21KT009601

APC-7 （講演番号:1A16）

CflowによるNASA巡航CRMの低速高迎角剥離流れの予測 ［課題1］

Prediction of Low-speed, High-angle-of-attack Separated Flows for the NASA-CRM Cruise Configuration using Cflow

上野 陽亮、安田 英将、澤木 悠太
Yosuke Ueno, Hidemasa Yasuda, Yuta Sawaki
川崎重工業（株） 航空宇宙システムカンパニー

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Kawasaki Powering your potential

Outline

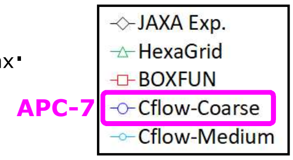
- **Outcome of APC-6**
  - Effect of **grid** (Provided vs Cflow)
- **Focus of APC-7**
  1. Effect of **turbulence model** (SA-noft2 vs SA-neg*)
  2. Effect of **time integration** (Local vs Global time step)
  3. Effect of **initial condition** (Impulsive vs Lower AoA)
- Summary

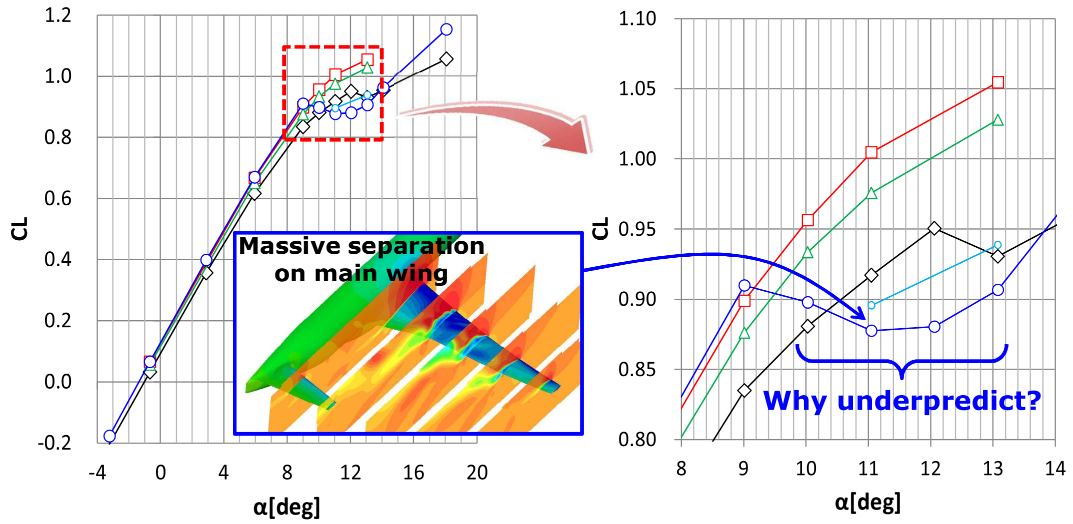
* The reason for using SA-neg in APC-7 is that SA-neg is used in another CFD workshop (AIAA HLPW-4) and has already been verified in our Cflow solver.

Outcome of APC-6

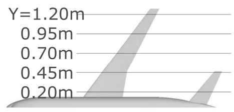
M=0.168
Re=1.06×10⁶

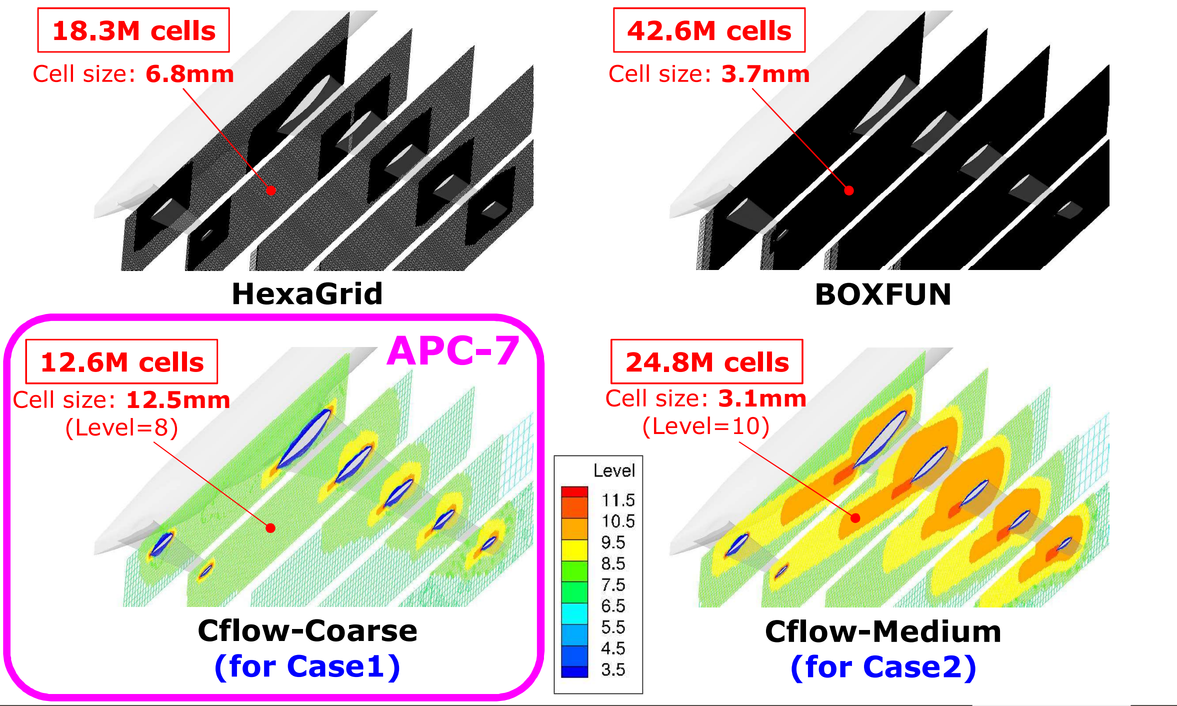
- **Effect of grid**
  - ✓ Provided grids overpredict stall angle and CL_{max}.
  - ✓ Cflow grids underpredict stall angle and CL_{max}.





Grid Comparison





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-neg** (Negative Spalart-Allmaras One-Equation Model) ***SA-noft2@APC-6**
Time Integration	**MFGS implicit method with local/global time stepping**
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).

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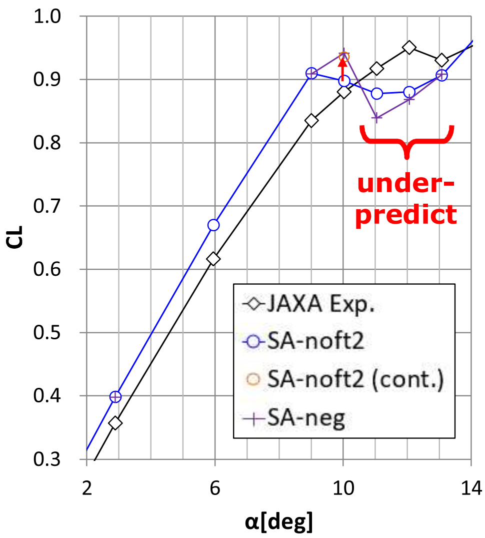
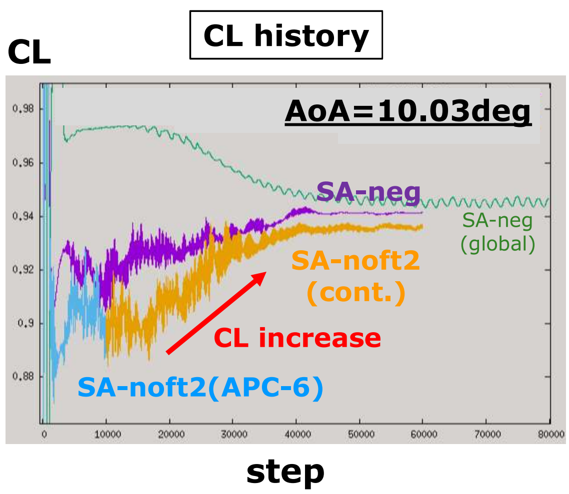
Focus of APC-7 (1) Effect of turbulence model

M=0.168
Re=1.06×10⁶





*APC-6: SA-noft2, only 10,000 steps
*APC-7: SA-neg, more than 50,000 steps

- SA-neg and SA-noft2 bring similar results for this case
- Further investigation on QCR and RC effects is needed

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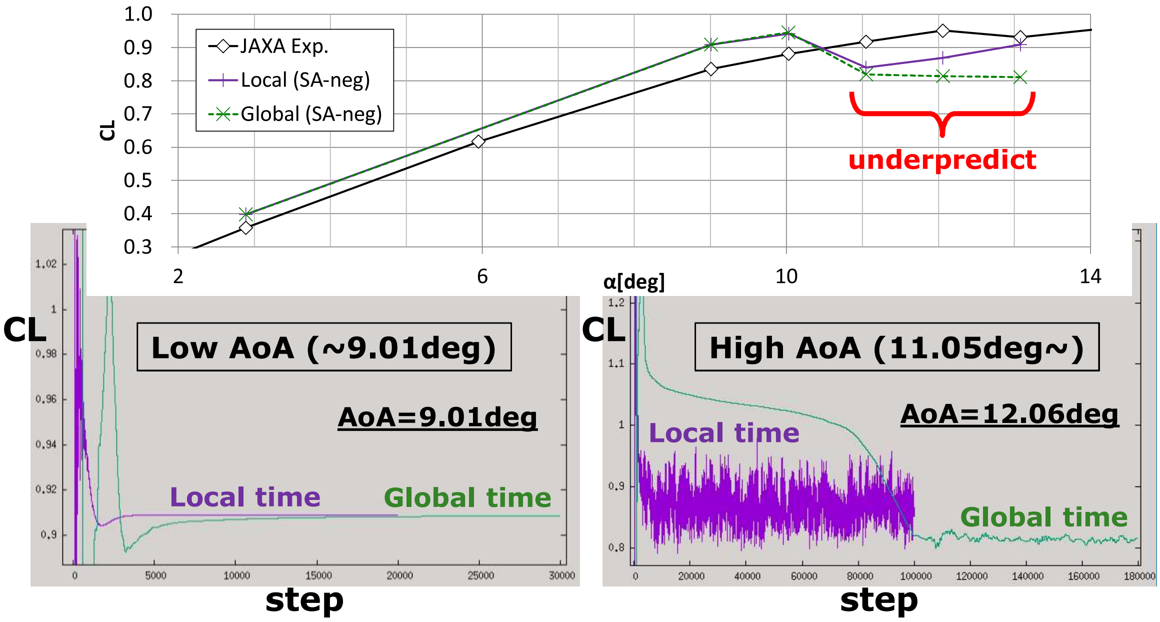
Focus of APC-7 (2)
Effect of time integration

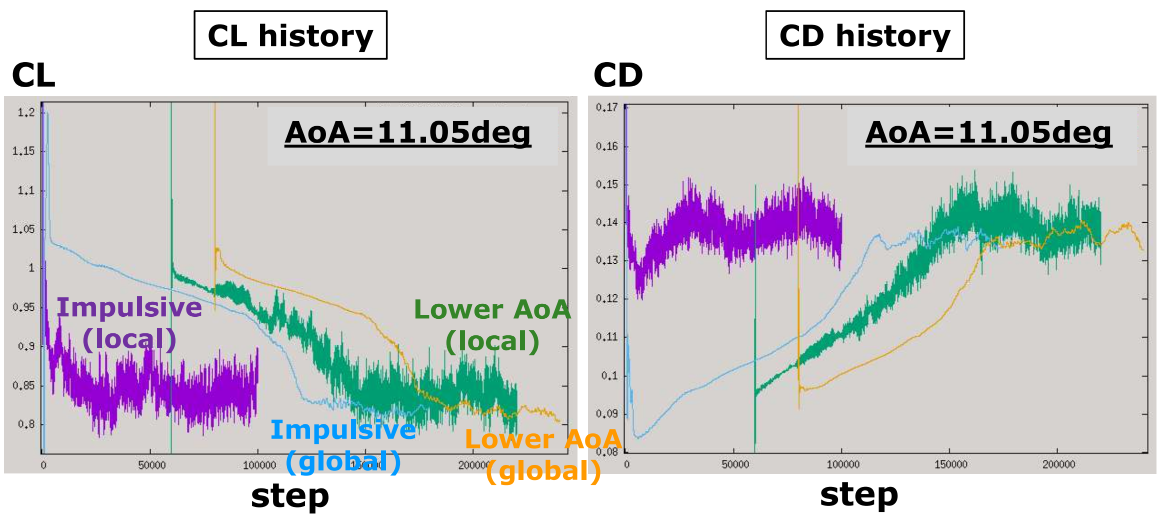
M=0.168
Re=1.06×10⁶



- Converge to same result (steady flow)
- Global needs more time steps
- Not converge (unsteady flow)
- Global needs more time steps

Focus of APC-7 (3)
Effect of initial condition

M=0.168
Re=1.06×10⁶



- Restart from the lower-AoA result (warm start) brings the same result as impulsive (cold start) both in local and global time steps

Summary

- For steady-state RANS computations with Cflow-Coarse grid used in APC-6, the effects of several computational parameters were investigated to improve predictive capability in low-speed high-angle-of-attack aerodynamics.

- **Lessons Learned: not improved…**
  - ✓ **Effect of turbulence model (SA-noft2 vs SA-neg):**
    little effect, need further investigation on QCR and RC effects
  - ✓ **Effect of time integration (Local vs Global time step):**
    similar results, global needs more time steps
  - ✓ **Effect of initial condition (Impulsive vs Lower AoA):**
    similar results (investigated only for AoA=11deg)

- Future work
  - ✓ Establish **"best practices"** (trade-off between accuracy and cost)
  - ✓ More complicated high-lift configuration (**CRM-HL**, see **2C09**)

Kawasaki, working as one for the good of the planet

"Global Kawasaki"

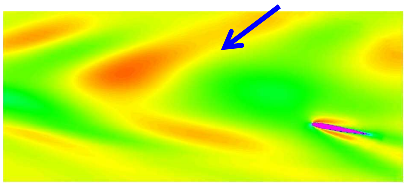
Kawasaki
Powering your potential

【補足】提出データについて

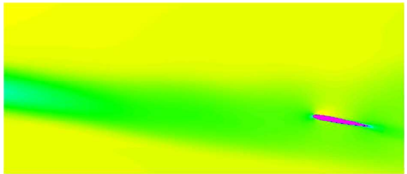
- ローカルタイムステップの定常解析結果は、高迎角(≧11deg)で解が収束せずに振動しているが、APC-6同様に今回事務局に提出したデータ(カデータ、可視化図)は最終ステップの瞬時値である。
- 一方、本資料に示したカデータ(CL, CD, Cm)は、圧力分と摩擦分を足し合わせたものであり、Cflowの解析ログから平均化して求めたものである。
- よって、APC事務局作成のまとめ資料と本資料のカデータは若干異なる。

提出データの一例

収束していない結果(p.8のCL履歴参照)の
最終ステップの瞬時値であるため斑な分布



Local time step

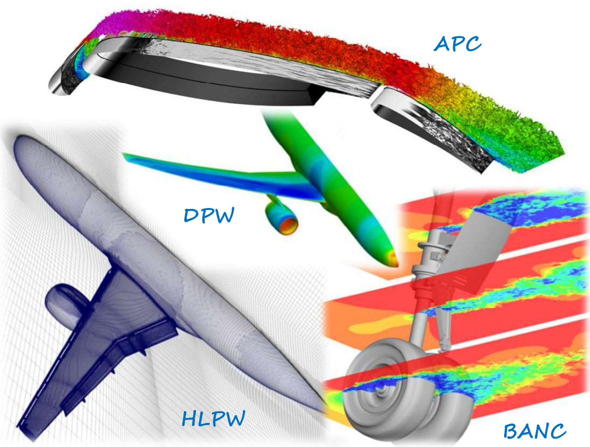


Global time step

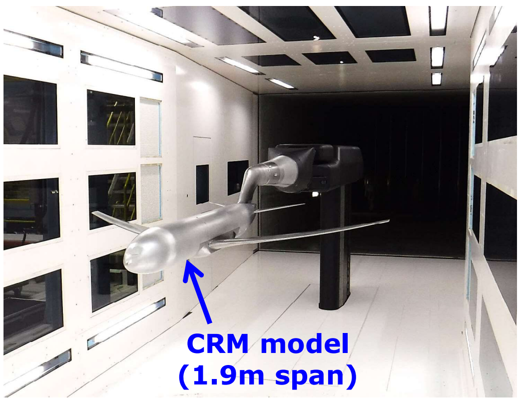
断面流速分布(Section YB, AoA=11.05deg)

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)

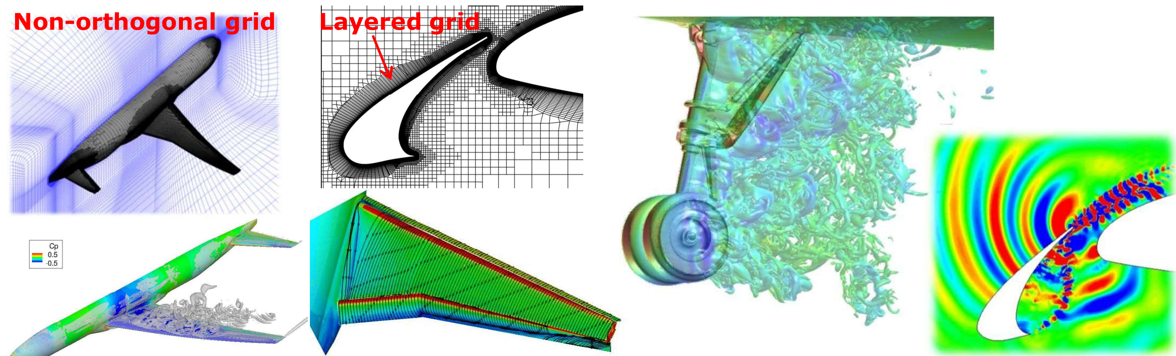
Cflow (KHI in-house CFD tool)

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

Cflow = Grid Generator + Flow Solver

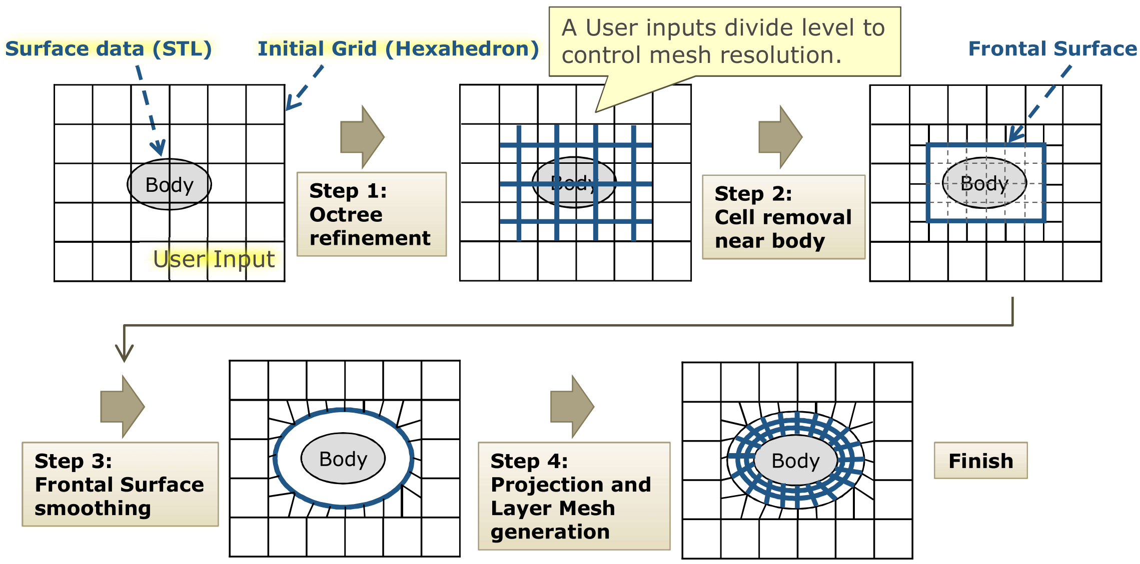
highly complicated | large-scale | unsteady

- ✓ Cflow has been validated in various workshops.



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

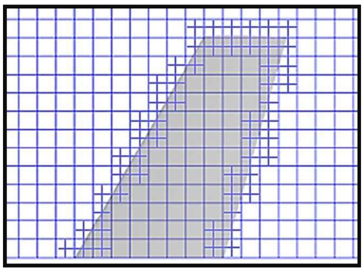
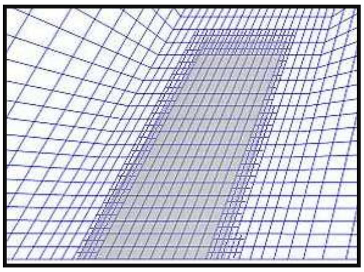
Grid Generation Procedure in *Cflow*



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

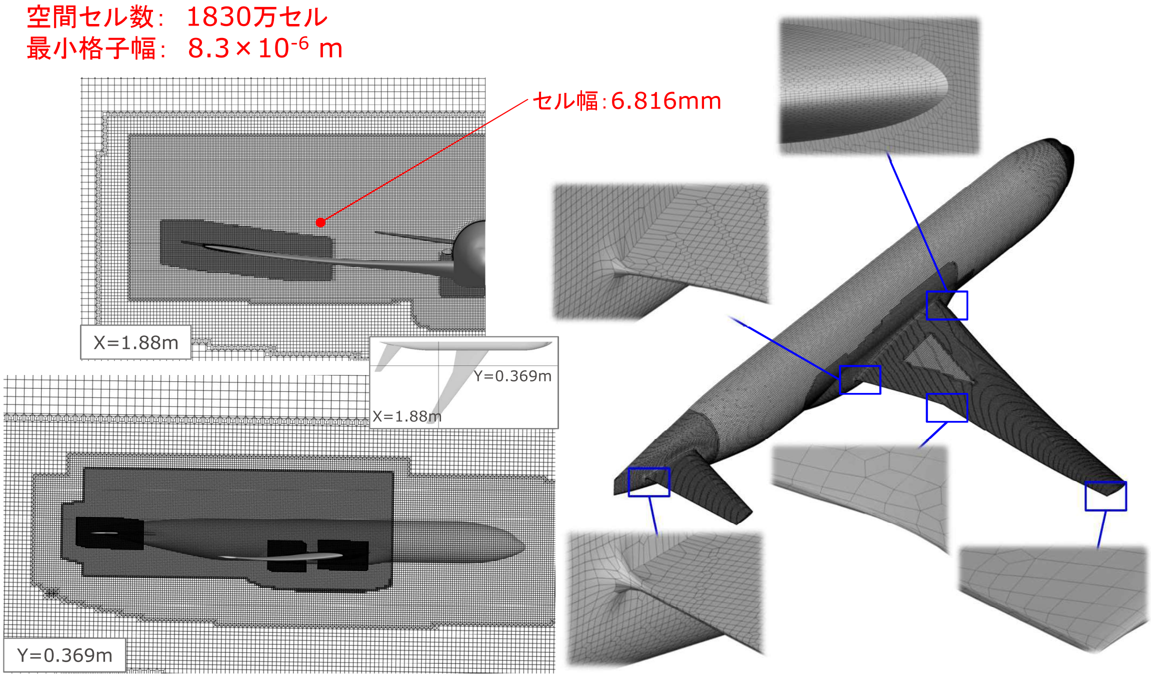
Initial Grid of *Cflow*

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**

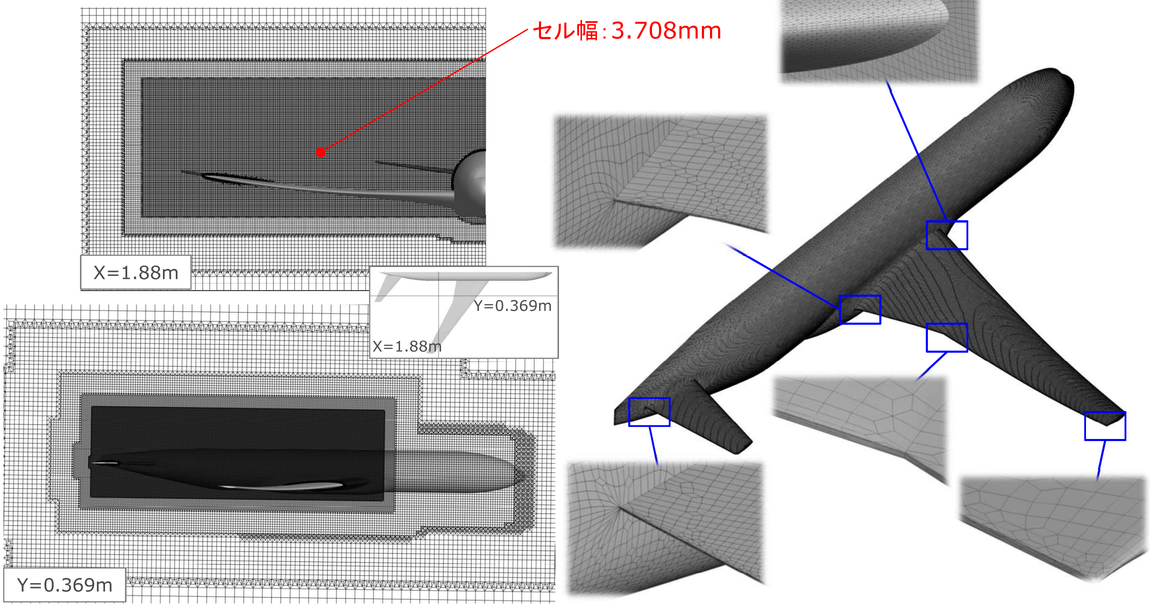
Grid (HexaGrid)

空間セル数：1830万セル
最小格子幅：8.3×10^{-6} m



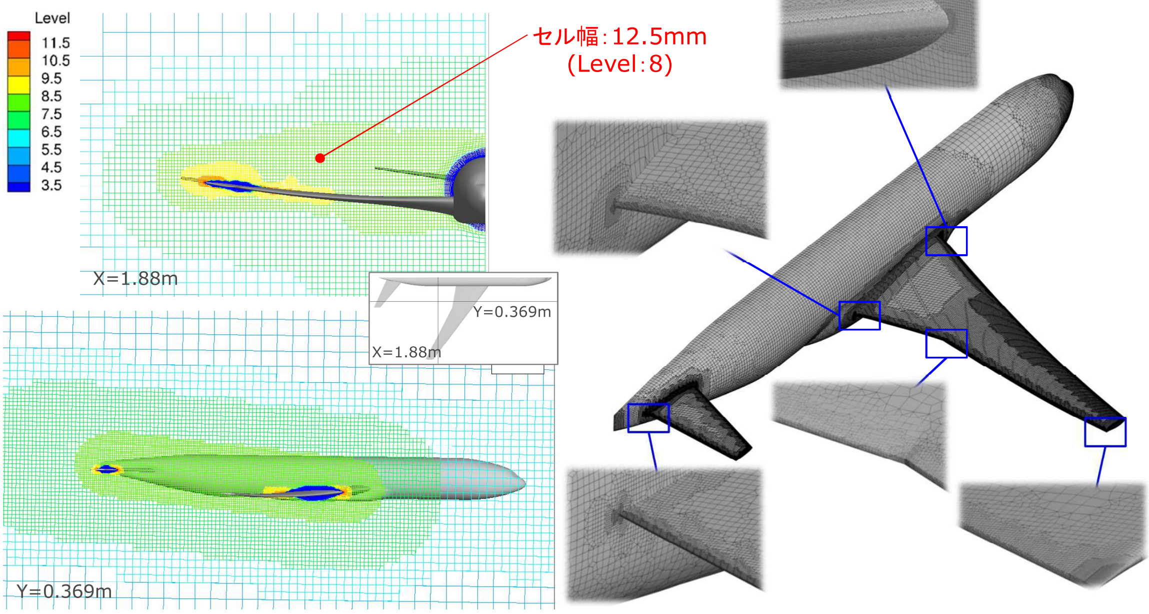
Grid (BOXFUN)

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