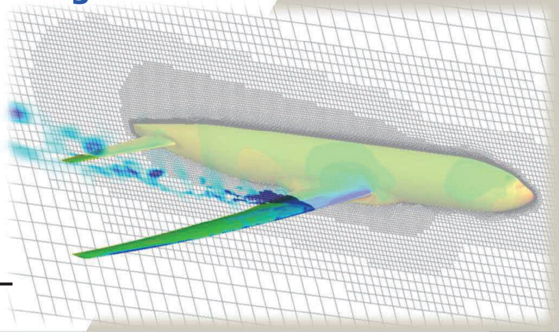
20KT014000

APC-6 （講演番号:1A09）

CflowによるNASA-CRM巡航形態の低速空力特性の予測 ［課題1, 2］

Prediction of Low-speed Aerodynamic Characteristics for NASA-CRM Cruise Configuration using Cflow



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2020年9月28日（月）
流力ANSS2020オンライン＠WebEx

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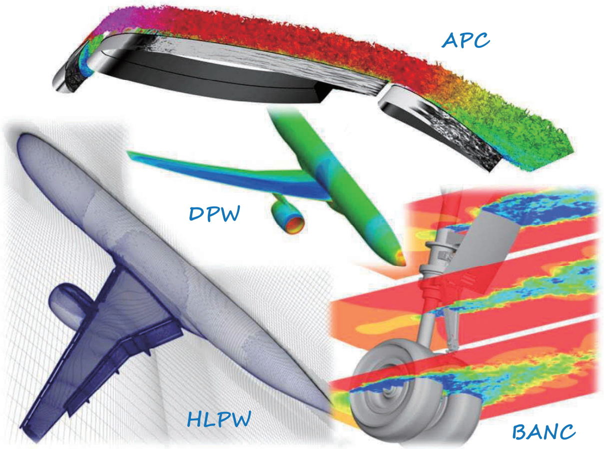
Outline

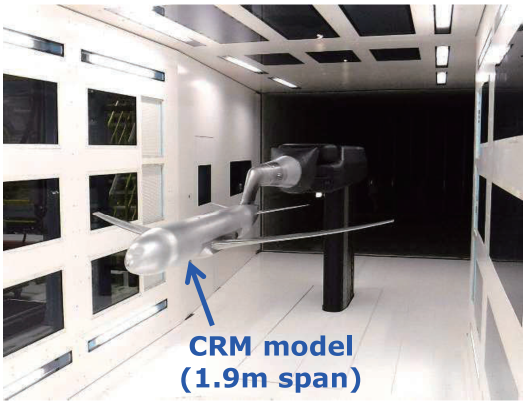
- Motivation
- Numerical Method
- Grid
- **Case1 : Steady**
  - Provided Grid (HexaGrid/BOXFUN) *partial AoA
  - Custom Grid (Cflow-Coarse) *all AoA
- **Case2 : Unsteady**
  - Provided Grid (HexaGrid) *data NOT submitted
  - Custom Grid (Cflow-Medium)
- Summary

Motivation

- **Practical use** of CFD in the aircraft design
- **Validation** of KHI in-house CFD tool for low-speed aerodynamics
- **Facilitation** of CFD-WTT collaboration



KHI in-house CFD tool "*Cflow*"
(highly complicated geometry, unsteady, large-scale)



KHI new wind tunnel
(low-speed, low-noise)

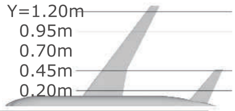
Numerical Method

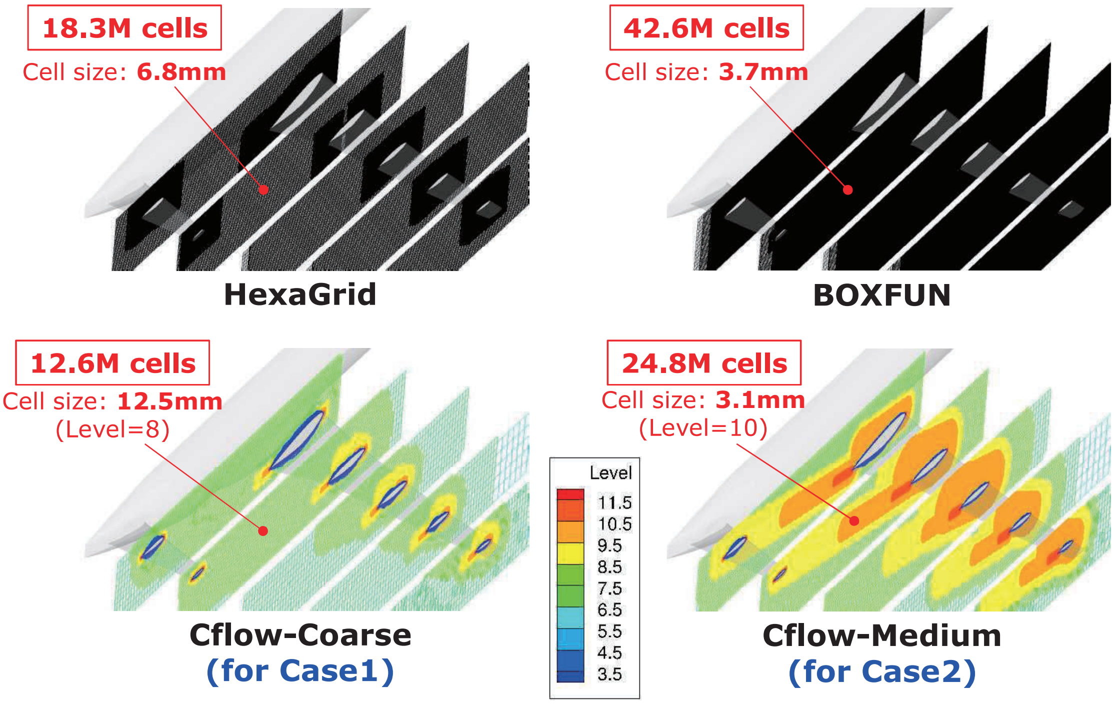
CFD tool	Cflow (KHI in-house)
Governing Equations	Three-dimensional compressible Navier-Stokes equations
Spatial Discretization	Cell-centered finite volume method with 2rd-order accurate reconstruction based on MUSCL
Inviscid Flux	SLAU (Simple Low-dissipation AUSM scheme)
Viscous Flux	2nd-order accurate central difference
Turbulence Modeling	SA-noft2 (Spalart-Allmaras model without ft_2 term) / DDES for Case2
Time Integration	MFGS implicit method (2nd-order for Case2)
Parallelization	Domain decomposition method with MPI

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, "***Japan Aerospace Exploration Agency's and Kawasaki Heavy Industries' Contribution to the Third High Lift Prediction Workshop,***" 2018 AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2018-1034).

Grid Comparison

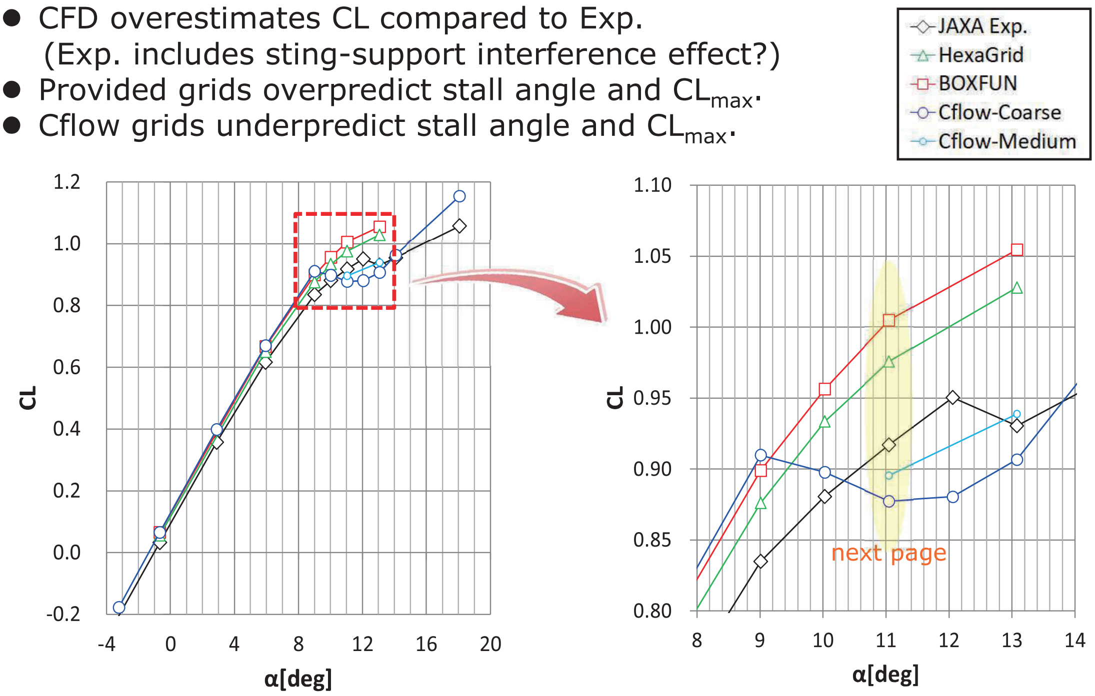


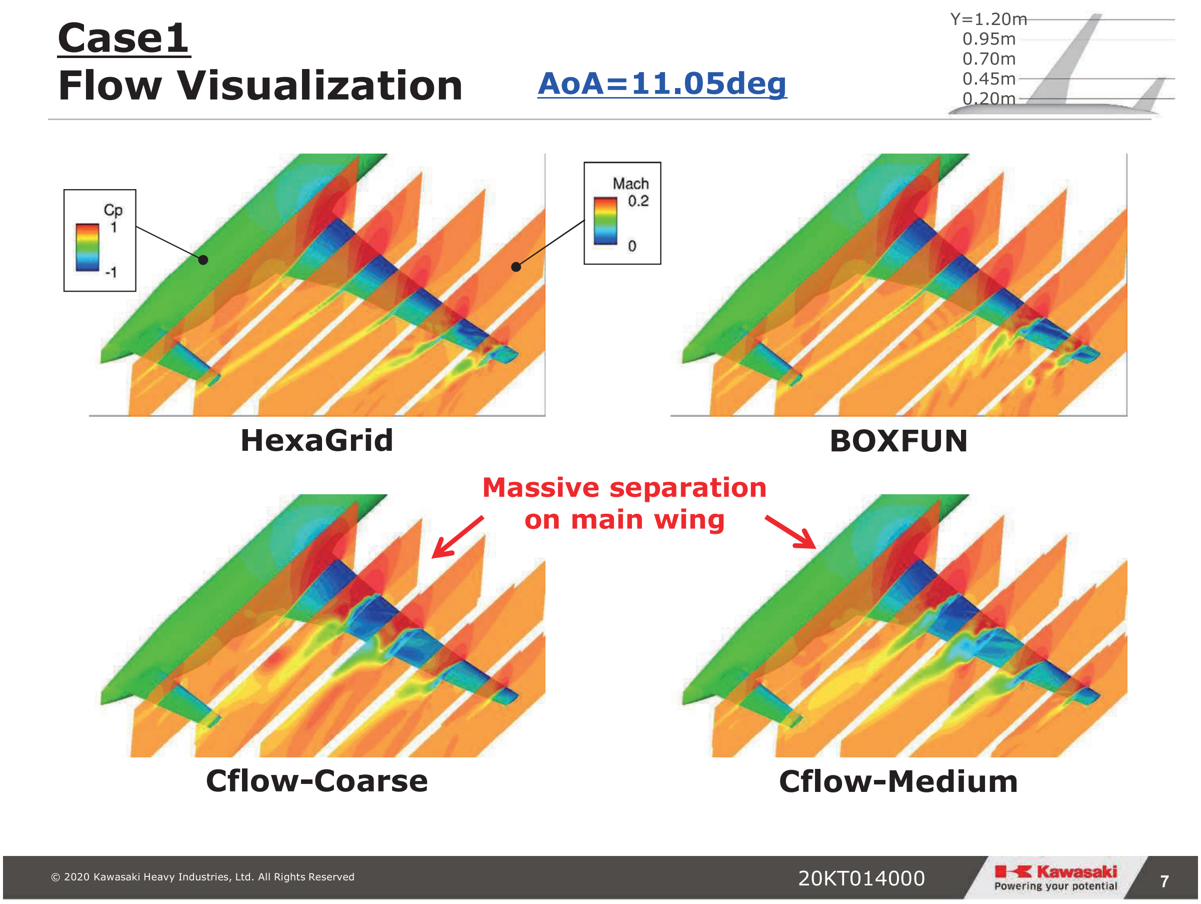


Case1
CL-Alpha

M=0.168
Re=1.06×10⁶

- CFD overestimates CL compared to Exp.
  (Exp. includes sting-support interference effect?)
- Provided grids overpredict stall angle and CL_{max}.
- Cflow grids underpredict stall angle and CL_{max}.




Case1
Flow Visualization
AoA=11.05deg
Y=1.20m
0.95m
0.70m
0.45m
0.20m
Cp
1
-1
Mach
0.2
0
HexaGrid
BOXFUN
Massive separation
on main wing
Cflow-Coarse
Cflow-Medium
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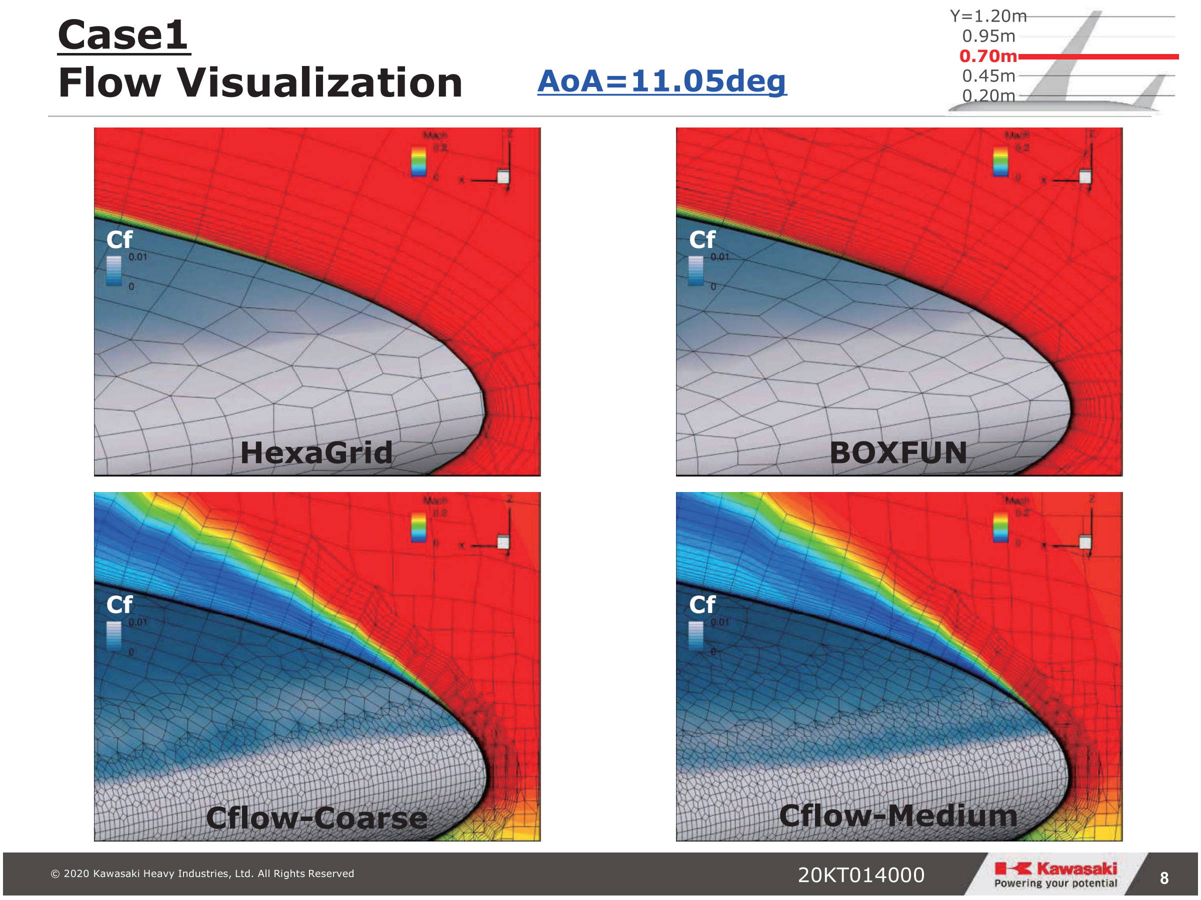
Case1
Flow Visualization
AoA=11.05deg
Y=1.20m
0.95m
0.70m
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0.20m
Cf
HexaGrid
BOXFUN
Cflow-Coarse
Cflow-Medium
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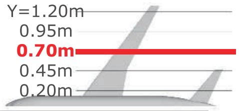
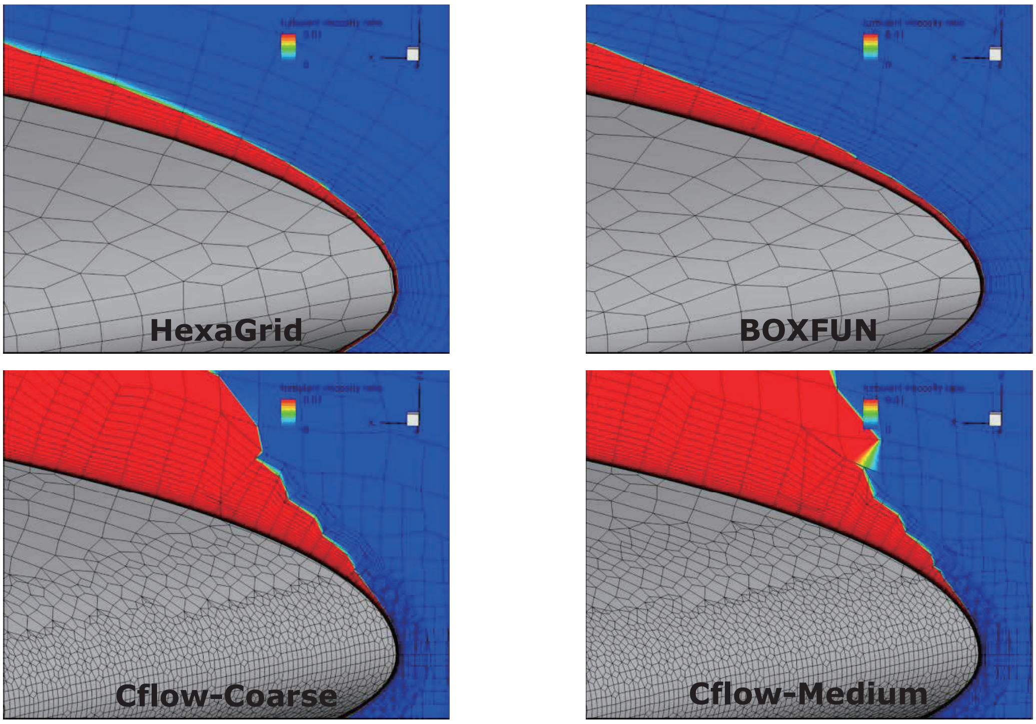
Case1
Flow Visualization

AoA=11.05deg

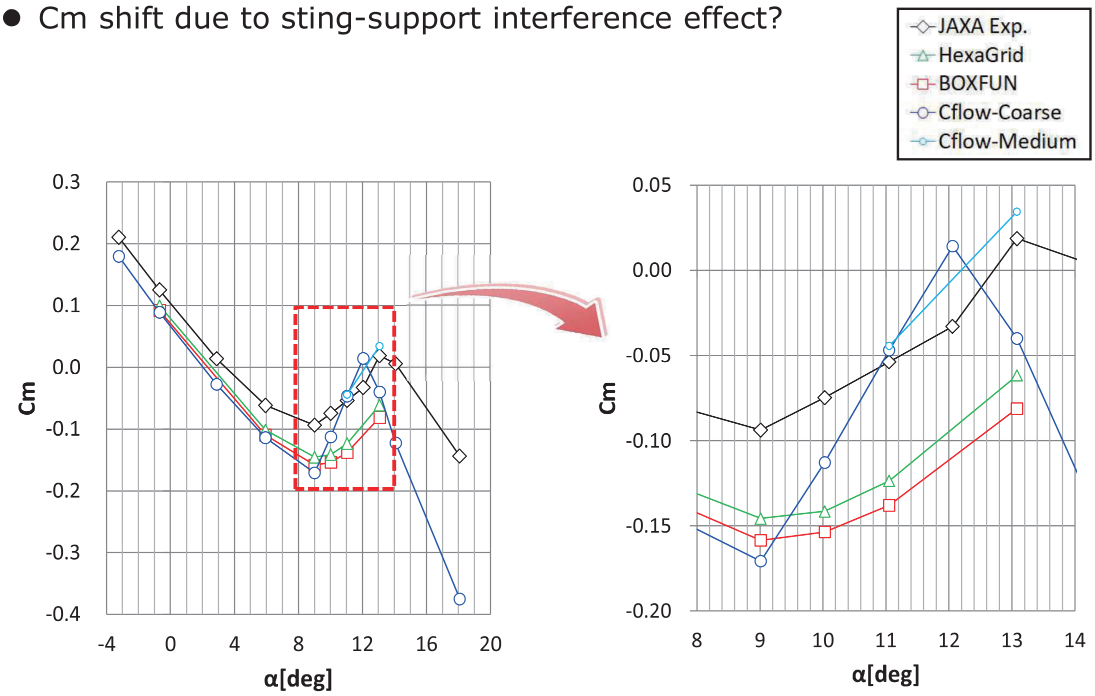




Case1
Cm-Alpha

M=0.168
Re=1.06×10⁶

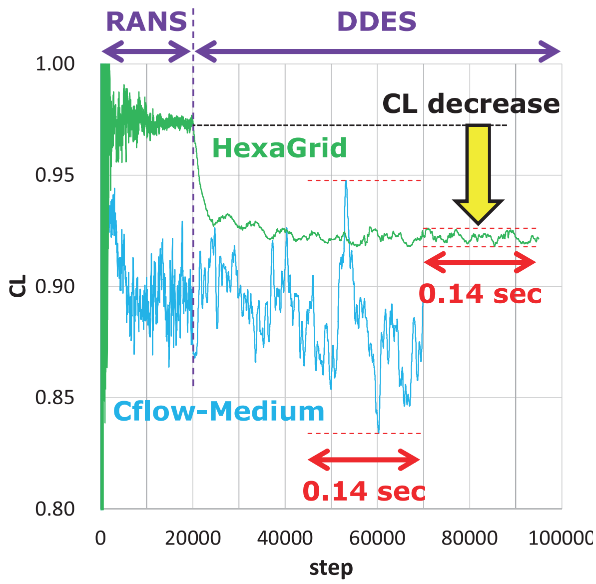
- Cm shift due to sting-support interference effect?



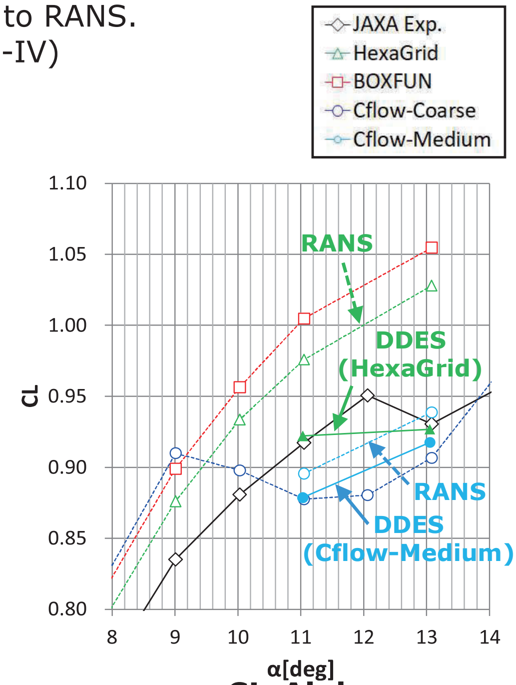
Case2
Time history of CL and CL-Alpha

M=0.168
Re=1.06×10⁶

- DDES brings CL decrease compared to RANS.
  (Similar tendency to 30P30N at APC-IV)

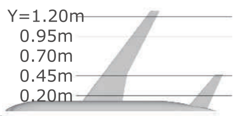


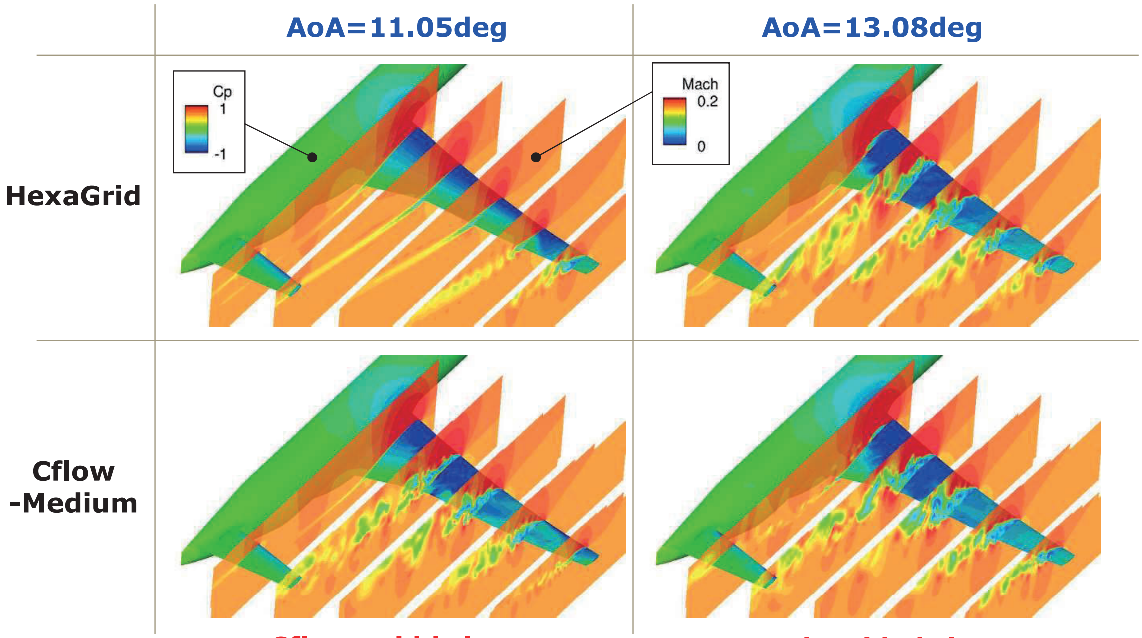
CL history (AoA=11.05deg)



CL-Alpha

Case2
Flow Visualization





Cflow grid brings massive separation

Both grids bring similar results

Summary

- An unstructured Navier-Stokes flow solver “*Cflow*” was applied to the prediction of low-speed aerodynamic characteristics for NASA-CRM cruise configuration.

- **Lessons Learned**
  - ✓ **Case1:** SA-based RANS results at high AoA are drastically dependent on grid.
  - ✓ **Case2:** SA-based DDES results tend to bring more separated flow (CL decrease) compared to RANS results.
  - ✓ **Our current RANS/DDES approaches are not practical for CL_{max} prediction.**

- Future work
  - ✓ Investigate more details on the effect of grid
  - ✓ New approach such as WMLES?

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【補足】定常解析における力の後処理について(1/2)

- 定常解析手法について： 今回のCase1の解析はローカルタイムステップを用いている。つまり、解が収束することを前提としているが、高迎角時の解析は収束せずに変動する場合もあった。
- 本資料に示した力データ（CL, CD, Cm）は、圧力分と摩擦分を足し合わせたものであり、Cflowの解析ログから平均化して求めたものである。
- 一方、APC事務局に提出した力データは、Cflowの解析最終ステップデータ（平均値ではなく瞬時値）から、市販の可視化ソフトを使って、圧力分と摩擦分を分離したものである。
- よって、APC事務局作成のまとめ資料と本資料の力データは若干異なる。特に定常解析でも収束せずに変動している高迎角時のデータについて、その差が顕著になっている。
- 次頁にCLにおける両データの違いを示す。

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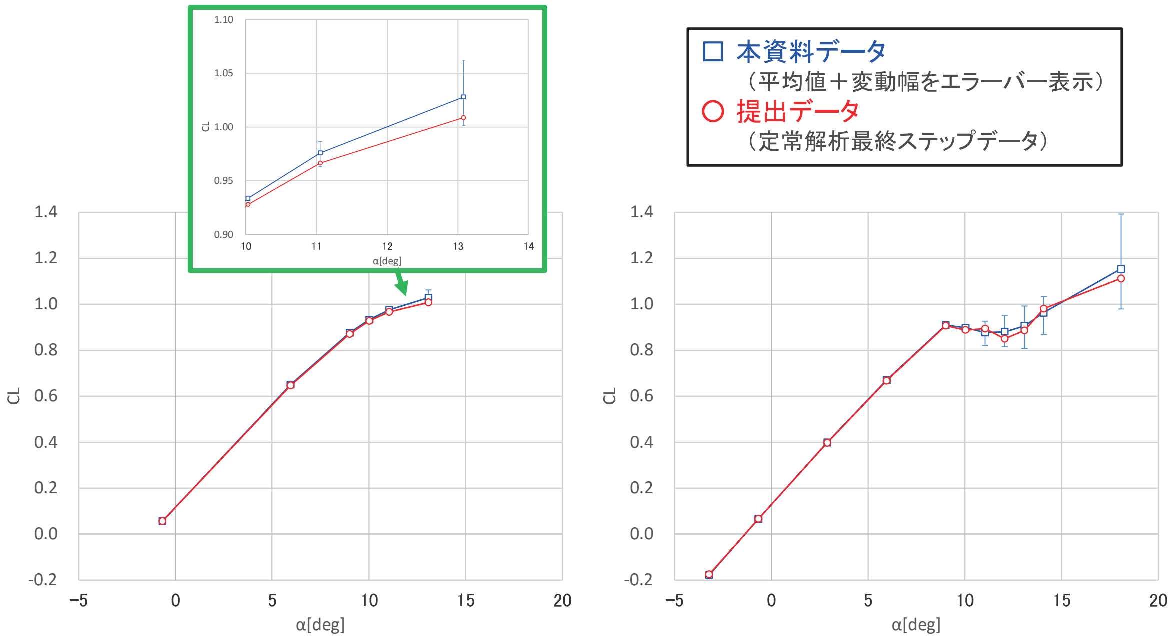
【補足】定常解析における力の後処理について(2/2)



HexaGrid Cflow-Coarse

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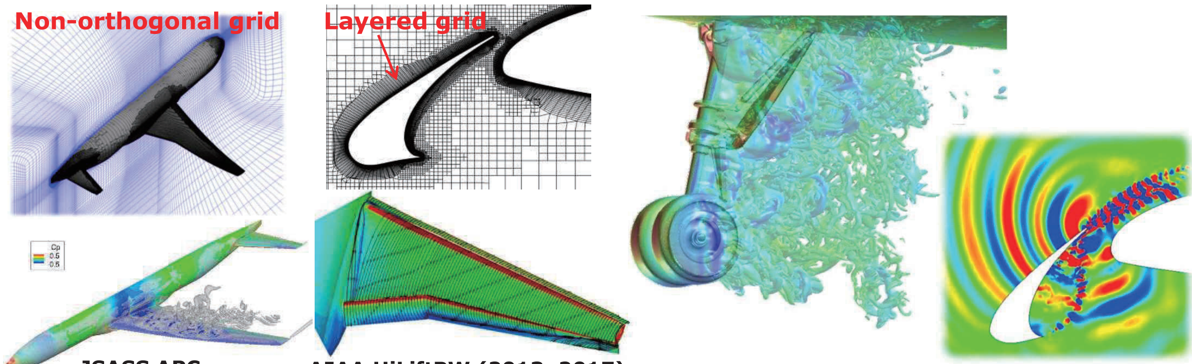
Cflow (KHI in-house CFD tool)

- ✓ **Kawasaki** originally developed ***"Cflow"***

Cflow = Grid Generator + Flow Solver

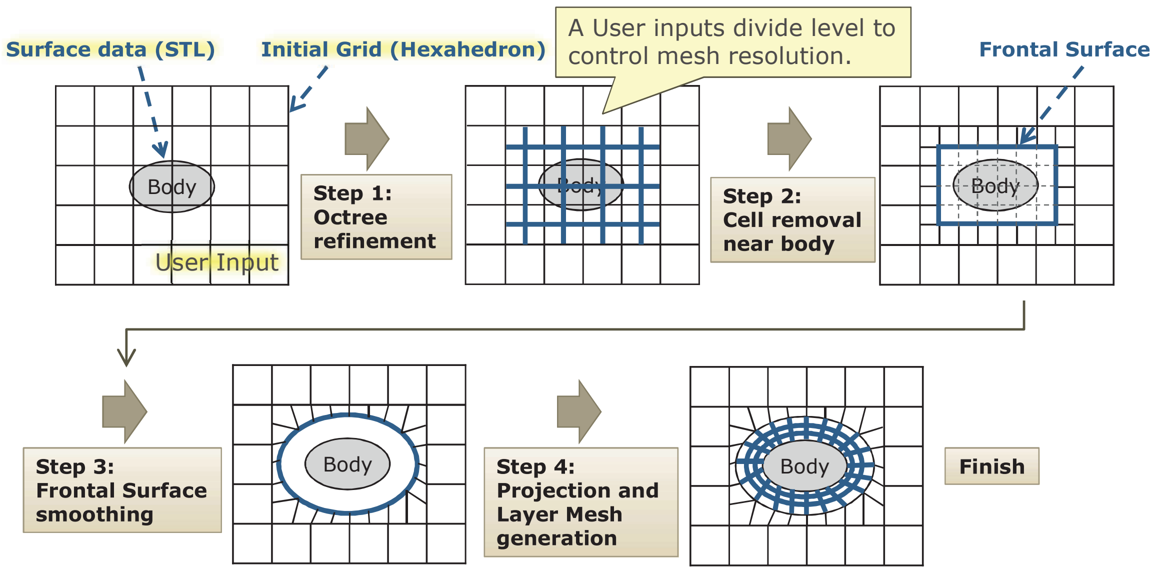
highly complicated | large-scale | unsteady

- ✓ Cflow has been validated in various workshops.



JSASS APC (2015-2019) **AIAA HiLiftPW (2013, 2017) Drag Prediction Workshop (2016)** **AIAA BANC Workshop (2010-2018)**

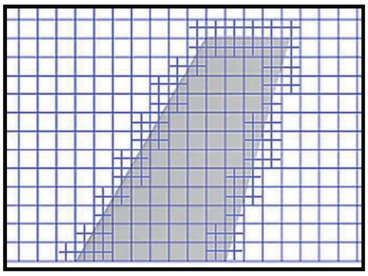
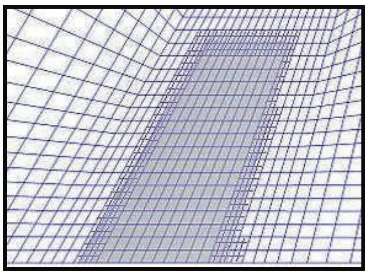
Grid Generation Procedure in *Cflow*



Cflow automatically generates body-fitted layered grids on no-slip walls to resolve boundary layers and hexahedral grids in the other regions.

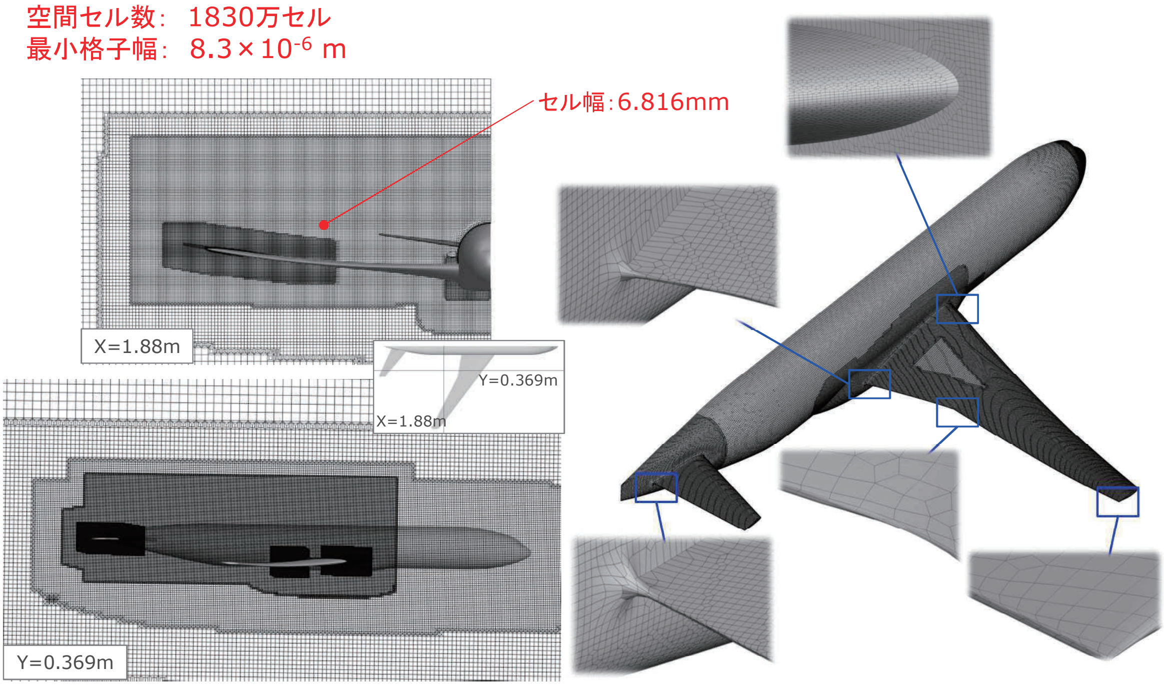
Initial Grid of *Cflow*

There are 2 options for initial grid of *Cflow*.

Cartesian Grid		*Non-orthogonal Grid*
	or	
･grid generation robustness ･unsteady simulation (resolving vortices) ･acoustic wave propagation		･reduction of total cells (high aspect ratio) ･sweptback cells ･oblique shock wave
⇩		⇩
Noise prediction from complicated geometry		**Steady simulations**

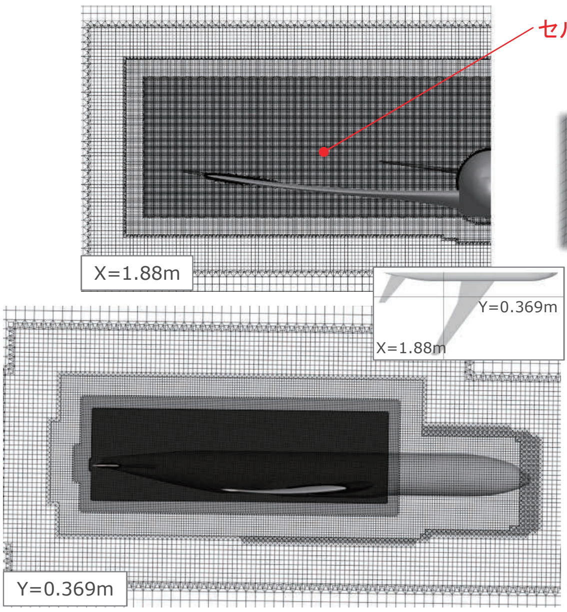
Grid (HexaGrid)

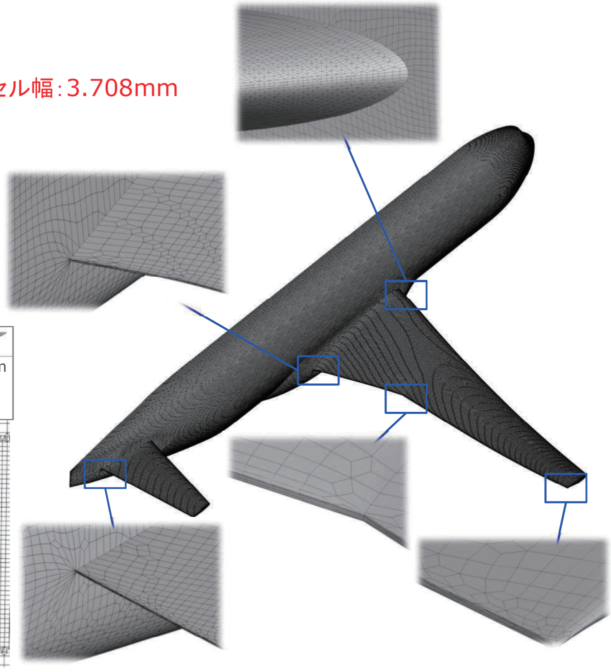
空間セル数：1830万セル
最小格子幅：8.3×10^{-6} m



Grid (BOXFUN)

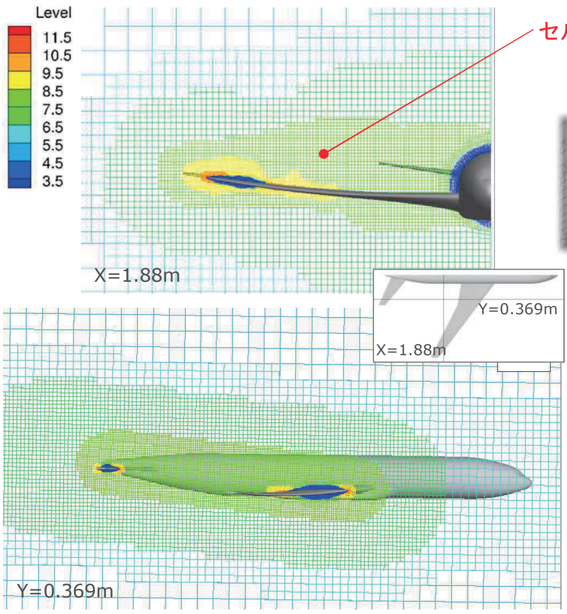
空間セル数: 4260万セル
最小格子幅: 5.2 × 10^{-6} m

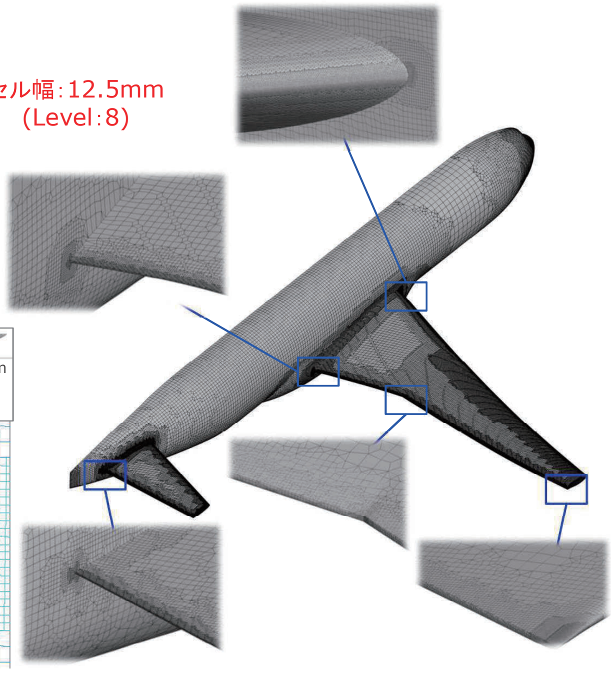




Grid (Cflow-Coarse)

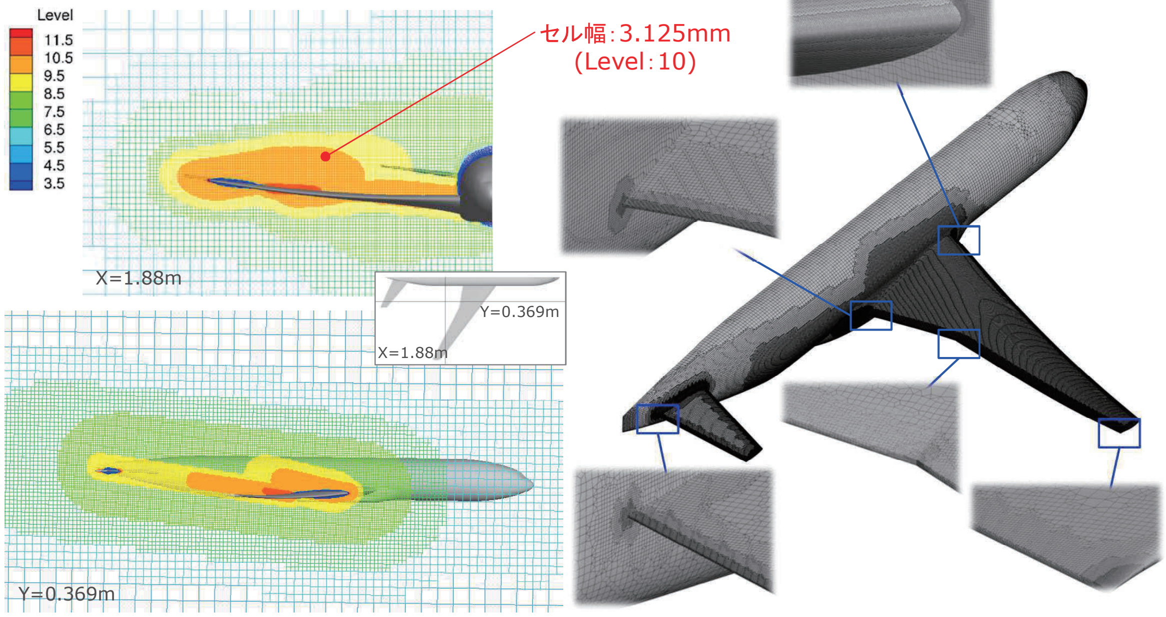
空間セル数: 1260万セル
最小格子幅: 8.0 × 10^{-6} m



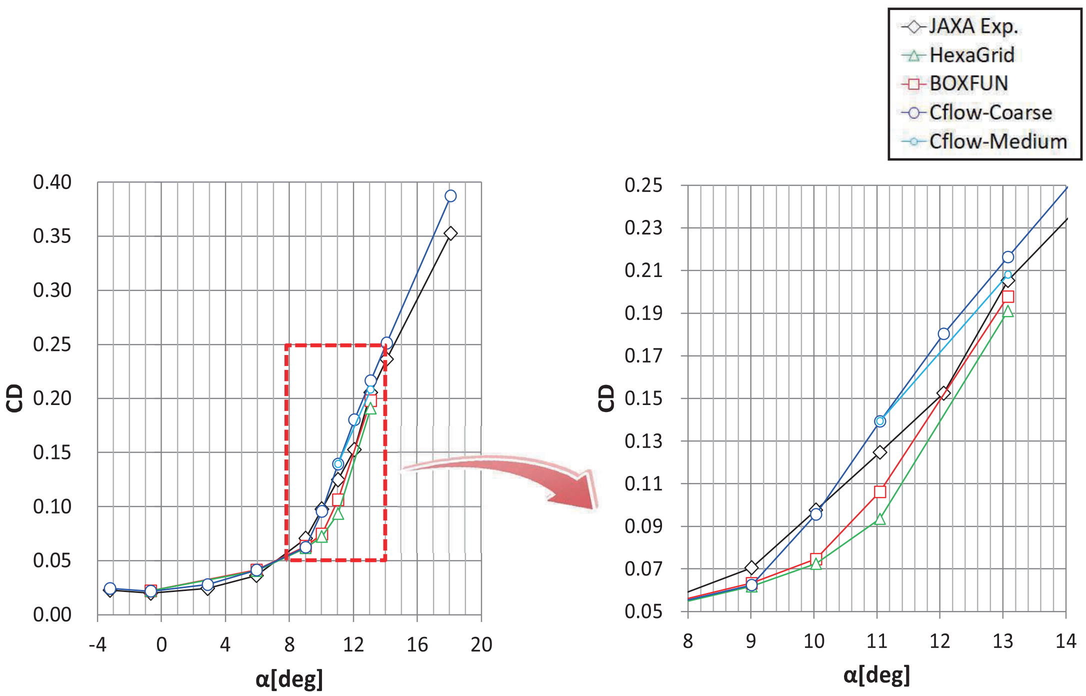


Grid (Cflow-Medium)

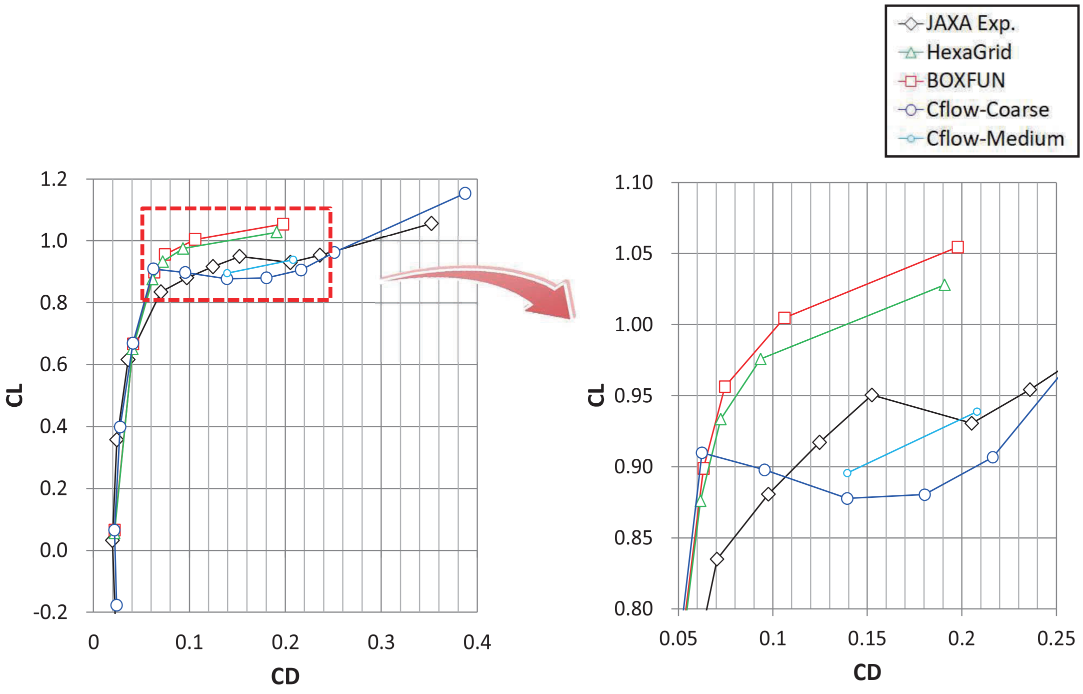
空間セル数: 2480万セル
最小格子幅: 8.0×10^{-6} m



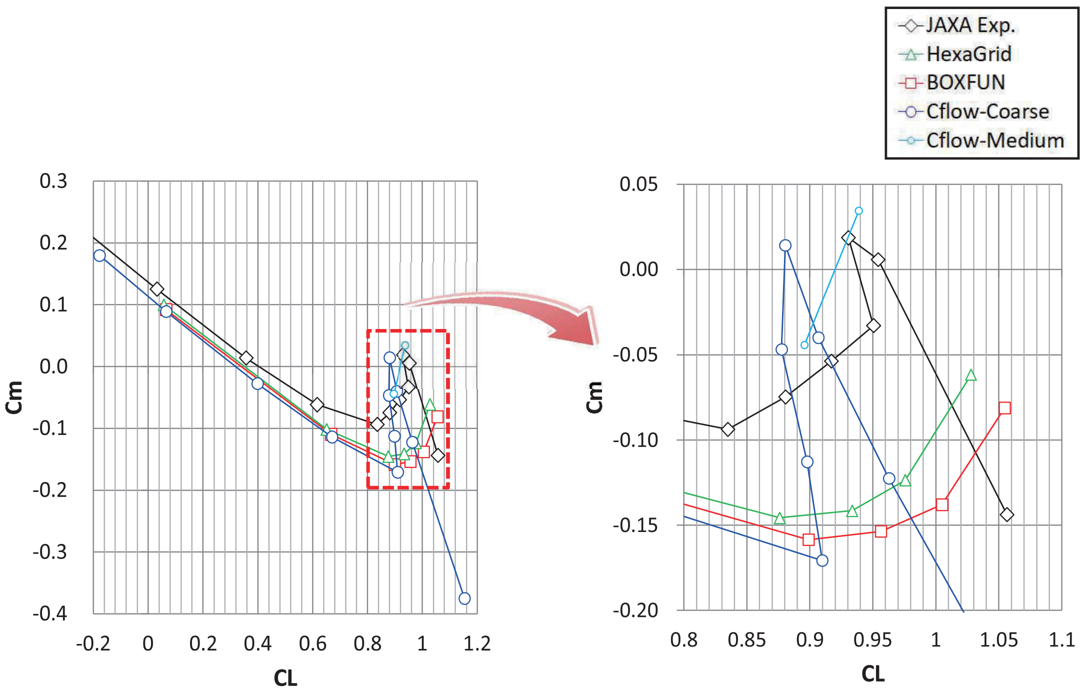
Case1
CD-Alpha



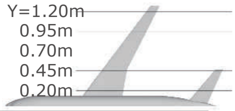
Case1
CL-CD

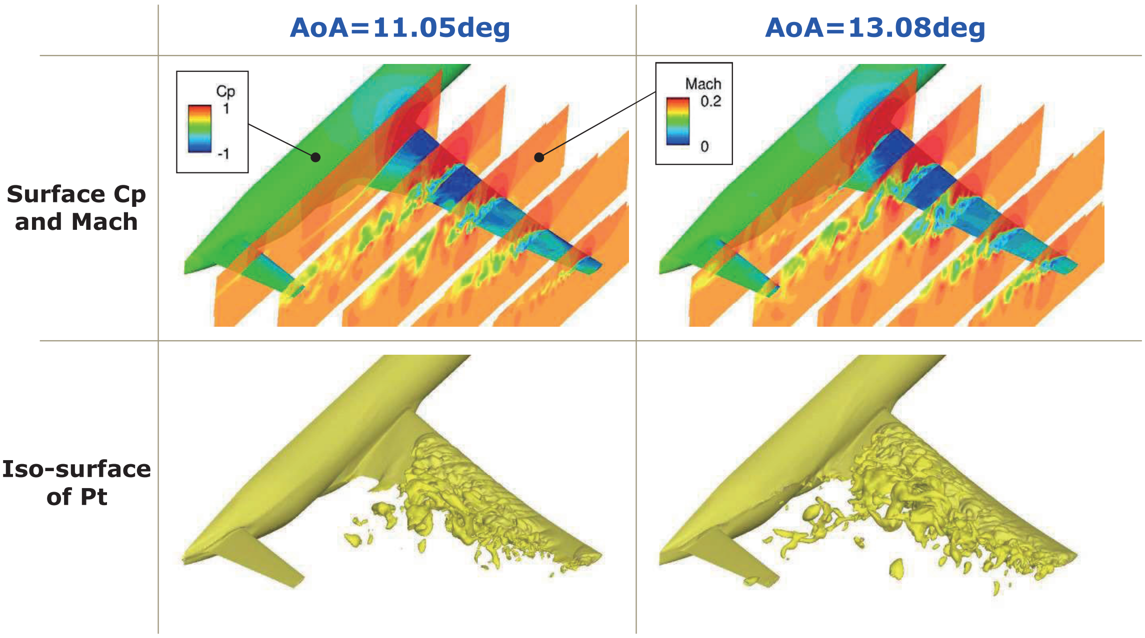


Case1
Cm-CL

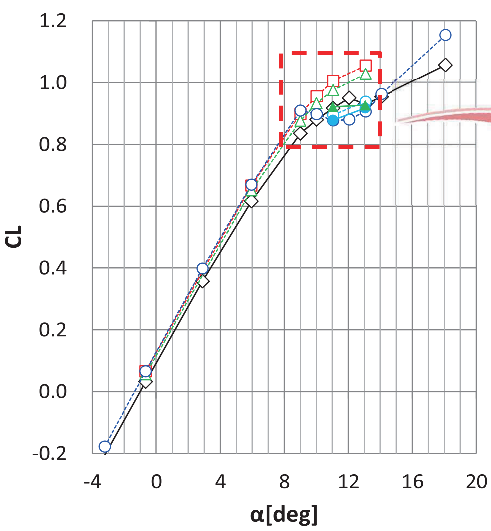


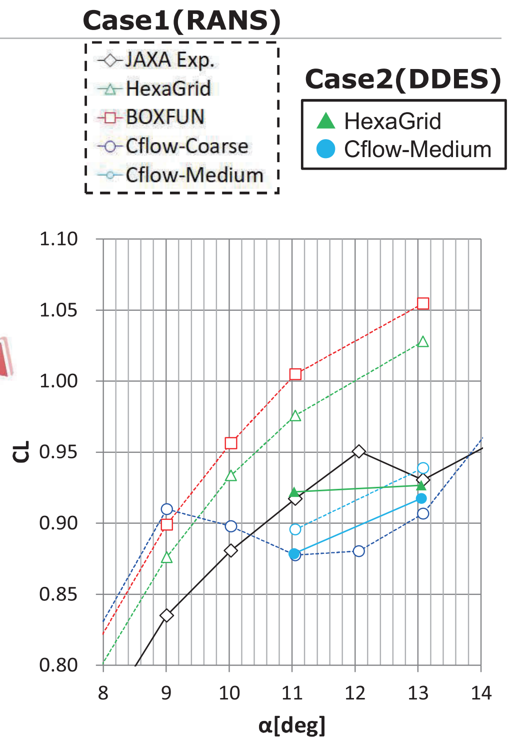
Case2
Flow Visualization (Cflow-Medium)



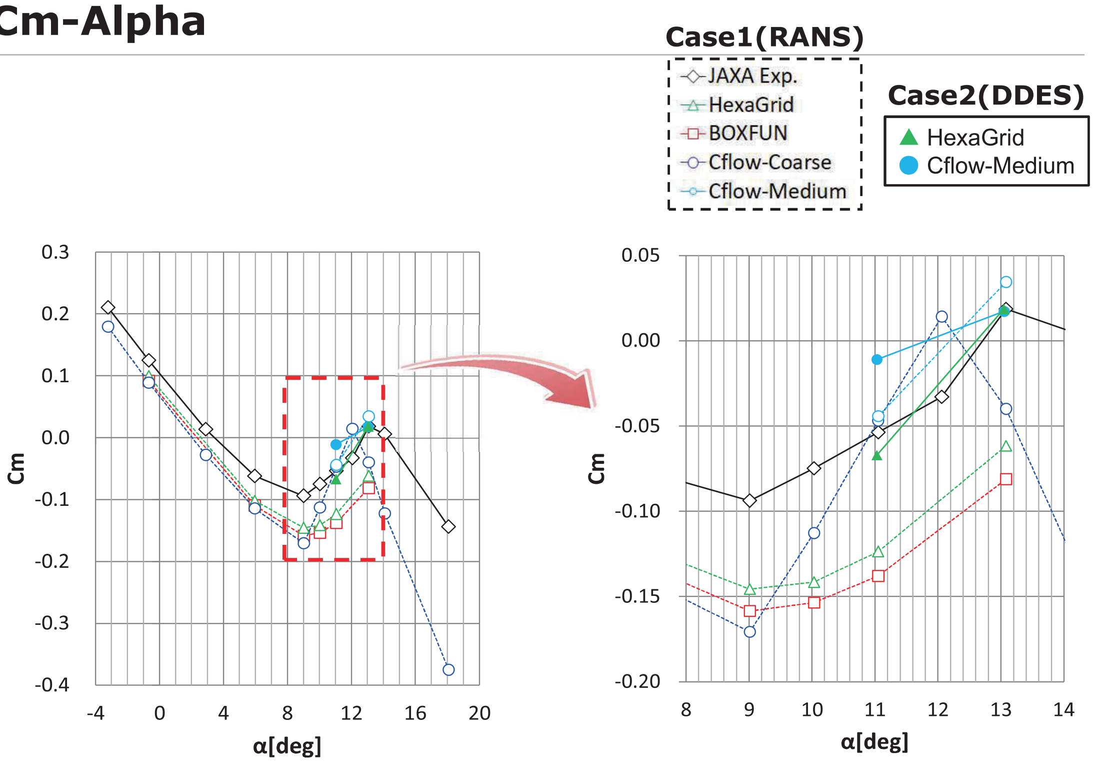


Case1&2
CL-Alpha





Case1&2
Cm-Alpha



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