Toward the Precise Aerodynamics Prediction of 30P30N Airfoil Using 2D Building-Cube Method

BCMを用いた
30P30Nの2次元空力予測精度の向上に向けた取り組み

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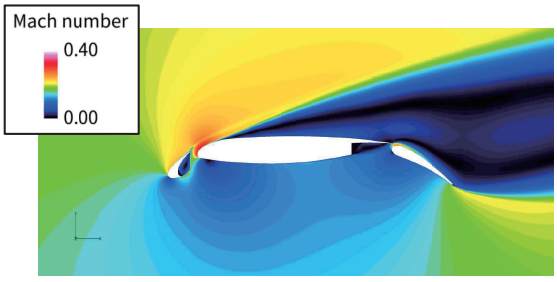
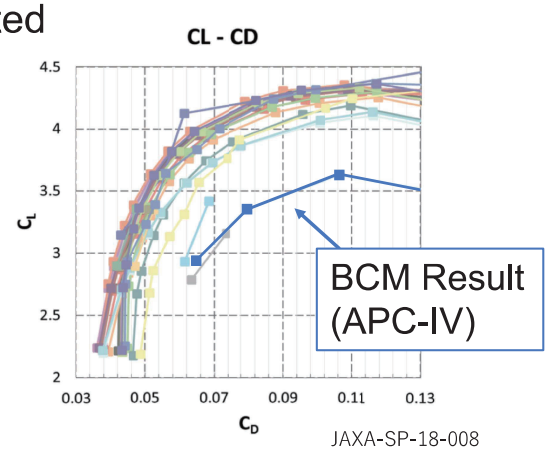
Background

BCM tend to ...

- Separation occurred at low angle of attack
- Drag coefficient is overestimated



Separation occurred at 16 deg



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Objective :

- Restart using converged flowfield for research the effect to separation
- C_d estimation using Wake integration
- Mesh adaptive to Slat

About BCM

BCM : Building-Cube Method

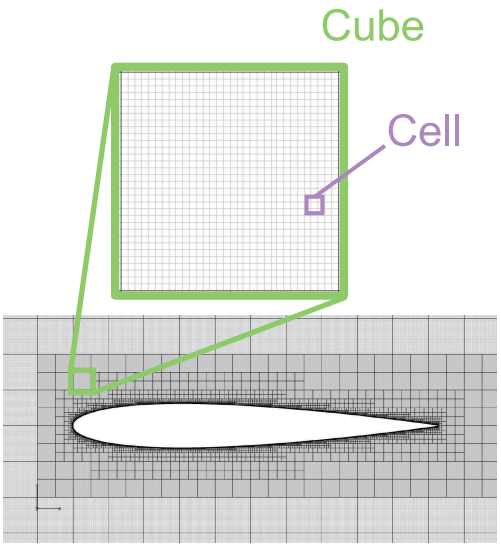
- Cartesian mesh based solver

Advantage

- Easy to parallel computing
- Easy to grid generation
- High order spatial accuracy

Disadvantage

- Shape representation is stare case (IBM is used)
- Difficulty in resolving the boundary layer for High Reynolds number



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Computational Method

How to set initial flowfield for different AoA

Using fully converged result

Converged flowfield ⇨ Change inlet flow angle ⇨ Start computation

Example :

0.0 deg converged ⇨ Change inlet flow 4.0 deg ⇨ 4.0 deg analysis start

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Computational Method

Governing Eq	Compressible NS Eq.
Discretization	Cell-centred finite volume
Inviscid Flux	SLAU 3rd-order MUSCL
Viscous Flux	2nd-order central difference
Time integration	LU-SGS
Turbulence model	SA-noft2-R

Wall boundary treatment

Immersed Boundary Method (IBM)

Density & Pressure → Zeroth-order interpolation

Velocity → Linear interpolation

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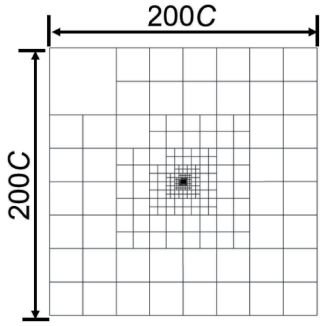
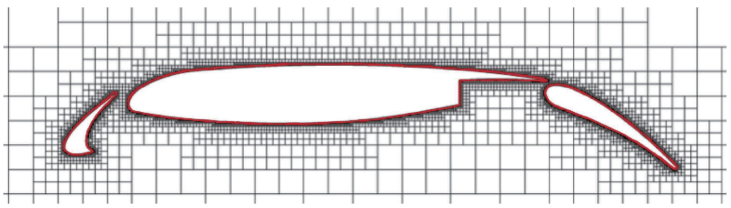
Grid information

	Minimum grid size	Total cube number	Total number of cells in a cube	Total number of cells
Fine (L1)	2.38E-5	15,645	32×32	16,002,048





Analysis of AoA

Black : Impulsive Start Orange : Restart

0.0 / 4.0 / 5.5 / 8.0 / 9.5 / 12 / 14 / 16 / 18 / 20 / 22 / 24 / 26 [deg]

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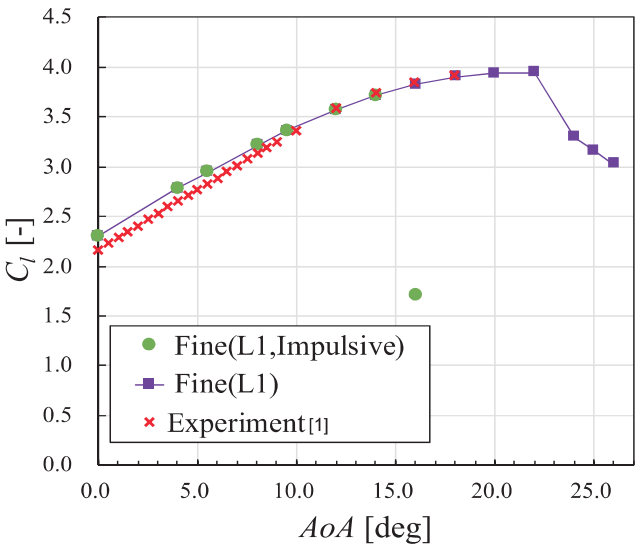
C_l - α



Fine(L1) AoA 16 deg

Fine(L1) AoA 24 deg

- No difference is observed from 4.0 to 14 deg.
- Restart computation causes separation at 24 deg.
  →Compared to impulsive start is delayed separation.

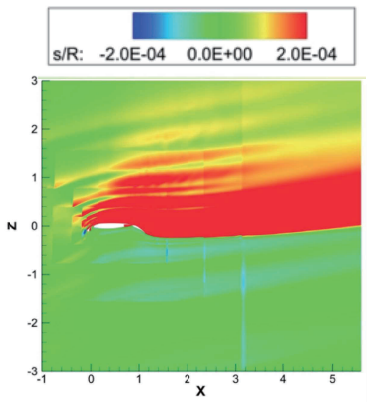
[1] AIAA 2014-2080 7

C_d Estimation : Wake integration

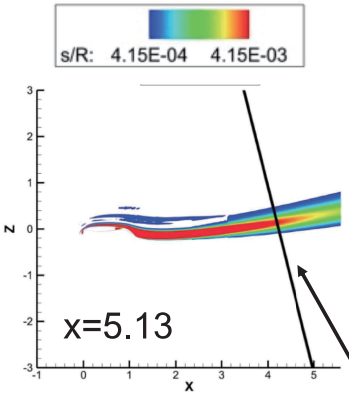
Calculation drag coefficient using delta of entropy

$$D_p = \int_{W_A} P_\infty \frac{\Delta s}{R} dz - \int_{W_A} \frac{P_\infty}{2} \left(\frac{\Delta s}{R}\right)^2 dz \qquad C_{D_p} = \frac{D_p}{1/2\,\rho U_\infty^2 S_w}$$

Δs :Delta of entropy
R :Gas constant



Original



Apply cutoff

Capture line

Contours of $\Delta S/R$ at AoA 14 deg

Value of cutoff

$$S_{cell} > C_{s_2} S_{max}$$

S_{cell} : Entropy at cells
C_{s2} : Cutoff constant[2]
S_{max} : Maximum value of entropy on capture line

[2] David L. Hunt, Russell M. Cummings, Michael B. Giles, "Wake Integration for Three-Dimensional Flowfield Computations: Applications", JOURNAL OF AIRCRAFT Vol. 36, No.2, March-April 1999, pp.366-373.

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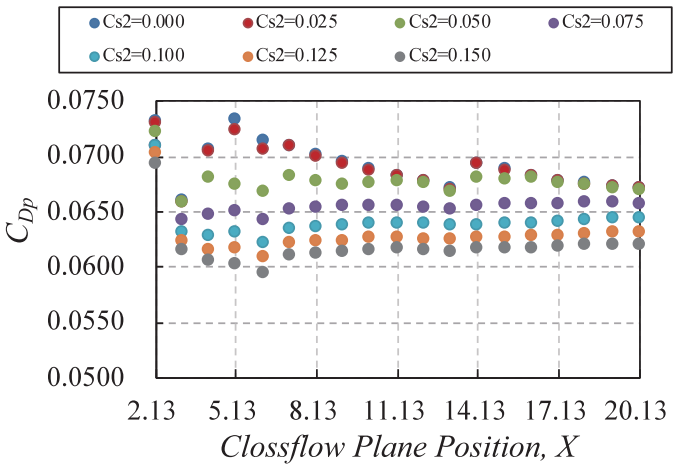
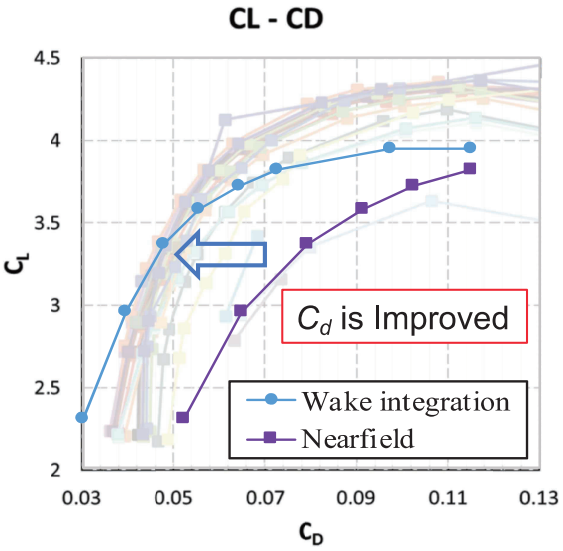
C_d Estimation : Wake integration



C_{DP} at AoA 14 deg



Cutoff constant C_{s2}=0.100

Drag coefficient is significantly different from other CFD results.
→ Better estimation compared to surface pressure computation.

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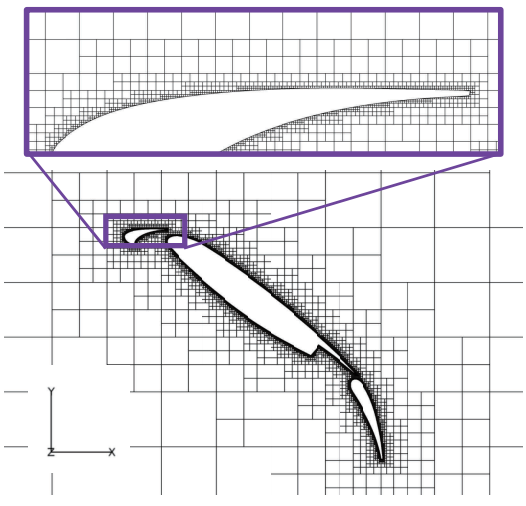
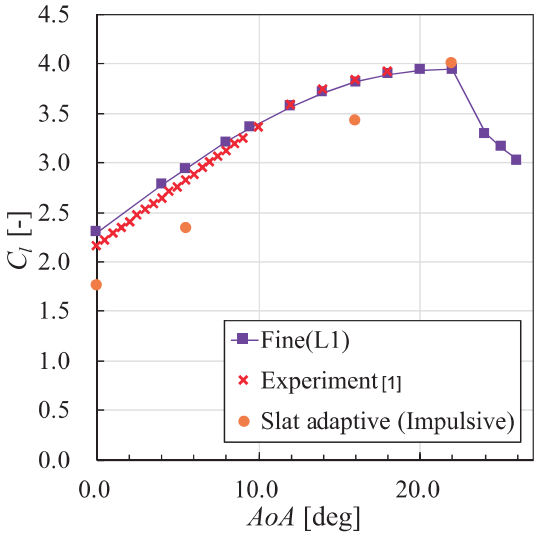
Slat Adaptive (Mesh rotation)

- Rotation of airfoil
- Adapted mesh to upper slat surface
- Equivalent mesh resolution to fine mesh





C_l is estimated low, but not separation occurred at AoA 16 deg.

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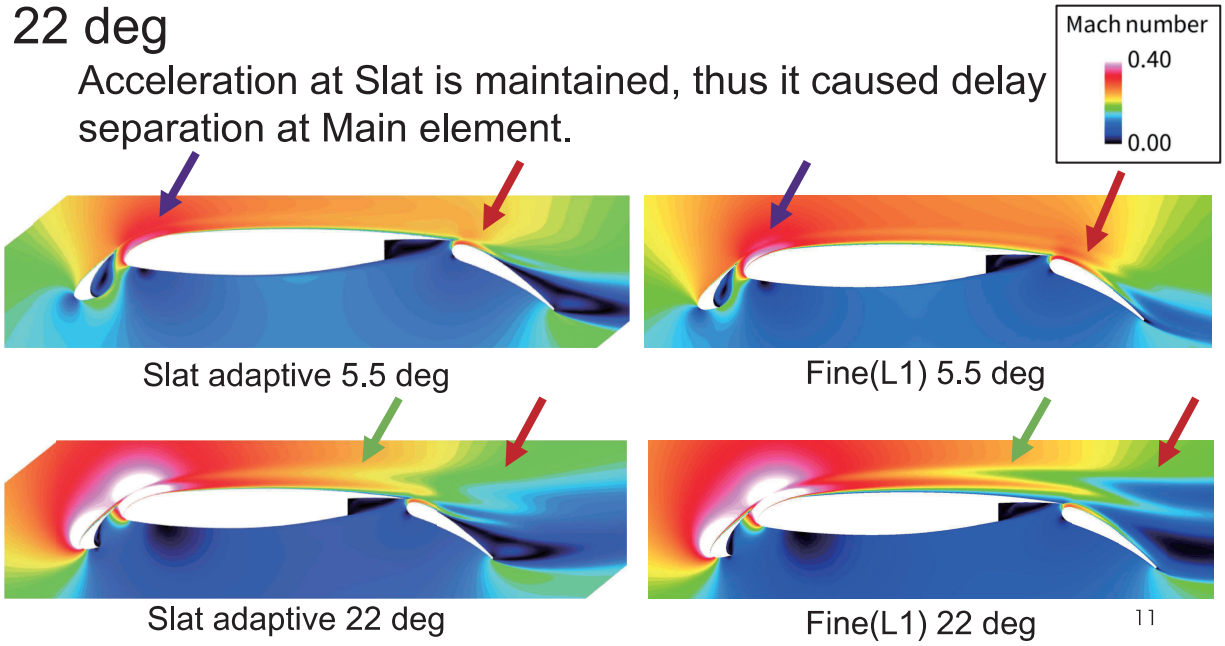
Slat Adaptive

5.5 deg

Flow speeds at leading edge of Main element and upper surface of flap are decreased.

22 deg

Acceleration at Slat is maintained, thus it caused delay separation at Main element.



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Summary

Restart using converged flowfield

- Initial value setting does not affect flowfield from AoA 4.0 deg for 14 deg.
- Restart can improve high AoA case better than impulsive start.

→Restart is effective method for BCM.

C_d estimation using Wake integration

- Wake integration improves drag coefficient accuracy.
- Amount of change in entropy is large at the boundary of cubes where their sizes are changed.

→The interpolation method may need to be modify.

Slat adaptive

- C_l is estimate small at low AoA.

→More investigation is need.

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