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APC-8 （講演番号:1C11）

CflowによるCRM-HLの検証解析

Prediction of Low-speed Flows for the CRM-HL Configuration using Cflow

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カワる、サキへ。
Changing forward

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Outline

- Objective
- Focus of APC-8
  1. Grid dependency study
  2. Effect of turbulence model
     - SA-neg vs SA-noft2-R-QCR
     - SA-noft2-R-QCR vs SA-noft2-R (effect of QCR)
     - SA-noft2-R-QCR crot 1.0 vs 2.0 (sensitivity analysis of crot)
- Summary

Objective

■ Participation case

	Case 1	Case 2	Case 3	Case 4
Submitted	○	×	△	○

■ Focus on the results of **Case1** in this presentation

● Case1

	SA-neg	SA-noft2-R-QCR	SA-noft2-R
Cflow Grid	○	○	○
JAXA Grid	○	×	×
Pointwise Grid	○	×	×

Focus 2

Focus 1

➢ **Focus 1 : Grid dependency study**
- CflowGrid vs. JaxaGrid vs. PointwiseGrid

Grid feature study and code to code comparisons

➢ **Focus 2 : Effect of turbulence model**
- SA-neg vs. SA-R-QCR vs. SA-R

Which turbulence model approaches the WTT results?

Numerical Method

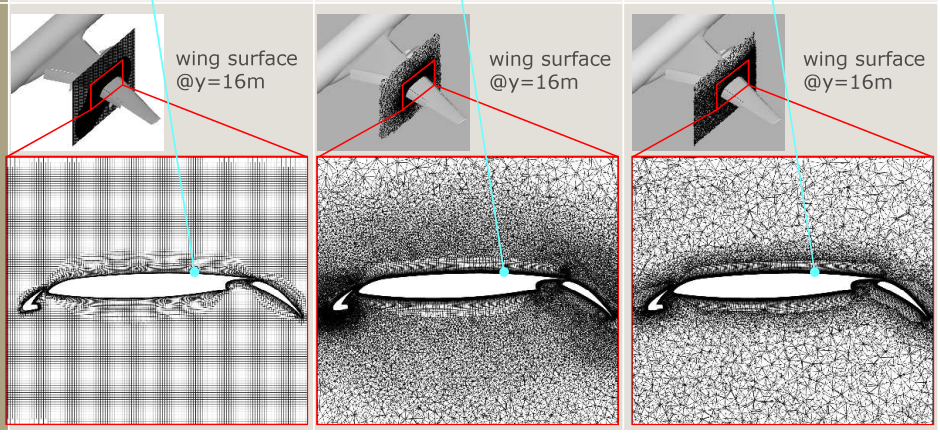
CFD tool	Cflow (KHI in-house)
Governing Equations	**RANS** (Reynolds Averaged Navier-Stokes equations)
Spatial Discretization	Cell-centered finite volume method with 2nd-order accurate reconstruction based on MUSCL
Inviscid Flux	**SLAU** (Simple Low-dissipation AUSM scheme)
Viscous Flux	2nd-order accurate central difference
Turbulence Modeling	**SA-neg** (Negative Spalart-Allmaras One-Equation Model) **SA-noft2-R/R-QCR** (for investigation of turbulence model effect)
Time Integration	**MFGS** implicit method with **local** time stepping

References for ***Cflow*** details

1. Ueno, Y. and Ochi, A., ***"Airframe Noise Prediction Using Navier-Stokes Code with Cartesian and Boundary-fitted Layer Meshes,"*** 25th AIAA/CEAS Aeroacoustics Conference, (AIAA 2019-2553).
2. Atsushi Hashimoto, Takashi Aoyama, Yuichi Matsuo, Makoto Ueno, Kazuyuki Nakakita, Shigeru Hamamoto, Keisuke Sawada, Kisa Matsushima, Taro Imamura, Akio Ochi, and Minoru Yoshimoto, ***"Summary of First Aerodynamics Prediction Challenge (APC-I),"*** 54th AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2016-1780).
3. Yasushi Ito, Mitsuhiro Murayama, Atsushi Hashimoto, Takashi Ishida, Kazuomi Yamamoto, Takashi Aoyama, Kentaro Tanaka, Kenji Hayashi, Keiji Ueshima, Taku Nagata, Yosuke Ueno and Akio Ochi, ***"TAS Code, FaSTAR and Cflow Results for the Sixth Drag Prediction Workshop,"*** *Journal of Aircraft*, Vol. 55, No. 4, pp. 1433-1457, 2018.
4. Yasushi Ito, Mitsuhiro Murayama, Yuzuru Yokokawa, Kazuomi Yamamoto, Kentaro Tanaka, Tohru Hirai, Hidemasa Yasuda, Atsushi Tajima and Akio Ochi, ***"JAXA's and KHI's Contribution to the Third High Lift Prediction Workshop,"*** Journal of Aircraft, Vol. 56, No. 3, pp.1080-1098, 2019.

Grid comparison

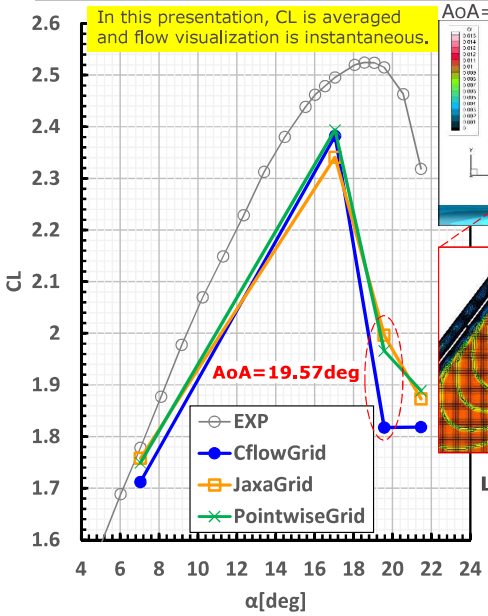
*These conform to the mesh generation guidelines(fuselage cell size, chord/spanwise spacing, y+ etc.) of HLPW4 and are equivalent to LevelC.

	CflowGrid	JaxaGrid	PointwiseGrid
Total number of cells	384M	209M	142M
Cell size @x≈44m	55mm	39mm	24mm
xz plane			

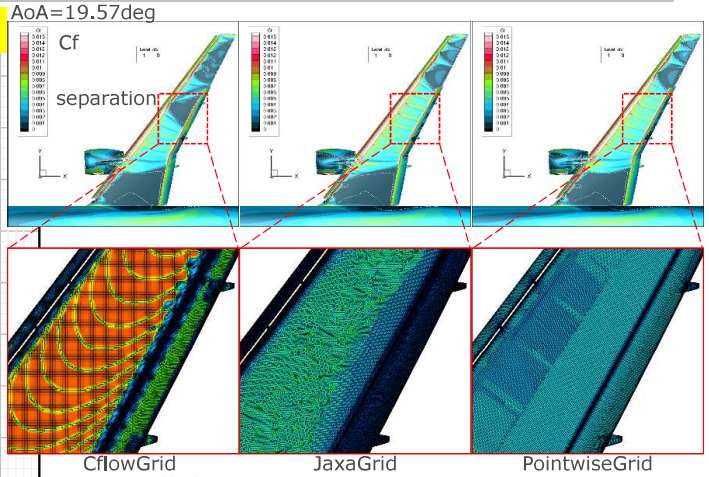
Grid dependency study

	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		

In this presentation, CL is averaged and flow visualization is instantaneous.



AoA=19.57deg



Largest cell size

cell volume of first cell off the wall : 0 0.0035[m³]

■ CflowGrid has the largest grid spacing on the wing.

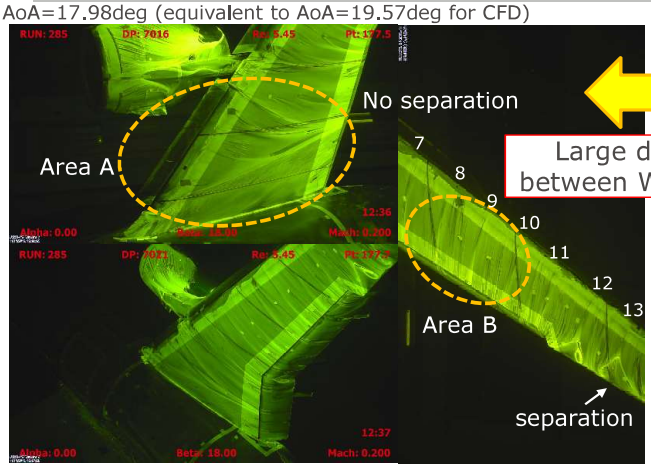
There is a possibility that it is necessary to pay attention to the surface grid spacing of the wing even if the grid is the same Level C.

Effect of turbulence model

Motivation for changing turbulence model

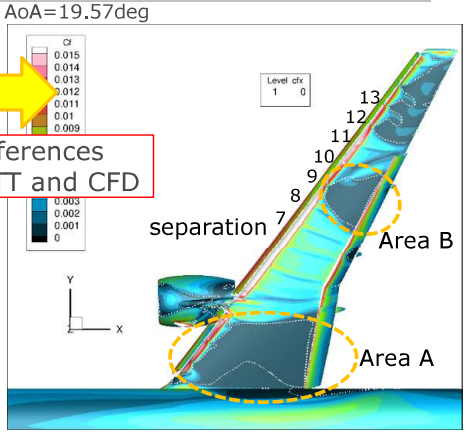
	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		

AoA=17.98deg (equivalent to AoA=19.57deg for CFD)



Large differences between WTT and CFD

AoA=19.57deg



In the case of SA-neg, large separation occurs at AoA=19.57deg in 3 grids.

- Change Turbulence Model to Reduce Separation in CFD
  - to suppress separation on area A → add QCR
  - to suppress separation on area B → add R (Rotation Correction)

Turbulence model is changed to SA-R-QCR to assess wing outboard/root effects.

Next slide

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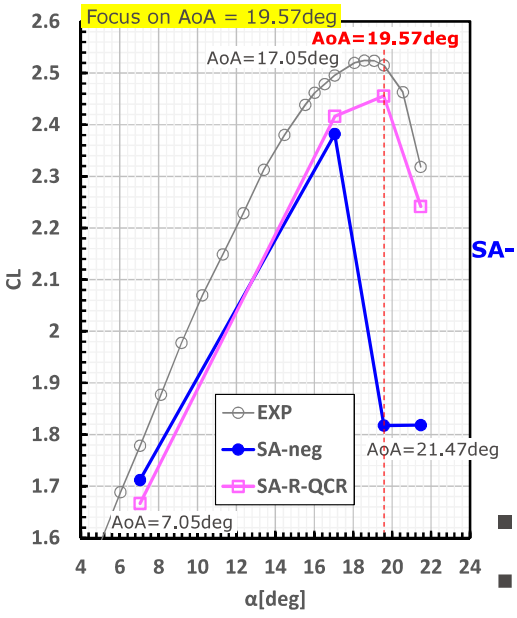
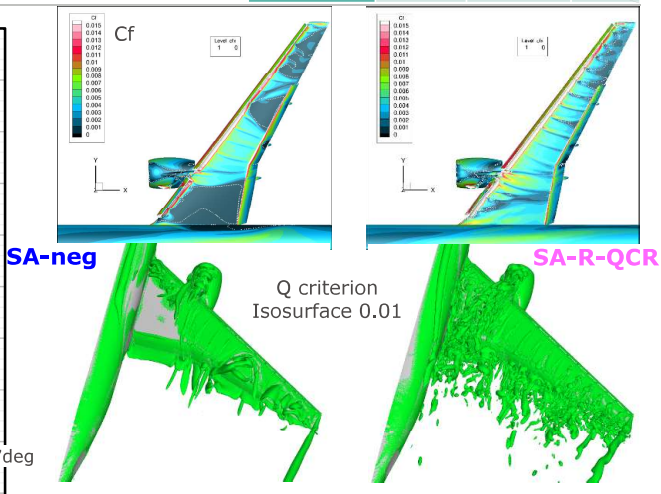
Effect of turbulence model SA-neg vs. SA-R-QCR

	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		





- By changing the turbulence model from SA-neg to SA-R-QCR CL approaches the WTT results.
- Differences appeared in both the corner flow and the vortex generated from the outboard wing.

Application of both R and QCR supress root and outboard separation.

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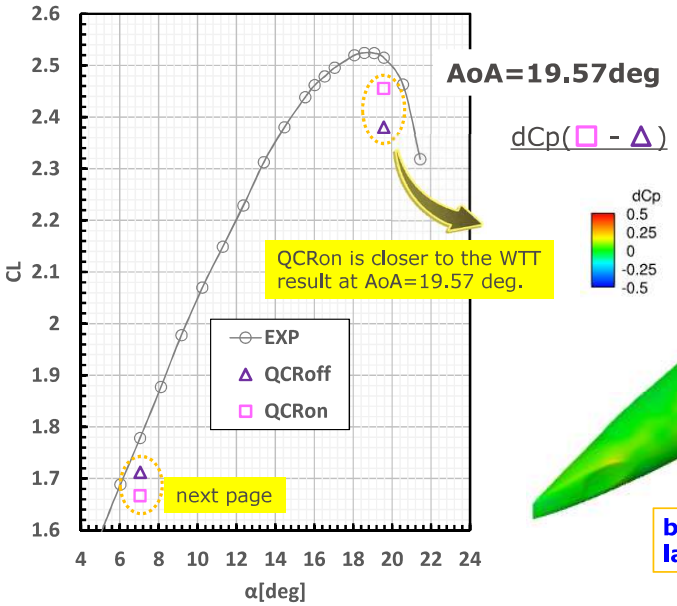
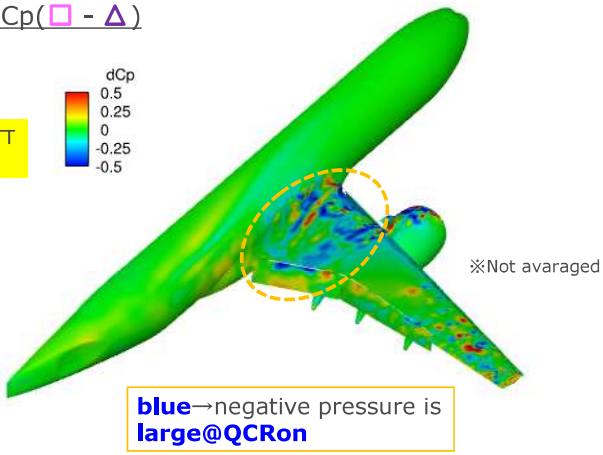
Effect of turbulence model SA-R-QCR vs. SA-R (1/2)

	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		



p.9 and 10 shows effect of QCR at AoA=19.57 and 7.05deg.



※Not avaraged

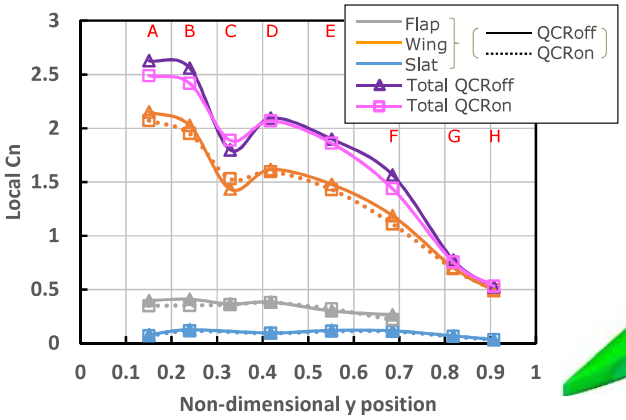
blue→negative pressure is **large@QCRon**

- QCRon approaches WTT at a high AoA.
- There is a difference between QCRon and QCRoff on the wing root side ; the negative pressure of QCRon is larger on the wing root side.

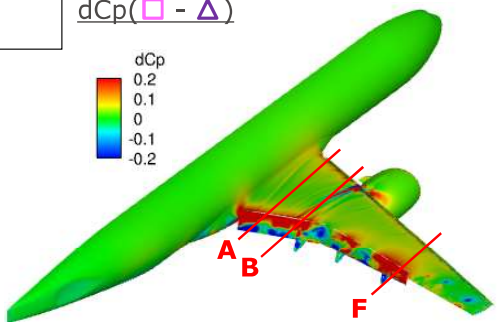
Effect of turbulence model SA-R-QCR vs. SA-R (2/2)

	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		

AoA=7.05deg The total CL of QCRoff is larger at AoA=7.05deg, differing from at AoA=19.57deg, and is close to the WTT result. (see p.9)



red→negative pressure is **large@QCRoff**



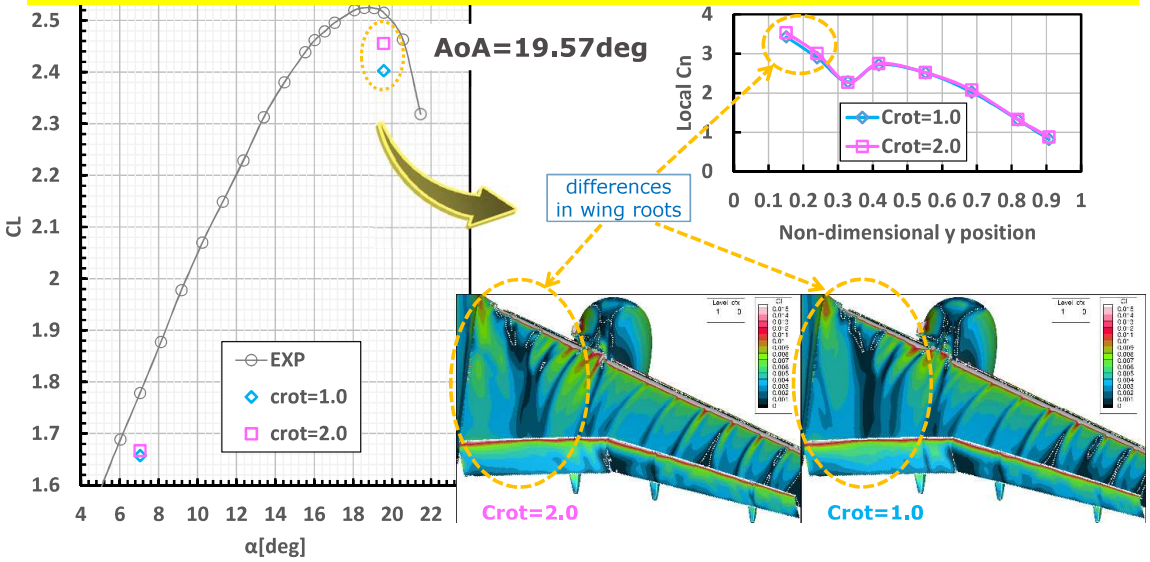
- QCRoff has a larger Cn than QCRon in the A and B sections on the wing root side and in the F section of the outboard wing.
- The Cp distribution in the flap is different between QCRon and QCRoff.
- It is necessary to see not only the integral value but also the flow field.

The turbulence model approaching the WTT result at high and low AoAs are not identical.

Effect of turbulence model Sensitivity of Crot (SA-R-QCR)

	SA-neg	SA-R-QCR	SA-R
CflowGrid	○	○	○
JaxaGrid	○		
PointwiseGrid	○		

Based on this study, it is considered that QCR is effective in predicting high AoA. (see p.9)
=>We change the Crot of the Rotation Correction in the turbulence model SA-R-QCR to analyze its sensitivity.



- The sensitivity analysis of Crot without changing the condition of QCRon shows a difference on the wing root side.

In this study, Crot = 2.0 is better.

Summary

- The grid dependency on the 3 grids and the effects of the turbulence model on the CRM-HL configuration were investigated.
- Lessons Learned
  - Grid dependency study
    - There is a possibility that it is necessary to pay attention to the surface grid spacing of the wing even if the grid is the same Level C.
  - Effect of turbulence model
    - At AoA=19.57deg, the **SA-R-QCR (Crot=2.0)** had the closest value to the WTT.
    - The turbulence model approaching the WTT result at high and low AoAs are not identical.
    - When SA-R/SA-R-QCR is applied, the effect of turbulence model is commonly observed sensitively on the wing root side.
    - In this study, Crot=2.0 of R (Rotation Correction) is closer to the WTT result than Crot=1.0.