Seventh Aerodynamics Prediction Challenge (APC-7)
2021/06/30, Online

Aerodynamic Analysis of NASA-CRM at Low Speed and High Angle of Attack conditions Using Hierarchical Cartesian Mesh and Recursive Fitting Method

階層型直交格子と再帰的なフィッティングを用いた
低速・高迎角条件におけるNASA-CRM巡航形態の空力予測

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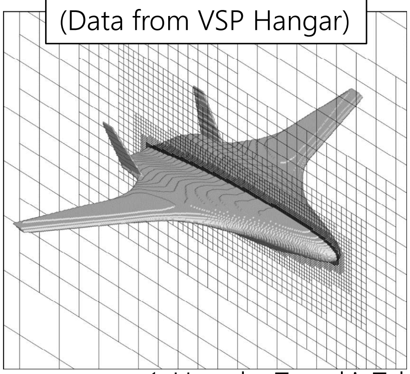
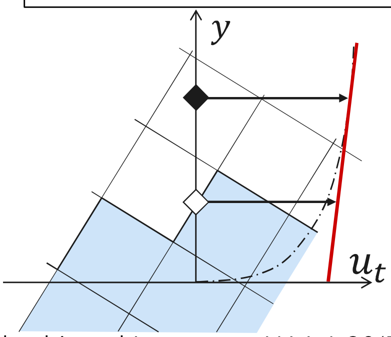
Background

- Development of **UTCart** for aerodynamic designing of aircraft.
  - Automatic grid generation based on octree structure.
  - Compressible RANS/DDES simulation with wall function.
  - Immersed Boundary method (**IBM**) on stair-step grids.
  - Simulation on cut-cell like grid is also developed[1,2] .

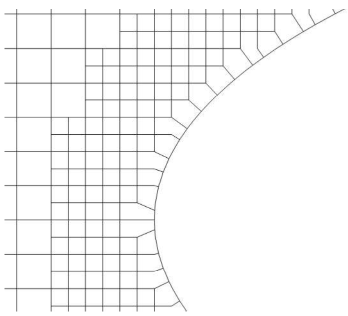
NASA N2A HWB
(Data from VSP Hangar)



Immersed boundary method
with wall function



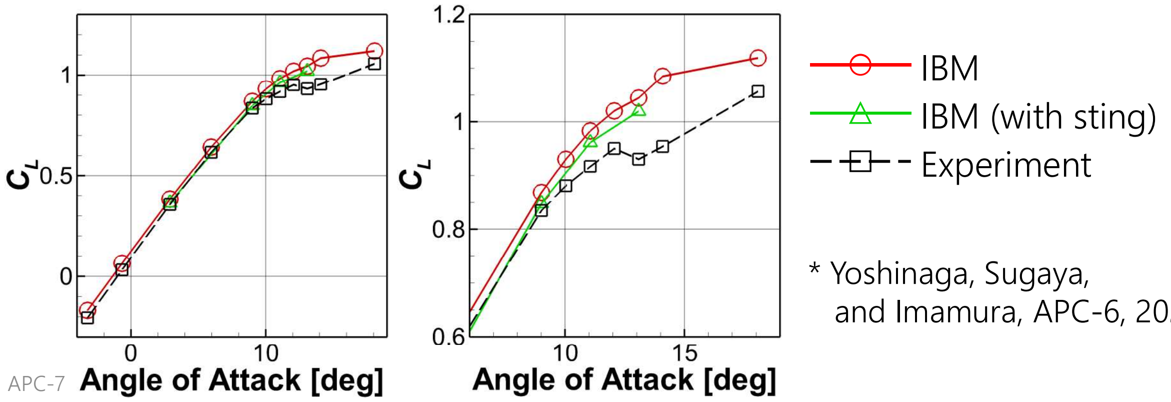
Automatic generation of
Cut-cell like grid



1. Harada, Tamaki, Takahashi, and Imamura, *AIAA J*, 2017.
2. 菅谷 and 今村, *日本航空宇宙学会論文集*, 2020.

Results of APC-6* (IBM simulation)

- A fair agreement of aerodynamics between UTCart and experiment at low AoA.
- Large *CL* than that of experiment at high AoA.
- **Influence of numerical methods on aerodynamics prediction needs to be investigated.**
- Further study of dependency on grid size is necessary.

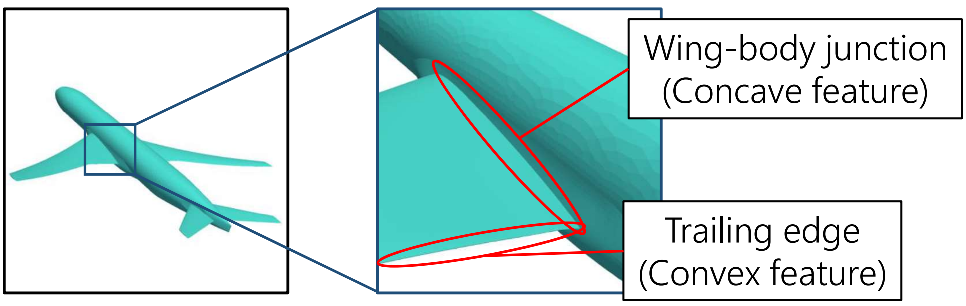


* Yoshinaga, Sugaya, and Imamura, APC-6, 2020.

Objective

Investigate prediction accuracy of flow simulation around NASA-CRM using Recursive Fitting Method.

- Cartesian grid based automatic body-fitted grid generation.
  - **Geometric features are approximately represented.**
- Comparison with simulation using IBM (APC-6).
  - **Conservation laws are satisfied in simulation using Recursive Fitting Method (RFM)**, as opposed to IBM.



Recursive Fitting Method (RFM)*

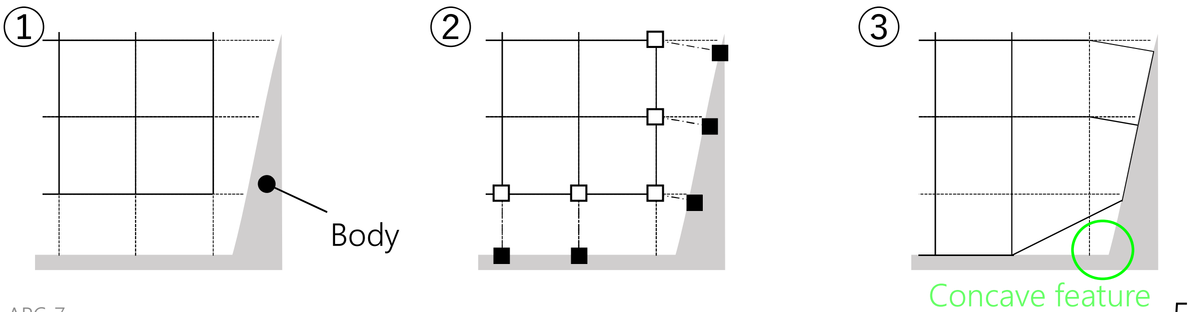
1. Generate the stair-step grid.
2. Calculate the closest points to the vertices of the cell faces.
3. Extend fluid cells to body surfaces.

○ Automatic grid generation around two- and three-dimensional bodies.

△ Cell faces does not match body surfaces around geometric features.

- Wing-body juncture, Trailing edge,...

→ <u>Necessary to modify cells around features.</u>



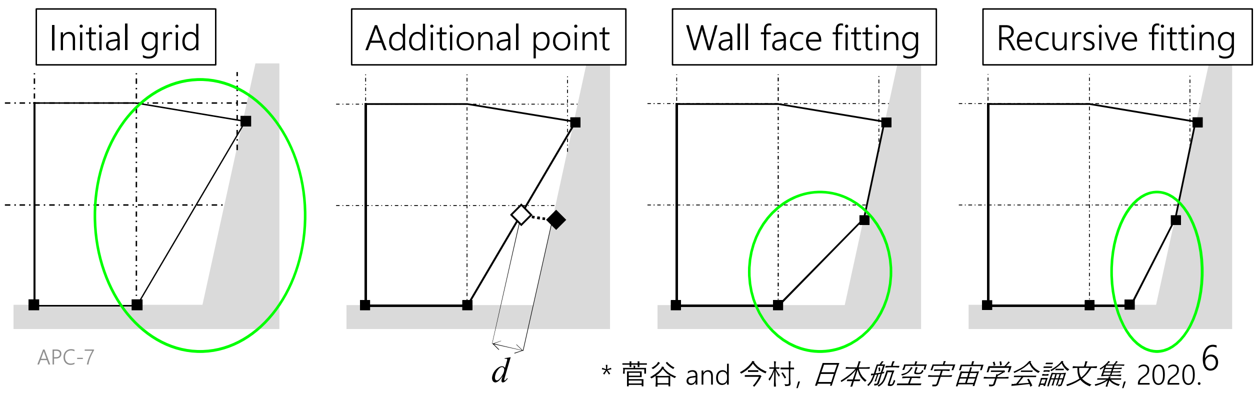
* 菅谷 and 今村, *日本航空宇宙学会論文集*, 2020.

Recursive Fitting Method (RFM)*

- <u>Recursively fitting the wall face to body surfaces</u>
- Modified the cell properties which is necessary for flow simulation

$$\frac{\partial (Q_C V_i)}{\partial t} + \sum_{j \in \mathrm{neighbor}(i)} F(Q_i, Q_j, \boldsymbol{n}_{ij}) s_{ij} = 0$$

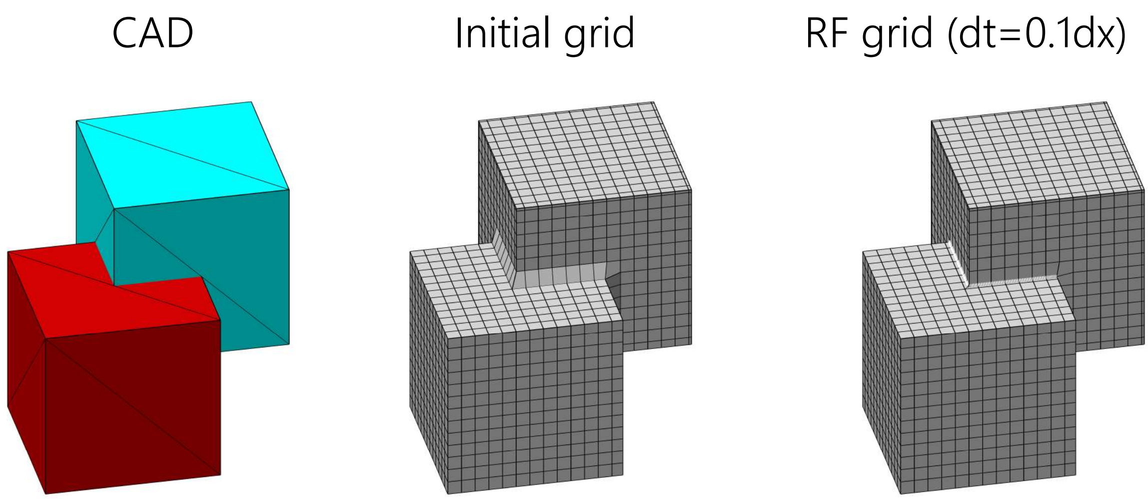
  - The number of cells and cell faces are kept unchanged.
- Repeating fitting procedure recursively until the distance between wall face and wall becomes smaller than user-specified parameter.



* 菅谷 and 今村, *日本航空宇宙学会論文集*, 2020.

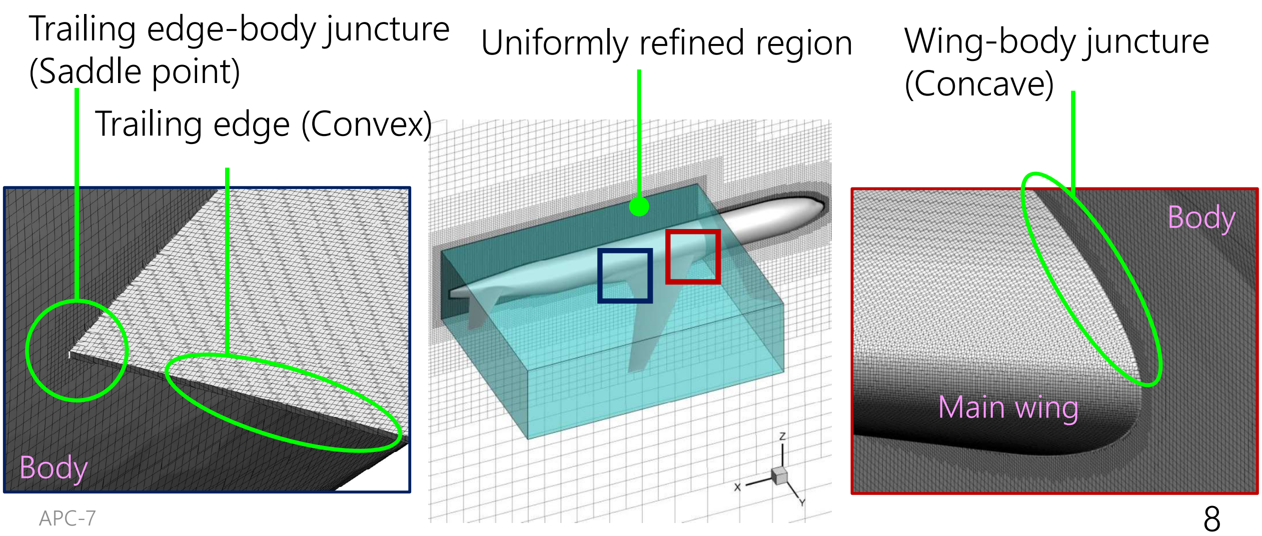
Example of RF grid

- Grid generation around Intersecting cubes.
- Features are approximately represented in RF grid.

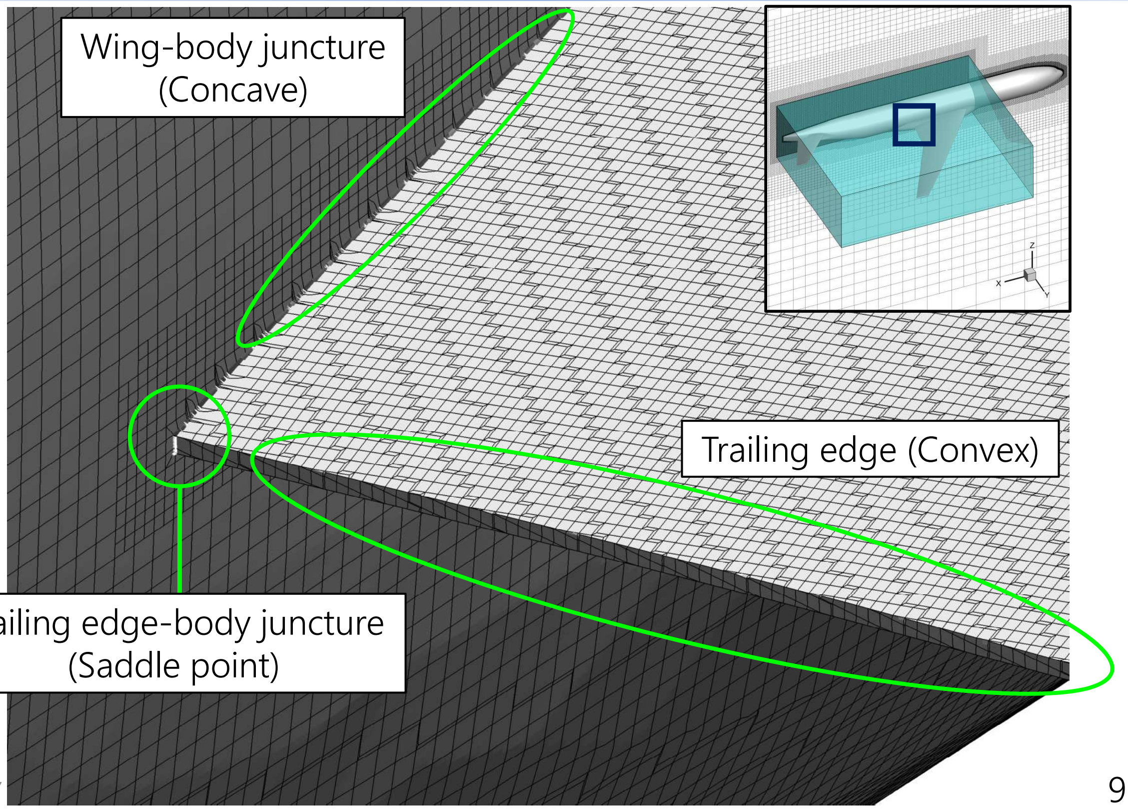


Computational Grid Setting

- Same grid setting as APC-6.
- Total cell number: 68.5 M
- $C_{MAC}/\Delta x$ ~ 655, y^{+}=40~100 on main wing
- Uniformly refined region between main wing and tail.



Computational Grid of NASA-CRM



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Numerical methods

- Turbulence Model (Steady) : SA-noft2-R (Crot=1)
- Turbulence Model (Unsteady) : DDES-protected*
  - RANS region is protected even when the stream-wise grid size is small.
- **Wall Function : SA wall model**

- Inviscid flux : Linear reconstruction+ SLAU
  - Limiter for recursively modified cells.
- Viscous flux : 2nd order Central difference

- Time integration(Steady) : MFGS + Local Time Stepping
  - Start from free-stream conditions.
- Time integration(Unsteady) : MFGS + BDF2 with 5 Inner Iteration
  - Restart form RANS results.
  - Courant number ~ 1 at wake region.

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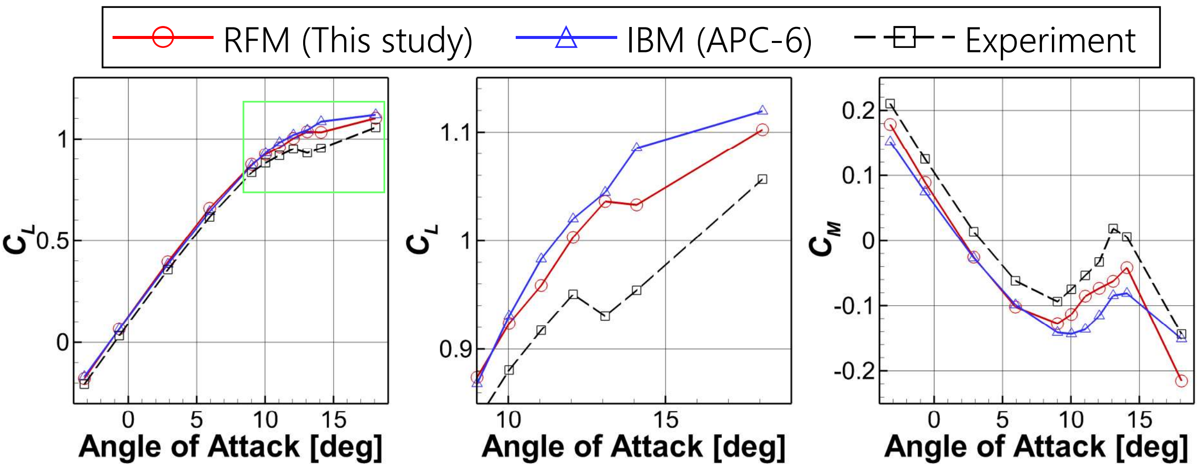
* 玉置 *et al.* ,第49期年会講演会講演集, 2018. 10

Case 1

Steady Simulation

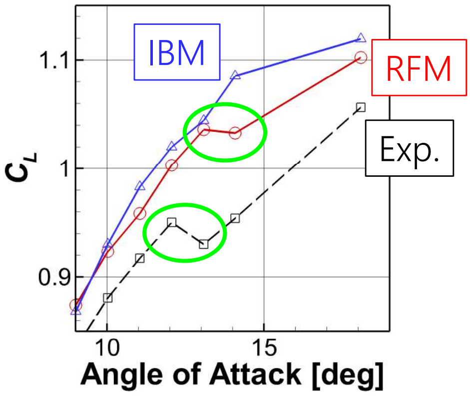
Alpha sweep

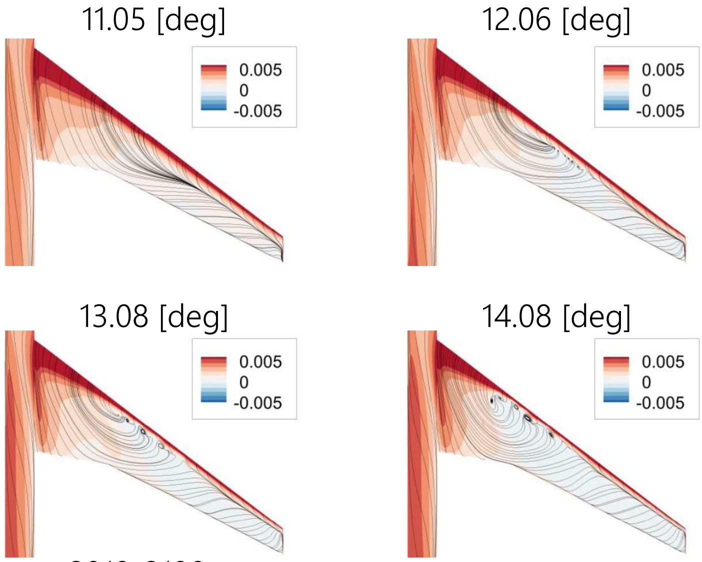
- A fair agreement between RFM, IBM, and exp. at low AoA.
- Predicted *CL* and *CM* using RFM is closer to exp. than those of IBM at high AoA.
  - *CL* decrease at AoA = 13.08 to 14.08 [deg] in RFM simulation.



Streamline and skin friction

- Separating region (*Cfx*<0) gradually expands as AoA increases.
- Causing discrepancy of *CL* between RFM and experiment.
  - *CL* of exp. suddenly changes at AoA=12 due to large flow separation*.





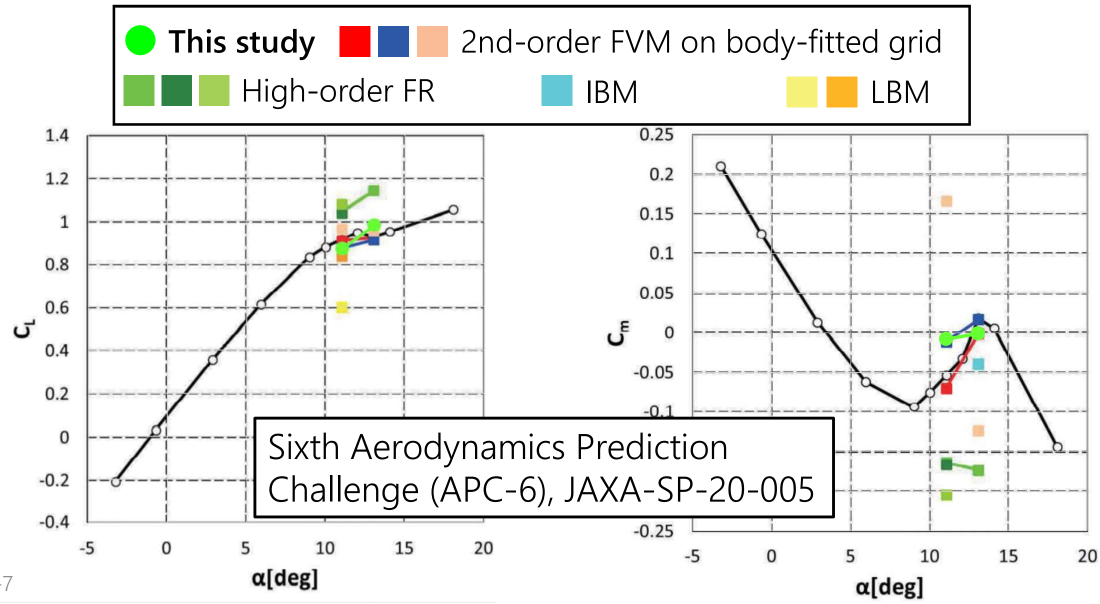
* Uchiyama et al. AIAA Paper 2019-2190.

Case 2

Unsteady Simulation

Comparison of aerodynamics coefficients

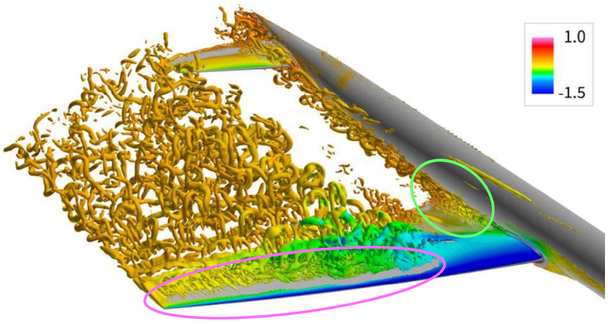
- Reasonable prediction of *CL* and *CM*.
- Similar results to simulations of 2nd-order FVM on body-fitted grids.



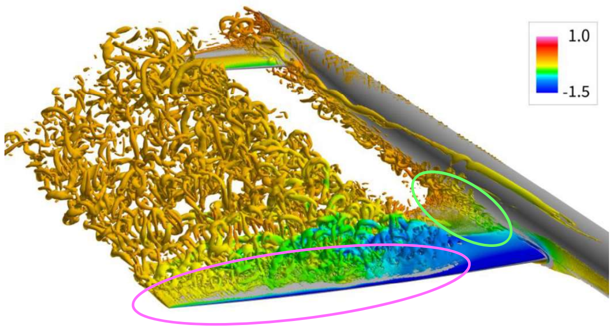
Q criterion

- Massive flow separation on main wing.
- Position of leading edge separation moves upstream as AoA increases.
- Vortices from wing-body junction.
  - Interfering with tail wing.

11.05 deg



13.08 deg



Conclusion

Turbulent flow simulation around NASA-CRM was conducted by using UTCart and Recursive Fitting Method.

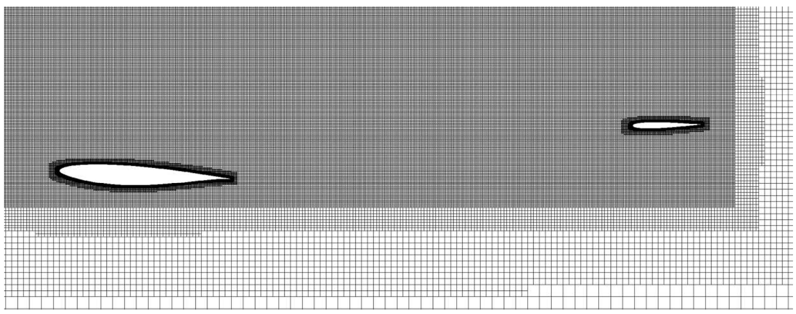
- Automatic grid generation based on Cartesian grids.
- Geometric features are approximately represented.
- Conservation laws are satisfied.

- In steady simulation, *CL* and *CM* of Recursive Fitting method are closer to exp. than those of Immersed Boundary method.
- Reasonable prediction of unsteady aerodynamic coefficients
    - similar to those of 2nd-order FVM on conventional body-fitted grid.

Appendix

Details of grid setting

- Grid size
  - Main wing, tail : 0.00153 C_{MAC}
  - Body : 0.00306 C_{MAC}
  - Wake : 0.0122 C_{MAC}
- Domain size: $200C_{MAC} \times 200C_{MAC} \times 200C_{MAC}$
- Time for grid generation
  - Immersed Boundary (APC-6): 31 min.
  - Recursive Fitting Method (This study) : 49 min.



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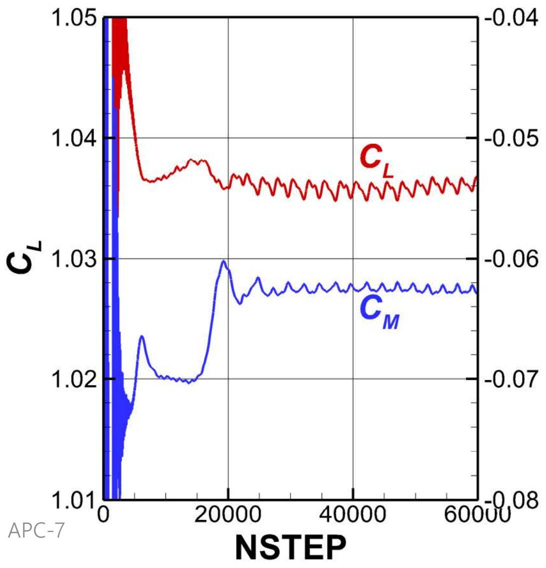
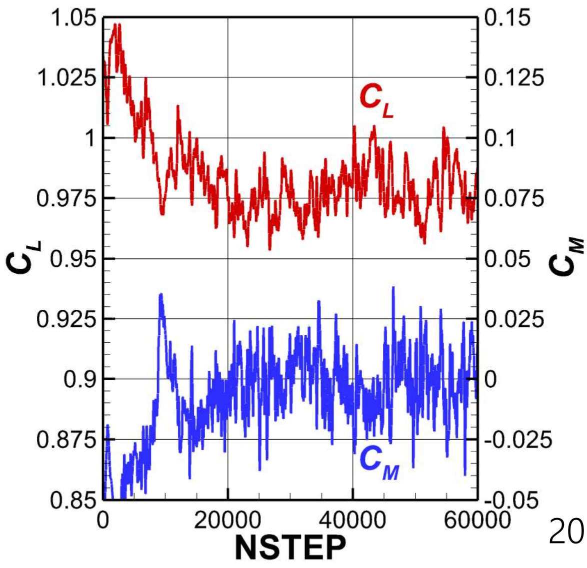
Time histories of *CL* and *CM*

- Initial conditions
  - Steady: Free stream conditions.
  - Unsteady: results of steady RANS simulation.

13.08 deg steady simulation



13.08 deg unsteady simulation



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PSD of Lift coefficient (Unsteady)

- PSD becomes large as AoA increases.
- Peak of PSD of main wing around St~1 in simulation at AoA=11.05 deg.