deg].



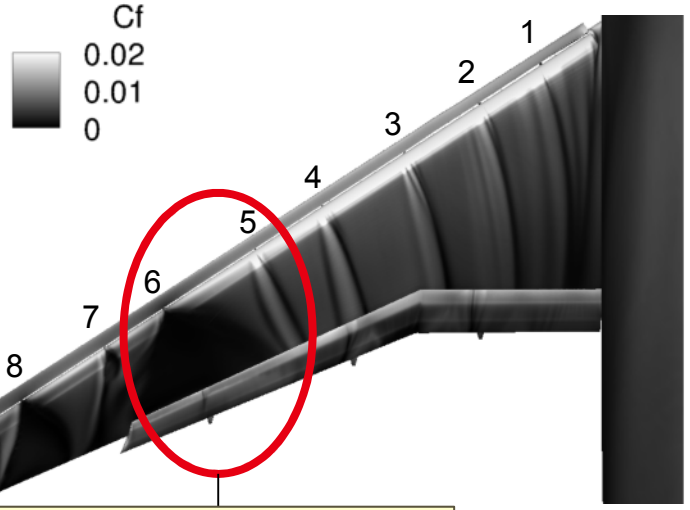
Effects of initial condition on surface flow

JSM
Nacelle-OFF



JAXA Grid

Cflow Grid

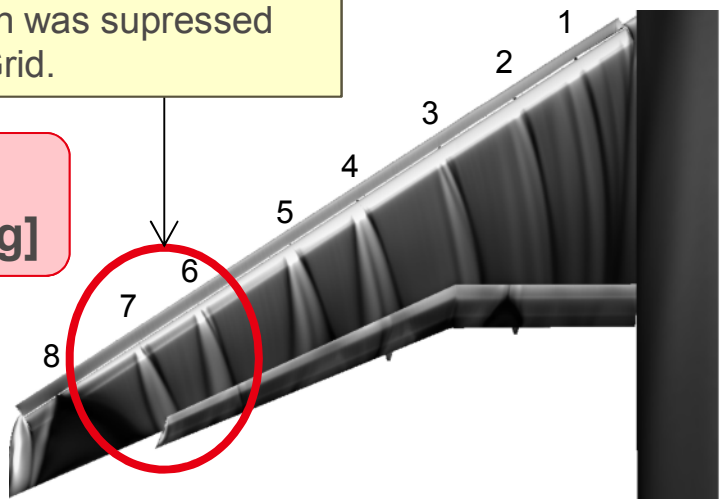


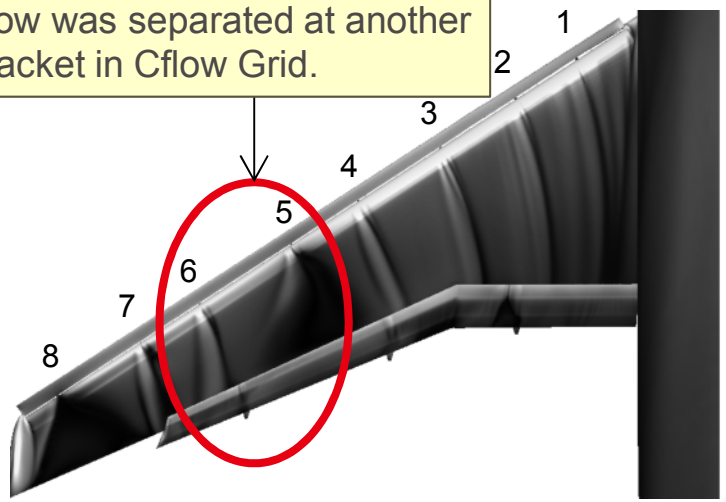
Impulsive Start

Separation was supressed in JAXA Grid.

Flow was separated at another bracket in Cflow Grid.

Start from AoA=14.54[deg]





Summary and Future Works

- HL-CRM full gap (Grid convergence) case
  - Results of *Cflow* Solver using B3 Grid and *Cflow* Grid were presented.
  - Grid convergence was obtained in both grids.
  - B3 grid had higher drag than *Cflow*. Lower grid density of B3 near flap gap and outer flap edge might induce flow separation.

- JSM case
  - Results of *Cflow* Solver using JAXA Grid and *Cflow* Grid for both Nacelle-ON/OFF configurations were presented.
  - CL of *Cflow* Grid droped earlier than experiment. This was caused by separation near wing tip.
  - Effects of initial condition was investigated. Starting lower AoA result improved flow field in JAXA Grid but not in Cflow Grid.
  - The separation issue seems to be grid dependency. This detail causes will be investigated in future work.

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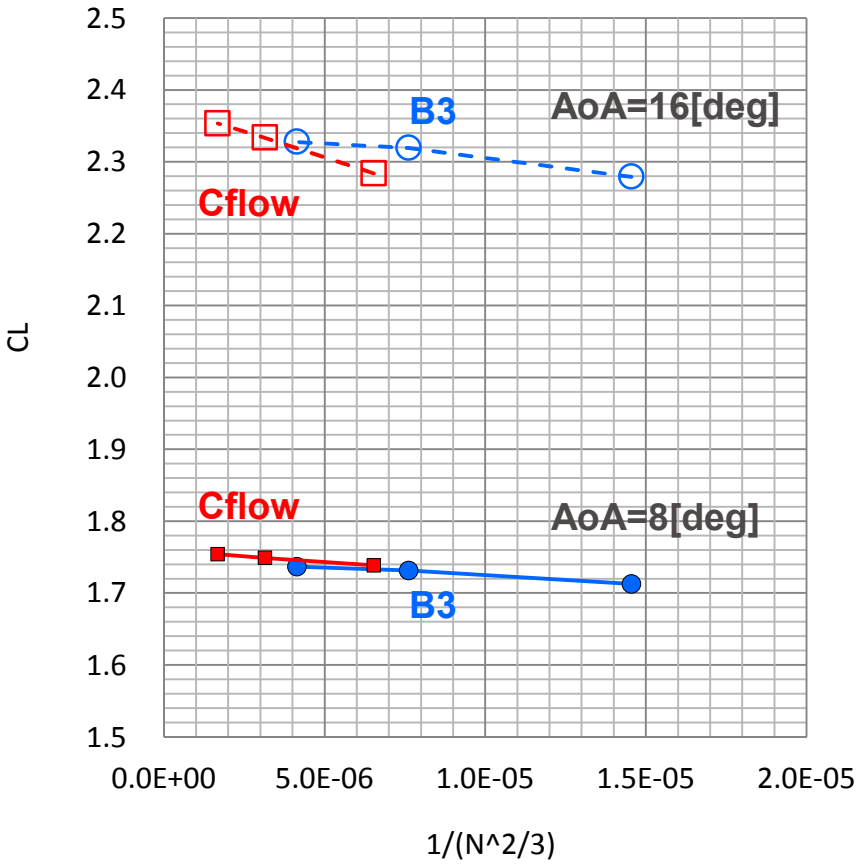
Case 1a,b – HL-CRM

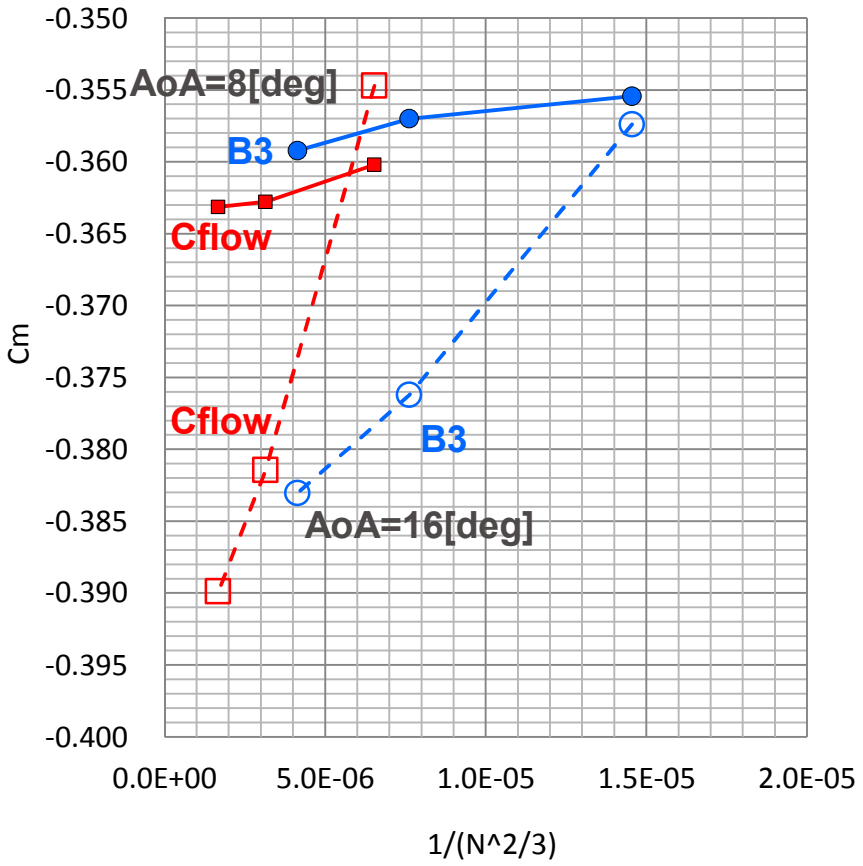
Grid Convergence

Grid Convergence – CL, Cm

CL

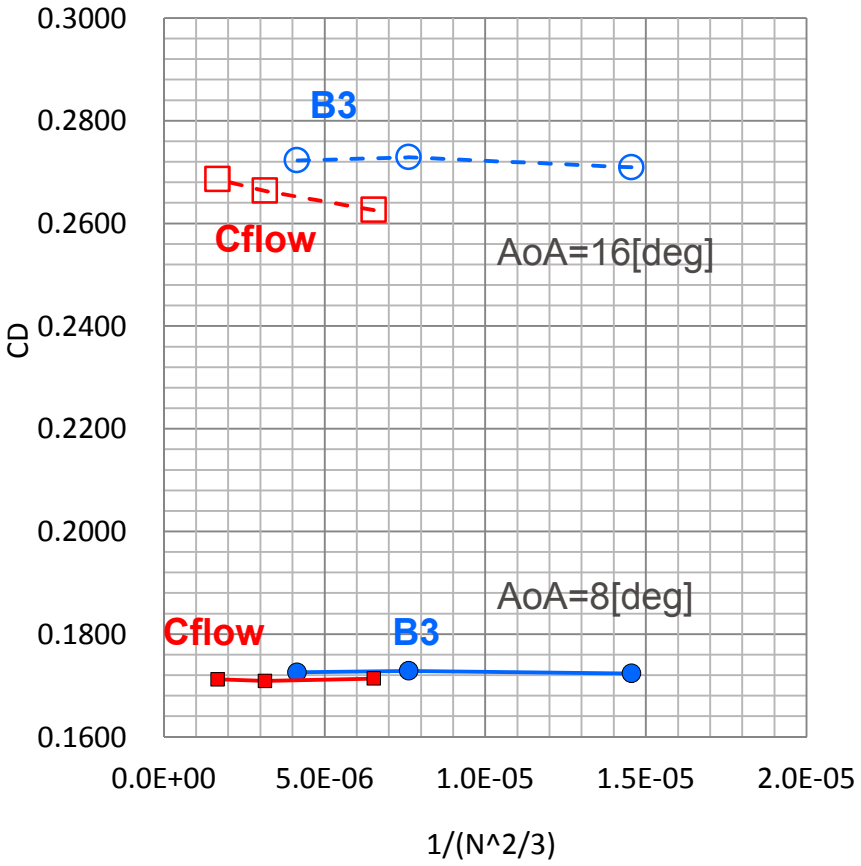


Cm



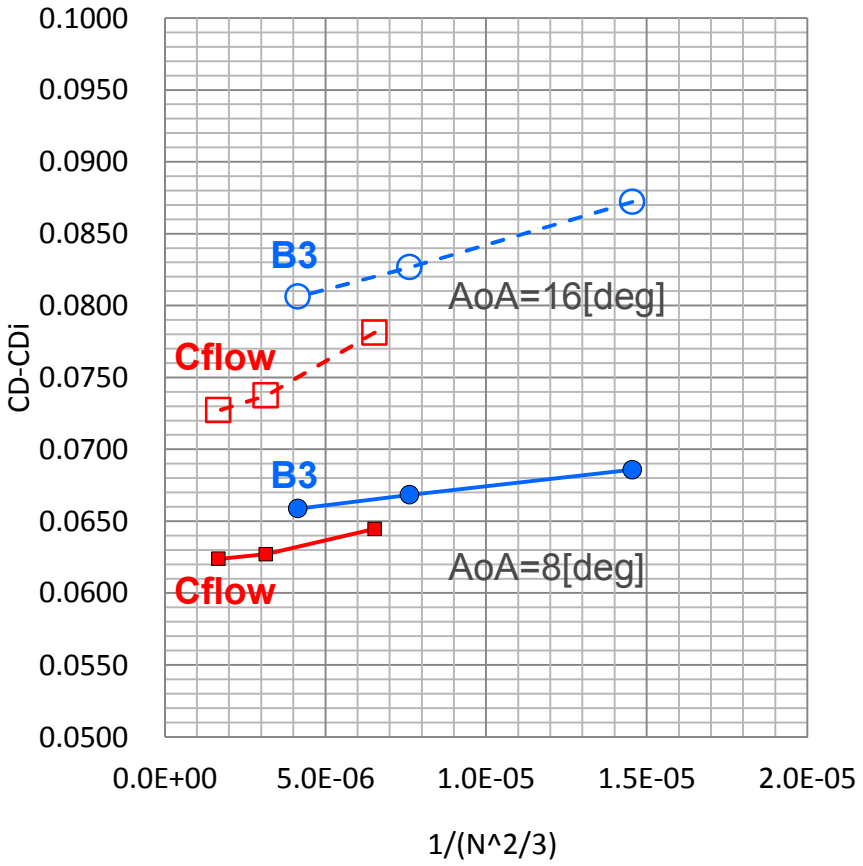
Grid Convergence – CD, CD-CDi

CD



CD-CDi

* CDi=CL2/(πAe), A=9.0, e=1

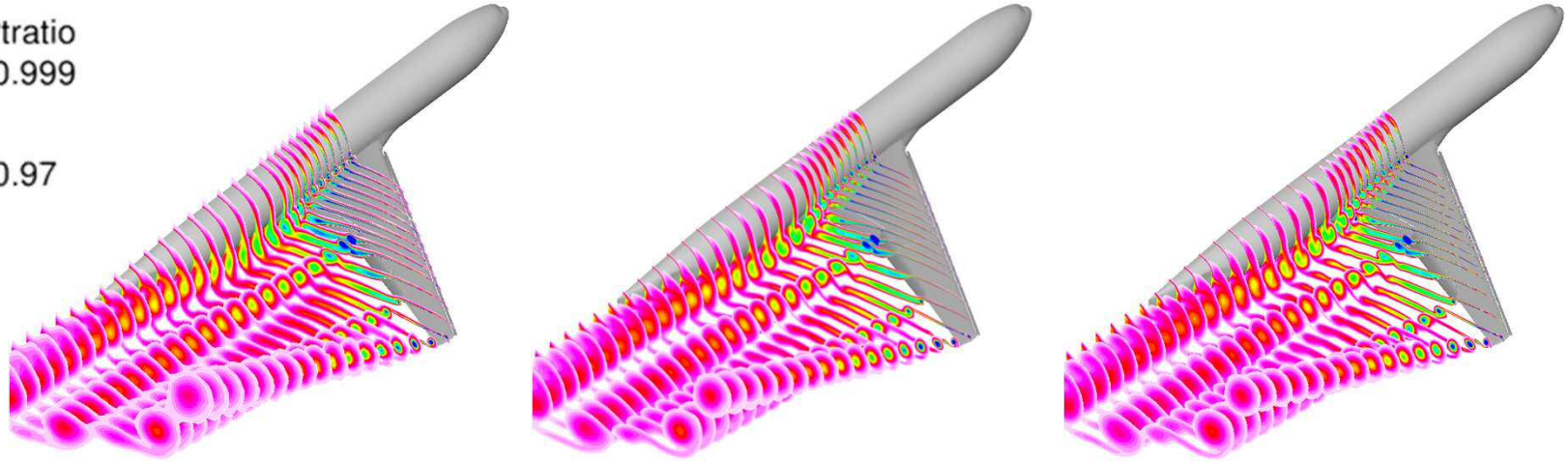


Total Pressure Ratio @ AoA=16[deg]

Coarse → Medium → Fine

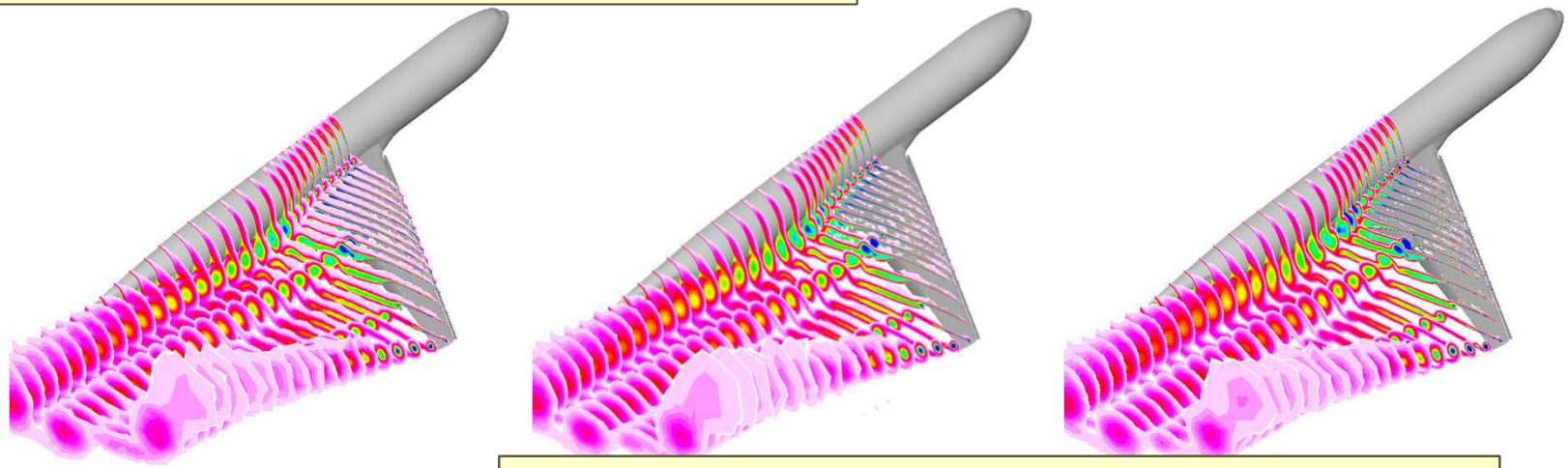
Ptratio
0.999
0.97

Cflow



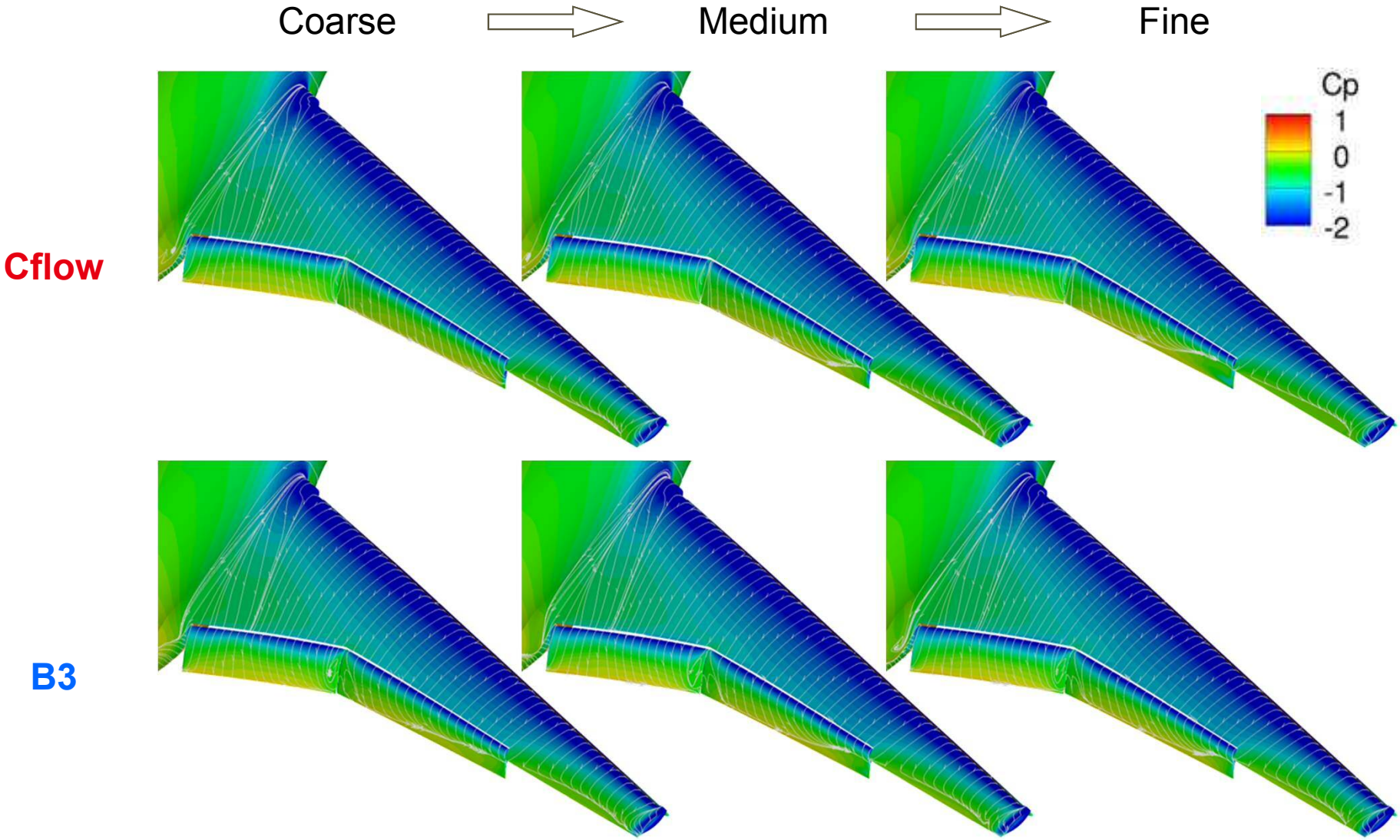
Artificial total pressure loss decreases in finer mesh.

B3

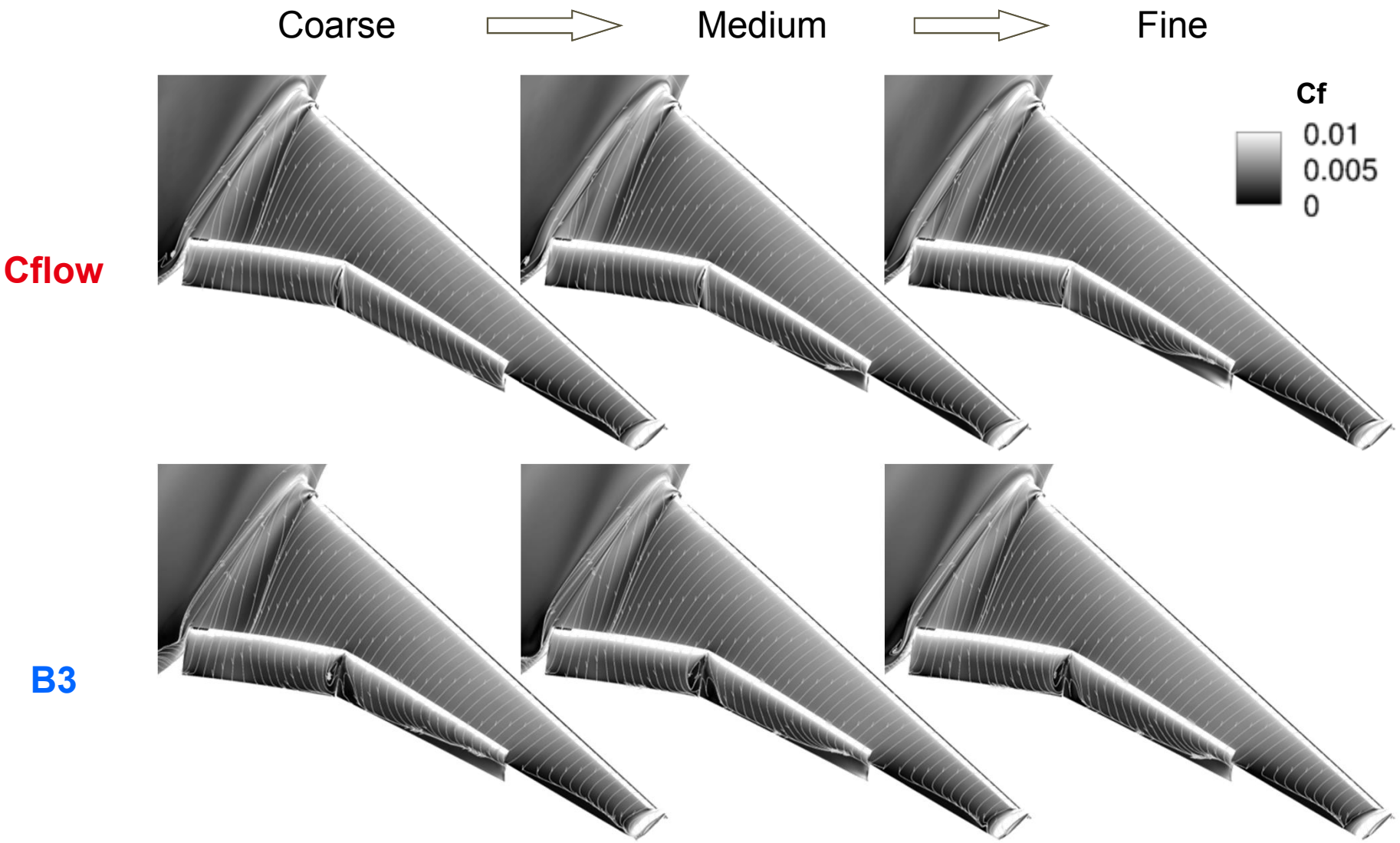


Separation at wing root seems large relative to Cflow Grid.

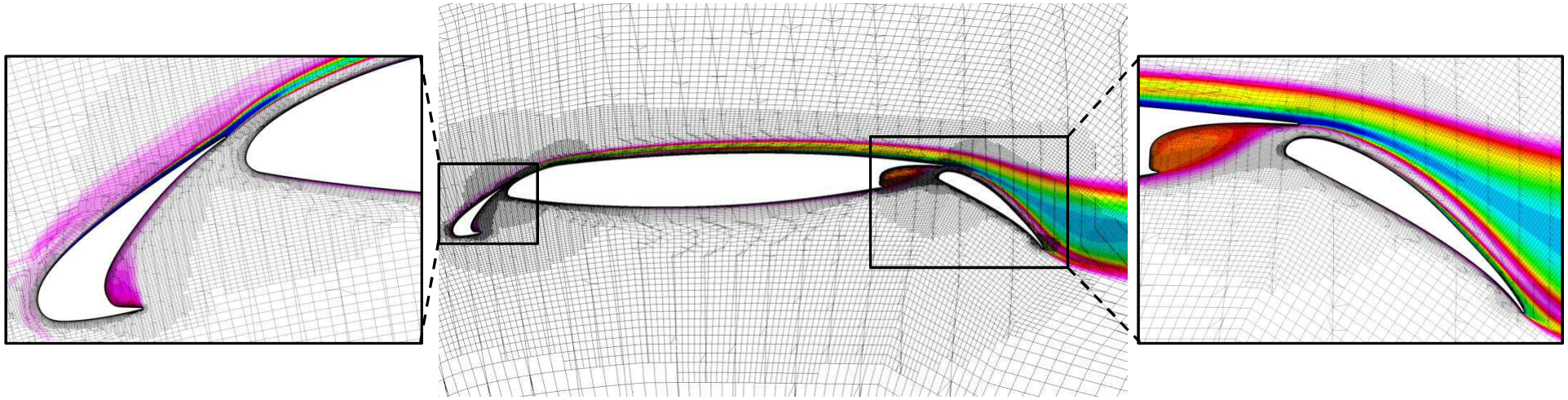
Surface streamlines with Cp @ AoA=16[deg]

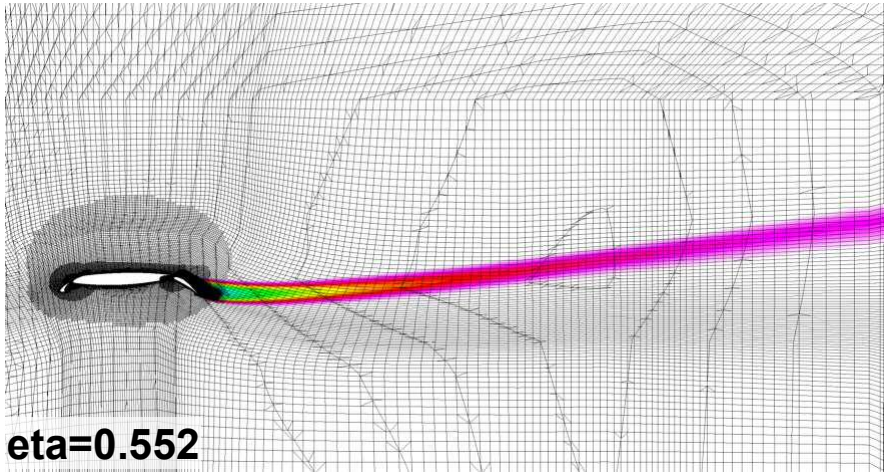


Surface streamlines with Cf @ AoA=16[deg]



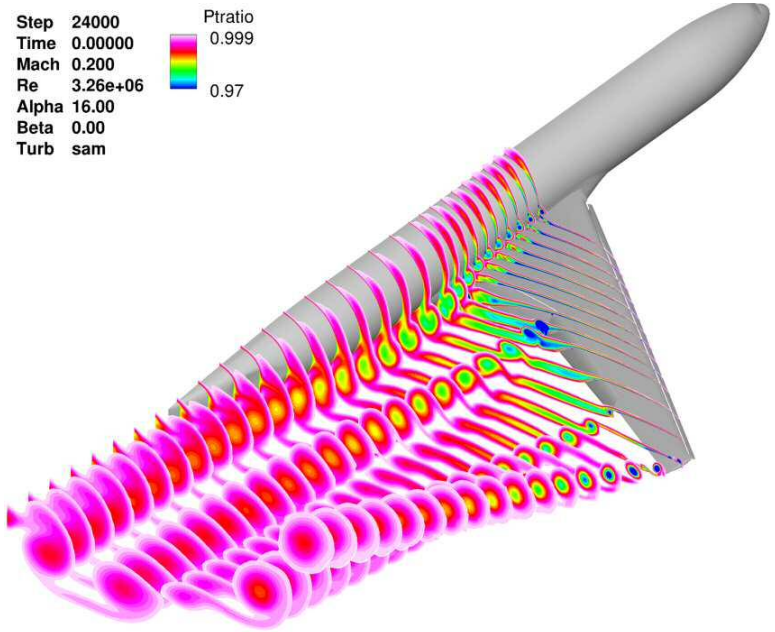
Total Pressure Ratio @ α=16° (CflowGrid, Medium)



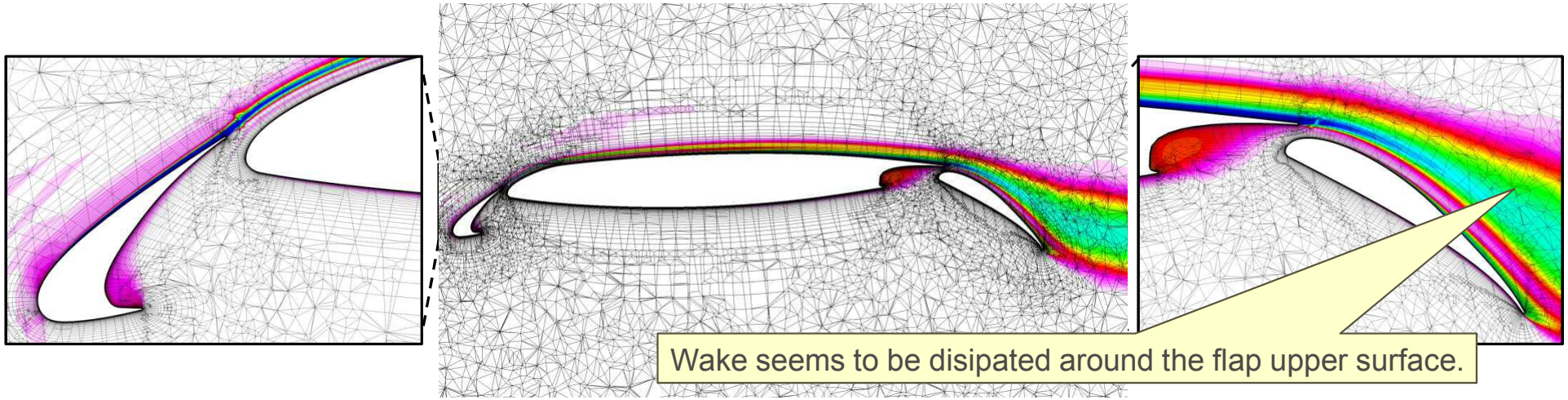


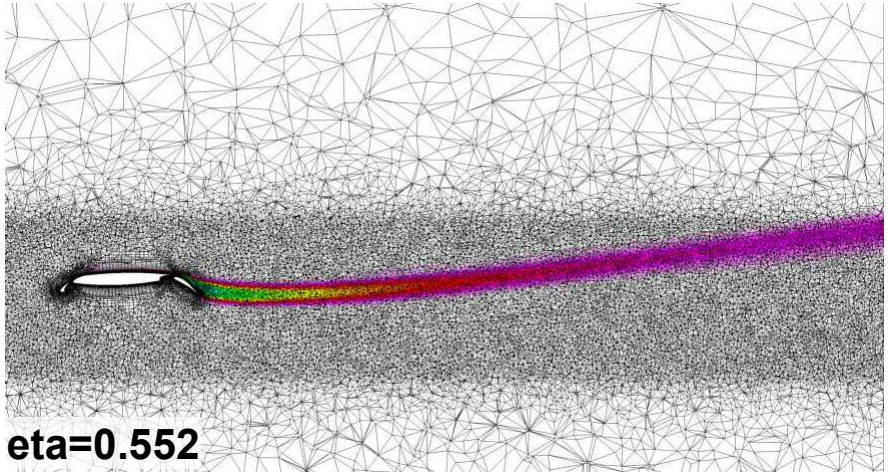
Step 24000
Time 0.00000
Mach 0.200
Re 3.26e+06
Alpha 16.00
Beta 0.00
Turb sam

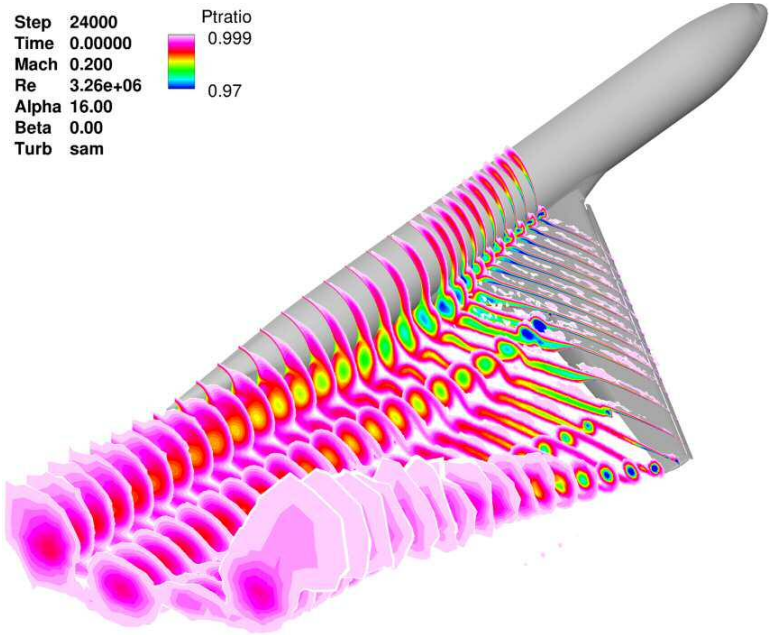
Ptratio
0.999
0.97



Total Pressure Ratio @ α=16° (B3, Medium)



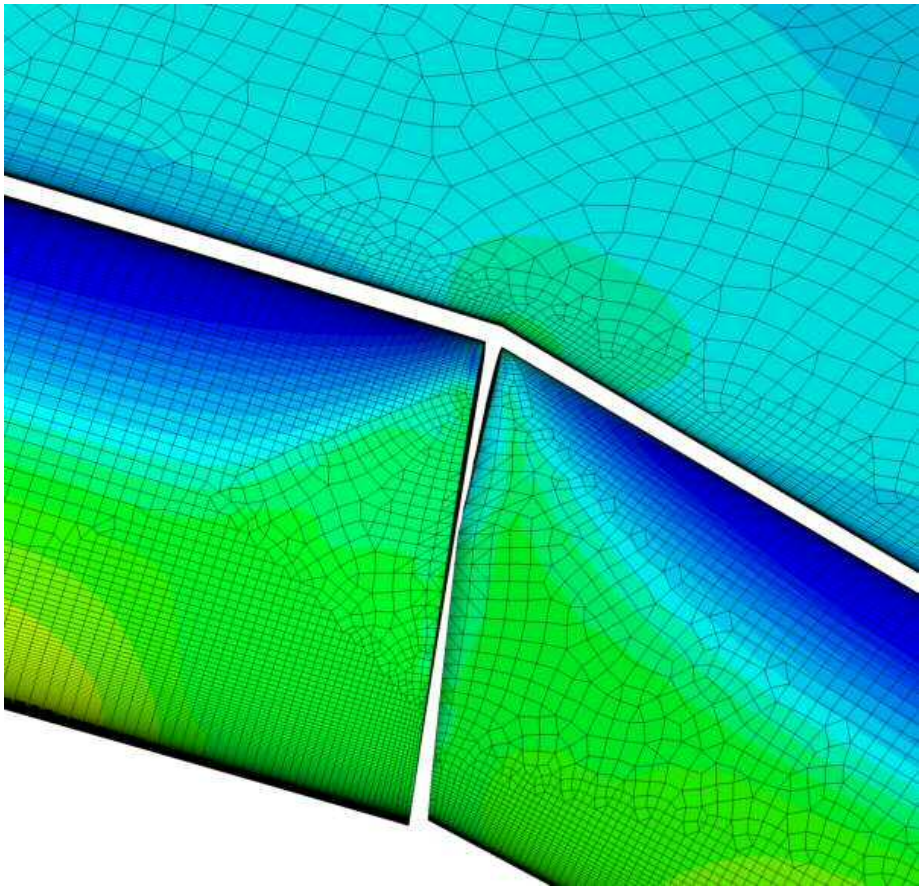


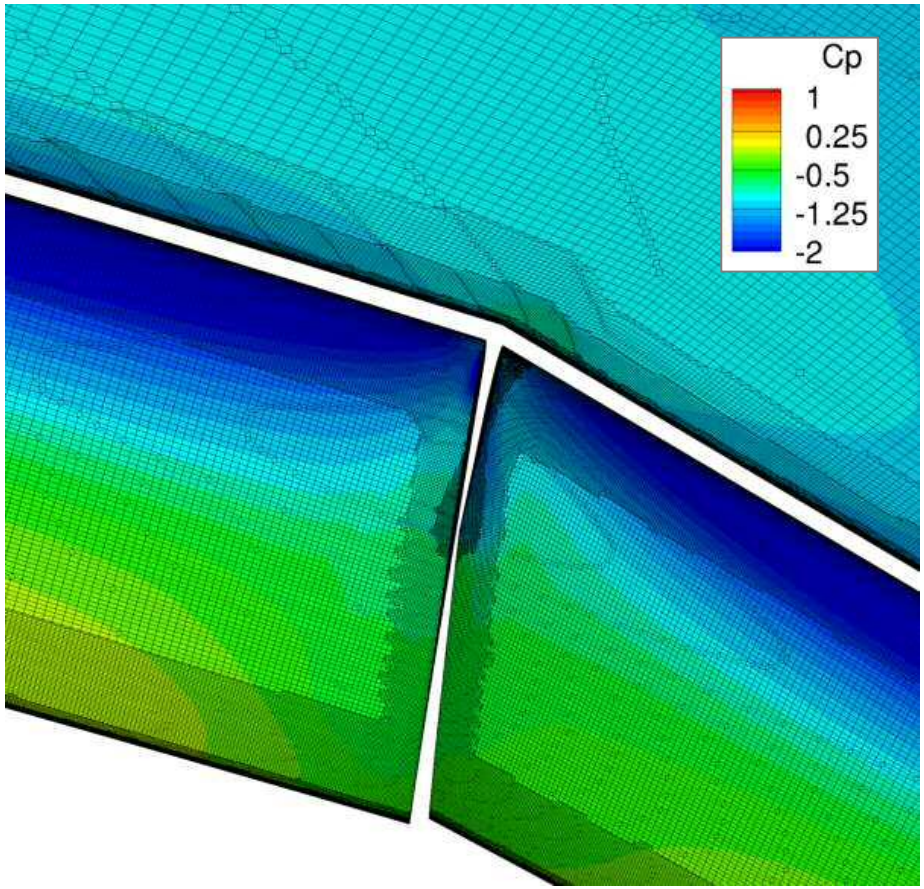


Surface Cp around Flap Gap (Medium)

B3

CflowGrid

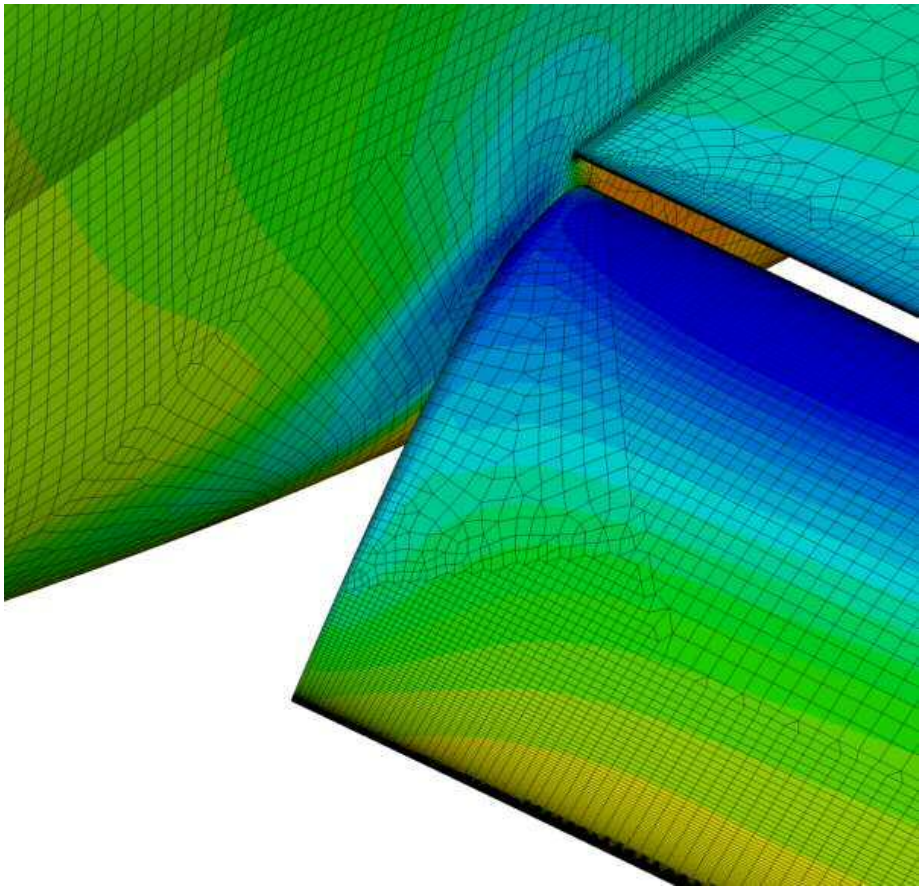


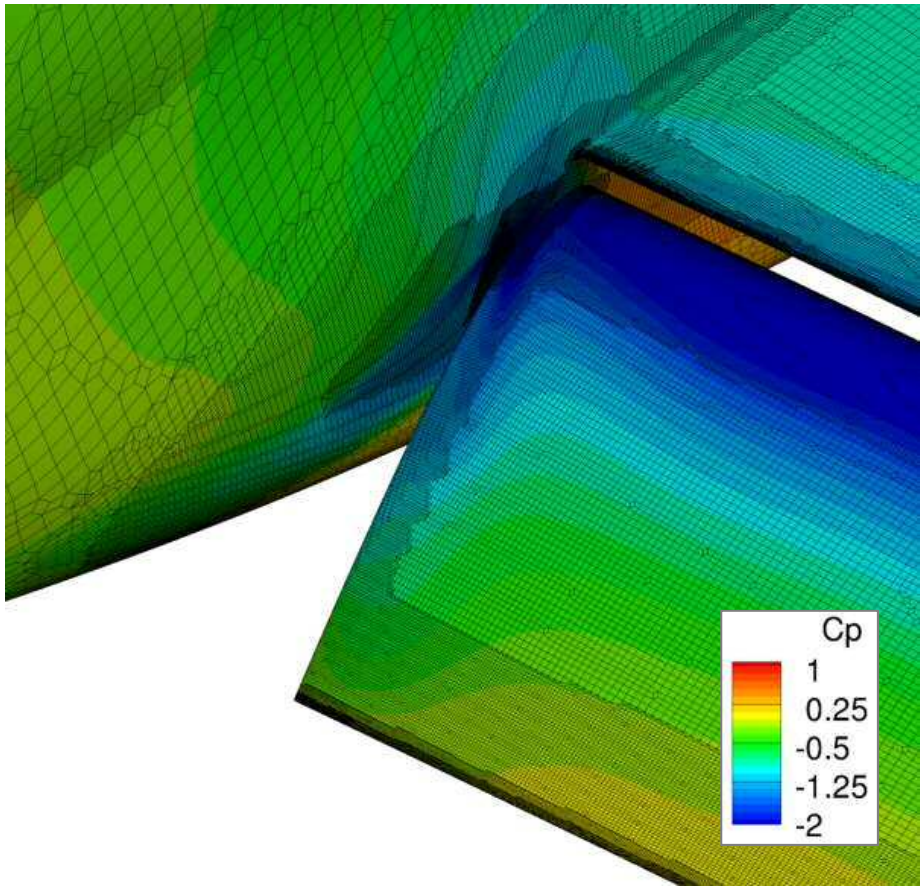


Surface Cp around Root Gap (Medium)

B3

CflowGrid

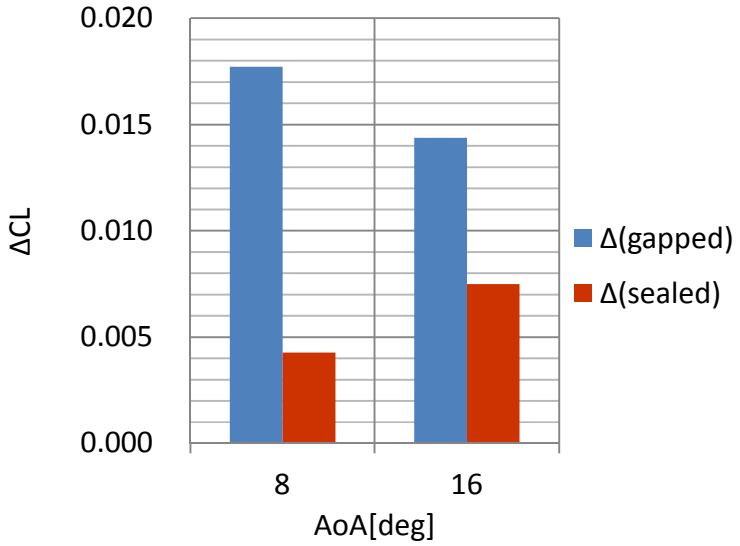


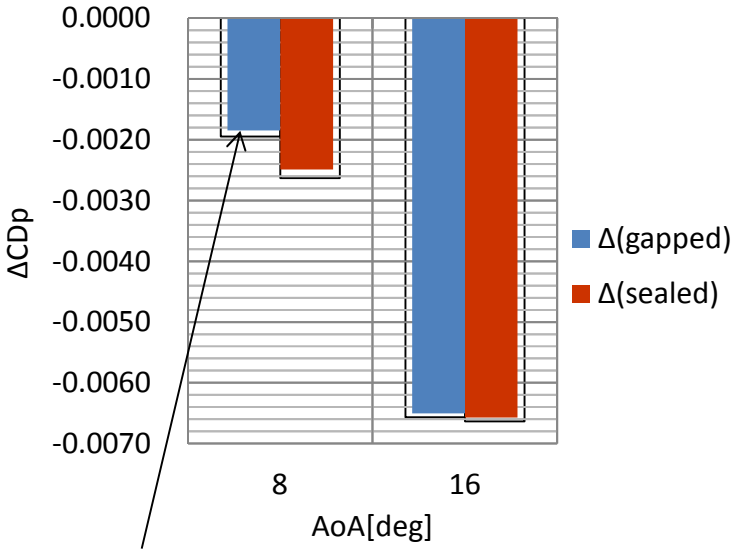


Case 1c,d – HL-CRM

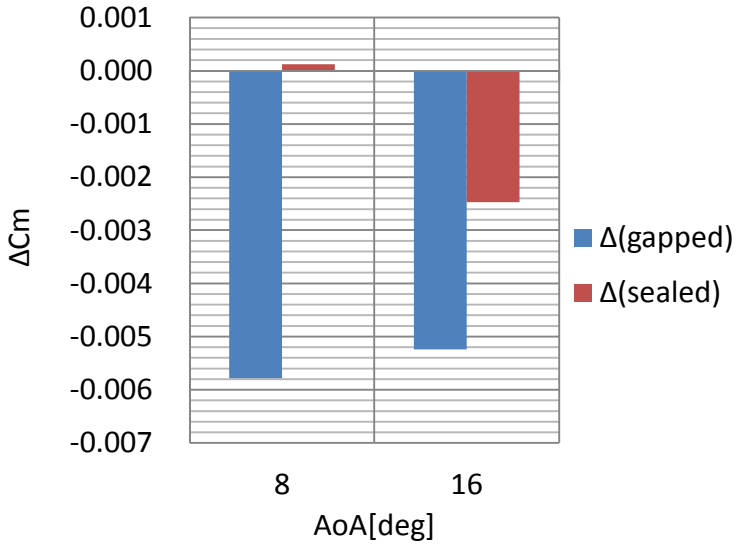
Partially Sealed Flap

Δ = (Cflow Grid) – (B3 Grid), Medium

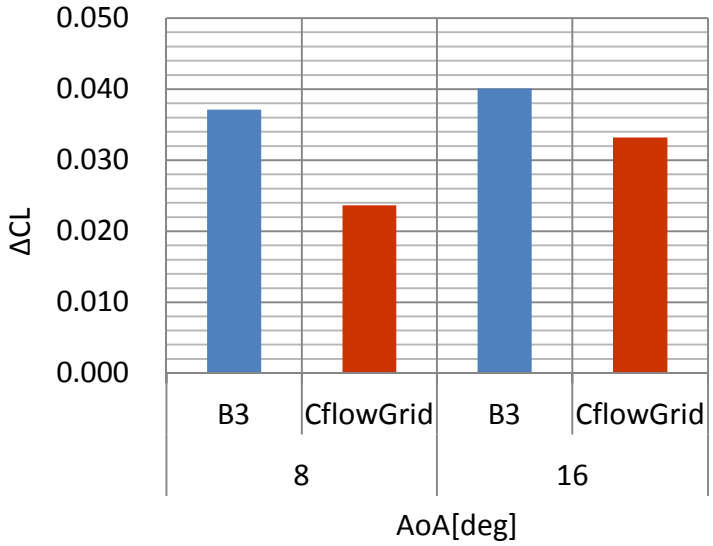


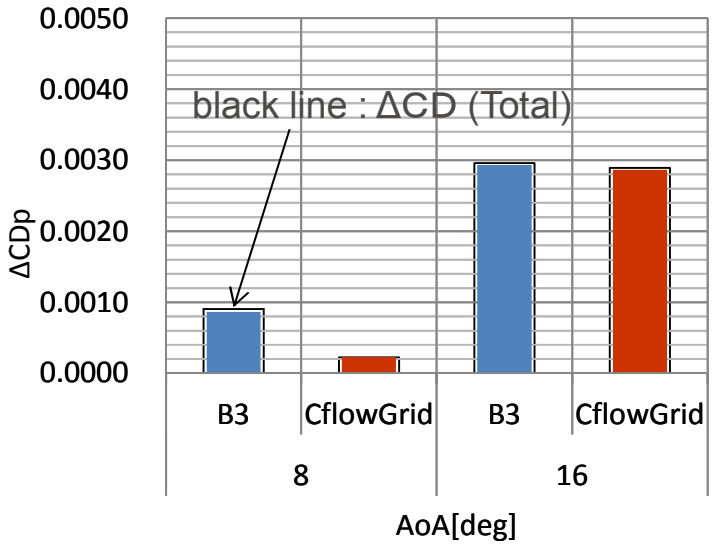


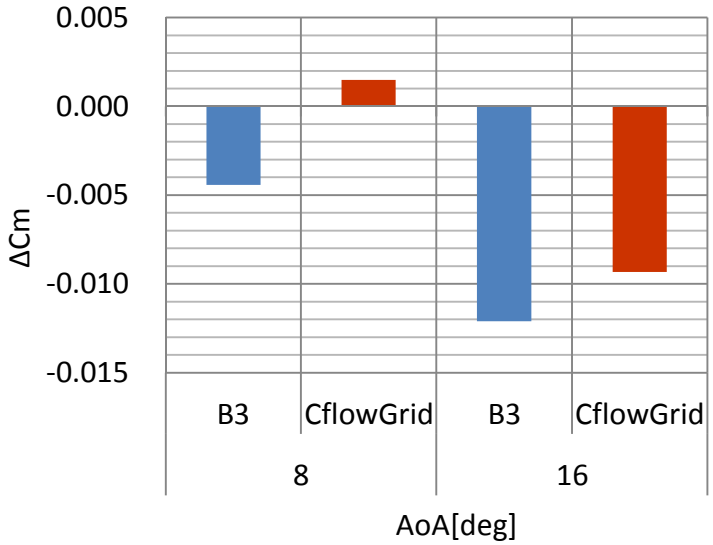
black line : ΔCD (Total)



Δ = (gapped-flaps) – (sealed-flaps), Medium





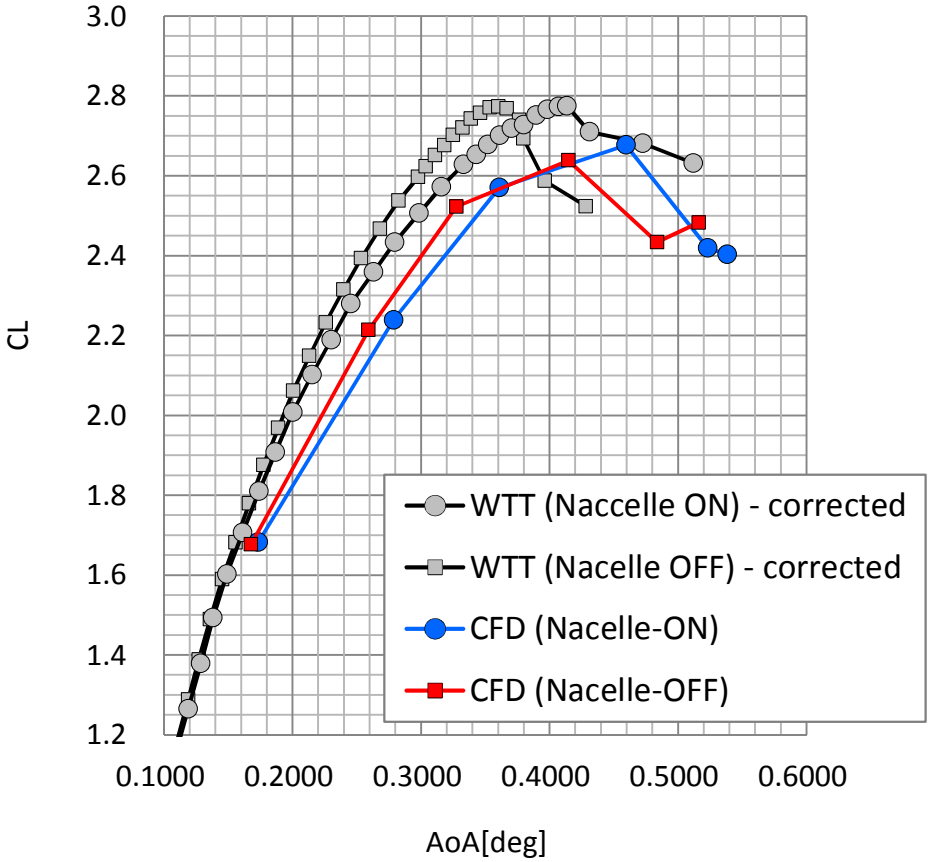


Case 2a-d JSM

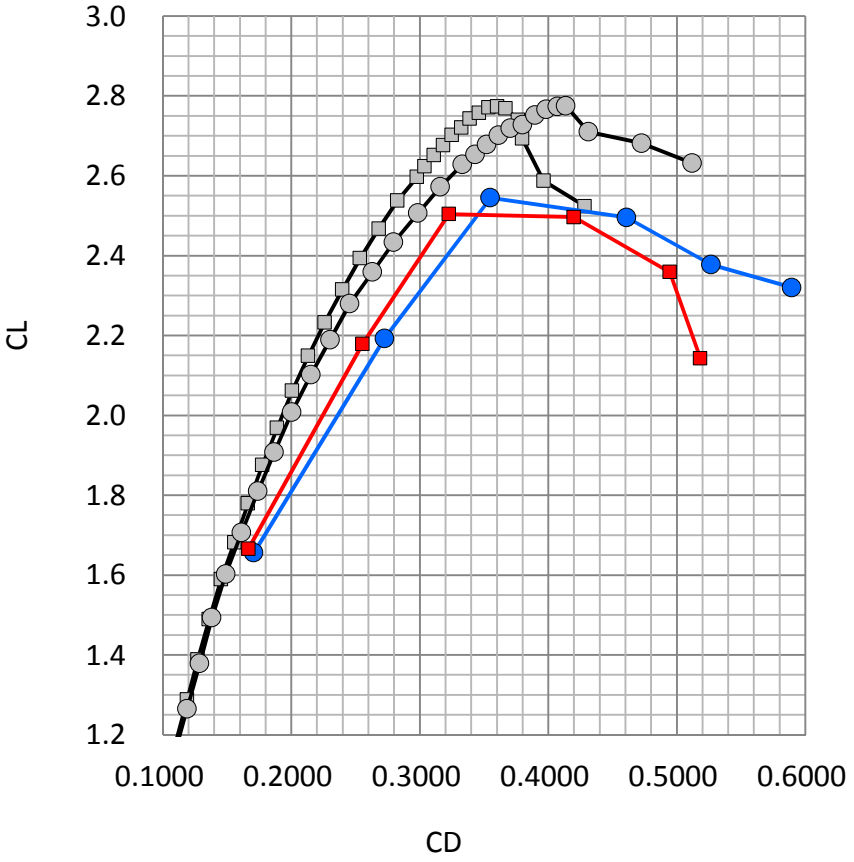
CL - CD

Mach	0.172
Re[-]	1.93 x 10^6

D-JSM_UnstrMixed_JAXA



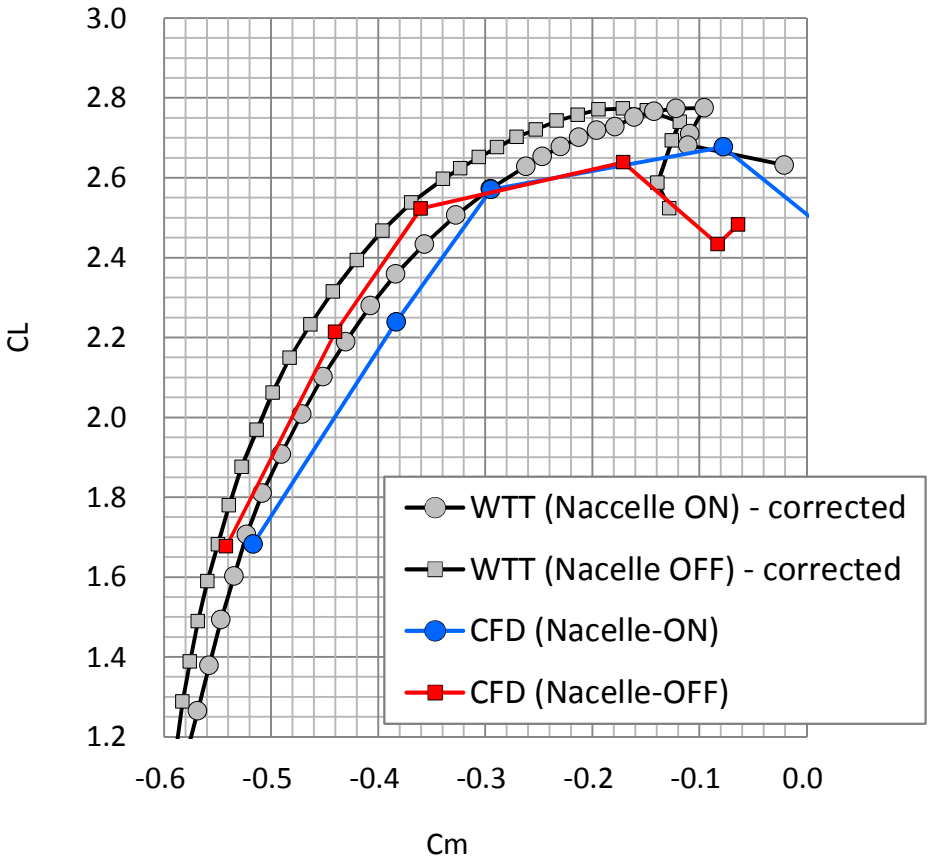
CflowGrid



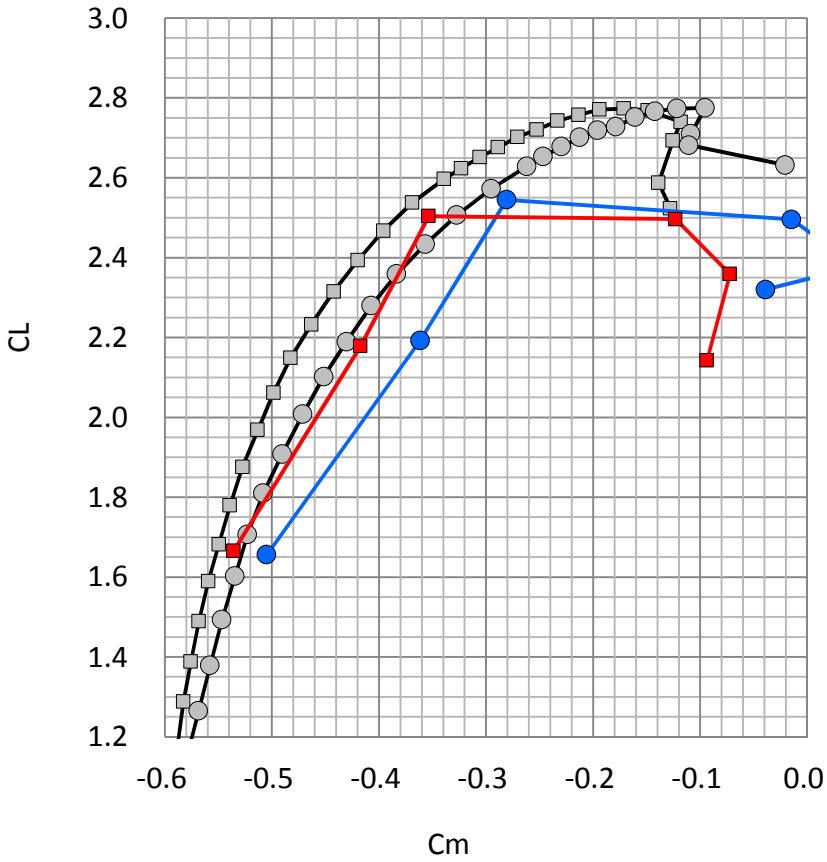
CL - Cm

Mach	0.172
Re[-]	1.93 x 10^6

D-JSM_UnstrMixed_JAXA

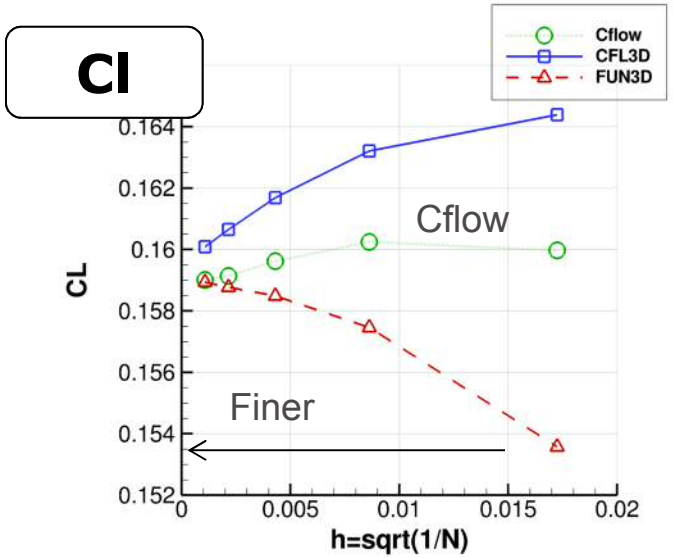


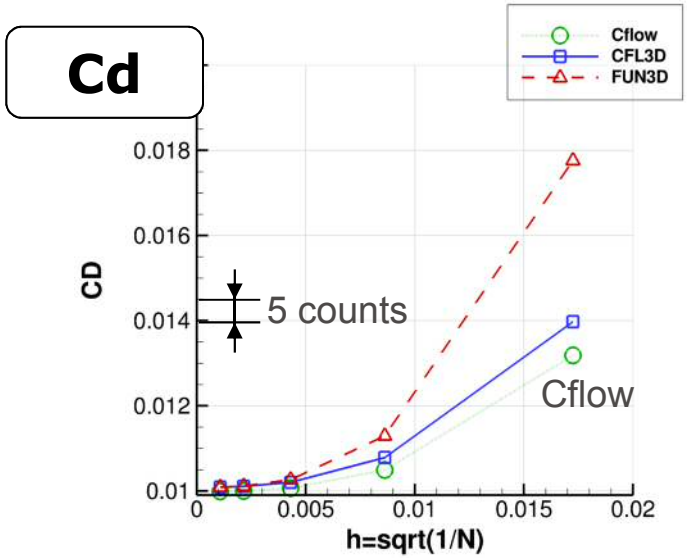
CflowGrid

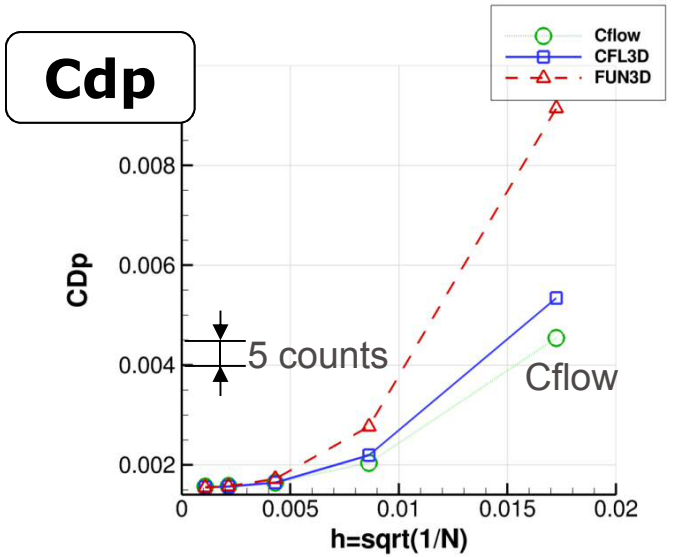


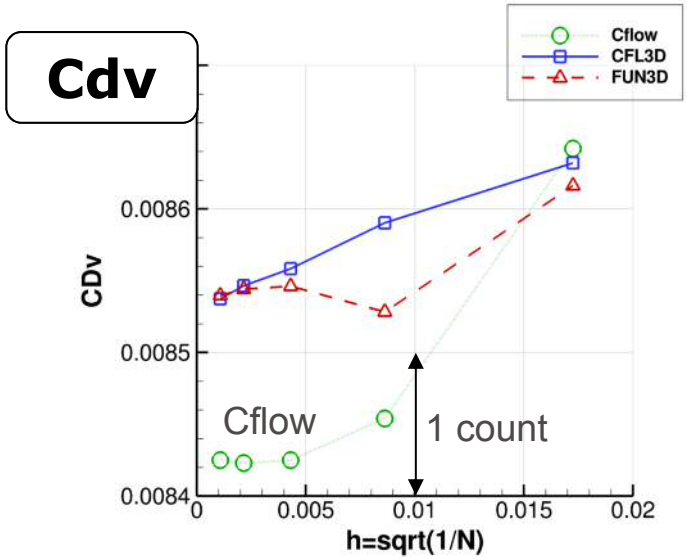
Case 3 – 2D Verification Case

Grid Convergence – Cl, Cd



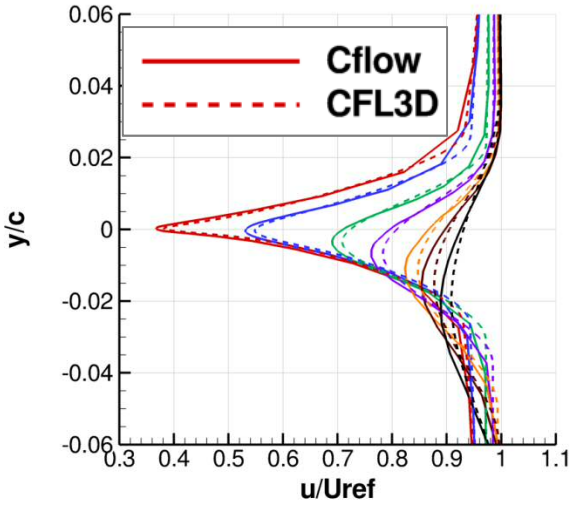




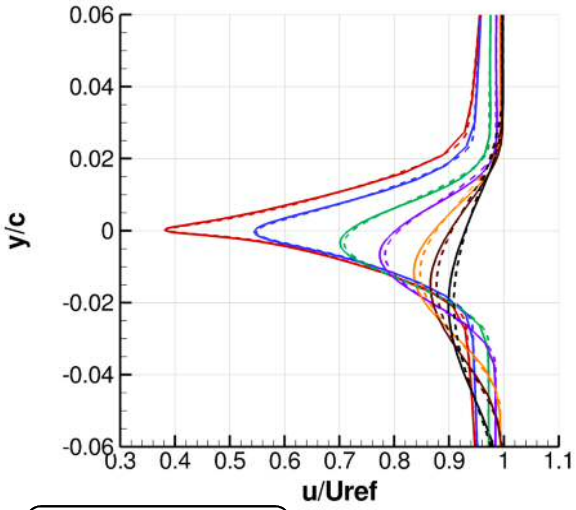


Wake (U-velocity)

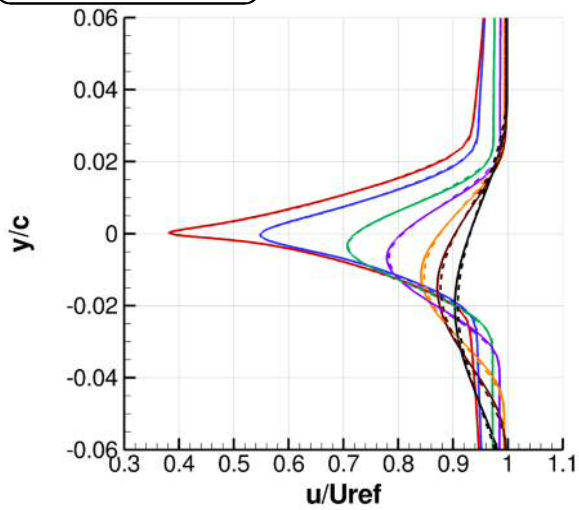
5th Finest



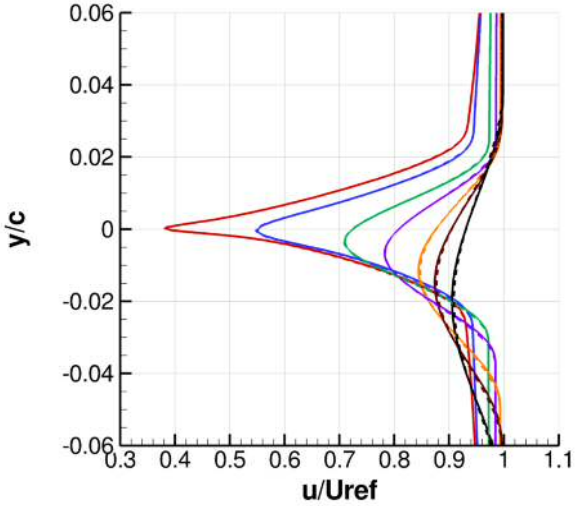
4th Finest



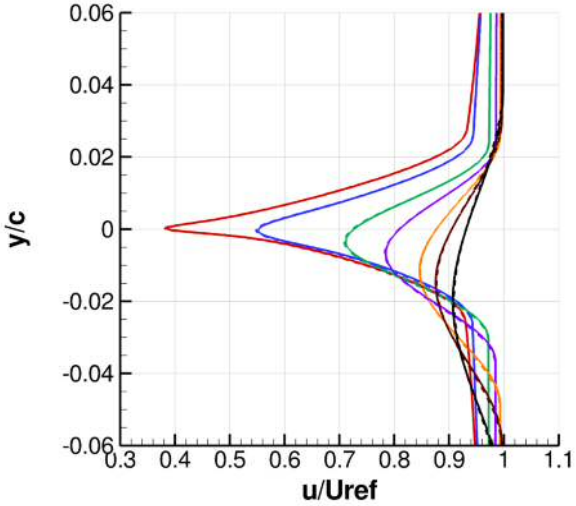
3rd Finest



2nd Finest



Finest



All CFL3D results are Finest Grid.