UTCartによる直交格子・埋め込み境界法を用いたNASA-CRM空力解析

Aerodynamic Analysis of NASA-CRM by UTCart using Cartesian Grid and Immersed Boundary Method

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2017/6/30 APC-III, Tokyo

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Agenda

- Background/Objective
- Computational Settings
- Results
  - Grid Convergence Study
  - Alpha-Sweep
- Conclusions

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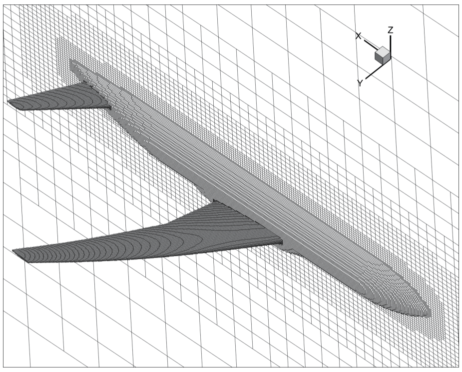
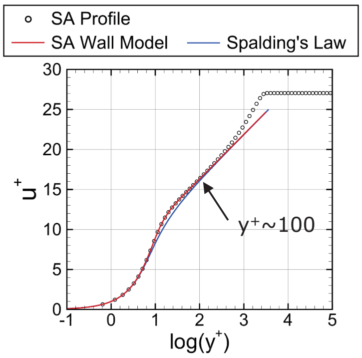
Background/Objective

- UTCart (The University of Tokyo Cartesian grid based automatic flow solver) is developed as a platform for aerodynamic designing
  - Automatic grid generator based on oct-tree structure
  - Compressible flow solver parallelized by MPI
  - The immersed boundary method with a wall function[1)]
- Prediction accuracy in flows around an aircraft should be confirmed





1) Tamaki, Y. et al AIAA J, 2017 (accepted).

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Test cases

- Grid convergence at α=2.94 deg
  - Coarse, medium, fine grids
  - Wing-body-tail (no support strut)

- Case 1 (Alpha-sweep)
  - Medium grid
  - Wing-body-tail (no support strut)

- Reference computation
  - FaSTAR on UPACS medium & fine grids

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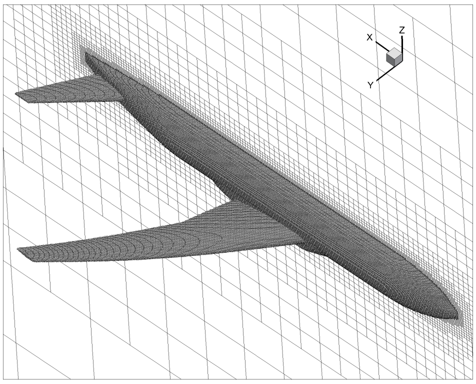
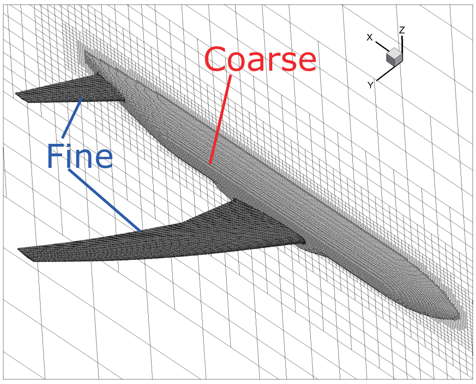
Update from APC-II

- Variable wall spacing (fine on wing upper surface and tail)
  - 282~850 cell/MAC

  ⇒ 750~1340 cell/MAC (upper surface)





- QCR-2000
- Force integration (flux-based method[2])

2) 玉置，今村，数値流体シンポジウム2016

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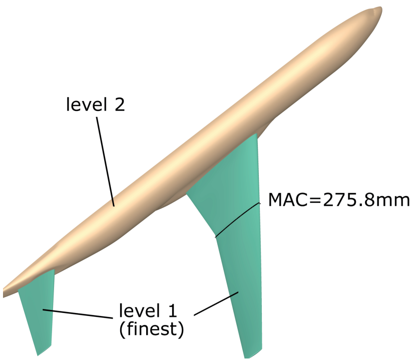
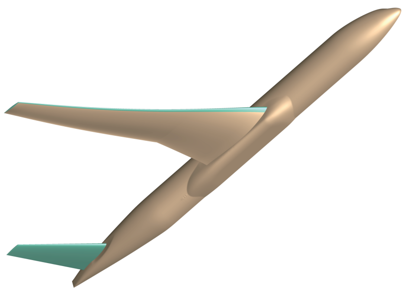
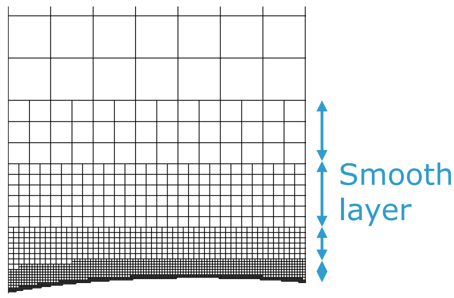
Grid Settings

	Coarse	Medium	Fine
Total cell number	24,415,860	50,323,727	97,041,807
Domain size in	4.80×10^4	3.60×10^4	5.40×10^4
Grid size (wing upper surface / tail) in	0.732 3/4	0.549 3/4	0.412
Grid size (wing lower surface / fuselage) in	0.366	0.274	0.206
Smooth layer (near field)	3	6	8
Smooth layer (far field)	3	3	3
MAC / Grid size (wing upper surface)	**753**	**1,004**	**1,339**







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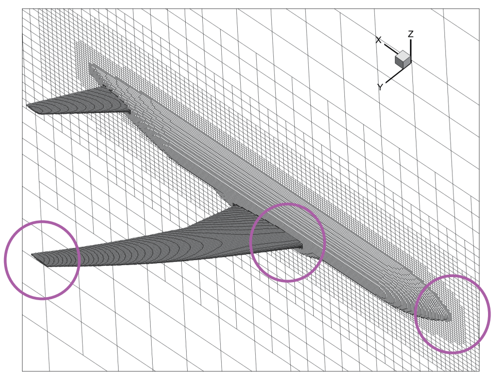
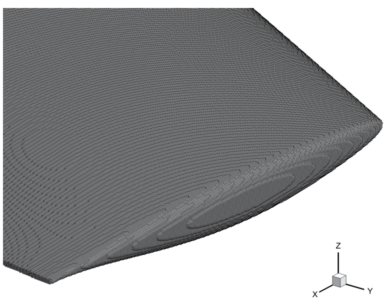
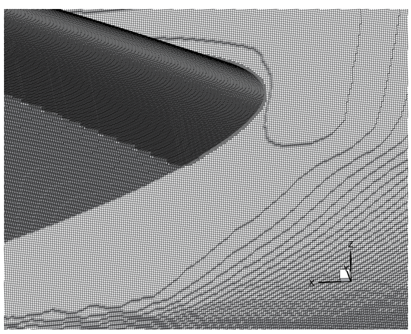
Grid Settings

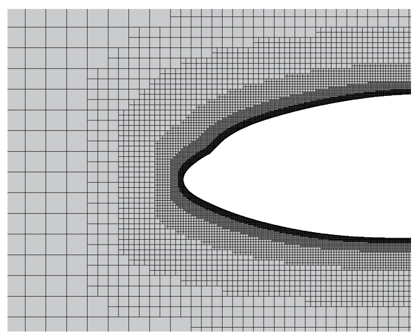


Overview: Very coarse grid (only for visualization)

Others: Medium grid







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Computational Methods

Solver	UTCart	FaSTAR
Turbulence Model	SA-noft2-R-**QCR2000**	
Inviscid flux	SLAU (AUSM-type)	
Spatial Scheme (Inviscid term)	Second–order MUSCL	
Limiter	Barth-Jespersen	Hishida
Spatial Scheme (Viscous term)	Second order central difference	
Gradient Estimation	Weighted least-squares (G)	GLSQ
Time Integration	MFGS	LUSGS

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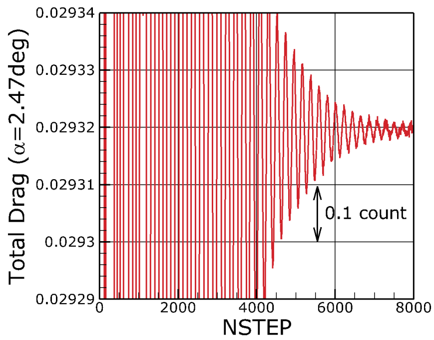
Computational Resources (UTCart)

For Medium grid (50M cells)

- Grid generation
  - Workstation, Xeon E5-2643 v3 @ 3.4GHz, 1core
  - 43 min, 50 GBRAM
- Flow calculation
  - Reedbush-U supercomputer (UTokyo), Xeon E5-2697 v4 @ 2.1 GHz, 144 cores (pure MPI)
  - 5.5 hours (8000 steps), 60 GBRAM



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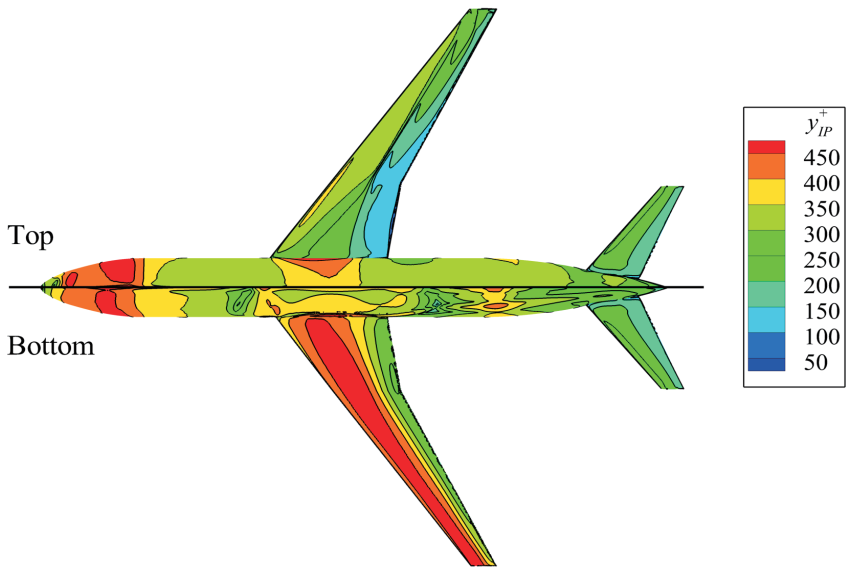
Surface y⁺ Distribution (α=2.94 deg)

- Medium grid
- y⁺ at IP height ($d_{IP} = 2\Delta x$)
- ~300 on the wing upper surface



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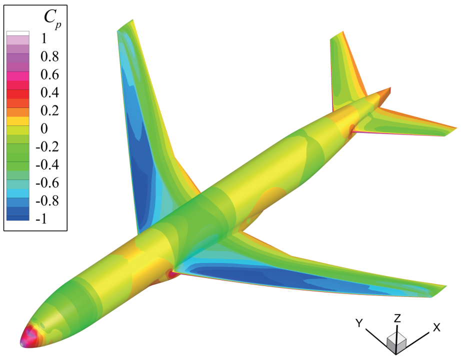
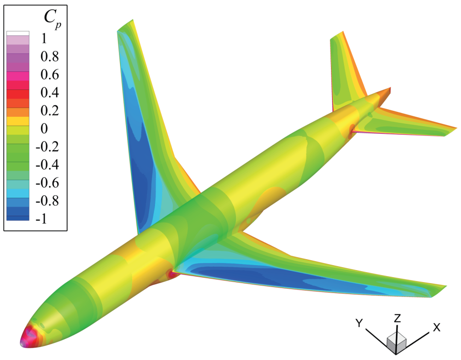
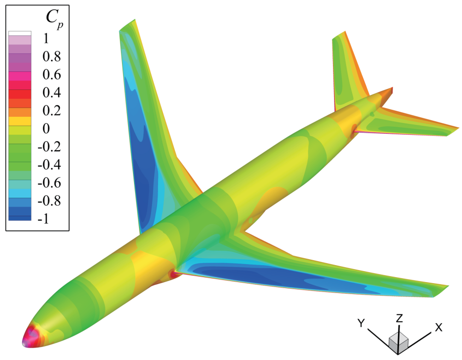
Grid Convergence (α=2.94 deg)



UTCart/Coarse (24M cells)



UTCart/Fine (97M cells)



FaSTAR/UPACS Fine
(30M cells)

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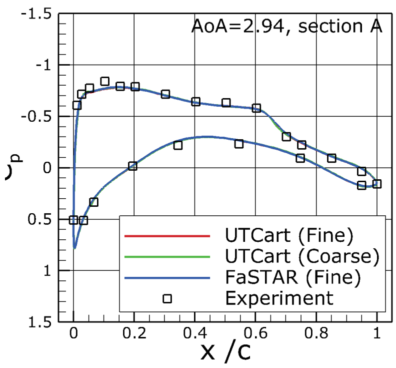
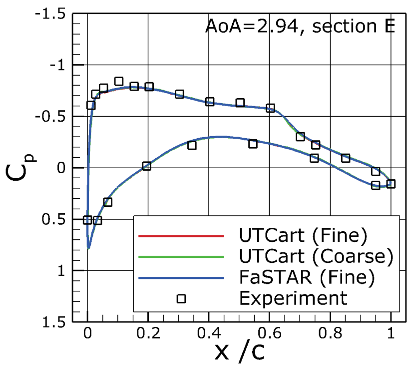
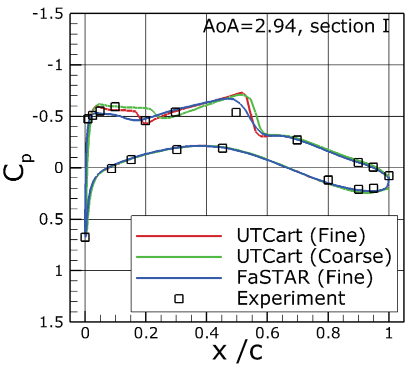
Grid Convergence at α=2.94 deg



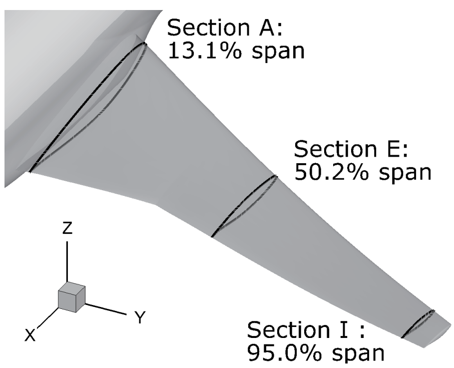
Section A



Section E



Section I



UTCart/
Coarse: 24M
Fine: 97M

FaSTAR/
Fine: 30M

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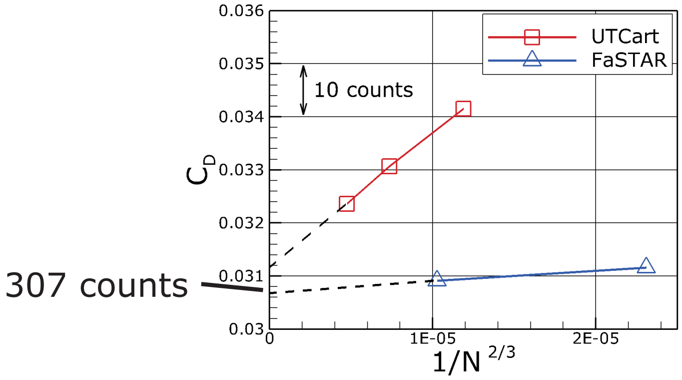
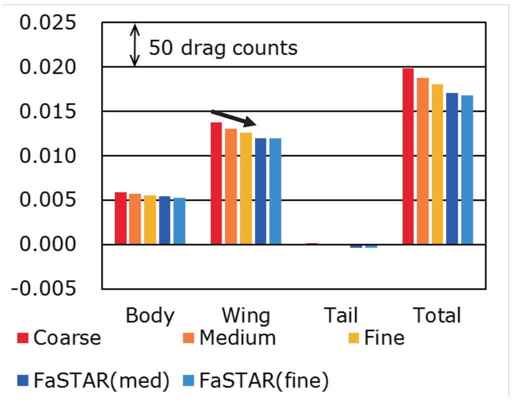
Grid Convergence at α=2.94 deg



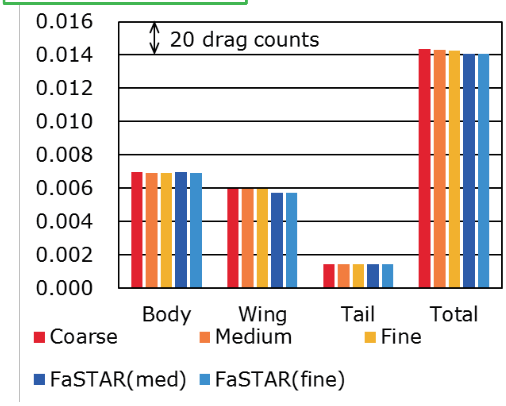
Drag count error

Coarse	35 (11%)
Medium	24 (8%)
Fine	15 (5%)

Pressure drag



Viscous drag



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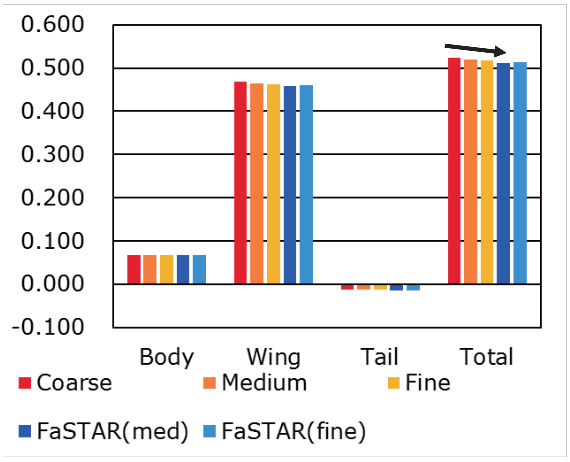
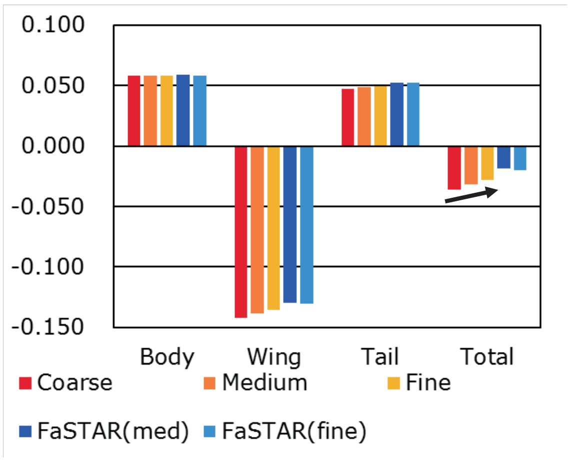
Grid Convergence at α=2.94 deg

Lift



Pitching moment



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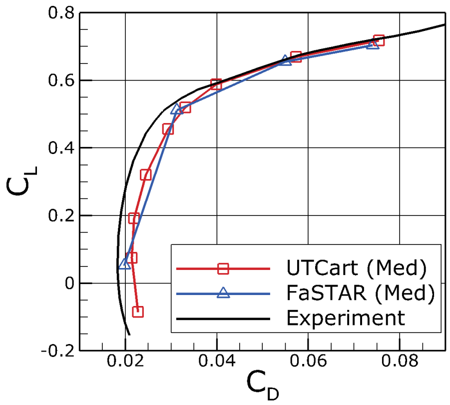
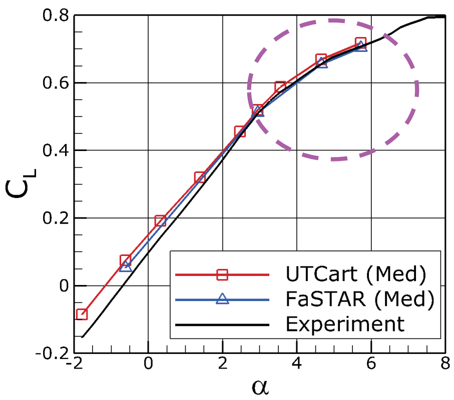
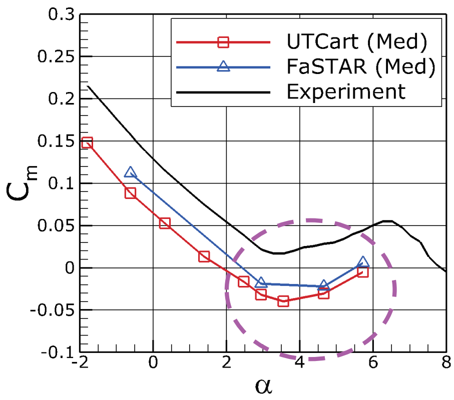
α-sweep (case1)

- Good agreement between the CFD results including non-linearity at high angles of attack

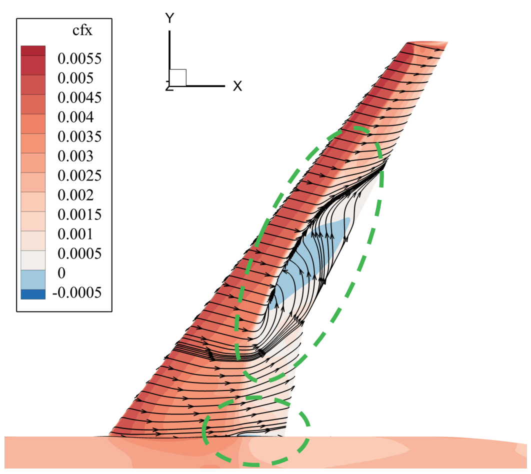




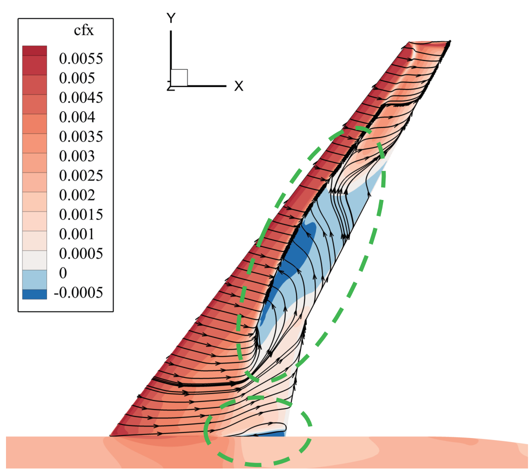


Surface Streamline (α=4.65 deg)

- Separation occurs at mid-span and root
- ✓ Friction in the separated region is small in the UTCart result (limitation of the wall function?)

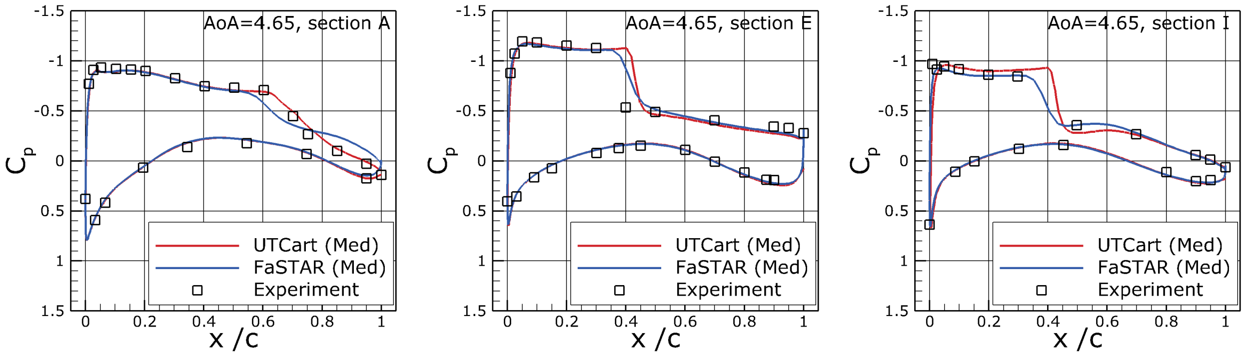


UTCart (Medium)

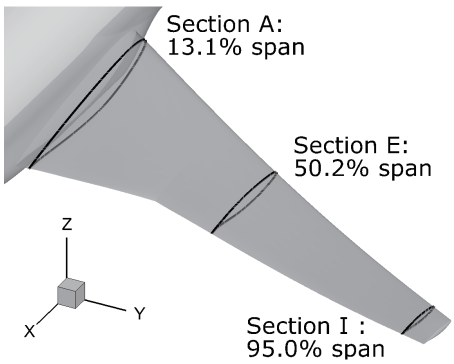


FaSTAR (Medium)

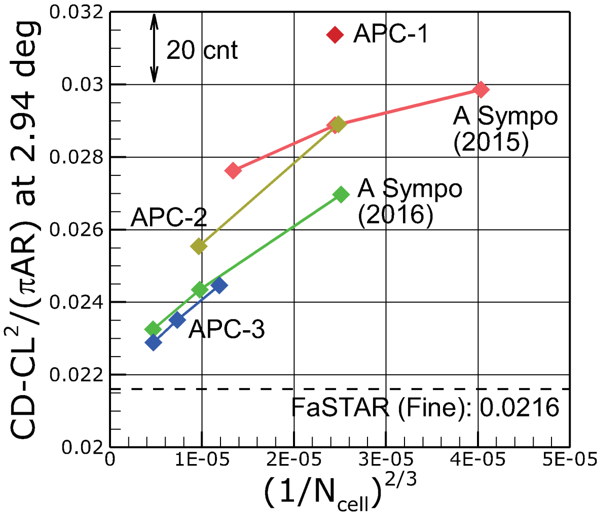
Surface pressure (α=4.65 deg)

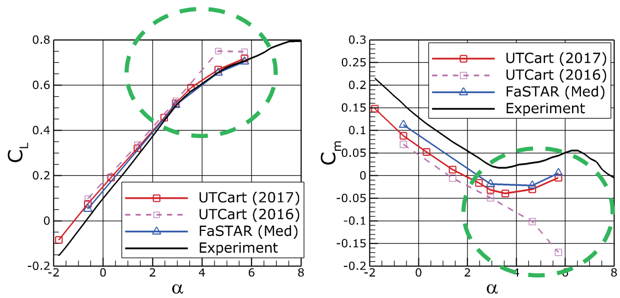


Section A　Section E　Section I



Improvement of UTCart in APC





- ✓ Drag prediction is improving (still +15 count)
  - Larger scale computation
  - Force integration
  - Variable cell size on wall
  - etc.
- ✓ Better prediction at high AoA
  - QCR
  - Variable cell size on wall

Conclusions

- Grid convergence is examined at α=2.94 deg
  - The trend of each aerodynamic coefficients is consistent with the reference CFD data
  - Fine grid result has 15 counts (5%) error of drag
- UTCart can predict non-linearity of the aerodynamic coefficient at the high-angles of attack
  - Prediction accuracy of flow separation/difference between CFD and experiment should be investigated further

We are grateful to JAXA for providing the unstructured CFD solver FaSTAR.