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Drag Prediction Using Automatic Hexahedra Grid Generation Method

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Objective

The objective of this study is evaluation of an automatic hexahedra grid generator, HexaGrid.

Contents

- ✓Features of HexaGrid
  - -Grid generated by HexaGrid
- ✓Flow solver (TAS)
- ✓Results
  - - Comparison with JAXA's other results. (MEGG3D+TAS, Gridgen+UPACS)

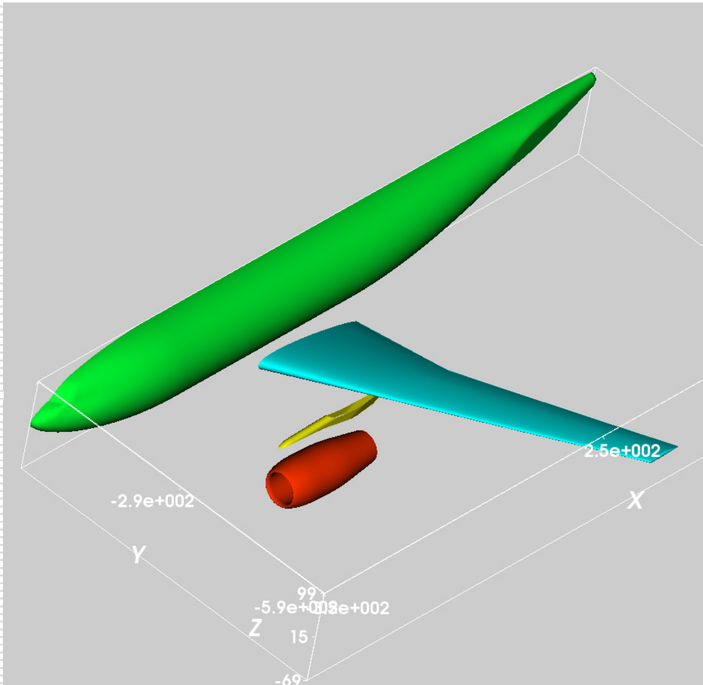
Features of HexaGrid

HexaGrid : Automatic grid generator based on hexahedral grid

- Unstructured mesh based on Cartesian mesh
  - Handles complex geometry
  - Automatic operation (very few control parameters)
  - Predominantly hexahedral element

- Input multi-component geometry in STL format

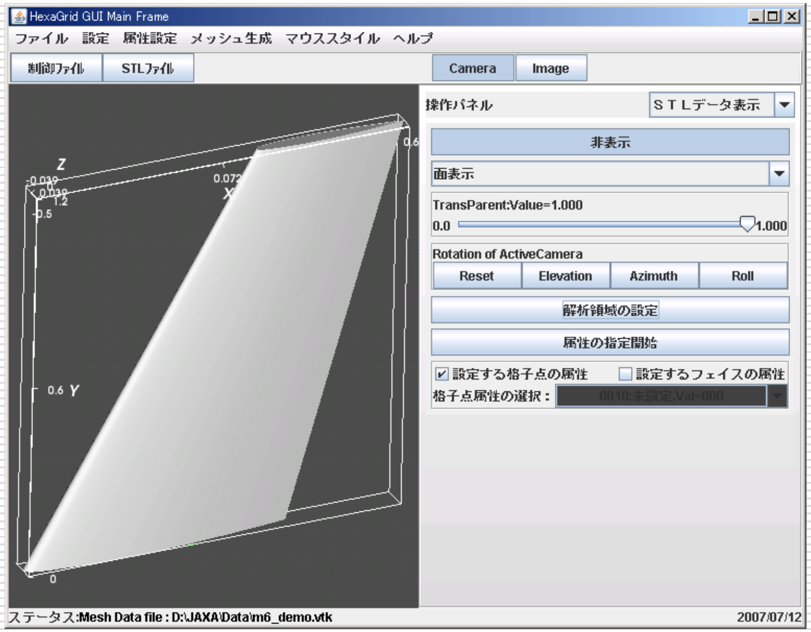
- Run on ordinary PC and
  JSS (JAXA Supercomputer System).



Input parameters

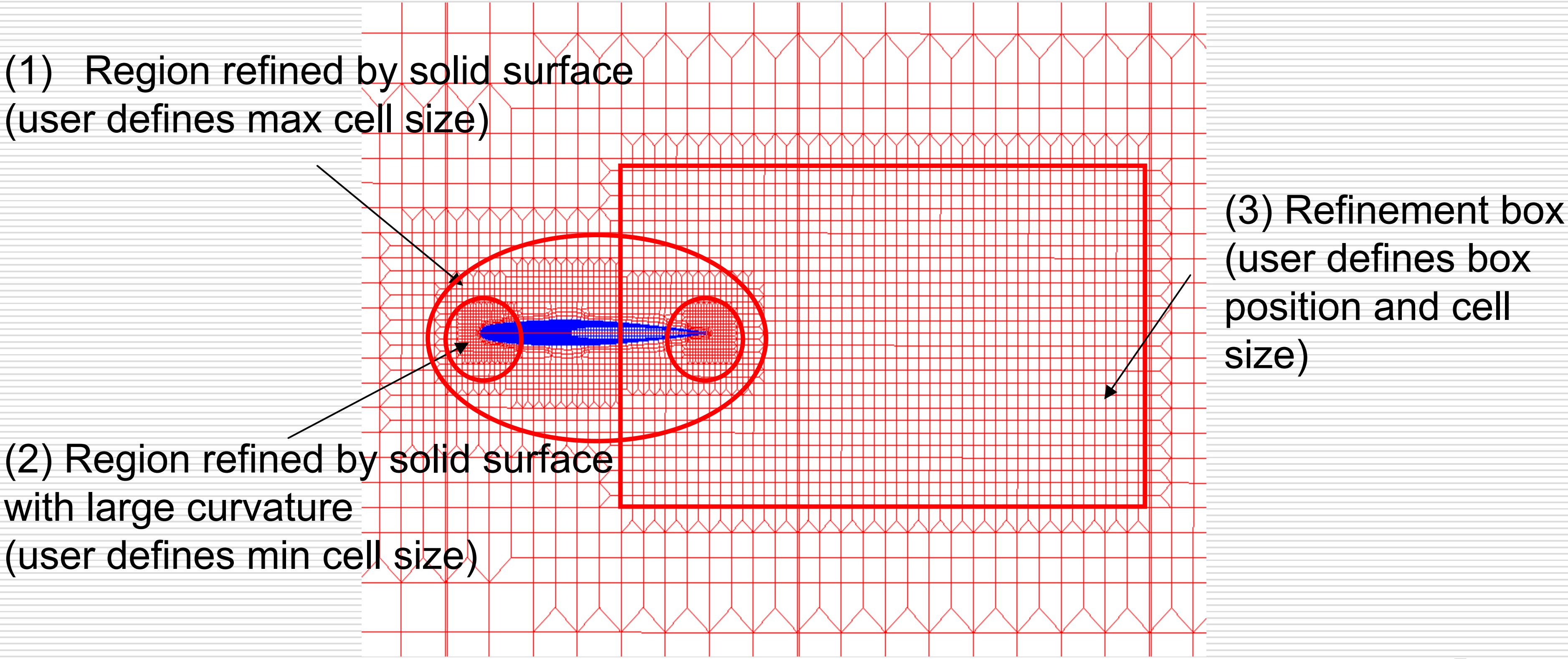
<u>Automatic operation using very few control parameters</u>

- Domain (max and min of x, y, z)
- Max and min cell size on the surface
- Layer parameter (thickness of first layer, expansion factor)



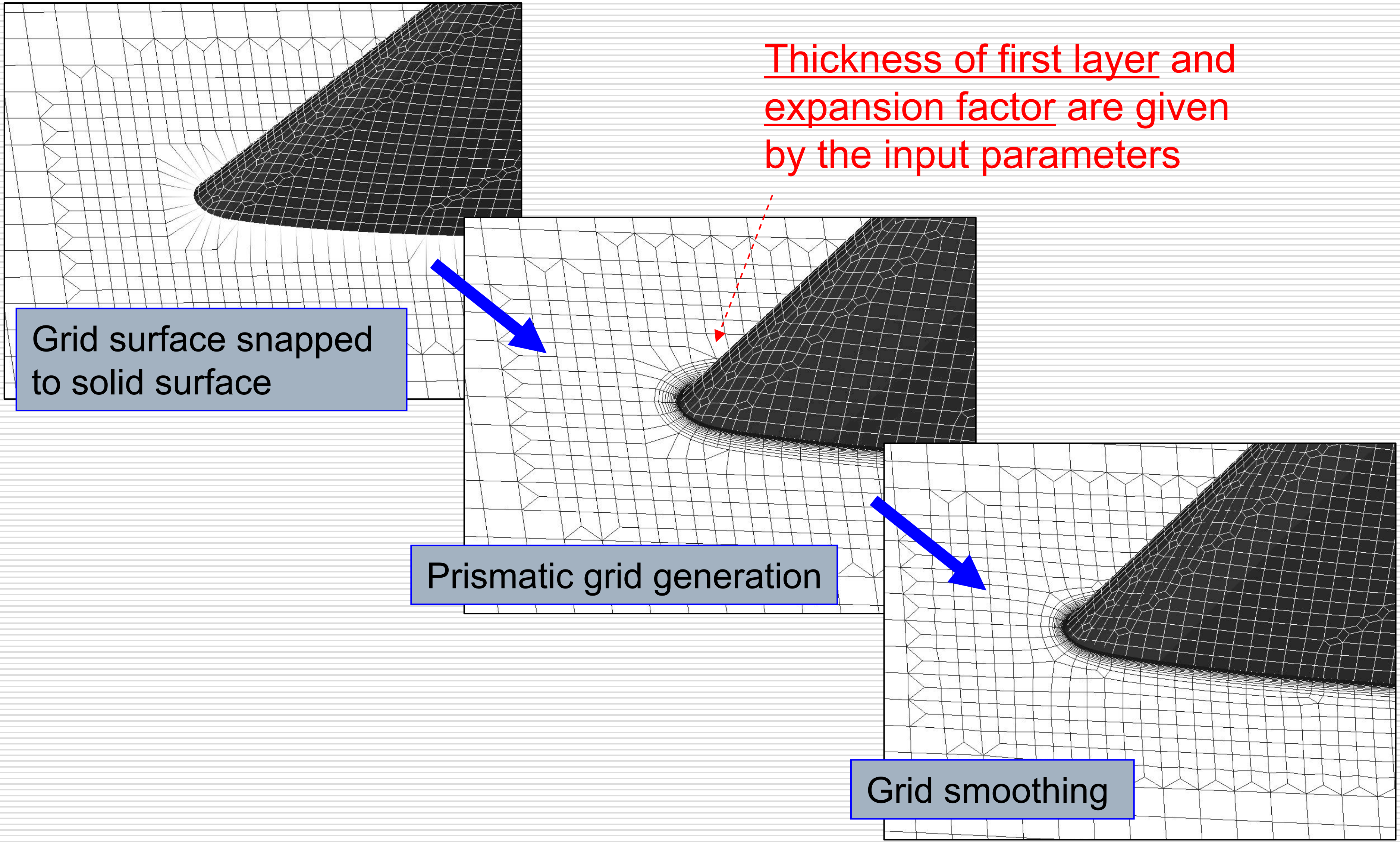
Mesh Refinement Control

- Start with one big element (= computational domain)
- Cartesian grid is generated by means of successive local refinement
- Each refinement divides a cell isotropically into eight child cells
- Refine the element using 3 criteria
- Each criterion has a target element size (user-defined)

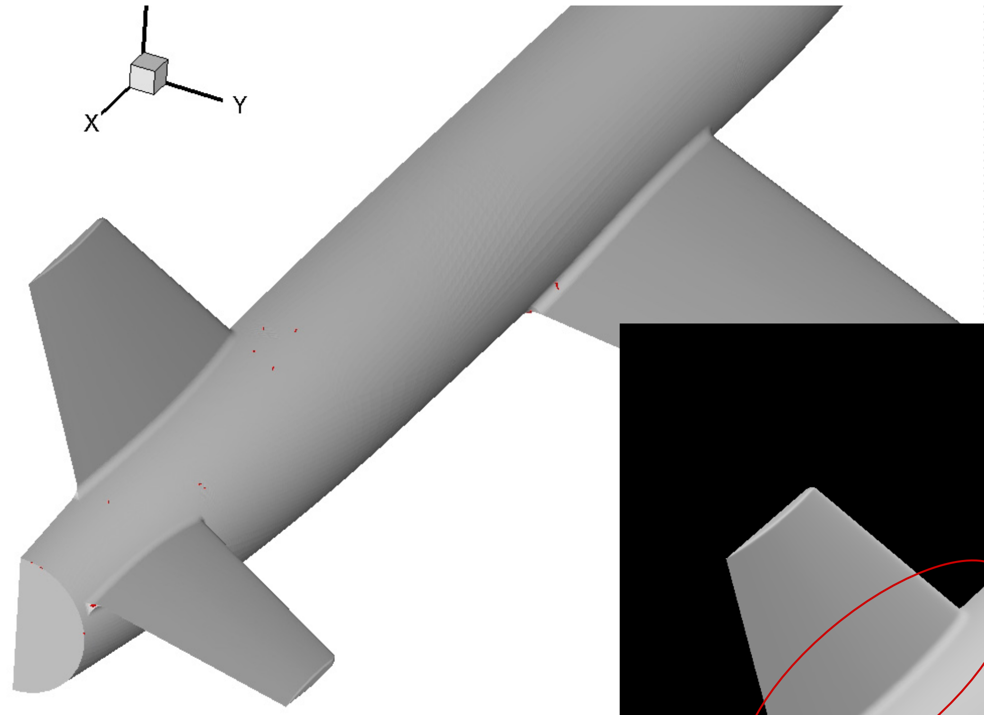


We do not use the refinement box for simplicity in this study.

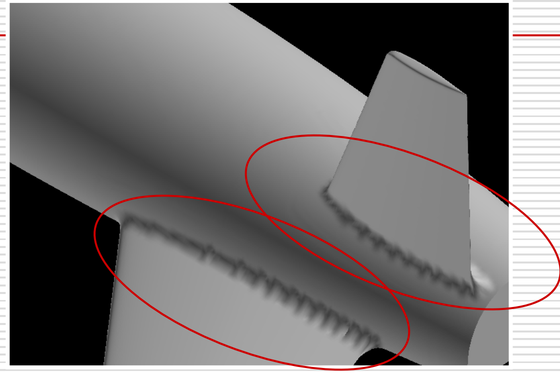
Prismatic grid generation



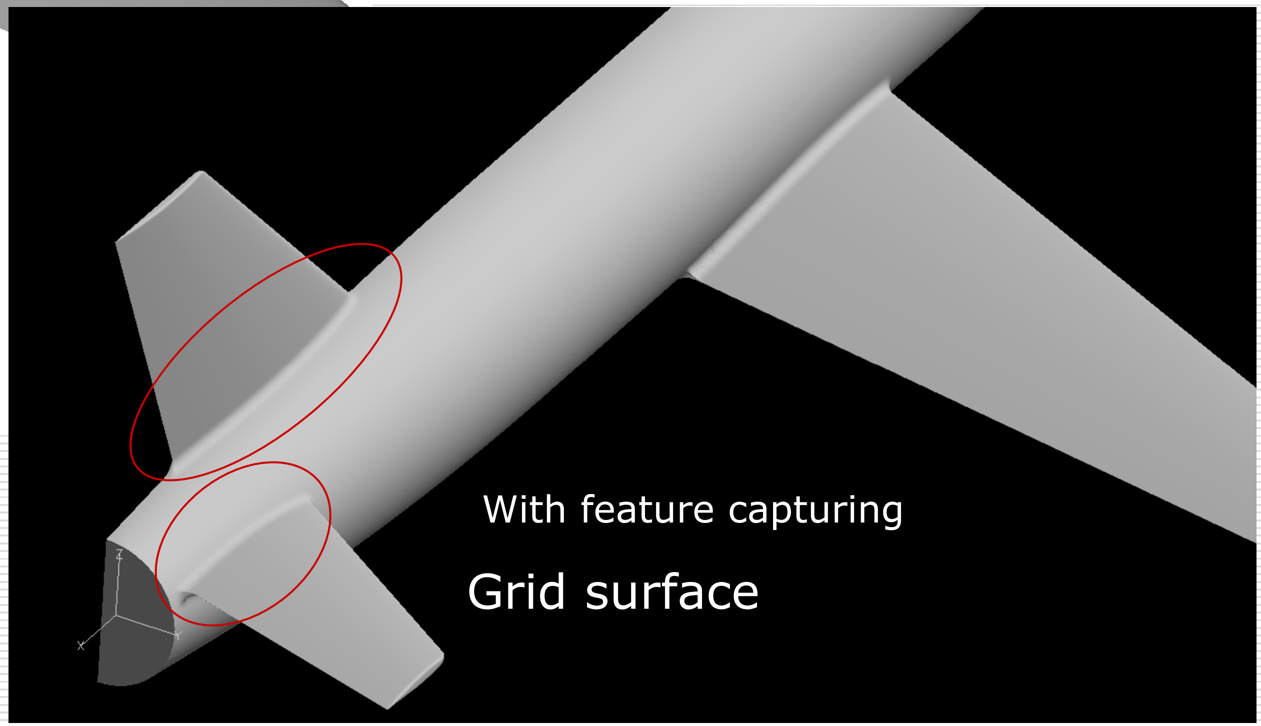
Feature capturing



STL data



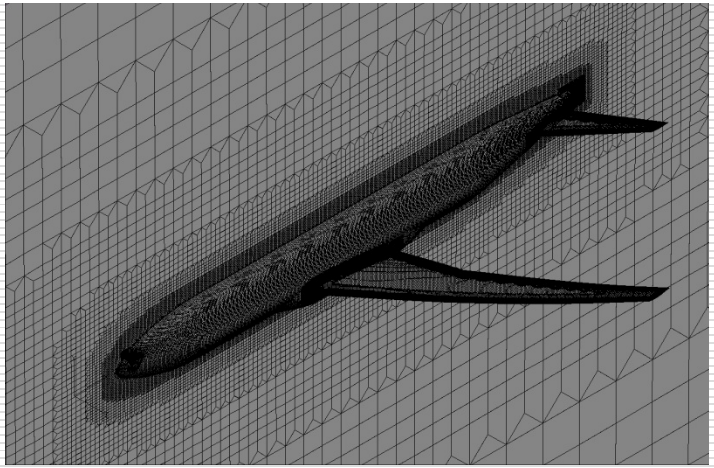
Without feature capturing

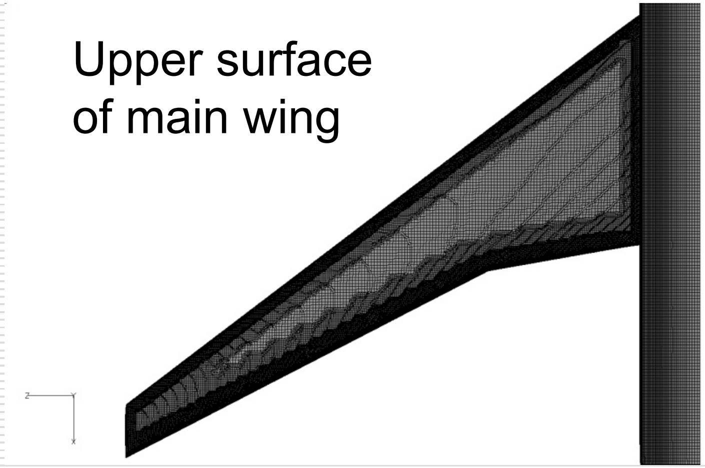


With feature capturing

Grid surface

Setting of gridding parameters



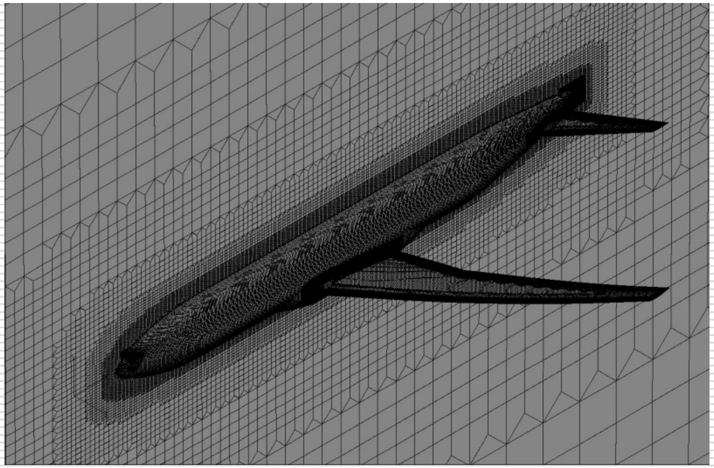


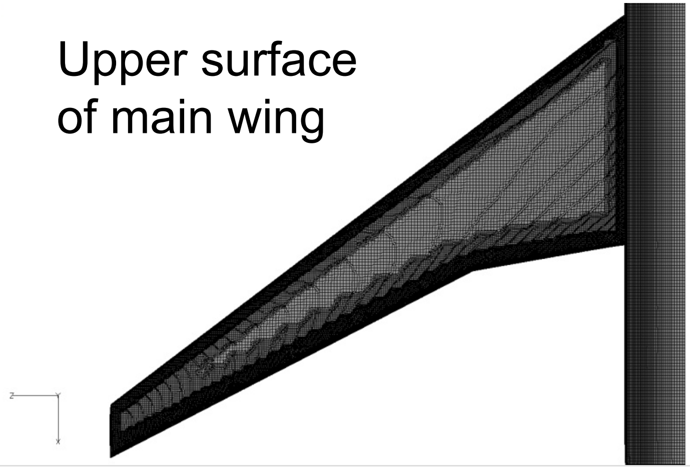
Setting parameter	Coarse	Medium	Fine
Max cell size on solid surface	5 in	5 in	5 in
Min cell size on solid surface	5 in	1.25 in ($=5/2^2$)	0.625 in ($=5/2^3$)
Expansion ratio of prism layers	1.25	1.25	1.25
Thickness of first prism layer	9.85E-4 in	9.85E-4 in	9.85E-4 in
Cubic domain size	100 C_{ref}	100 C_{ref}	100 C_{ref}

Reference Chord length = 275.80 in

Gridding Guidelines

Setting of gridding parameters





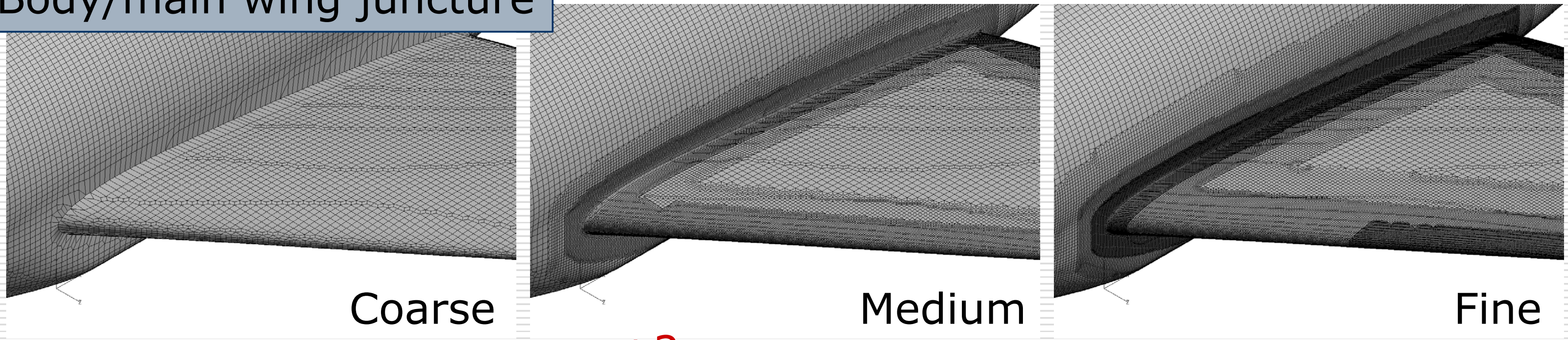
Setting parameter	Coarse	Medium	Fine
Max cell size on solid surface	5 in	5 in	5 in
Min cell size on solid surface	5 in	1.25 in (=$5/2^2$)	0.625 in (=$5/2^3$)
Expansion ratio of prism layers	1.25	1.25	1.25

0.1% of local chord at LE, TE ➔ 0.11-0.47in for the main wing
(Gridding Guidelines)

➔ 10-50 times larger grid size (Coarse grid)
3-10 times larger grid size (Medium grid)
1.5-6 times larger grid size (Fine grid)

Grids generated with HexaGrid

Body/main wing juncture



+2 +3

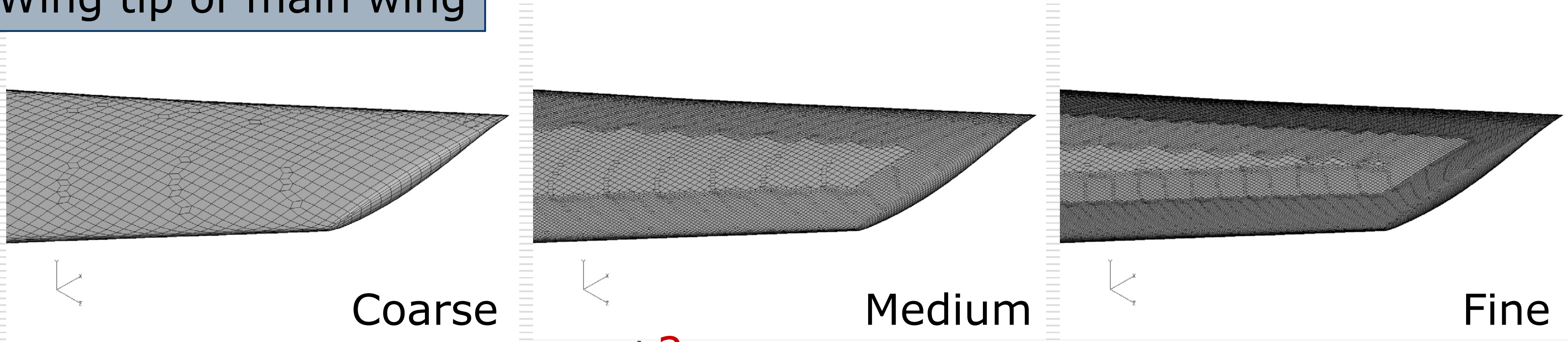
	Coarse	Medium	Fine
Number of refinement process	13	15	16
Number of prism layers	35	29	26
Node count	3,213,783	11,055,602	36,601,899
Cell count	3,644,942	12,654,764	41,630,191
Boundary node count	105,686	295,394	757,593
Boundary face count	106,272	297,697	762,131
Prismatic cell count	1,932,525	7,145,542	17,752,826

✓Feature line is clearly captured

3.5M (Coarse), 10M (medium), 35M (fine) are required by the guideline.

Grids generated with HexaGrid

Wing tip of main wing



+2 +3

	Coarse	Medium	Fine
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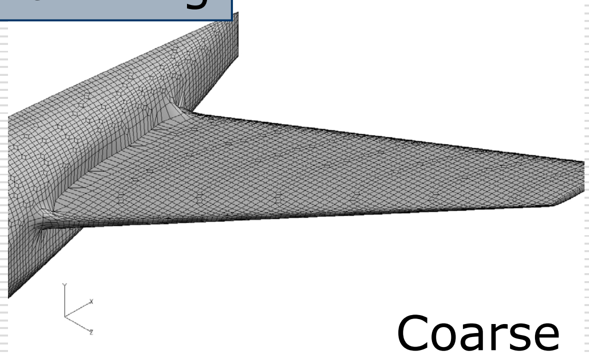
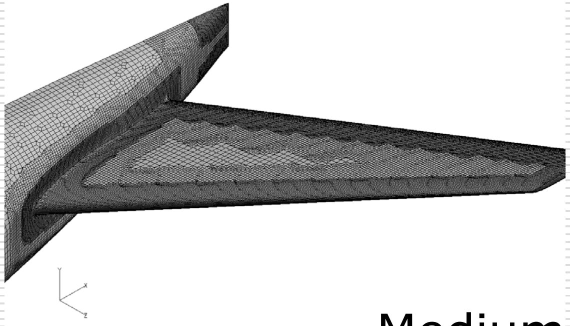
3.5M (Coarse), 10M (medium), 35M (fine) are required by the guideline.

Grids generated with HexaGrid

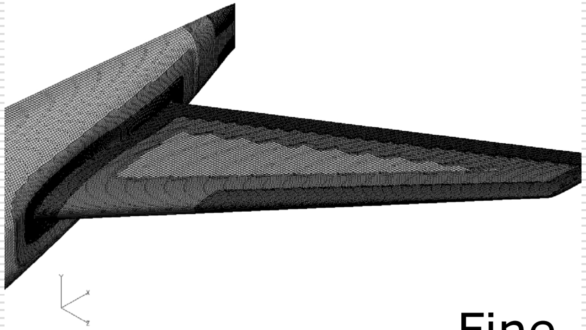
Tail wing



Coarse



Medium



Fine

+2 +3

	Coarse	Medium	Fine
Number of refinement process	13	15	16
Number of prism layers	35	29	26
Node count	3,213,783	11,055,602	36,601,899
Cell count	3,644,942	12,654,764	41,630,191
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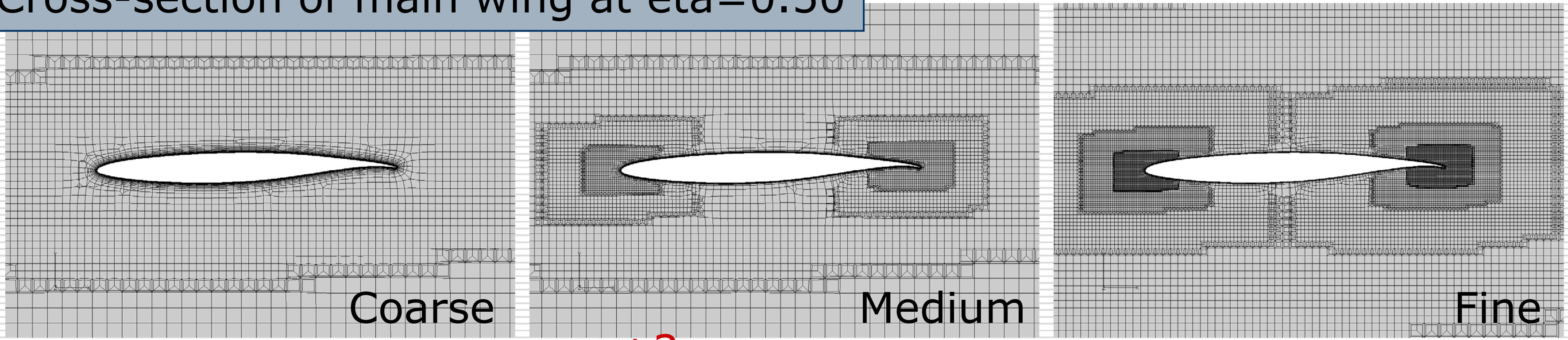
3.5M (Coarse), 10M (medium), 35M (fine) are required by the guideline.

Grids generated with HexaGrid

Cross-section of main wing at eta=0.50



+2 +3

	Coarse	Medium	Fine
Number of refinement process	13	15	16
Number of prism layers	35	29	26
Node count	3,213,783	11,055,602	36,601,899
Cell count	3,644,942	12,654,764	41,630,191
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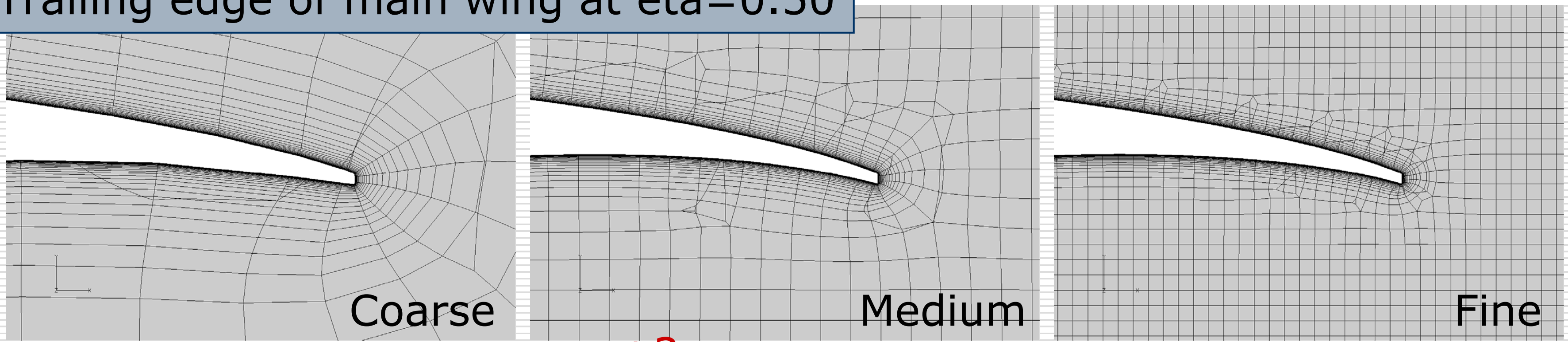
3.5M (Coarse), 10M (medium), 35M (fine) are required by the guideline.

Grids generated with HexaGrid

Trailing edge of main wing at eta=0.50



	Coarse	Medium	Fine
Number of refinement process	13	15 (+2)	16 (+3)
Number of prism layers	35	29	26
Node count	3,213,783	11,055,602	36,601,899
Cell count	3,644,942	12,654,764	41,630,191
Boundary node count	105,686	295,394	757,593
Boundary face count	106,272	297,697	762,131
Prismatic cell count	1,932,525	7,145,542	17,752,826

✓5-6 nodes are located across the TE base.

✓The total thickness of prism layer is decreasing.

3.5M (Coarse), 10M (medium), 35M (fine) are required by the guideline.

Flow Solver Configuration

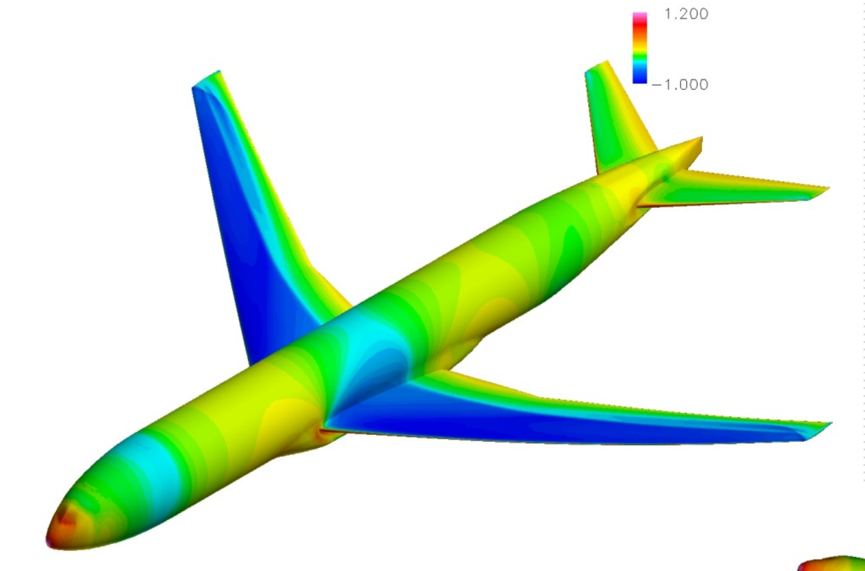
TAS-code

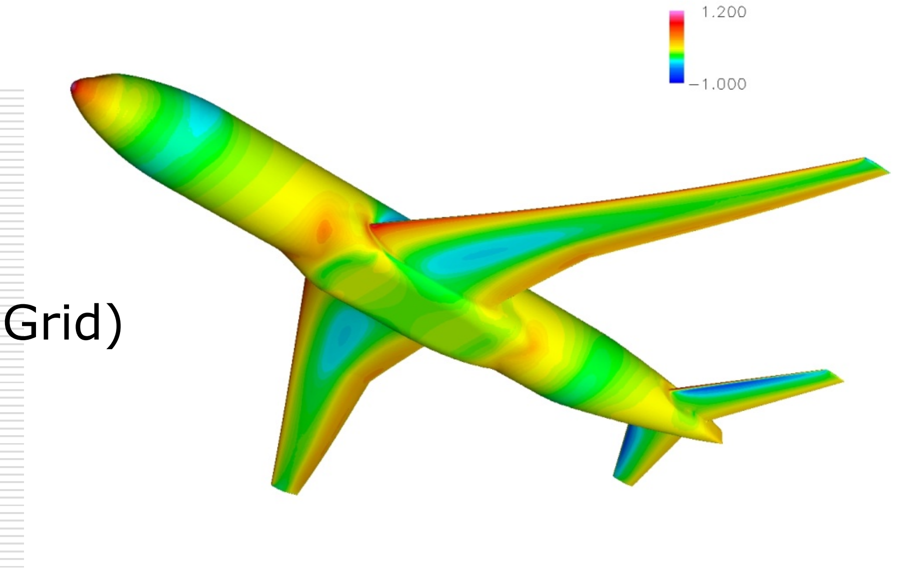
(**T**ohoku University **A**erodynamic **S**imulation code)

- ✓Mesh: Unstructured grid
- ✓Discretization: Cell vertex, finite volume method
- ✓Flux: HLLEW (Harten-Lax-van Leer-Einfeldt-Wada)
- ✓Accuracy: Second order by a linear reconstruction with Venkatakrishnan's limiter and U-MUSCL
- ✓Time integration: LU-SGS
- ✓Turbulence model: Spalart-Allmaras (SA)

As for the SA model, the trip term and the ft2 function are not included. A modified production term is used.

Results

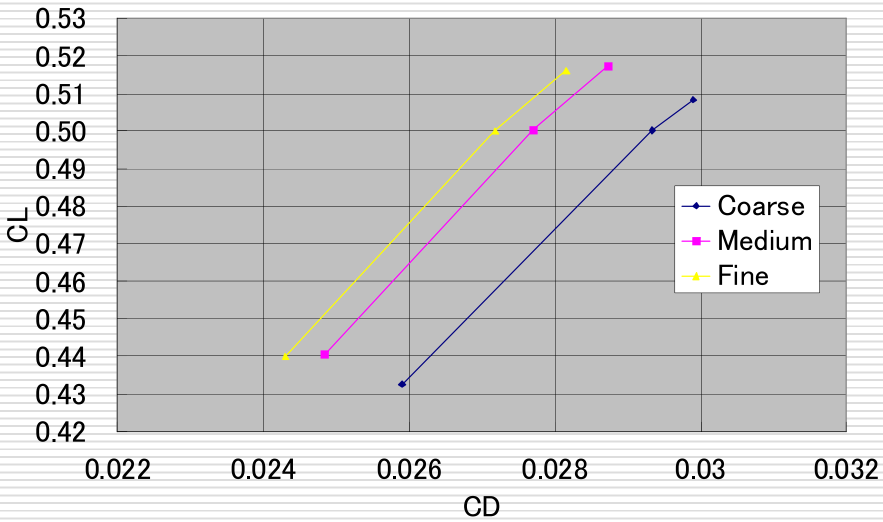


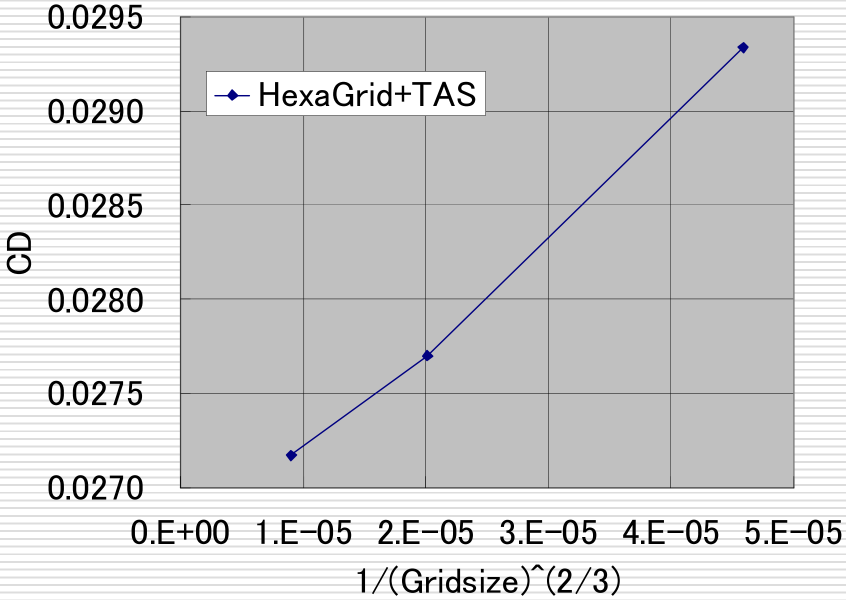


Cp contours
(M=0.85, CL=0.50, Medium Grid)

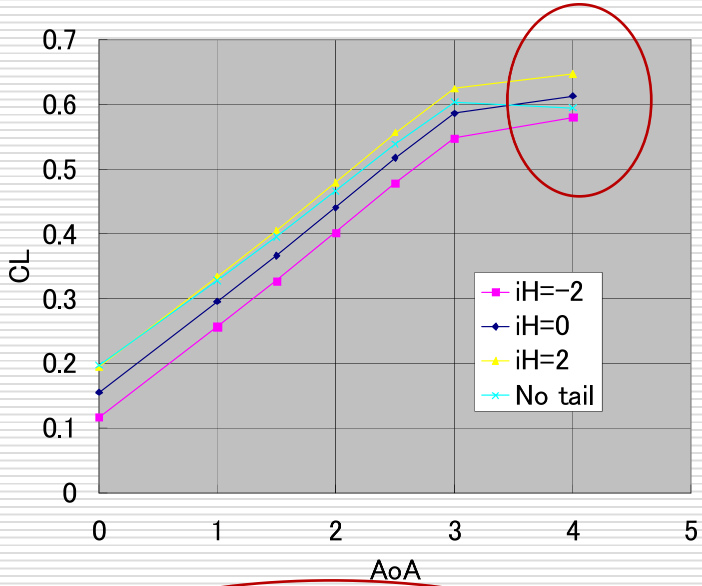
1.1 Grid convergence study

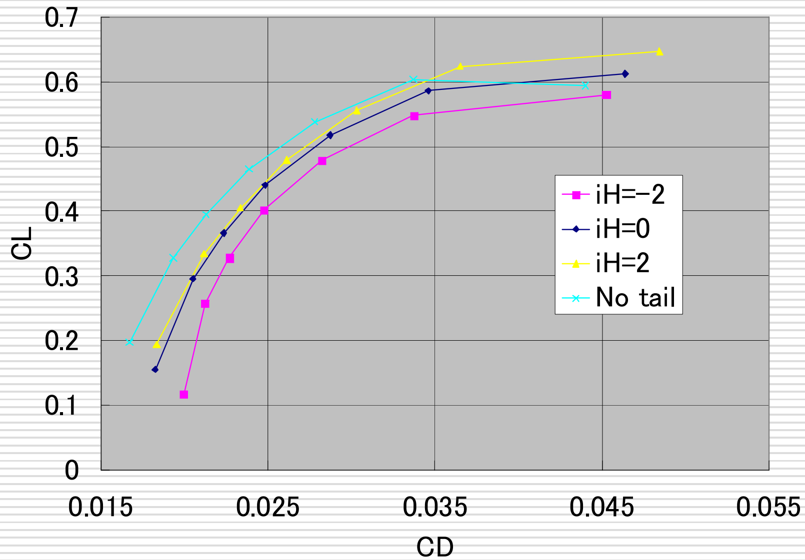
M=0.85, CL=0.50
Coarse, medium, fine grids

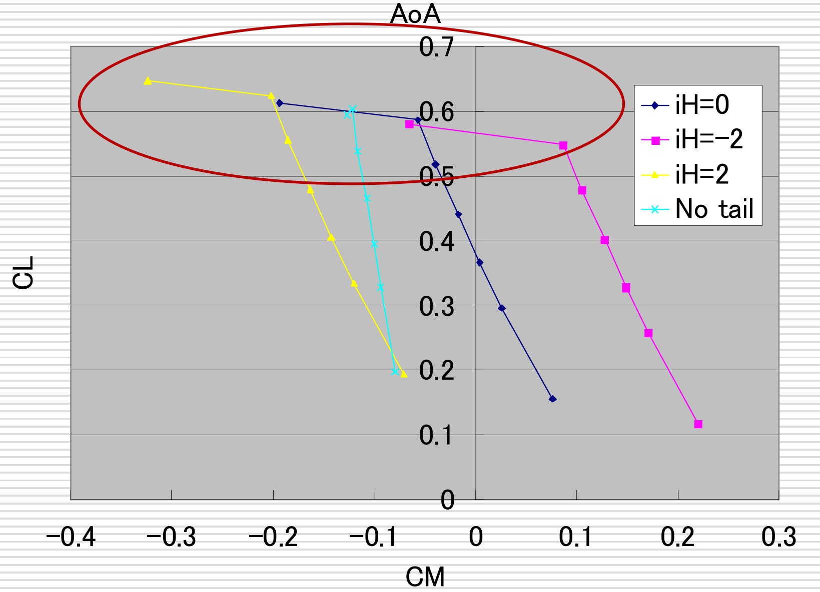


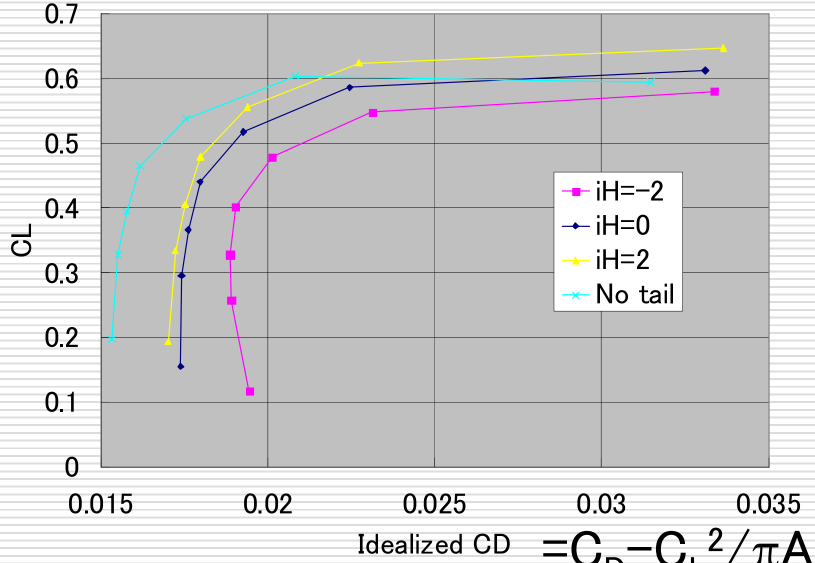


1.2 Downwash study





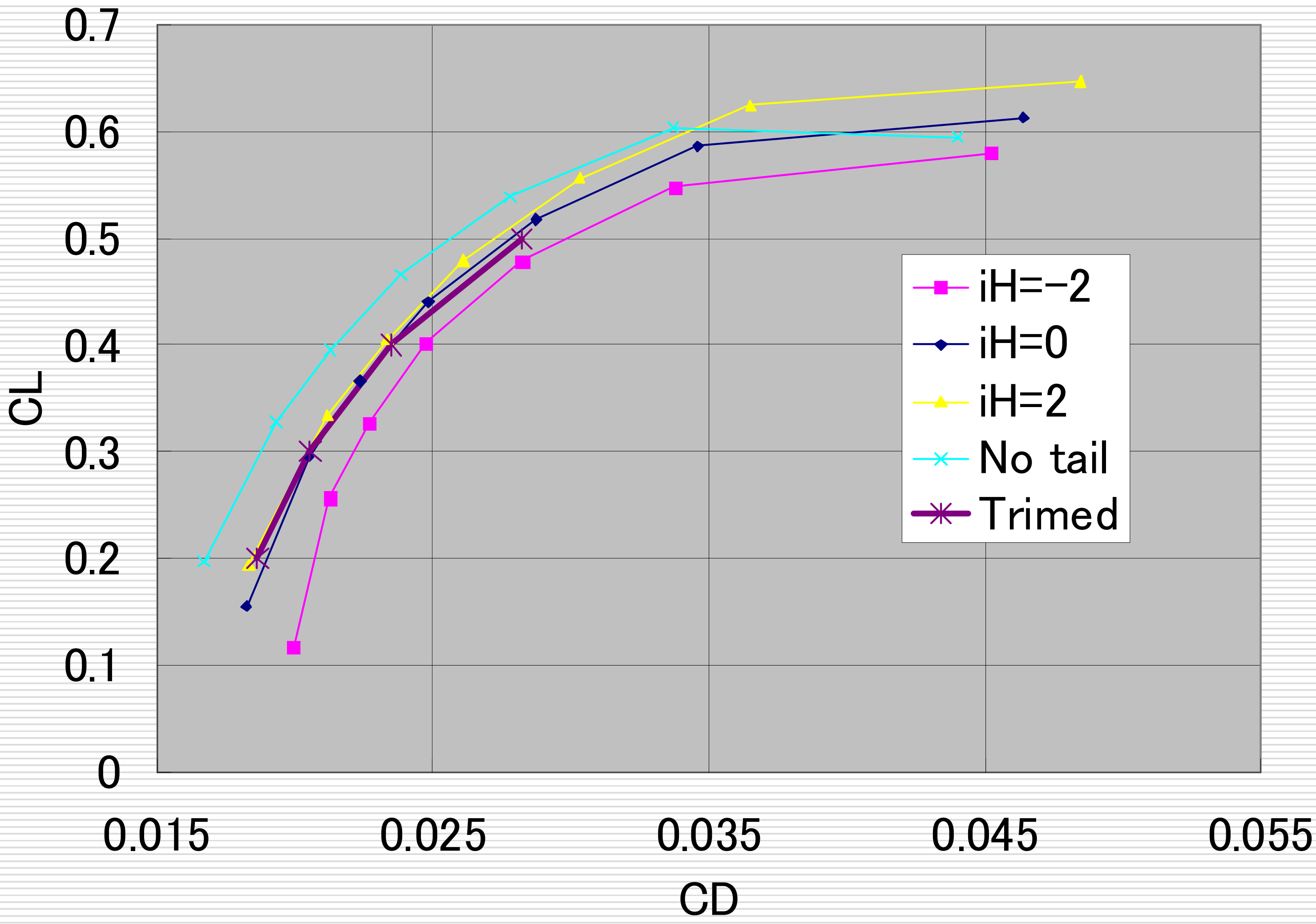




$=C_D - C_L^2/\pi AR$

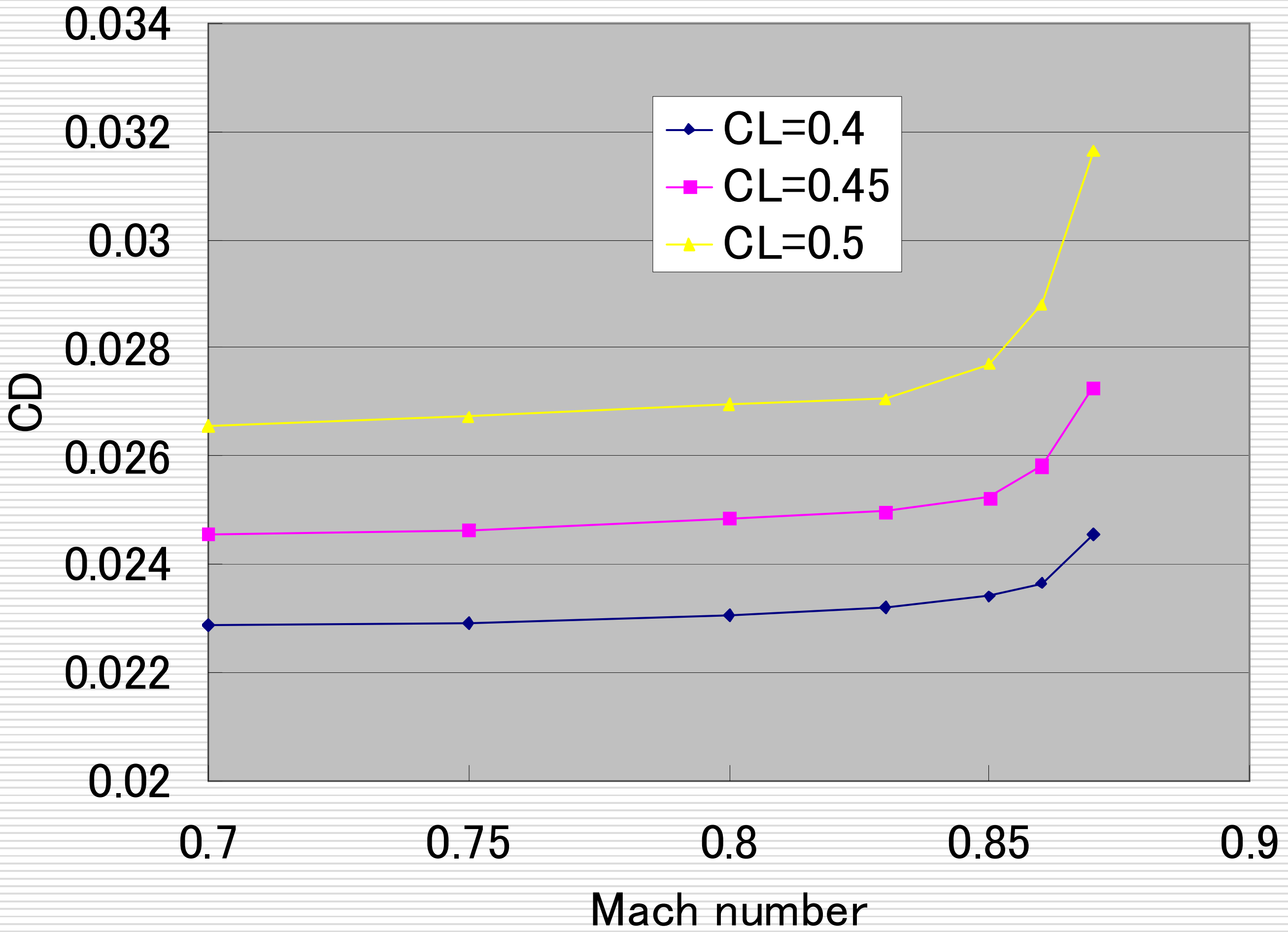
Trim Drag

TRIMMED DRAG POLAR => Interpolate iH at fixed CL to calculate CM_TOT = 0.



2 Mach sweep study

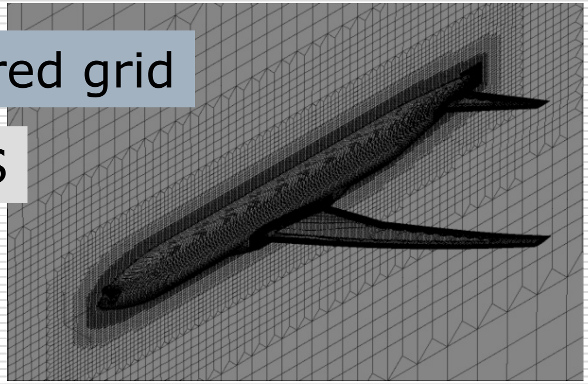
CD at CL=0.4, 0.45, and 0.5 for M=0.7-0.87

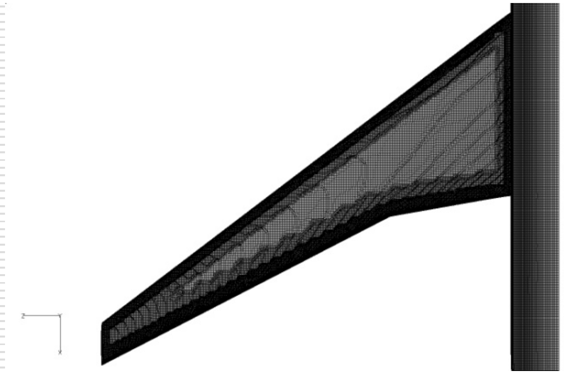


Comparison with other results

Hexa unstructured grid

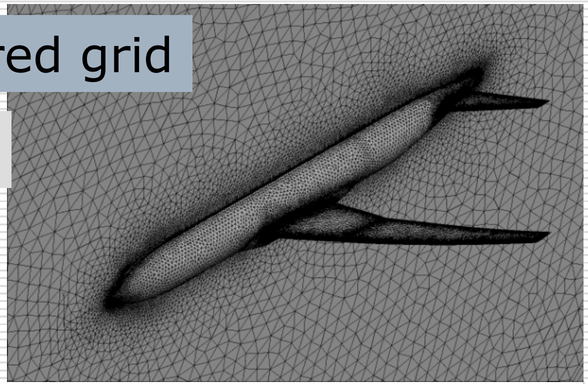
HexaGrid + TAS

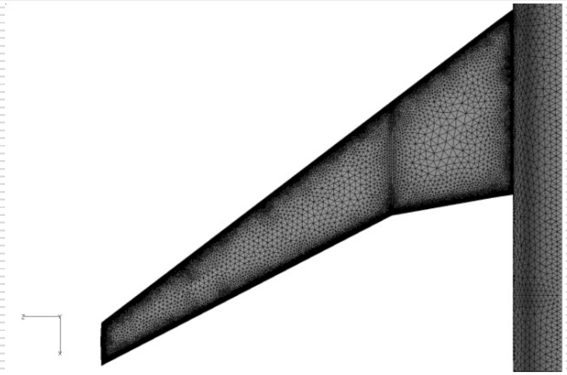




Tetra unstructured grid

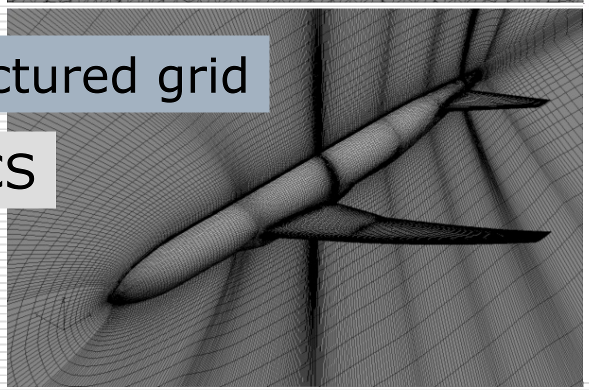
MEGG3D + TAS

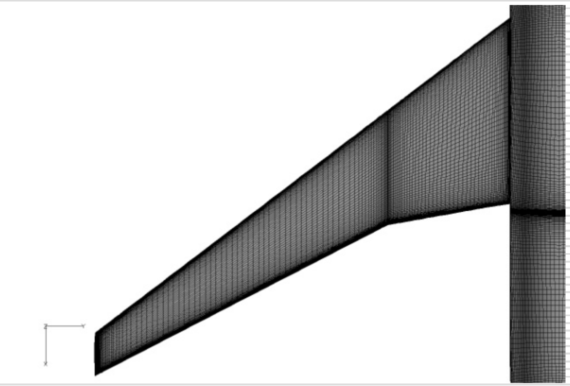




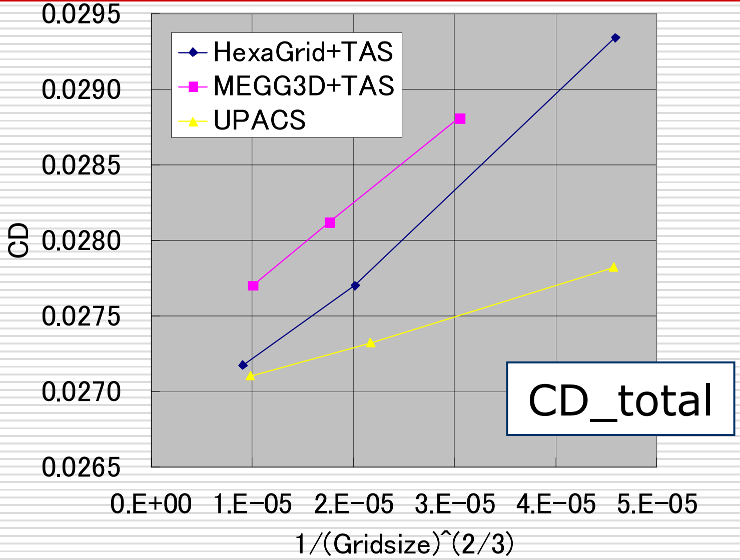
Multi-block structured grid

Gridgen + UPACS



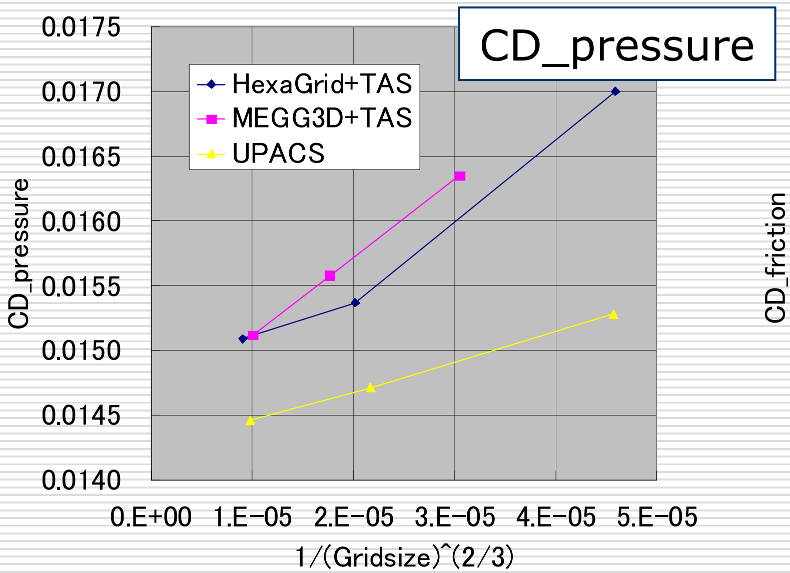


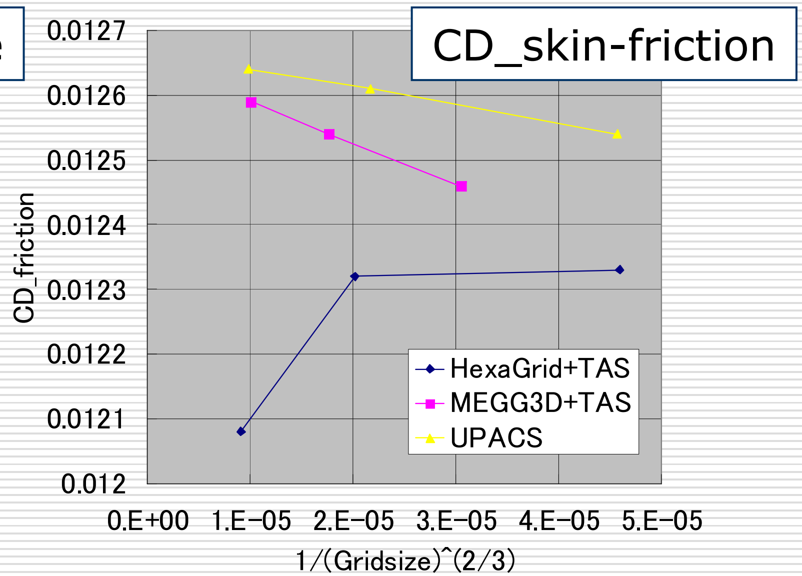
Grid convergence study



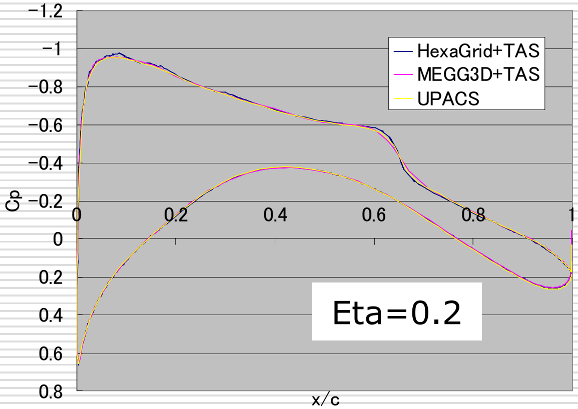
Grid convergence study of iH=0 model at CL=0.500, M=0.85

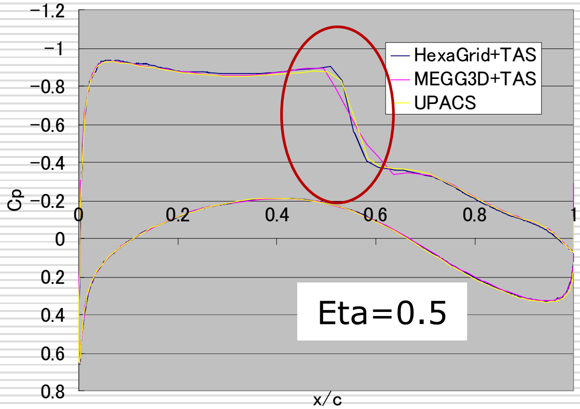
✓Large sensitivity of grid size
✓HexaGrid+TAS results are between MEGG3D+TAS and UPACS.
(The results of HexaGrid are comparable to the manual methods.)

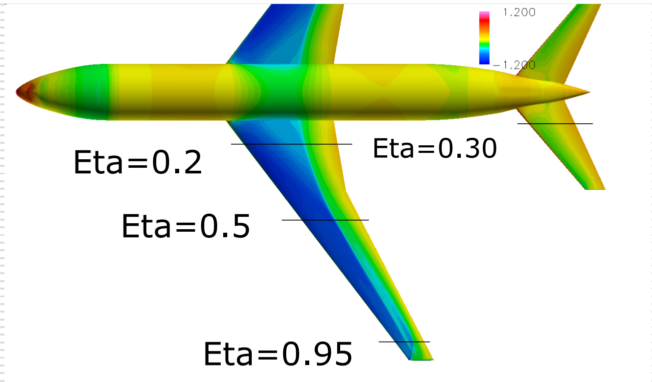


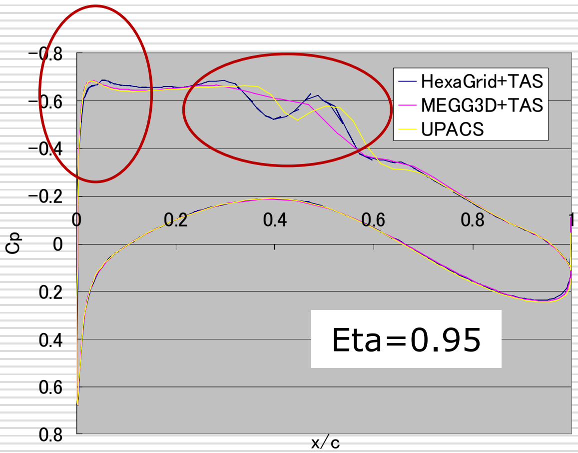


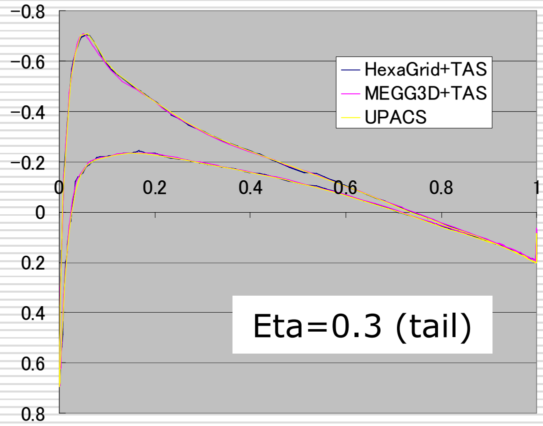
Cp distribution (Medium, iH=0, CL=0.5)









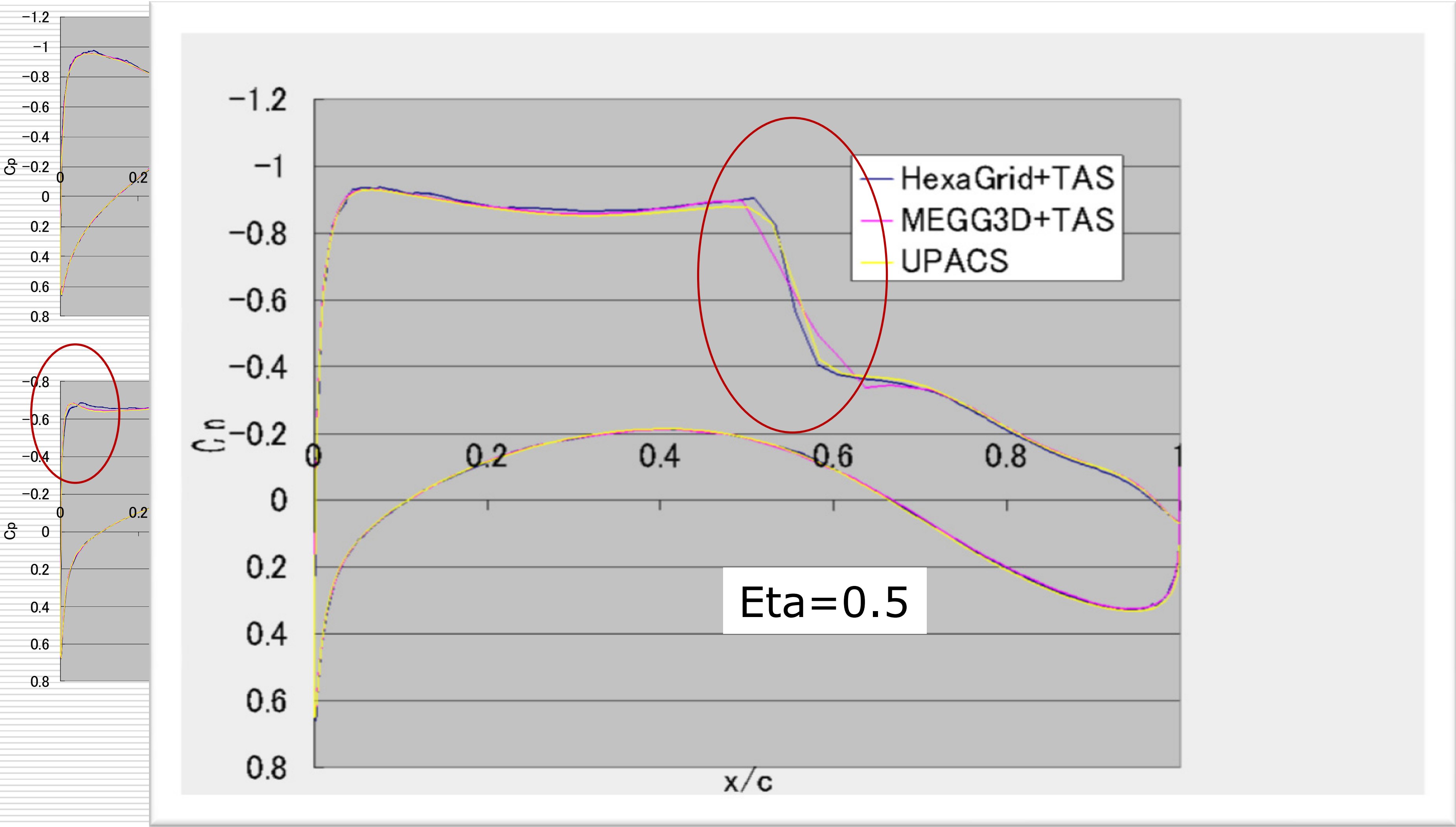


✓HexaGrid results agree well with the other results.

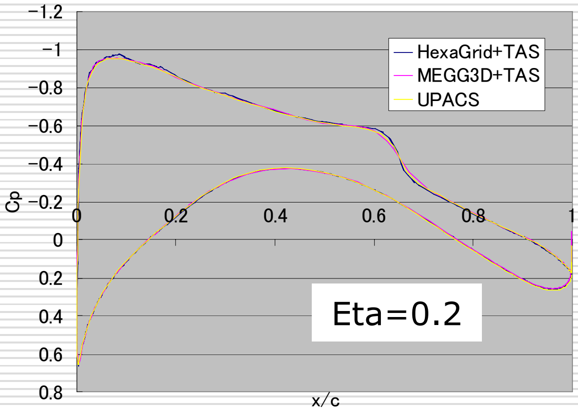
✓The shock wave in the middle of wing is well captured with HexaGrid.

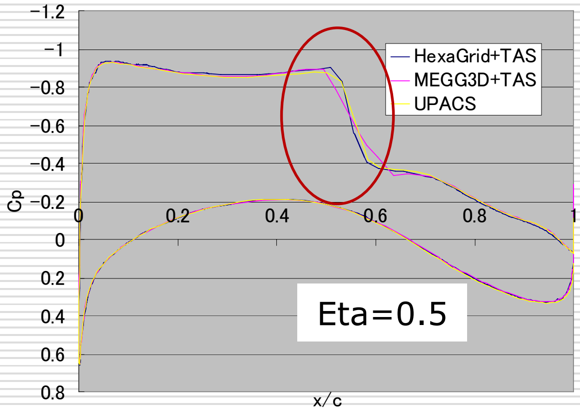
✓The suction peak is smaller than the others at the wing tip due to the coarse LE grid.

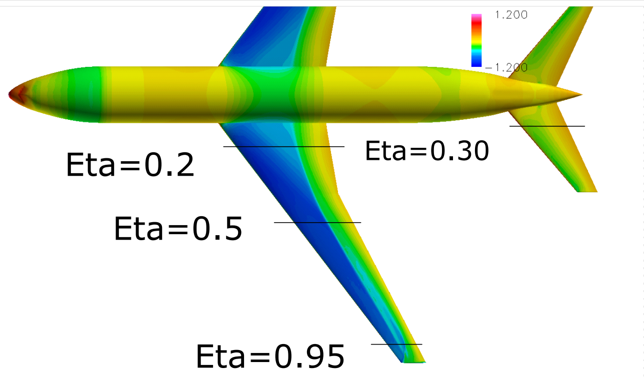
Cp distribution (Medium, iH=0, CL=0.5)

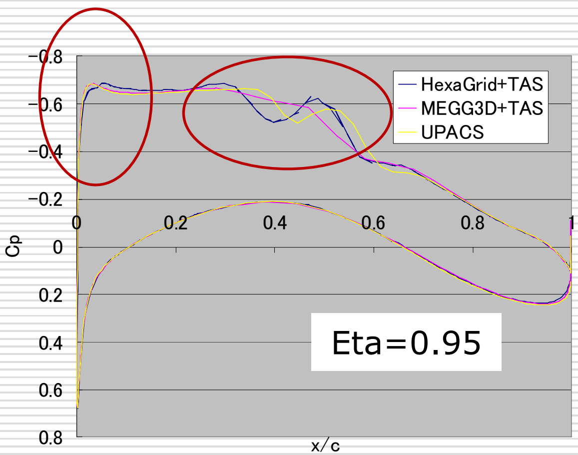


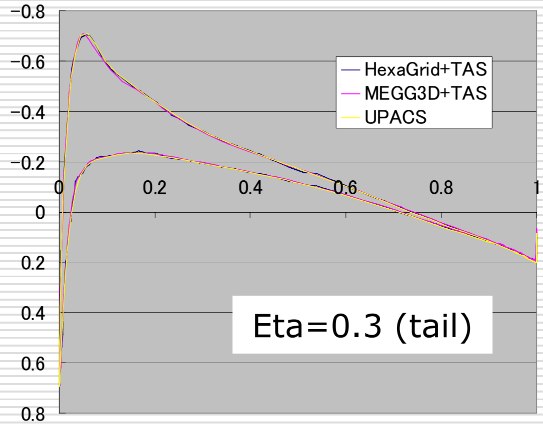
Cp distribution (Medium, iH=0, CL=0.5)









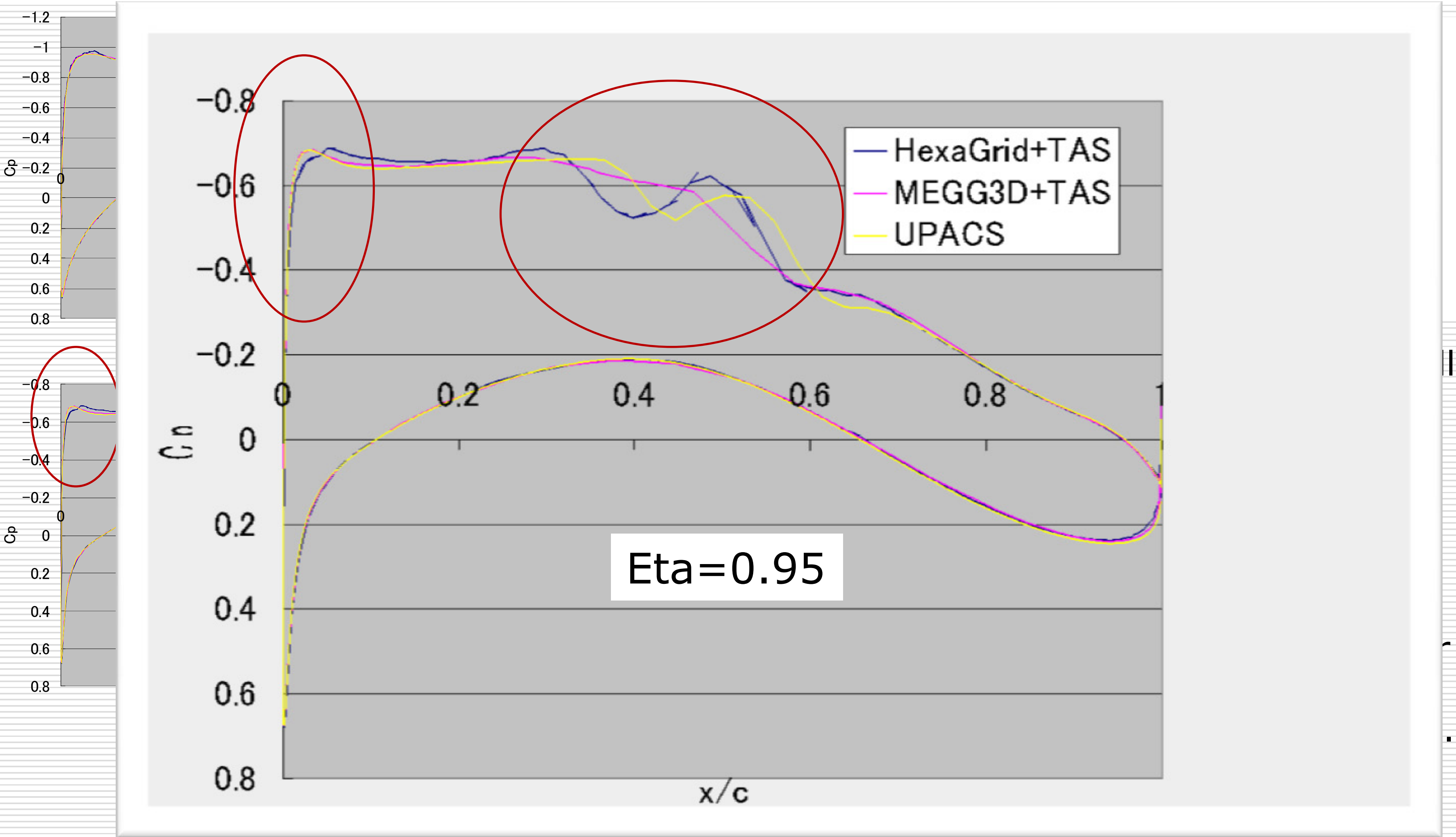


✓HexaGrid results agree well with the other results.

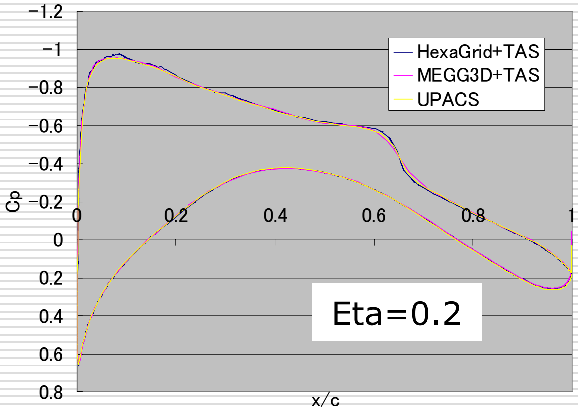
✓The shock wave in the middle of wing is well captured with HexaGrid.

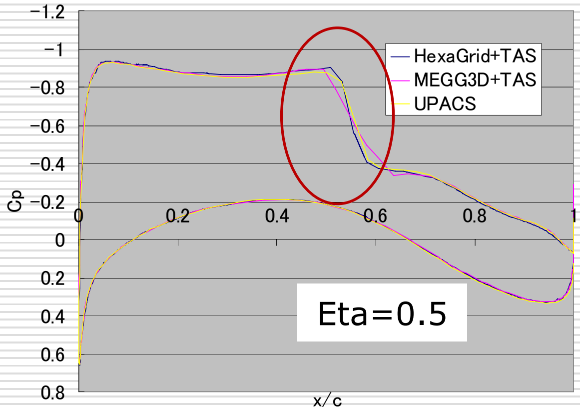
✓The suction peak is smaller than the others at the wing tip due to the coarse LE grid.

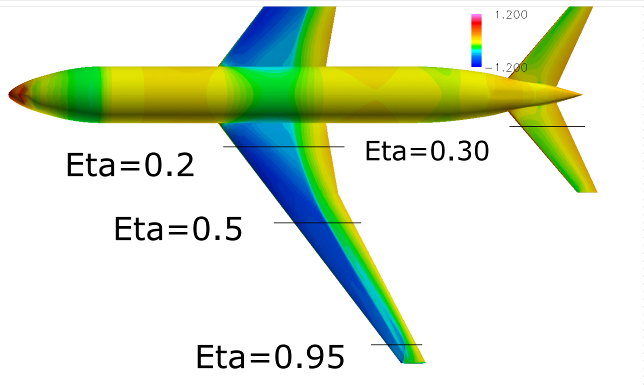
Cp distribution (Medium, iH=0, CL=0.5)

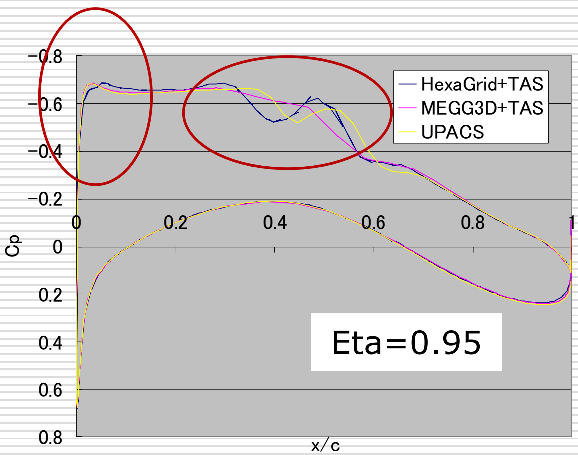


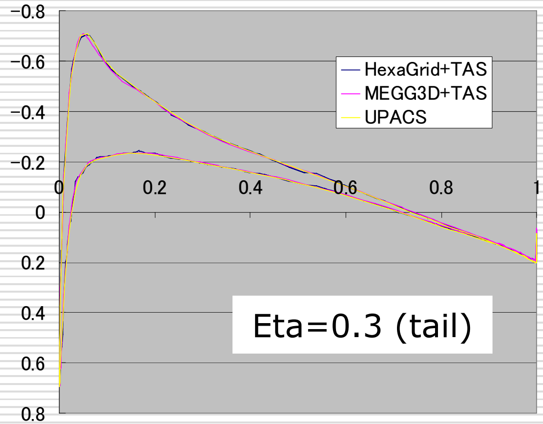
Cp distribution (Medium, iH=0, CL=0.5)









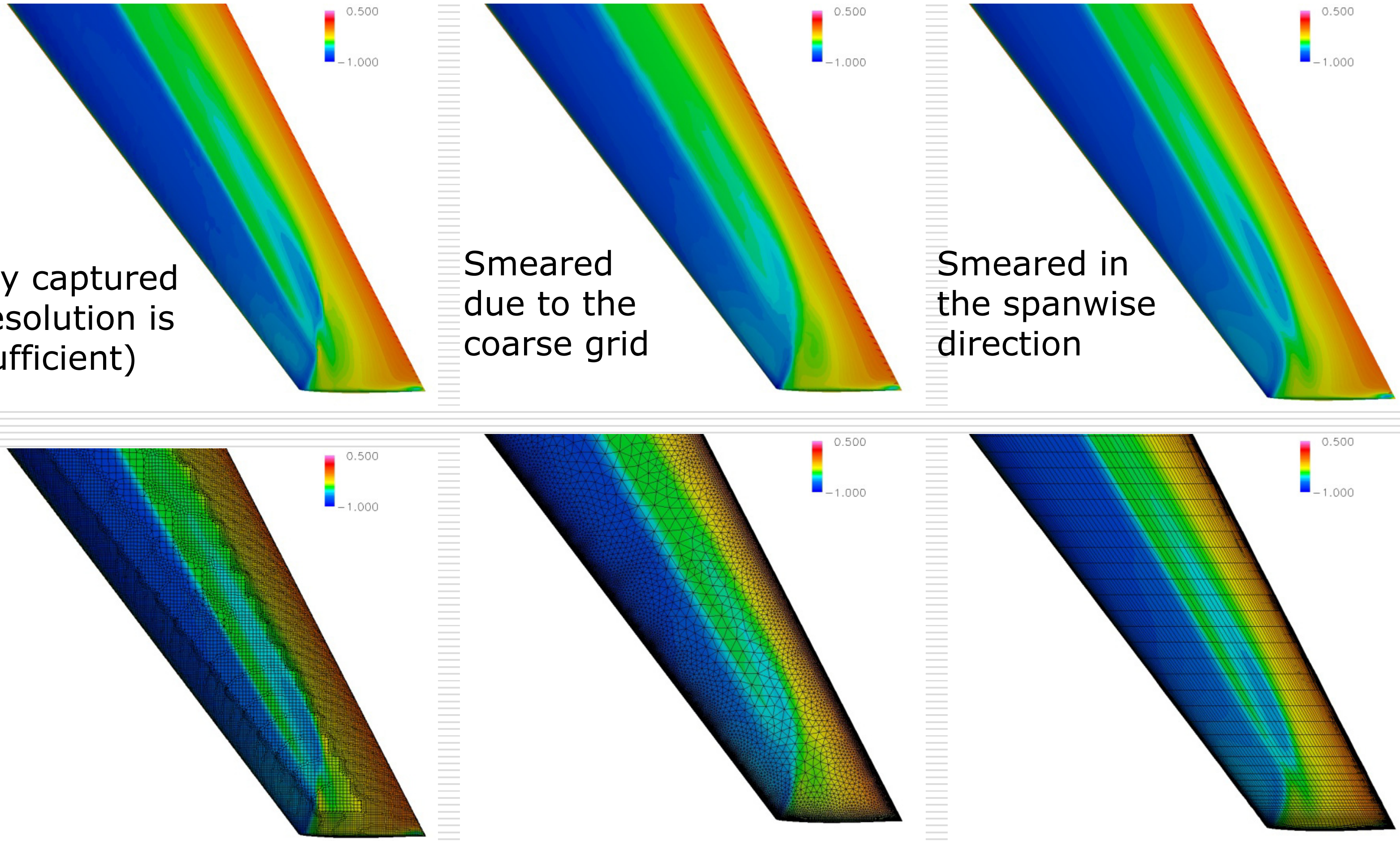


✓HexaGrid results agree well with the other results.

✓The shock wave in the middle of wing is well captured with HexaGrid.

✓The suction peak is smaller than the others at the wing tip due to the coarse LE grid.

Wing tip Cp contours (CL=0.5, medium grid)



Clearly captured (LE resolution is not sufficient)

Smeared due to the coarse grid

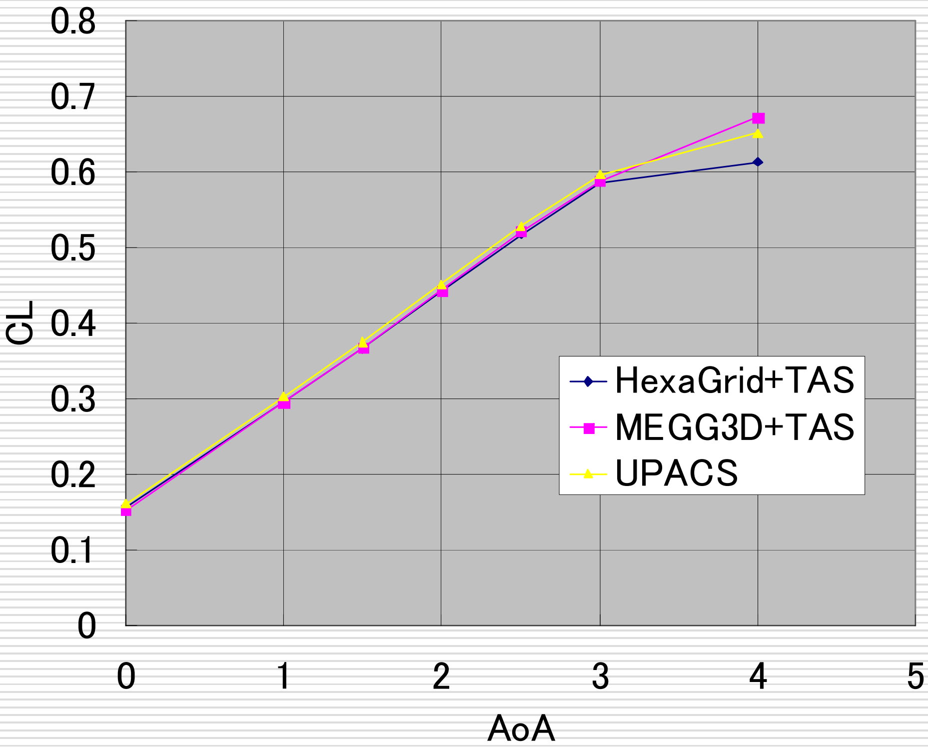
Smeared in the spanwise direction

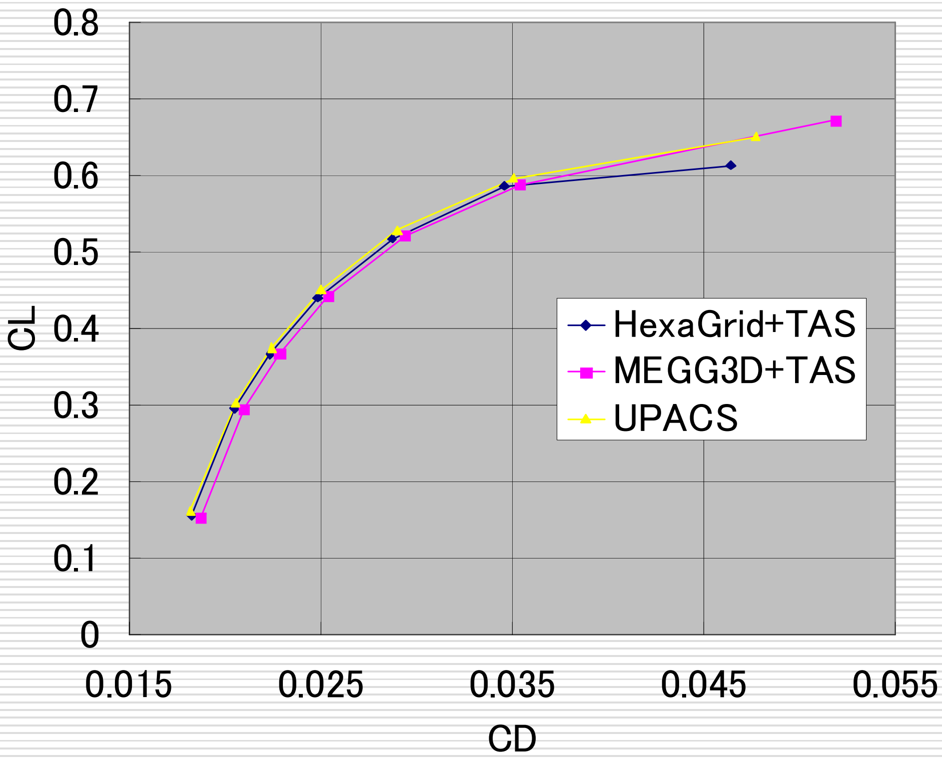
HexaGrid

MEGG3D

UPACS

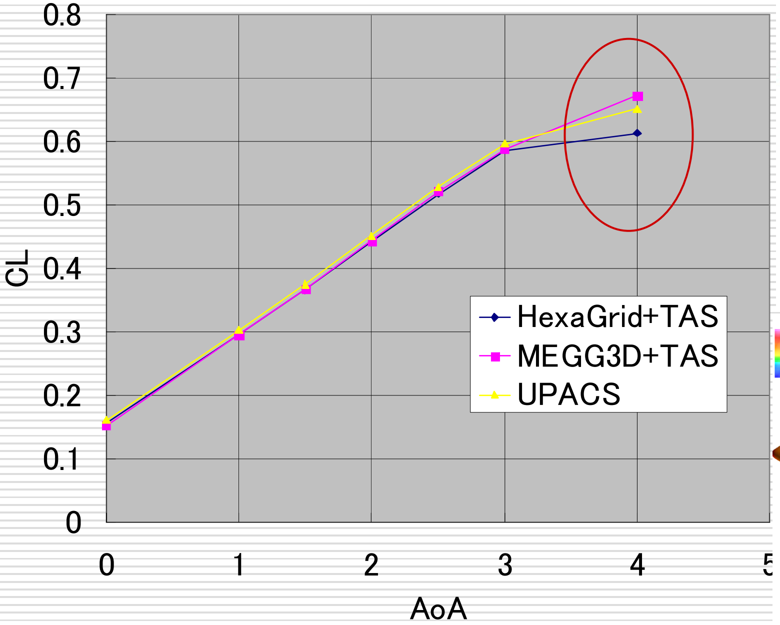
Angle sweep (iH=0, medium grid)

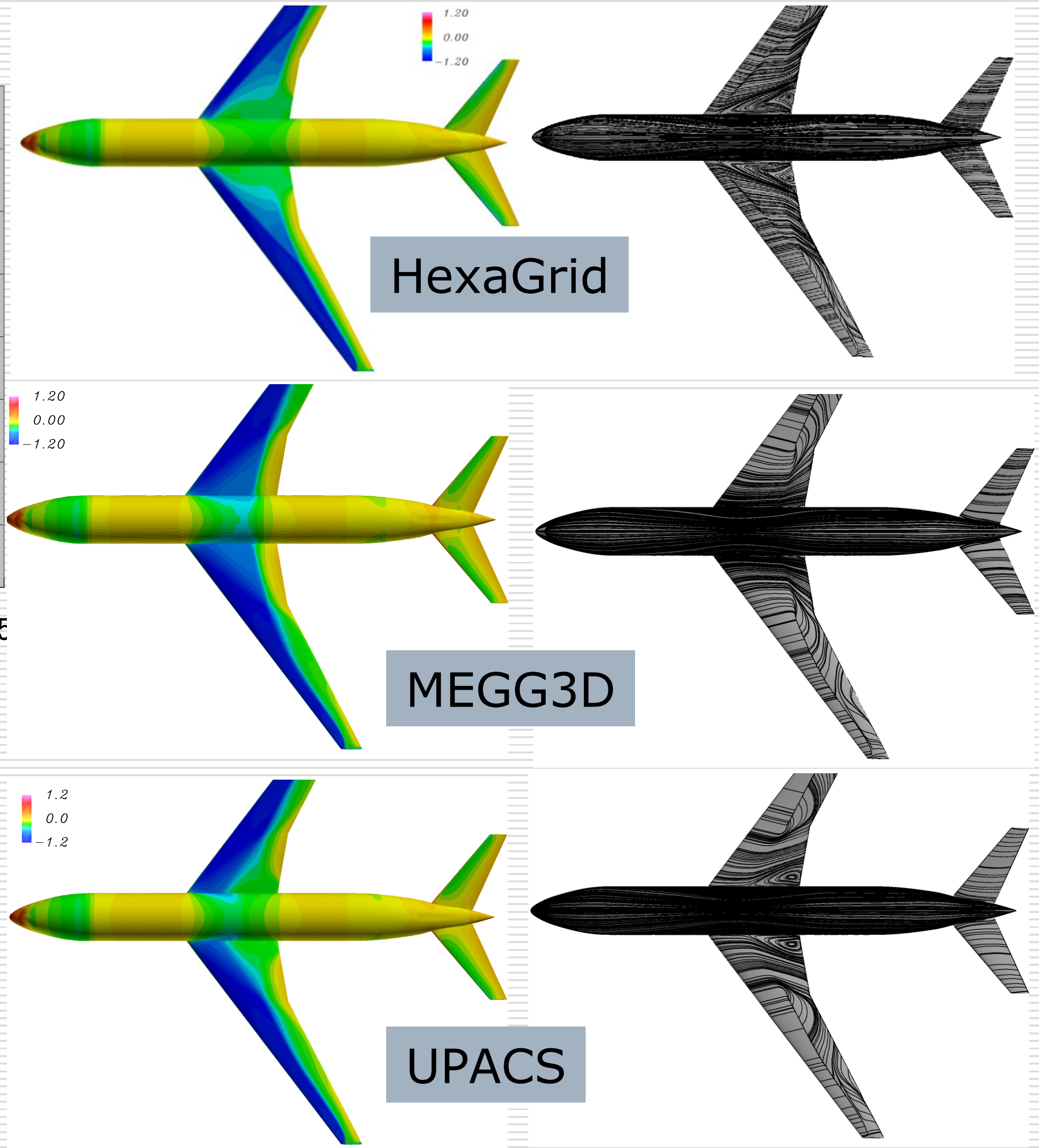




HexaGrid results agree well with the other results.

Stalled flow at AoA of 4deg





The separation line and pattern are largely affected by the grid topologies.

Conclusion

- Capability and limitation of HexaGrid
  - Automatic method, prism layer, feature capturing, mainly hexahedral element ➔ Good
  - Coarse LE and TE grids ➔ Not good

- HexaGrid results agree well with the other grids (tetra unstructured grid, multi-block structured grid).
  ➔HexaGrid can automatically generate grids comparable to manual methods.

- The shock wave in the middle of wing is well captured with HexaGrid.

- Larger separation is observed in the case of HexaGrid.