1A12

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Aerodynamic Analysis for NASA-CRM Using “FaSTAR”, “BOXFUN” and “HexaGrid”

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Contents

- ■Objects and targets of this study
- ■Setup of “FaSTAR”
- ■Grid configuration
- ■Difference between “BOXFUN” and “HexaGrid” grids
- ■Results
  - □Convergence histories of aerodynamic coefficients
  - □Comparisons of aerodynamic coefficients
  - □Comparisons of aerodynamic coefficients’ errors
  - □Pressure distributions on the wing surface at 18.08° AoA
- ■Conclusions

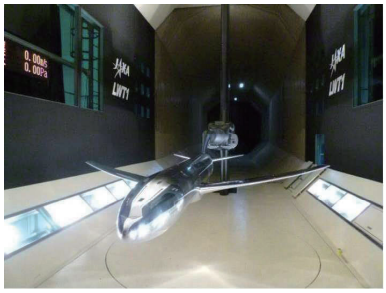
Objects and targets of this study

■ Objects

- To compare aerodynamic coefficients of two types JAXA-provided grids for RANS calculations on the NASA-CRM in low-speed and high-AoA.
- To examine the effect of the grid differences on the accuracy of CFD predictions of aerodynamic performance.

■ Targets of calculations

- NASA-CRM(Body + Wing + Tail, Non-deformation, Non-support)



3

Setup of “FaSTAR”

Solver	FaSTAR
Discretization method	Cell-centered FVM
Inviscid Flux	HLLEW-scheme
Viscous Flux	Central difference method
Time Integration	LU-SGS
Turbulence Model	SA-noft2-R
Grid	BOXFUN / HexaGrid

M	0.168
T_{ref}	310K
Re	1.06E+06
C_{ref}	1.0000
b_{ref}	4.1942
S_{ref}	3.90926
(X,Y,Z)	(4.8075, 0.0, 0.64521)

AoA	-3.22	-0.67	2.89	5.95	9.01	10.03	11.05	12.06	13.08	14.08	18.08
BOXFUN	○	○	○	○	○	○	○	○	○	○	○
HexaGrid	○	○	○	○	○	○	○	○	○	○	○

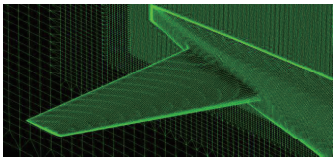
Note: In this study, only Task 1 (steady-state) was calculated

4

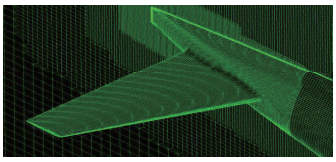
Grid configuration of computational domain

■Setup of “BOXFUN”/”HexaGrid” grid

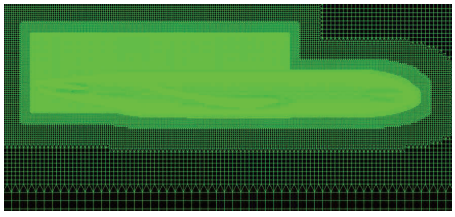
Software used to grid generation	BOXFUN	HexaGrid
Number of grids	42,553,974	18,266,329
Minimum grid size	6×10^{-6}	1.1×10^{-5}
y^+	1.0	1.8 (at LE)



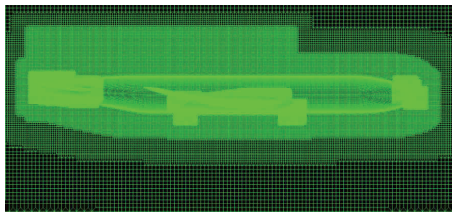
BOXFUN



HexaGrid



BOXFUN

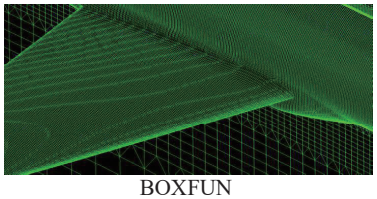


HexaGrid

5

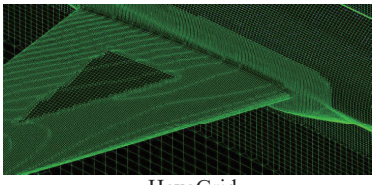
Difference between “BOXFUN” and “HexaGrid” grids

■“BOXFUN” and “HexaGrid” grid images

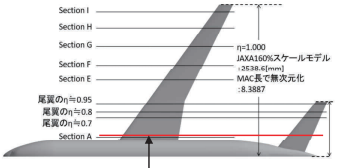


BOXFUN

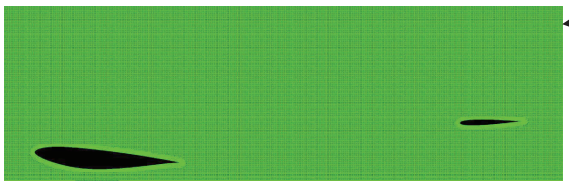
<Upper surface grid on the wing>
Finer “BOXFUN” than “HexaGrid”



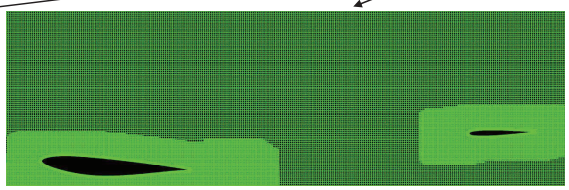
HexaGrid



Grid shape cutting out in a red section



BOXFUN



HexaGrid

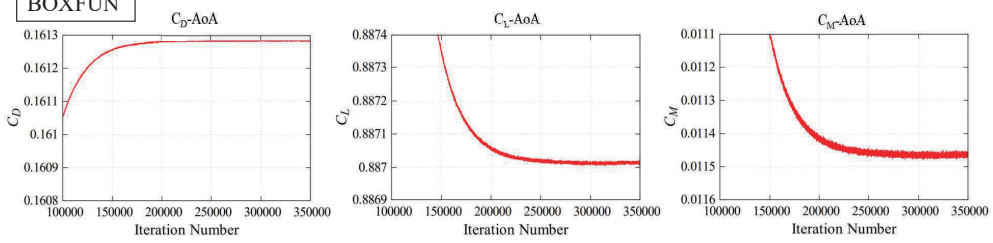
<Space grid above and behind the wing>
“BOXFUN” has a finer grid than “HexaGrid”

6

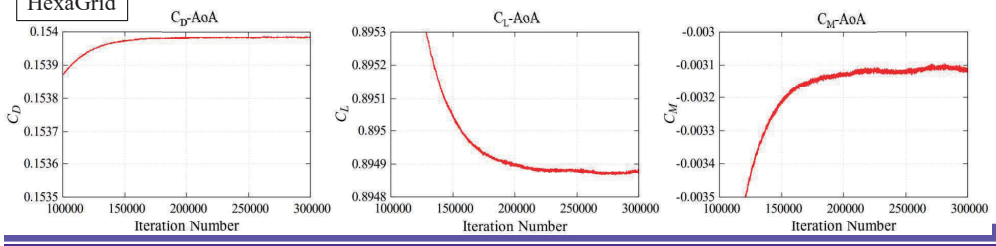
Results: Convergence histories of aerodynamic coefficients

■ The following figures show the history of the Aerodynamic Coefficient calculations at AoA=12.06° .

BOXFUN



HexaGrid

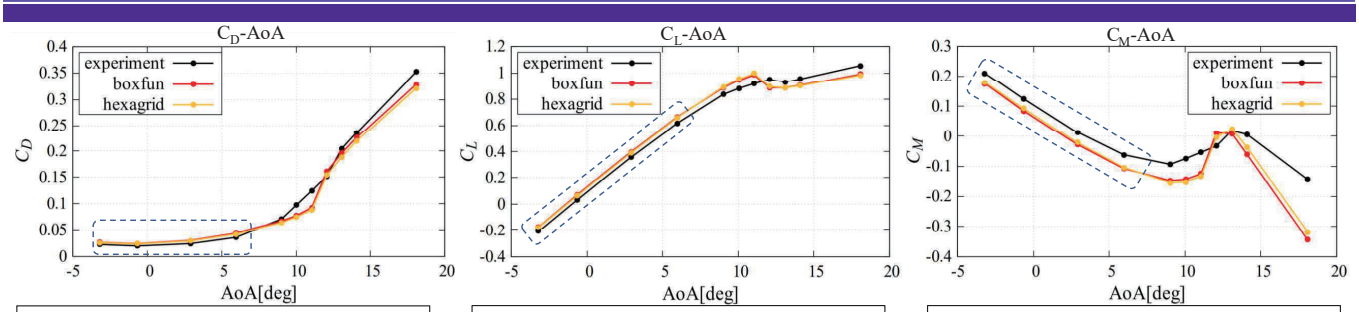


<Amplitude of Aerodynamic Coefficient>
- ■ BOXFUN
  - □ C_D:1.5e-6
  - □ C_L:6.5e-6
  - □ C_M:1.1e-5
- ■ HexaGrid
  - □ C_D:2.0e-6
  - □ C_L:8.0e-6
  - □ C_M:1.4e-5

■ Each calculated value converged to a constant value.
■ The amplitude of the calculated value is less than 1e-4.

7

Results: Comparisons of aerodynamic coefficients (1)



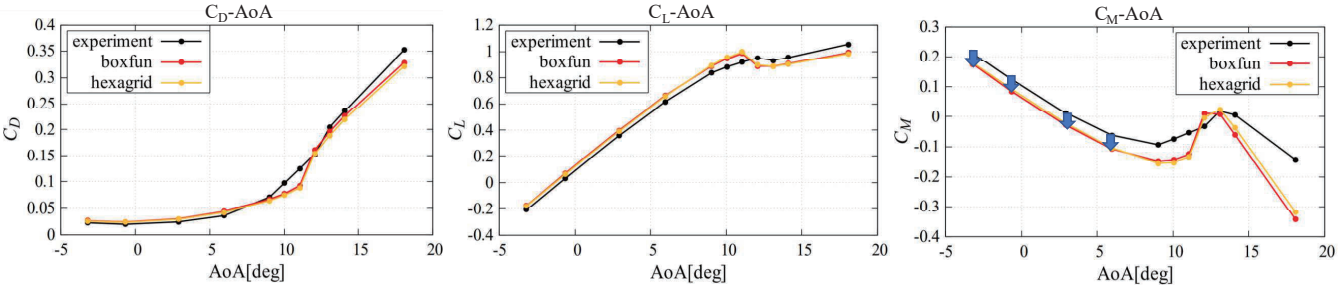
Calculated values of drag coefficient
- ■ Low AoA : ≳ experimental values
- ■ 10.03° and 11.05° : < experimental values
- ■ 11.05° ~12.06° : rapid increase

Calculated values of lift coefficient
- ■ Low AoA : ≳ experimental values, linear increase
- ■ 9.01° ~ : slow increase
- ■ 11.05° ~ 12.06° : significant drop

Calculated values of moment coefficient
- ■ Low AoA : < experimental values
- ■ 9.01° ~ : gradual increase
- ■ 11.05° ~ 12.06° : significant increase

8

Results: Comparisons of aerodynamic coefficients (2)



Low AoA(-3.22° ~5.95°)
- high precision calculations

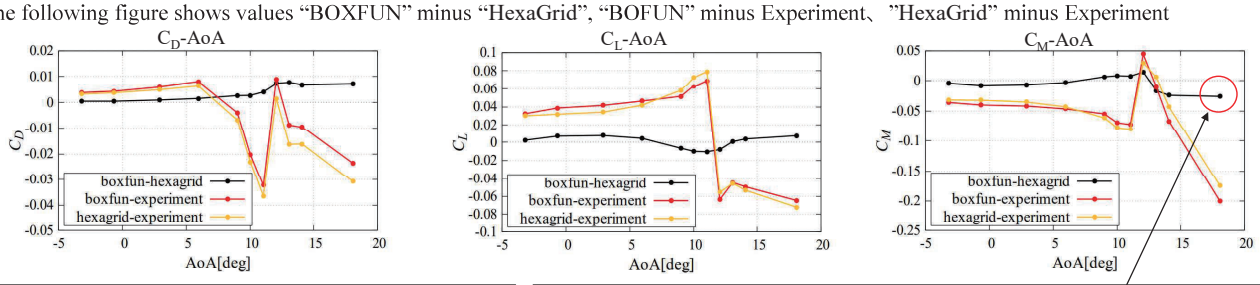
AoA to progress separation of the boundary layer (9.01° ~12.06°)
- At 9.01° , boundary layer on the wing separates and stall begins.
  ⇒ The separation of the boundary layer develops significantly between 11.05° and 12.06° and stalls more rapidly than the experiment.

AoA after the stalling(13.08° ~18.08°)
- Calculated value is less than the experimental value.
- The difference between calculated and experimental values increases as the AoA increases.
- Moment coefficients drop particularly sharply.

9

Results: Comparisons of aerodynamic coefficients' errors

- The following figure shows values "BOXFUN" minus "HexaGrid", "BOFUN" minus Experiment、"HexaGrid" minus Experiment



- Difference between "BOXFUN" and "HexaGrid" case
  - Nearly constant at low AoA
  - Increases as the AoA increases
- Difference between computational and experimental values
  - -3.22° ~5.95° : slightly increases with increases AoA
  - 9.01° ~12.06° : changes dramatically with increases AoA
  - 13.08° ~18.08° : increases with increases AoA

Difference in moment coefficient at 18.08° AoA : -0.025
Largest difference of aerodynamic cefficients between "BOXFUN" and "HexaGrid" case

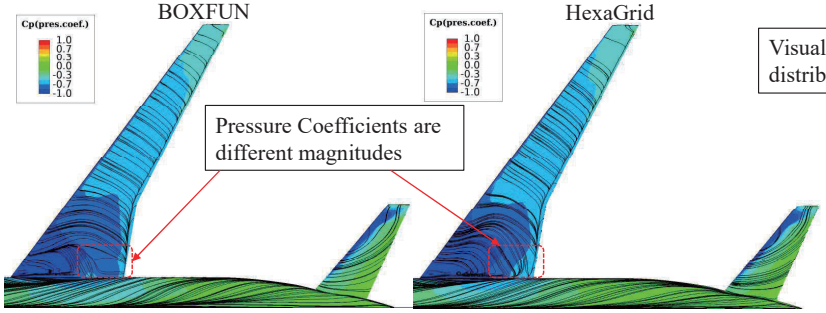
⇒Examine the factors that caused the large difference at 18.08° AoA

10

Pressure distribution in wing surface at AoA 18.08° (1)

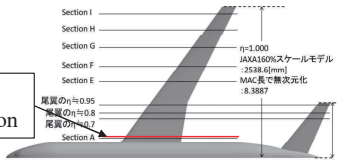
Pressure coefficient on the upper surface of wing

BOXFUN HexaGrid



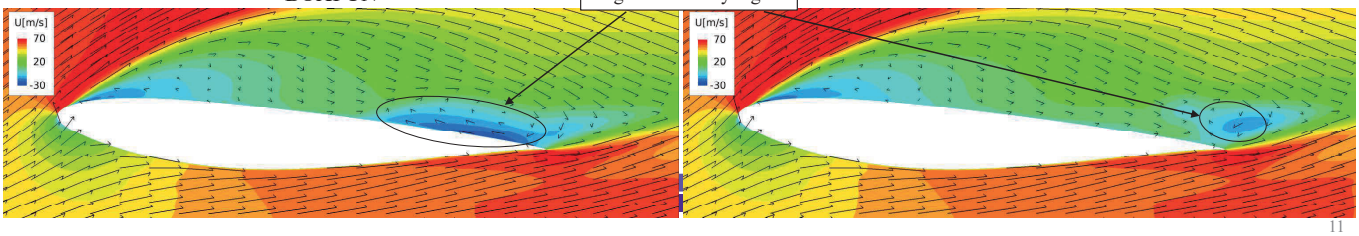
Pressure Coefficients are different magnitudes

Visualizing the velocity distribution in a red section



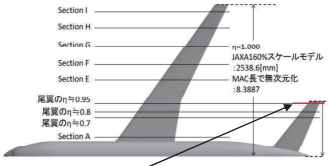
- Negative velocity region at the upper surface of the wing in the "BOXFUN" case was larger than in the "HexaGrid" case
  ⇒The negative pitching moment of the "BOXFUN" case was higher than that of the "HexaGrid" case
  ⇒ Moment coefficient in the "BOXFUN" case is calculated to be smaller than in the "HexaGrid" case

BOXFUN Negative velocity region HexaGrid



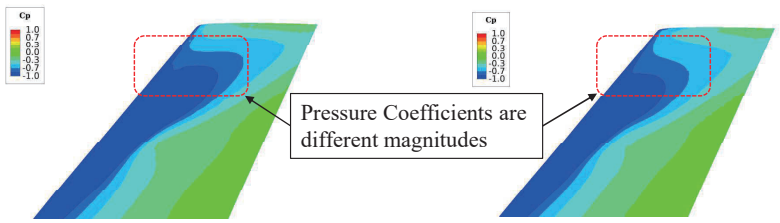
11

Pressure distributions on the wing surface at AoA 18.08° (2)



Pressure coefficient on the upper surface of tail

BOXFUN HexaGrid



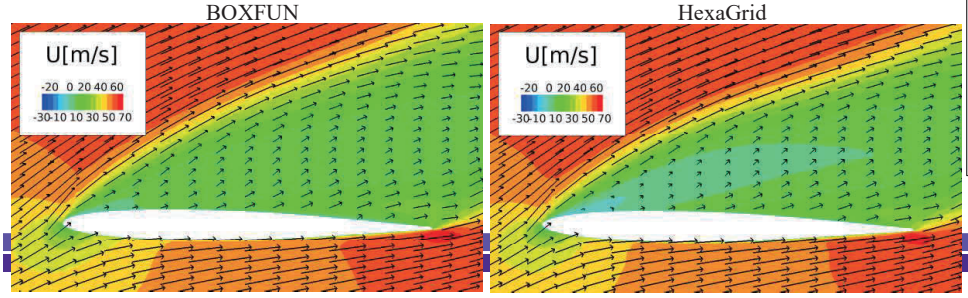
Pressure Coefficients are different magnitudes

Visualizing the velocity distribution in a red section

- BOXFUN
  Velocity distribution in front of upper surface of tail: ≒20m/s
- HexaGrid
  Velocity distribution in front of upper surface of tail: ≒10m/s

⇒Velocity distribution on the upper surface of the tail in the "BOXFUN" case is higher than in the "HexaGrid" case
⇒Negative pressure on the upper surface of the wing in the "BOXFUN" case is stronger than in the "HexaGrid" case
⇒ Moment coefficient in the "BOXFUN" case is calculated to be smaller than in the "HexaGrid" case

BOXFUN HexaGrid



12

Conclusions

The following results were shown by this study

- The aerodynamic coefficients at low AoA are faithfully reproduced from experiments
- The prediction accuracy of the aerodynamic coefficients at high AoA is low
- The difference in the moment coefficient at 18.08° AoA between the “BOXFUN” and “HexaGrid” grids was caused by the following factors :
  - The negative pitching moment of the “BOXFUN” case was higher than that of the “HexaGrid” case because:
    1. The negative velocity region at the upper surface of the wing in the “BOXFUN” case was larger than in the “HexaGrid” case
    2. The velocity distribution on the upper surface of the tail in the “BOXFUN” case is higher than in the “HexaGrid” case