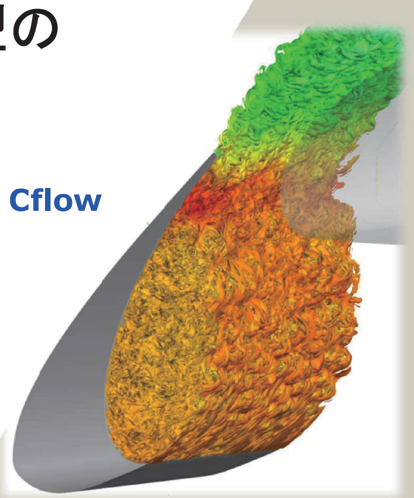
APC-V

Cflowによる三翼素高揚力翼型の空力騒音検証解析　[課題3]

Validation of aerodynamic noise from 3-element high-lift configuration using Cflow



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2019年7月1日（月）
早稲田大学

Kawasaki
Powering your potential

Outline

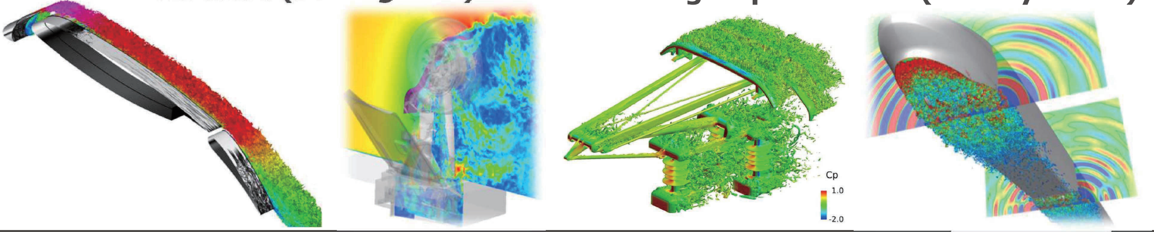
- Motivation
- CFD tool "***Cflow***"
- Numerical Methodologies
- **Outcome of APC-IV**
  - AoA Sensitivity
  - Grid Sensitivity
- **Effect of turbulence model**
  - SA-DDES
  - Laminar (Implicit LES) **[new computation for APC-V]**
- Summary

Motivation

- **CFD has become instrumental tool in the design**
- KHI in-house CFD tool being applied to the development of low-noise and environmentally friendly products
- APC / AIAA-BANC for **validation of unsteady computations**

Aircraft (Boeing 787)

High-speed Train (E5 Hayabusa)



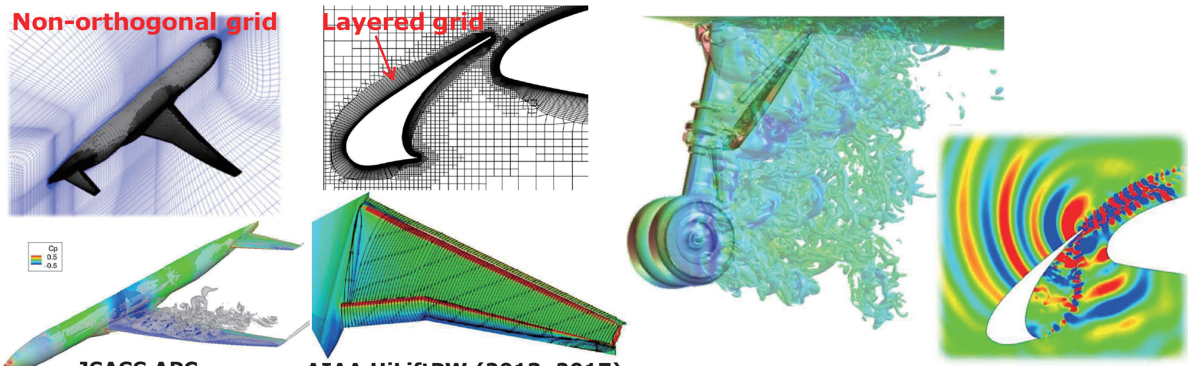
Cflow (KHI in-house CFD tool)

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

Cflow = Grid Generator + Flow Solver

highly complicated | large-scale | unsteady

✓ Cflow has been validated in various workshops.

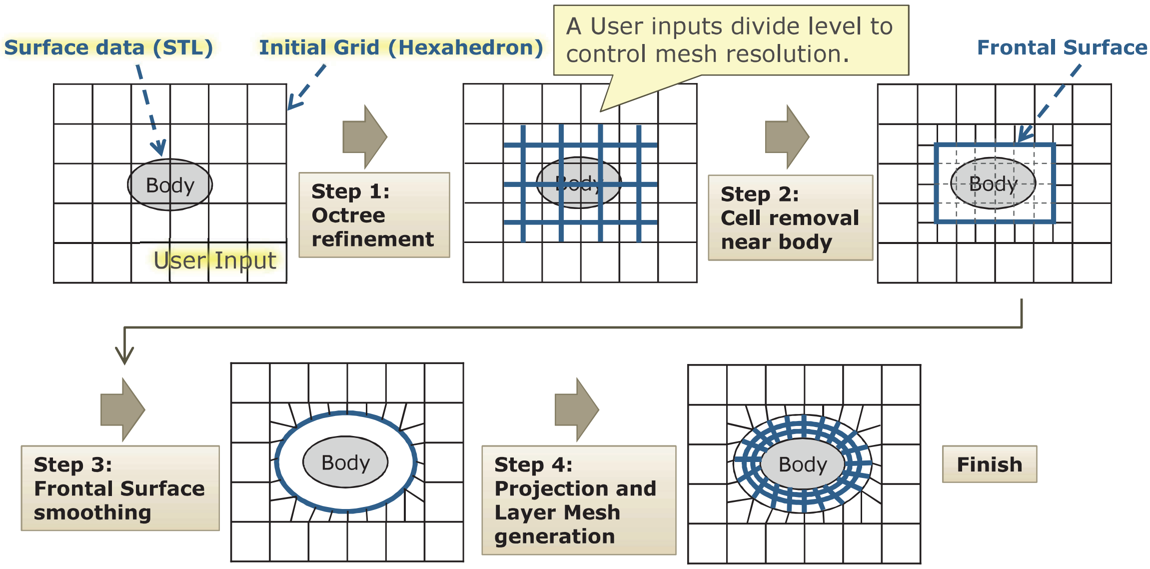


JSASS APC (2015-2017)

AIAA HiLiftPW (2013, 2017)
Drag Prediction Workshop (2016)

AIAA BANC Workshop (2010-2018)

Grid Generation Procedure in *Cflow*

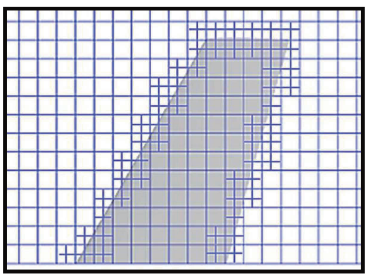


Cflow automatically generates body-fitted layered grids on no-slip walls to resolve boundary layers and hexahedral grids in the other regions.

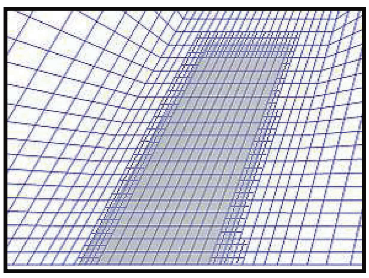
Initial Grid of *Cflow*

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

Cartesian Grid or ***Non-orthogonal Grid***



or



Cartesian Grid:
- grid generation robustness
- unsteady simulation (resolving vortices)
- acoustic wave propagation

→ **Noise prediction from complicated geometry**

Non-orthogonal Grid:
- reduction of total cells (high aspect ratio)
- sweptback cells
- oblique shock wave

→ **Steady simulations**

Numerical Method for Unsteady Simulation

CFD tool	Cflow (KHI in-house)
Governing Equations	Three-dimensional compressible Navier-Stokes equations
Spatial Discretization	Cell-centered finite volume method with pseudo 3rd-order accurate reconstruction based on MUSCL
Inviscid Flux	SLAU (Simple Low-dissipation AUSM scheme)
Viscous Flux	2nd-order accurate central difference
Turbulence Modeling	DDES based on SA-noft2 (Spalart-Allmaras model without ft_2 term)
Time Integration	2nd-order MFGS implicit method
Parallelization	Domain decomposition method with MPI

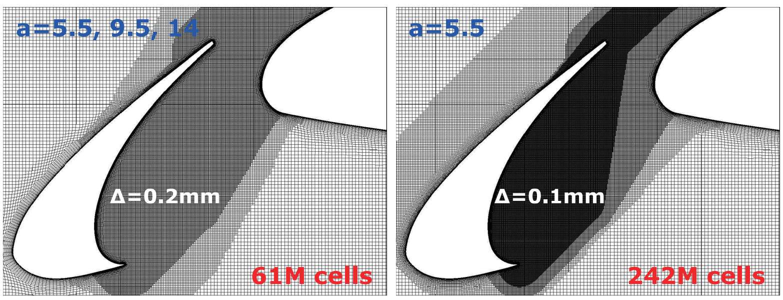
References for ***Cflow*** details
1. Ueno, Y. and Ochi, A., ***"Airframe Noise Prediction Using Navier-Stokes Code with Cartesian and Boundary-fitted Layer Meshes,"*** 25th AIAA/CEAS Aeroacoustics Conference, (AIAA 2019-2553).
2. Atsushi Hashimoto, Takashi Aoyama, Yuichi Matsuo, Makoto Ueno, Kazuyuki 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).

Mesh and Computational Case (APC-IV)

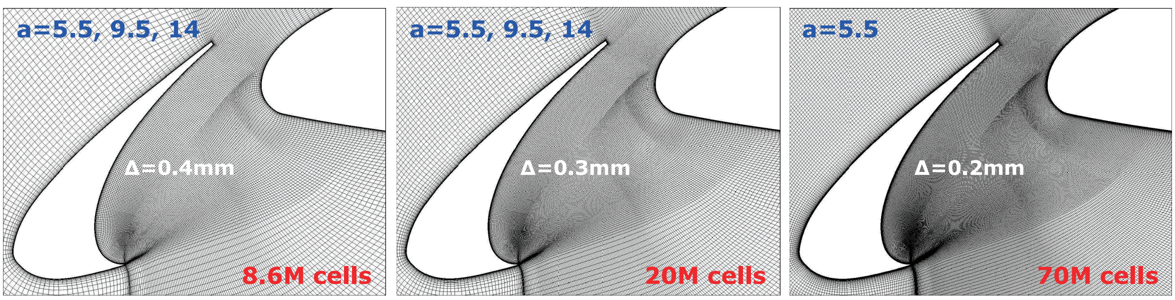
- 5 meshes (2-inch span)
- 11 cases for APC-IV

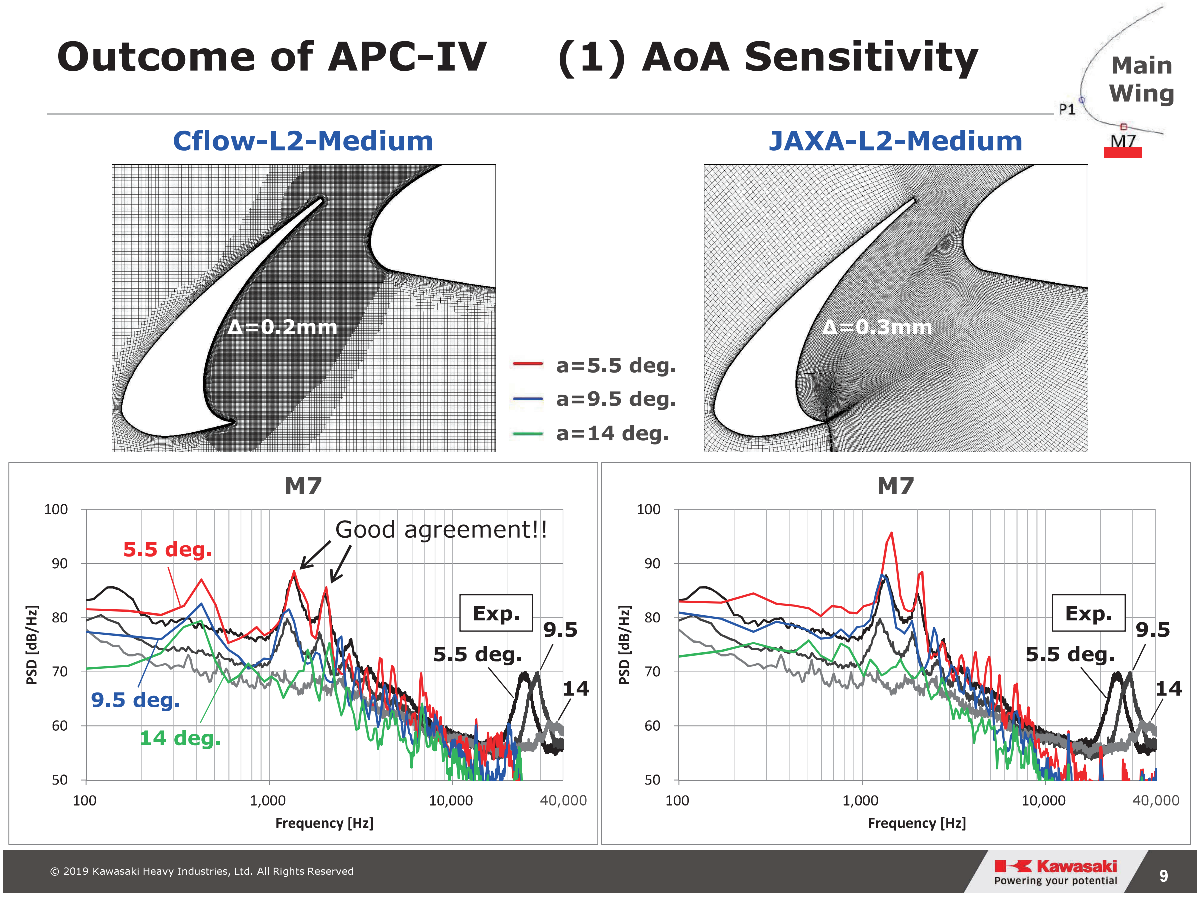
dt=0.588×10^{-6} sec
Time record=10.4 c/U$_\infty$

Cflow-L2-Medium　Cflow-L3-Fine



JAXA-L1-Coarse　JAXA-L2-Medium　JAXA-L3-Fine




Outcome of APC-IV (1) AoA Sensitivity
Main Wing
P1
M7
Cflow-L2-Medium
JAXA-L2-Medium
Δ=0.2mm
Δ=0.3mm
a=5.5 deg.
a=9.5 deg.
a=14 deg.
M7
Good agreement!!
5.5 deg.
9.5 deg.
14 deg.
Exp.
9.5
5.5 deg.
14
PSD [dB/Hz]
Frequency [Hz]
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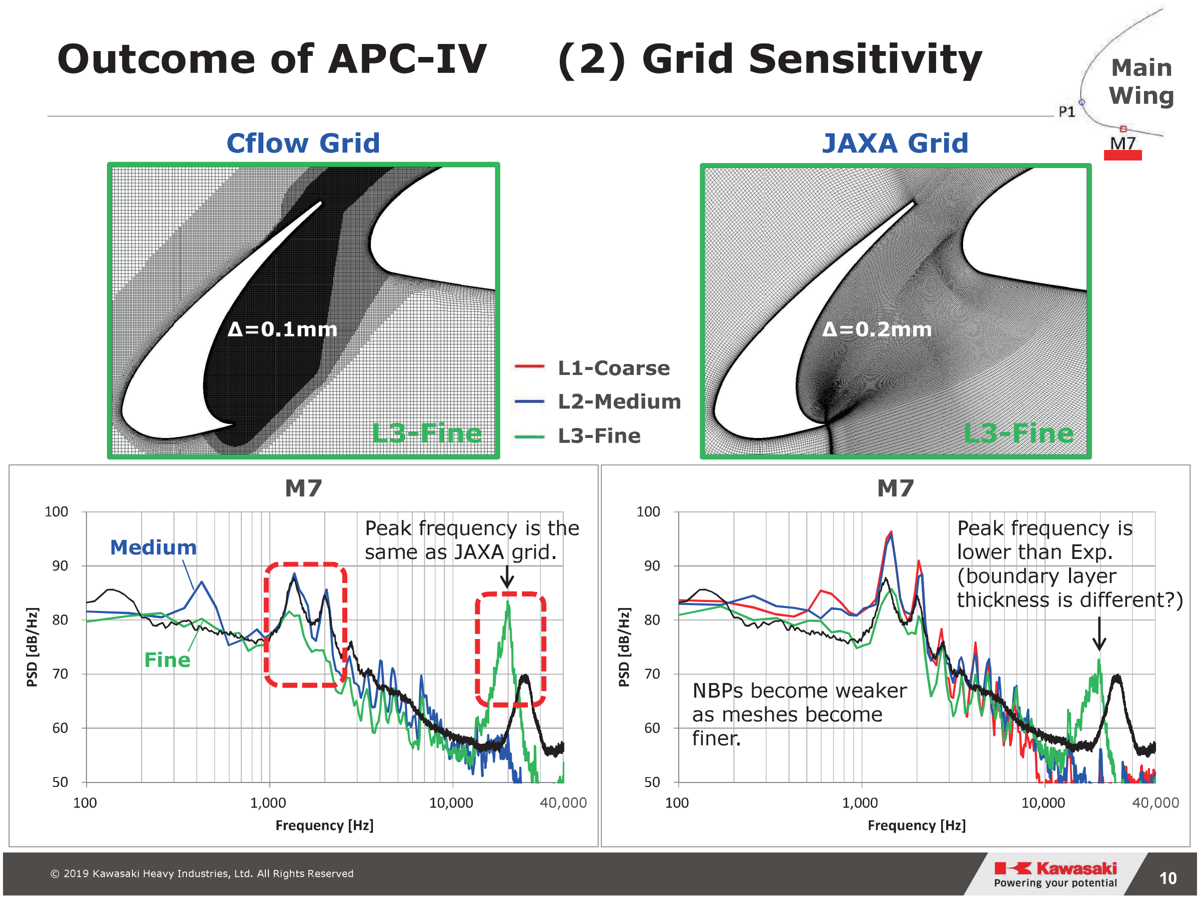
Outcome of APC-IV (2) Grid Sensitivity
Main Wing
P1
M7
Cflow Grid
JAXA Grid
Δ=0.1mm
Δ=0.2mm
L3-Fine
L1-Coarse
L2-Medium
L3-Fine
M7
Medium
Fine
Peak frequency is the same as JAXA grid.
Peak frequency is lower than Exp. (boundary layer thickness is different?)
NBPs become weaker as meshes become finer.
PSD [dB/Hz]
Frequency [Hz]
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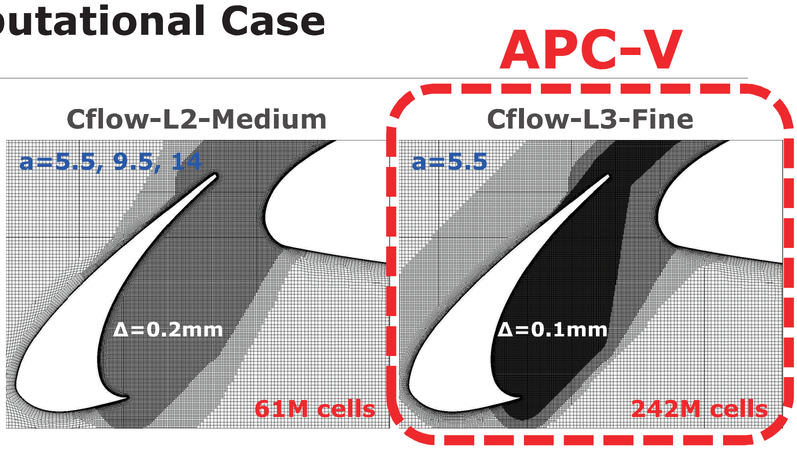
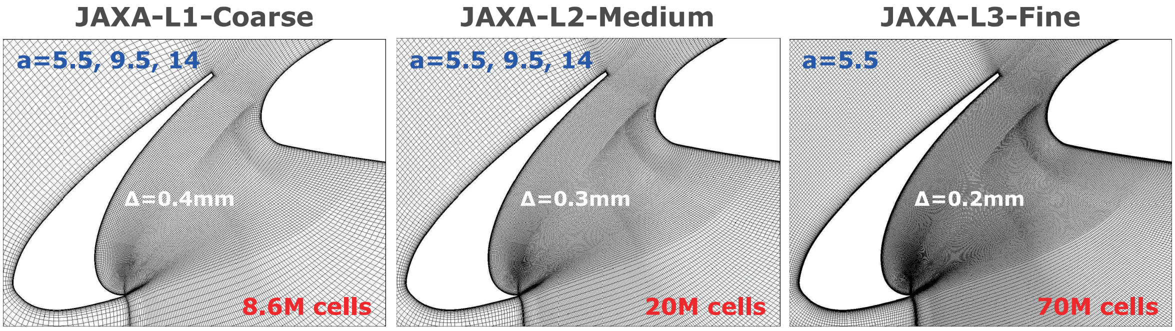
Mesh and Computational Case

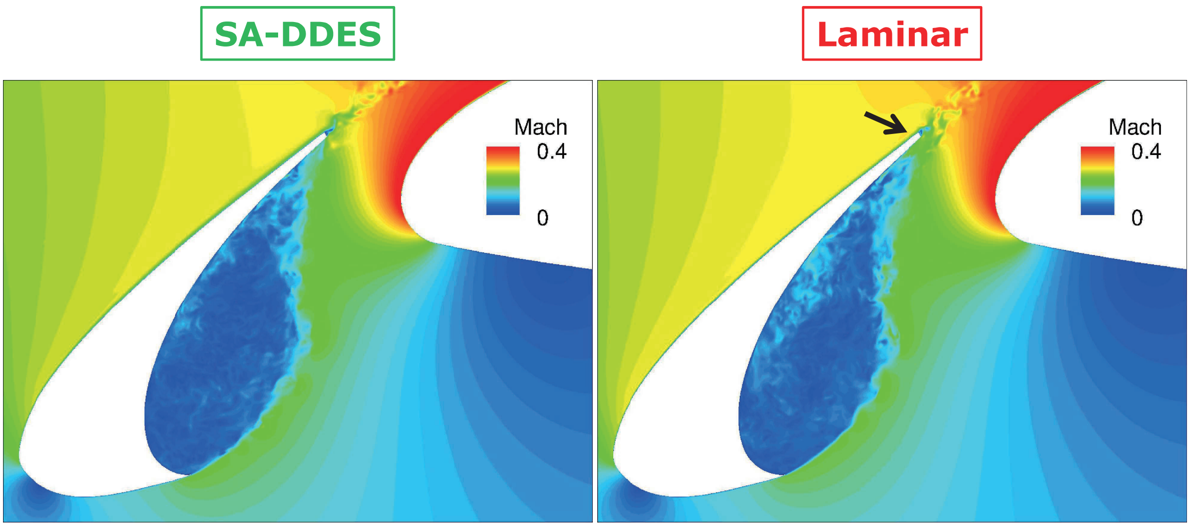
- 5 meshes (2-inch span)
- 11 cases for APC-IV
- 2 cases for APC-V at a=5.5 deg. with Cflow-L3-Fine grid
  - ✓ SA-DDES
  - ✓ Laminar (ILES)

dt=0.588×10^{-6} sec
Time record=10.4 c/U_∞





Instantaneous Velocity Distribution



- ✓ Thinner boundary layer thickness
- ✓ Higher velocity

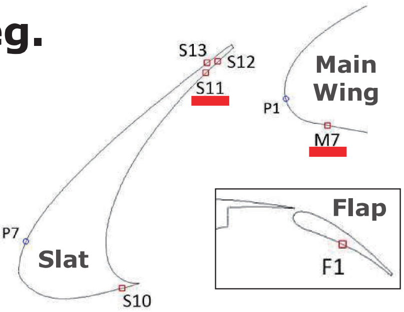
【課題3-1】

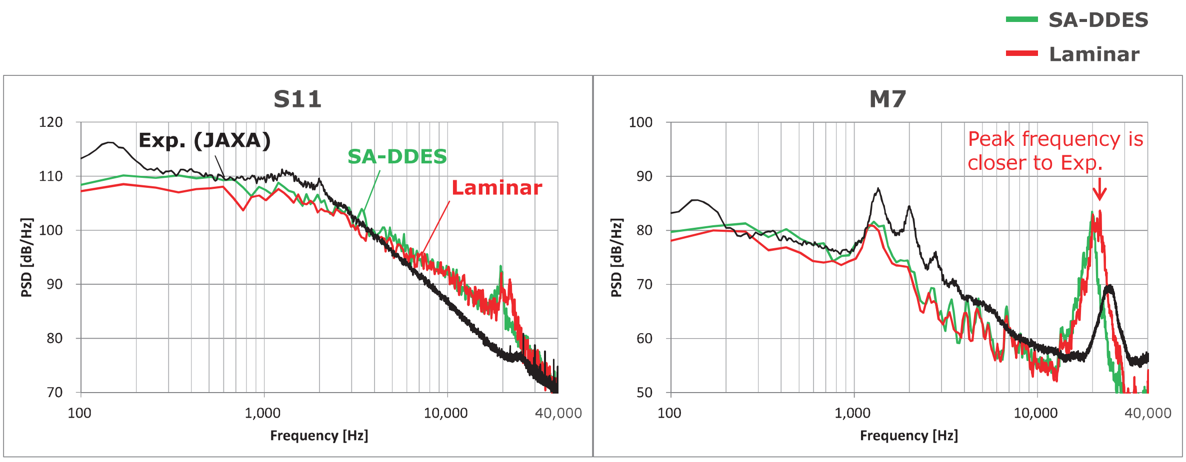
音響予測（近傍場）

Surface Pressure Fluctuations

SA-DDES vs Laminar at a=5.5 deg. (Cflow-L3-Fine grid)

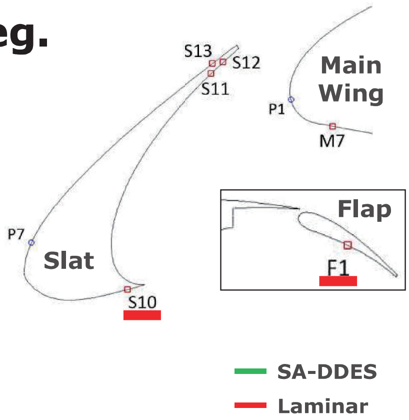
- The high-frequency peak associated with the vortices from the slat trailing edge
  - ✓ SA-DDES: **20kHz**
  - ✓ Laminar: **22kHz (closer to Exp.)**
  - ✓ Exp.: **24kHz**
- Underestimated NBPs in both computations

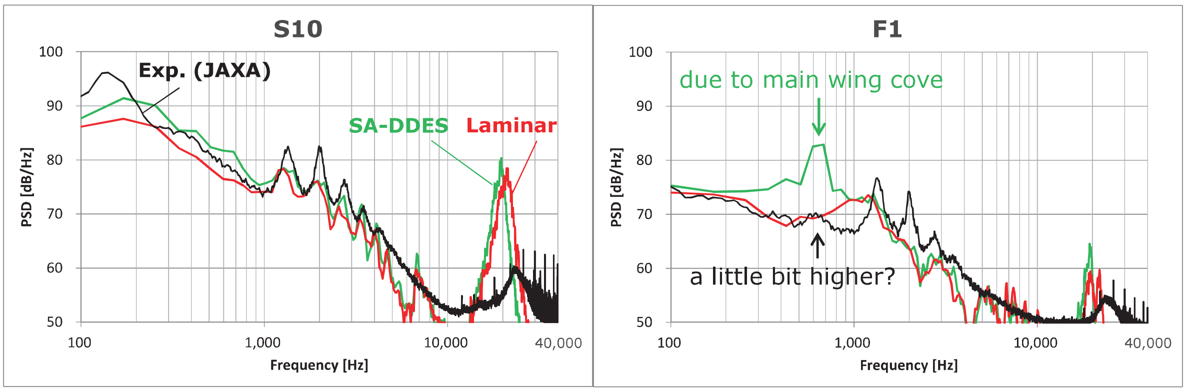




SA-DDES vs Laminar at a=5.5 deg. (Cflow-L3-Fine grid)

- The high-frequency peak associated with the vortices from the slat trailing edge
  - ✓ SA-DDES: **20kHz**
  - ✓ Laminar: **22kHz (closer to Exp.)**
  - ✓ Exp.: **24kHz**
- Underestimated NBPs in both computations
- The low-frequency peak (600-700 Hz) due to the main wing cove is observed only in SA-DDES





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【課題3-2】

音響予測（遠方場）

Far-field Noise Predictions

using Solid FWH with integrating all 3 wing elements of 1-inch span

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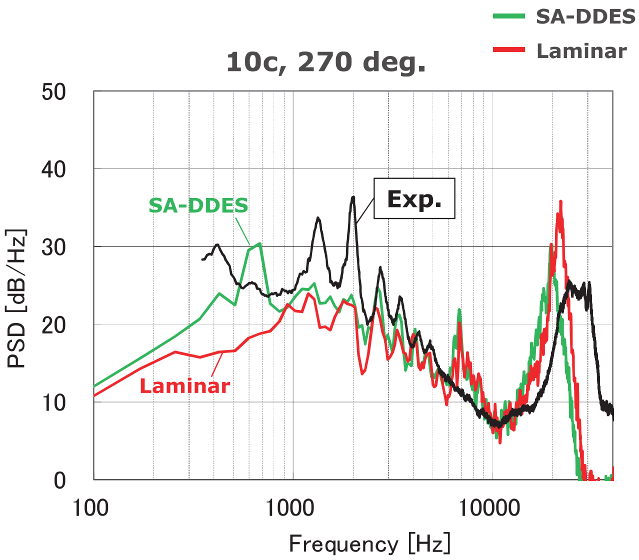
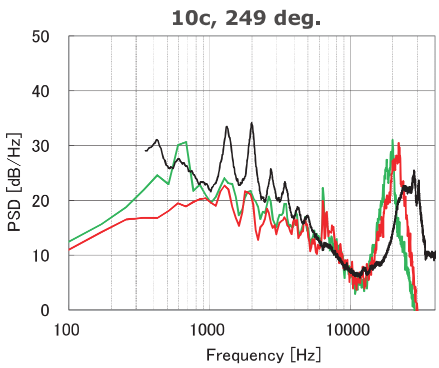
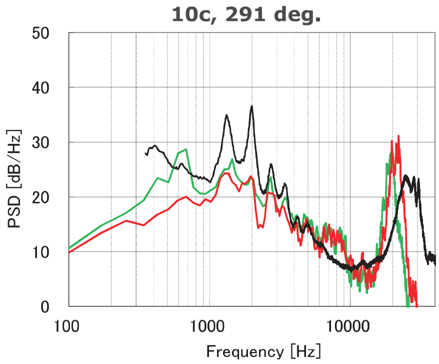
SA-DDES vs Laminar at a=5.5 deg. (Cflow-L3-Fine grid)

- Similar results to near-field are obtained
  - ✓ High-frequency peak
  - ✓ NBPs
  - ✓ Low-frequency peak



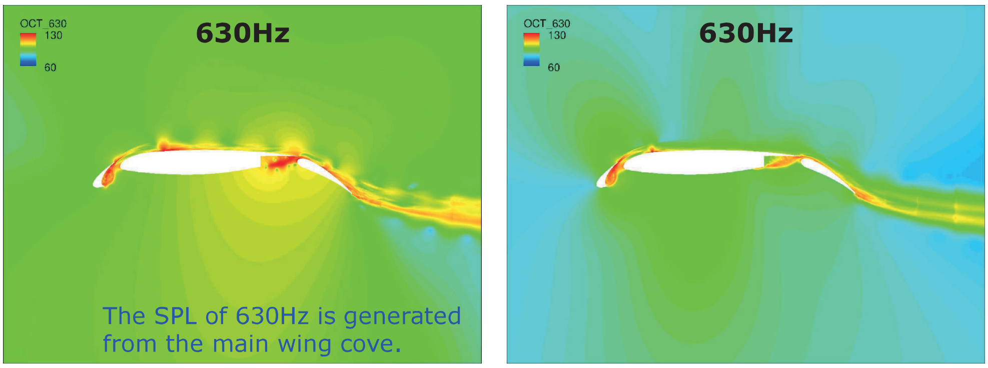




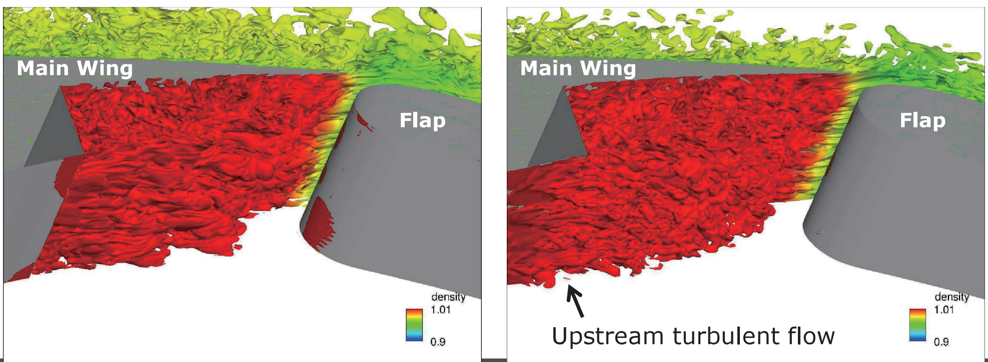
dB-map and Main Wing Cove Flow

SA-DDES | Laminar

dB-map



Flow field



Summary: Lessons Learned

- **Laminar (Implicit LES) computation** brought
  - ✓ thinner boundary layer thickness
  - ✓ higher-frequency peak noise from the slat trailing edge (closer to Exp.)
  - ✓ underestimated NBPs (same as SA-DDES)
  - ✓ absence of low-frequency peak noise from the main wing cove

- Slat noise characteristics are greatly dependent on angle of attack (or lift), so **it is important to simulate flap flow field precisely (separation?) for accurate noise prediction.**

- Different lift would bring
  - ✓ different reattachment point of slat cusp shear layer
  - ✓ different NBP levels and frequencies
  - ✓ different peak level and frequency from the slat trailing edge

Kawasaki, working as one for the good of the planet

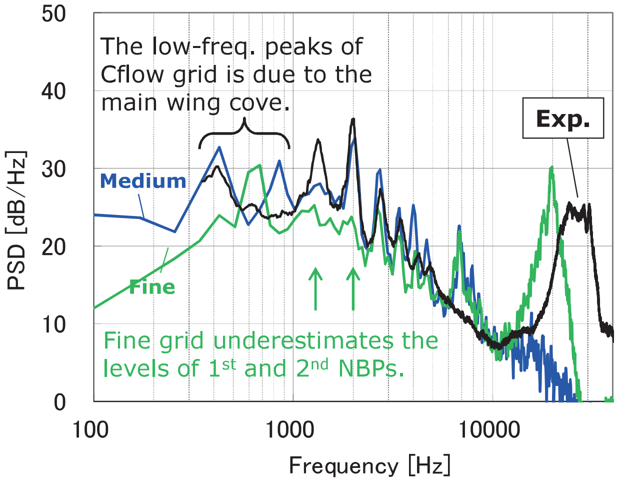
"Global Kawasaki"

Grid Sensitivity at a=5.5 deg. (Cflow L2 and L3 grids)

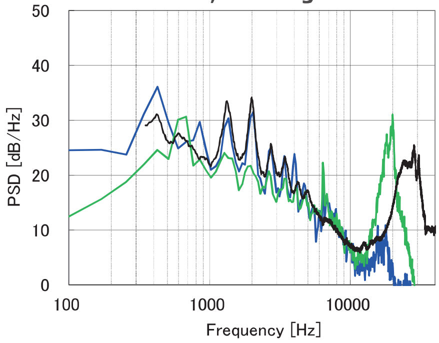
- 基本的に近傍場と同じ傾向を示している。
- JAXA格子での迎角依存性も、同様の傾向。(図示なし)
- Cflow格子の1kHz以下のピークは主翼コーブから発生。(JAXA格子では発生しない)

— Cflow-L2-Medium
— Cflow-L3-Fine

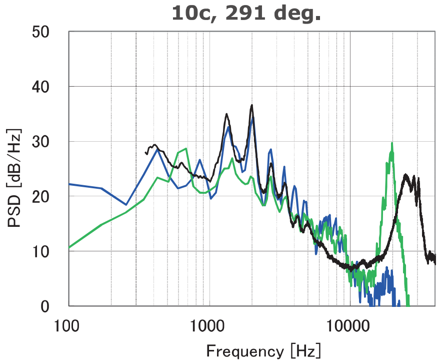
10c, 270 deg.



10c, 249 deg.



10c, 291 deg.



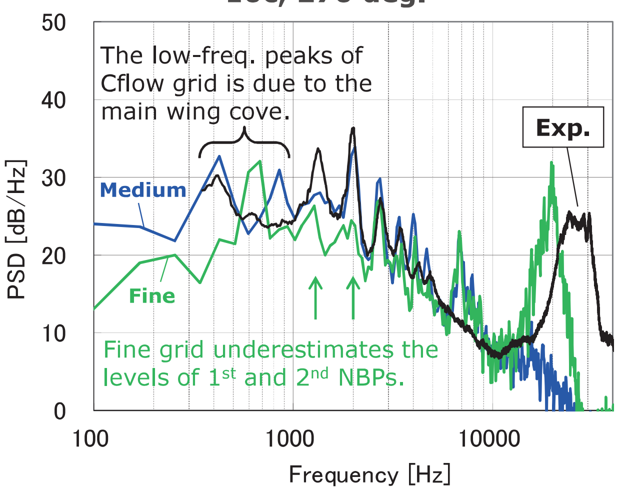
Grid Sensitivity at a=5.5 deg. (Cflow L2 and L3 grids)

※解析時間短い(APC-IV発表時)

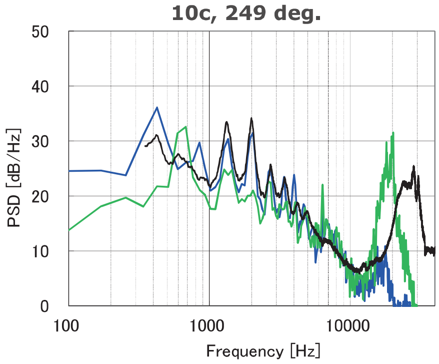
- 基本的に近傍場と同じ傾向を示している。
- JAXA格子での迎角依存性も、同様の傾向。(図示なし)
- Cflow格子の1kHz以下のピークは主翼コーブから発生。(JAXA格子では発生しない)

— Cflow-L2-Medium
— Cflow-L3-Fine

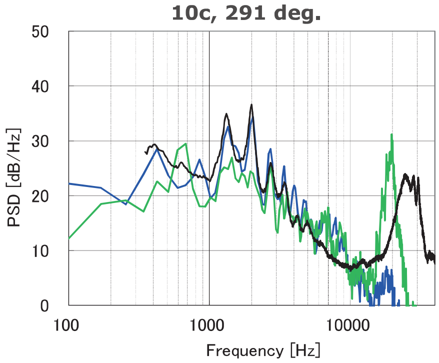
10c, 270 deg.



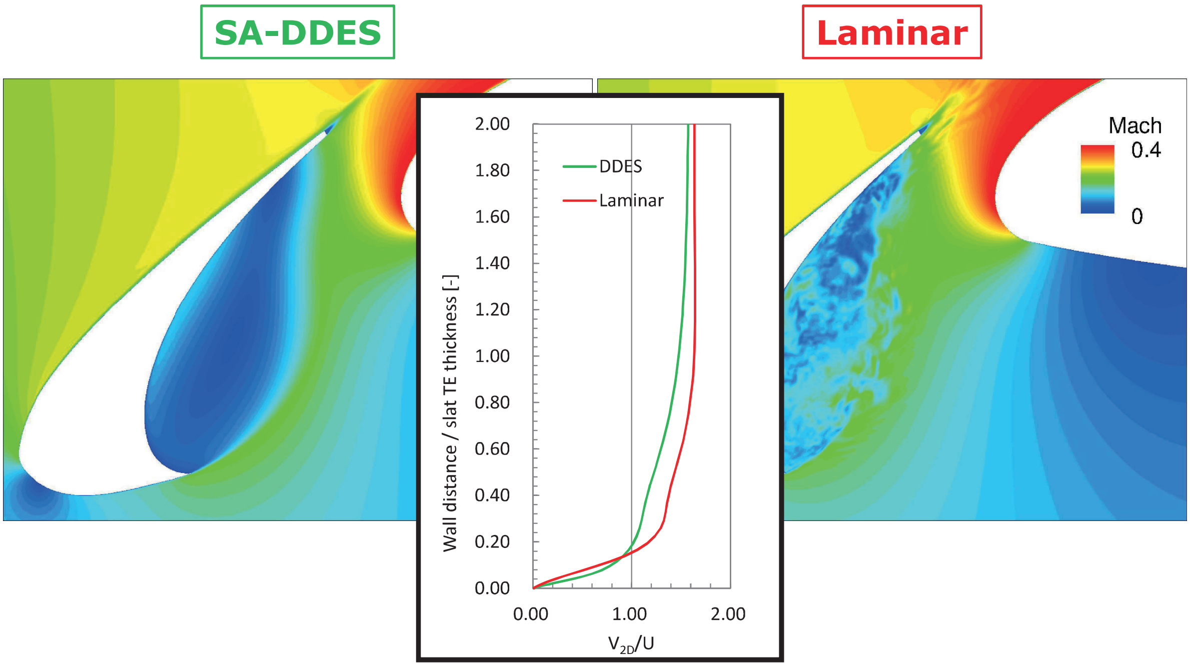
10c, 249 deg.



10c, 291 deg.

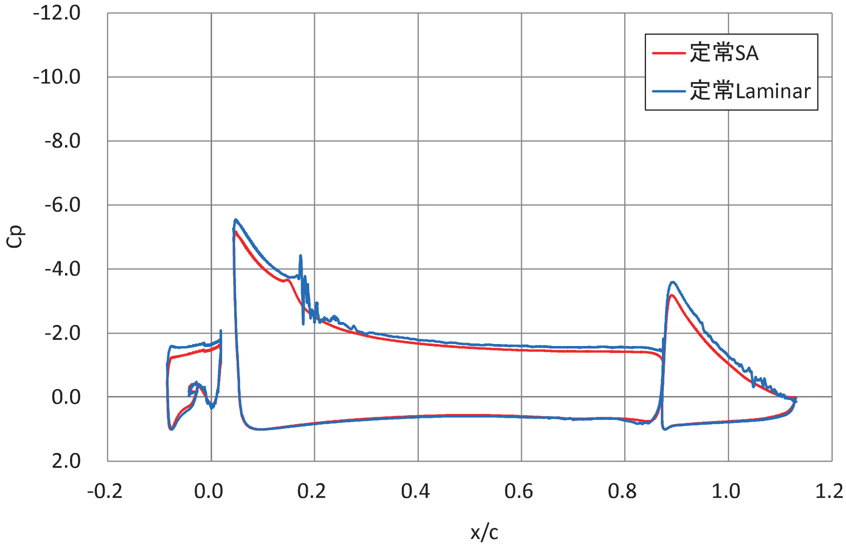


Velocity Distribution (Steady Computation)



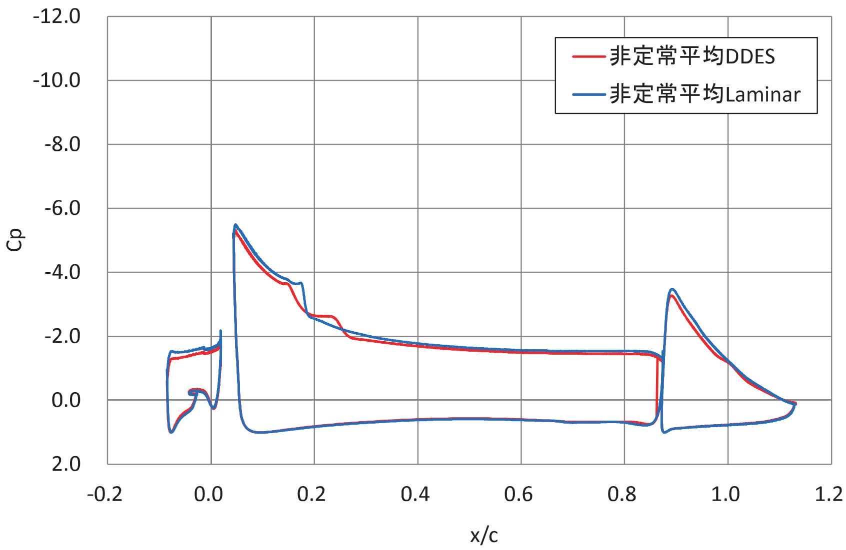
CD, CL and Cp (Steady Computation)

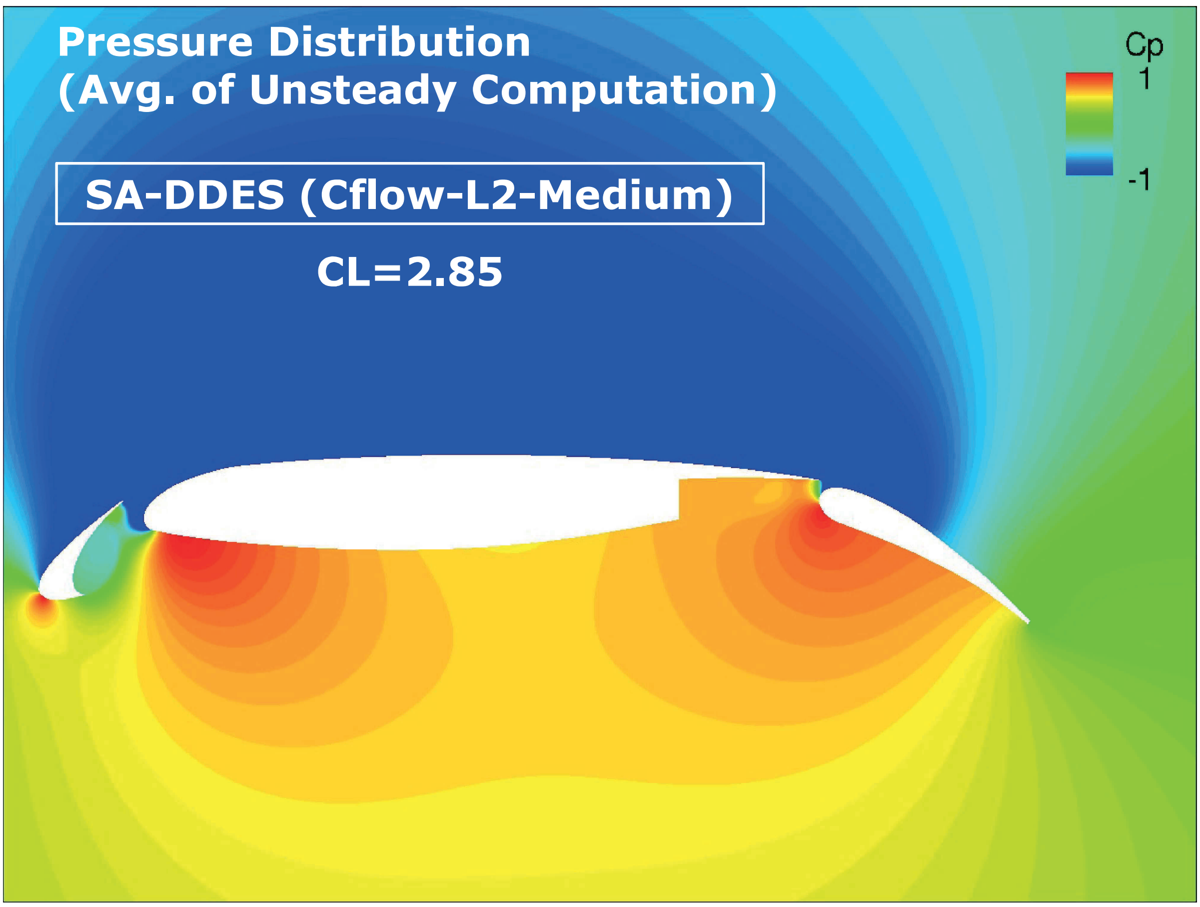
	CD	CL
SA	0.04295	2.89
Laminar	0.02684	3.14

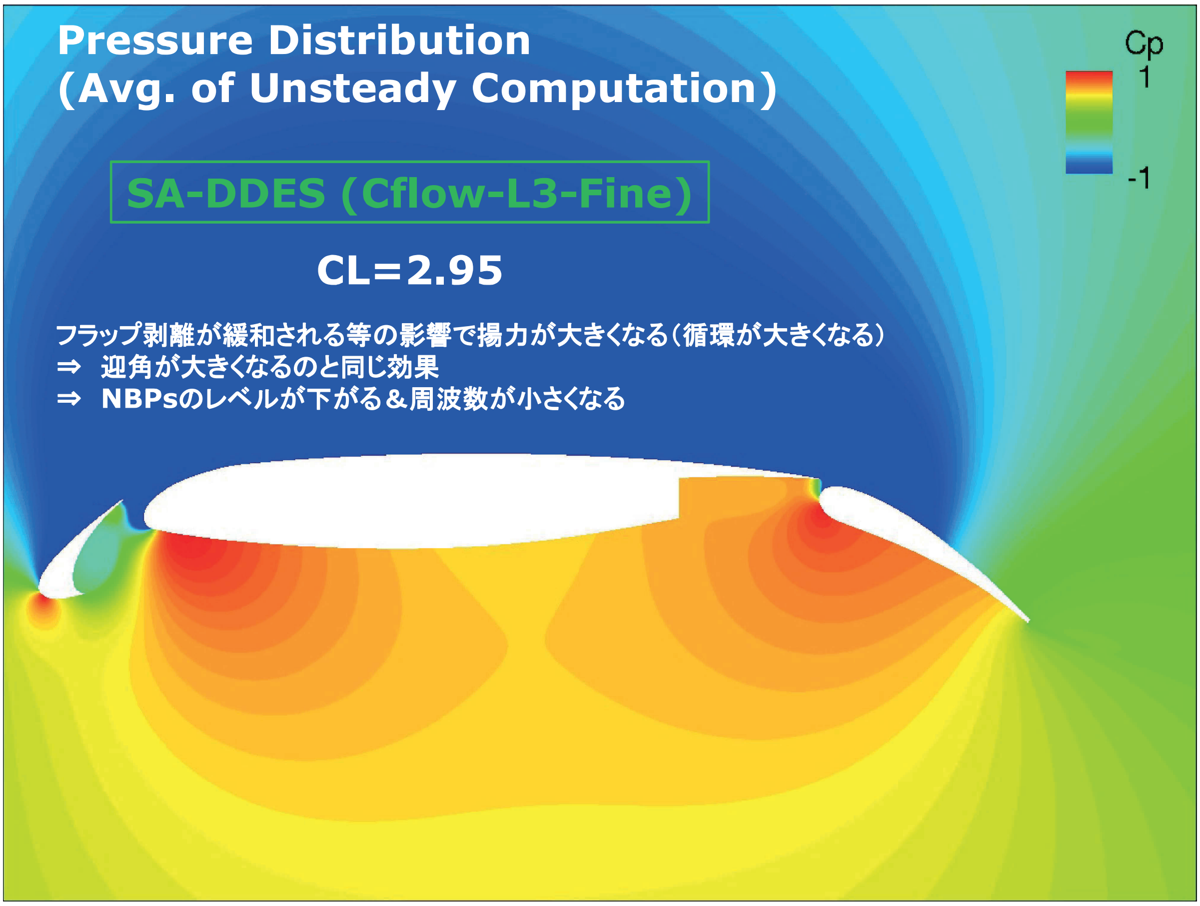


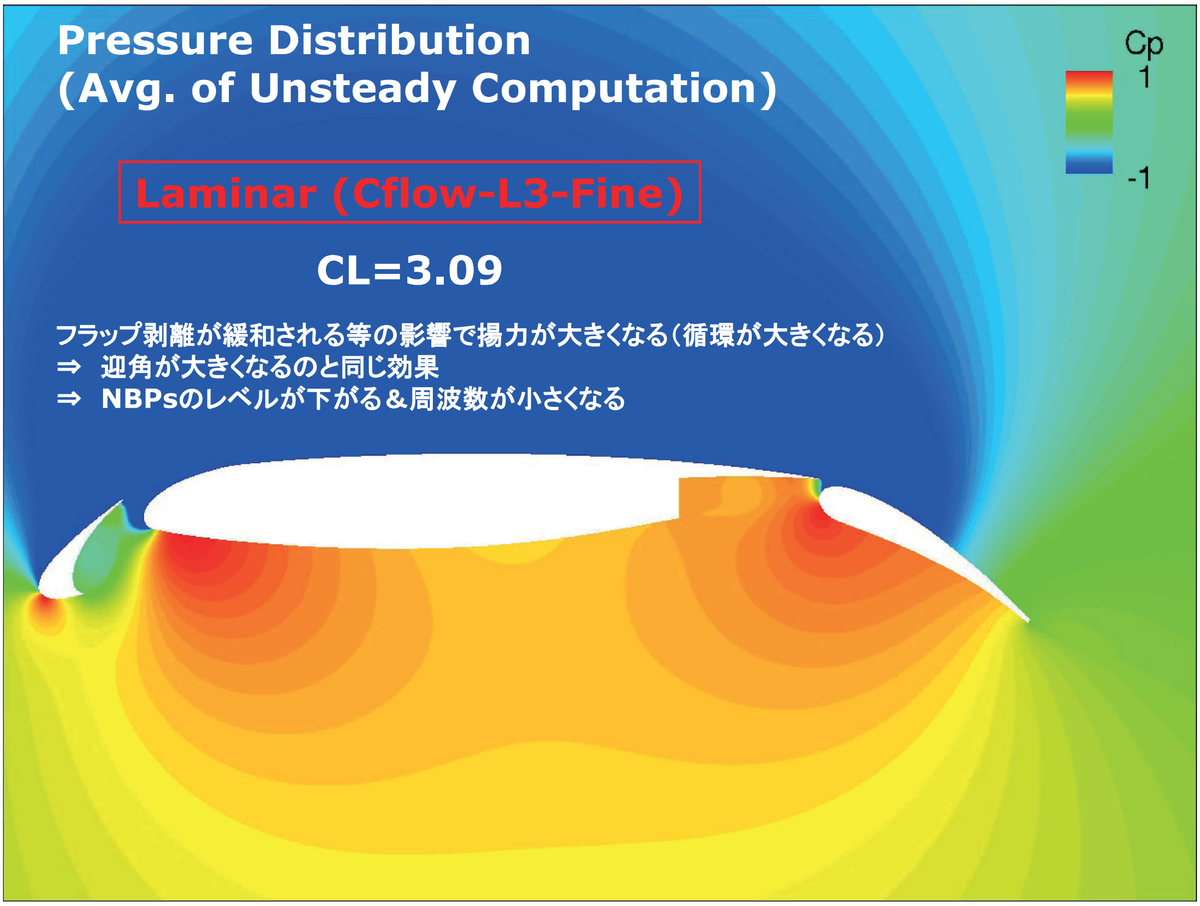
CD, CL and Cp (Avg. of Unsteady Computation)

	CD	CL
SA-DDES	0.04092	2.95
Laminar	0.02800	3.09






Pressure Distribution
(Avg. of Unsteady Computation)
Cp
1
-1
SA-DDES (Cflow-L3-Fine)
CL=2.95
フラップ剥離が緩和される等の影響で揚力が大きくなる(循環が大きくなる)
⇒ 迎角が大きくなるのと同じ効果
⇒ NBPsのレベルが下がる＆周波数が小さくなる


Pressure Distribution
(Avg. of Unsteady Computation)
Cp
1
-1
Laminar (Cflow-L3-Fine)
CL=3.09
フラップ剥離が緩和される等の影響で揚力が大きくなる(循環が大きくなる)
⇒ 迎角が大きくなるのと同じ効果
⇒ NBPsのレベルが下がる＆周波数が小さくなる