

APC-IV

## Cflowによる 三翼素高揚力翼型の 空力騒音検証解析

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

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宮崎市民プラザ

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### 本発表の概要 **Overview**

- 川崎重工の自社開発CFDソフト「**Cflow**」による、  
課題3の音響予測結果(近傍場・遠方場)を示す。
- 使用ソルバーと格子
  - Solver: "**Cflow**" (**Kawasaki in-house**)
  - Grids: 2 types of grid
    - ✓ **Cflow grid (Kawasaki in-house):**  
unstructured, Cartesian-based, layered grid on non-slip walls
    - ✓ **JAXA grid (provided):** structured, multiblock
- 発表の焦点
  - **格子依存性(Grid Sensitivity):** AoA=5.5 deg.
    - ✓ 格子サイズの違い(Coarse, Medium, Fine)
    - ✓ 自作格子(Cflow grid)と提供格子(JAXA grid)の違い
  - **迎角依存性(AoA Sensitivity):** AoA=5.5, 9.5, 14 deg.

## 非定常解析手法 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<br>with pseudo 3 <sup>rd</sup> -order accurate reconstruction based on MUSCL |
| Inviscid Flux          | SLAU (Simple Low-dissipation AUSM scheme)   |
| Viscous Flux           | 2 <sup>nd</sup> -order accurate central difference  |
| Limiter                | none  |
| Turbulence Modeling    | DDES based on SA-noft2 (Spalart-Allmaras model without $f_{t2}$ term)   |
| Time Integration       | 2 <sup>nd</sup> -order MFGS implicit method   |

### ■ References for **Cflow** details

1. Nagata, T., Ueno, Y., and Ochi, A., "Validation of new CFD tool using Non-orthogonal Octree with Boundary-fitted Layer Unstructured Grid," 50th AIAA Aerospace Sciences Meeting, (AIAA 2012-1259).
2. Ueno, Y., Nagata, T., and Ochi, A., "Aeroacoustic Analysis of the Rudimentary Landing Gear Using Octree Unstructured Grid with Boundary-fitted Layer," 18th AIAA/CEAS Aeroacoustics Conference, (AIAA 2012-2284).
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," 55th AIAA Aerospace Sciences Meeting, AIAA SciTech, (AIAA 2017-0959).
4. 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).

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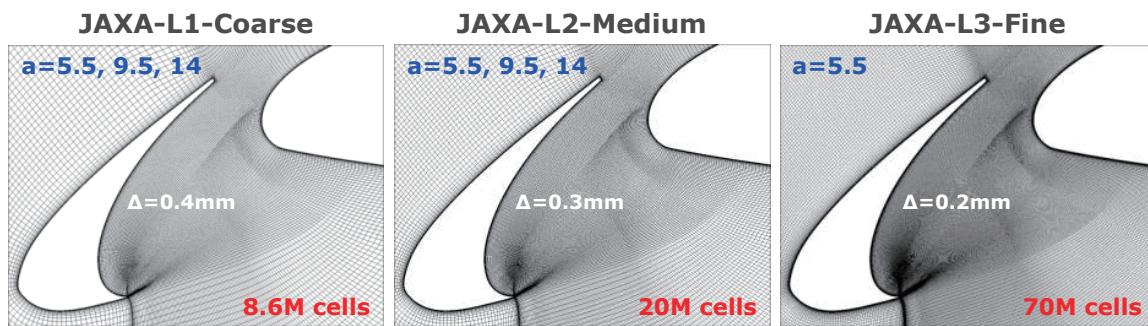
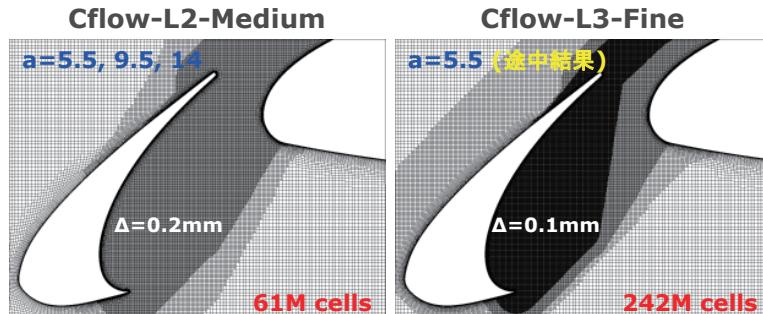
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## 解析ケース Case Summary

- 5 meshes (2-inch span)
- **11 cases**
- One computation is ongoing. (Cflow-Fine)

**dt=0.588 × 10<sup>-6</sup> sec**  
**Time record=10.4 c/U<sub>∞</sub>**

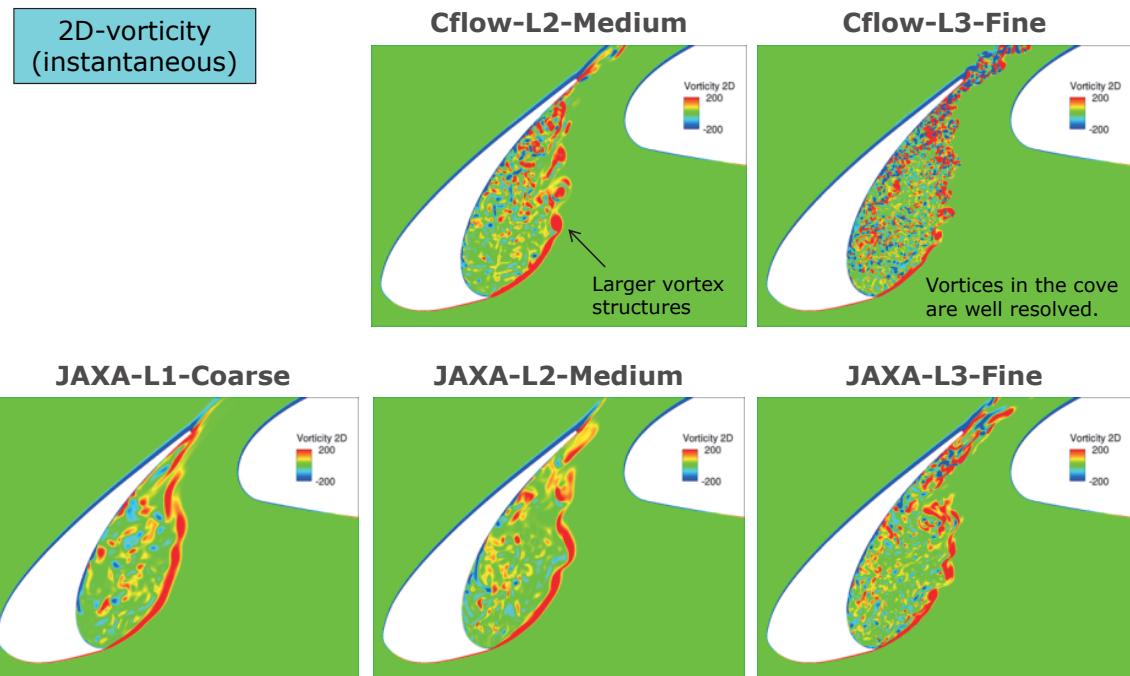


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## Flow Visualization ( $\alpha=5.5$ deg.)



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## 【課題3-1】

### 音響予測(近傍場)

### Surface Pressure Fluctuations

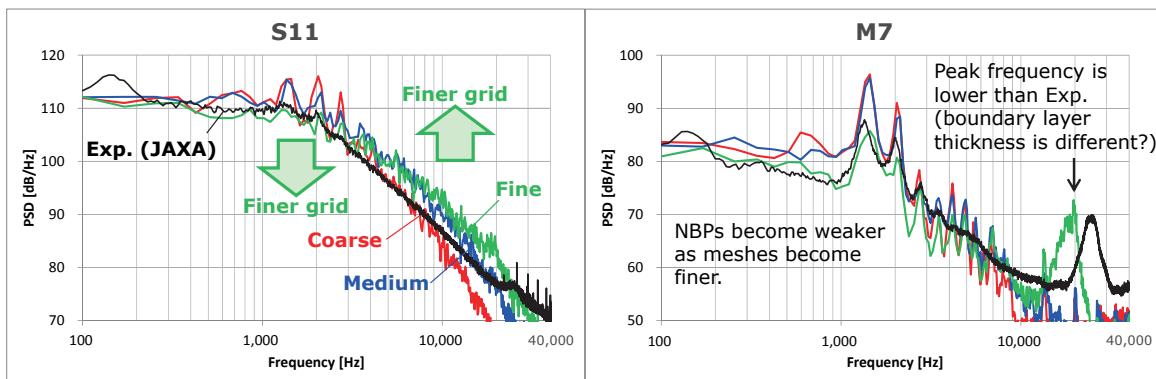
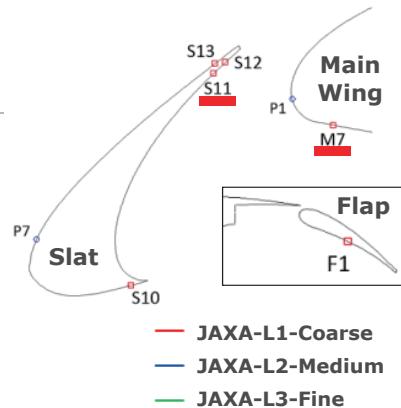
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## Grid Sensitivity at $\alpha=5.5$ deg. (JAXA L1, L2 and L3 grids)

- 格子が細かくなると、narrow-band peaks (NBPs)は小さくなる。一方で、高周波側のレベルは大きくなる。
- スラット後縁からの渦放出に起因する20kHz付近のピークは、Fine格子で確認できるが、風試よりも周波数がやや小さい。スラット後縁での境界層厚さが、風試に比べてCFD(全場乱流)の方が厚い?



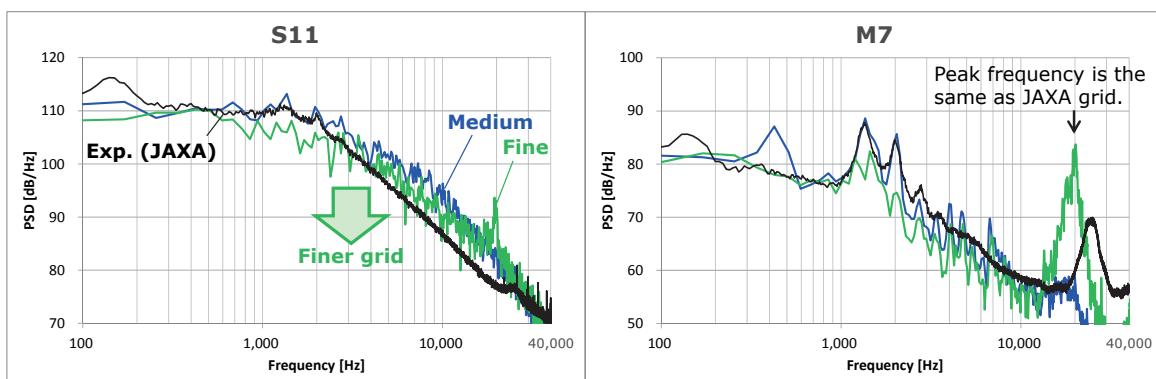
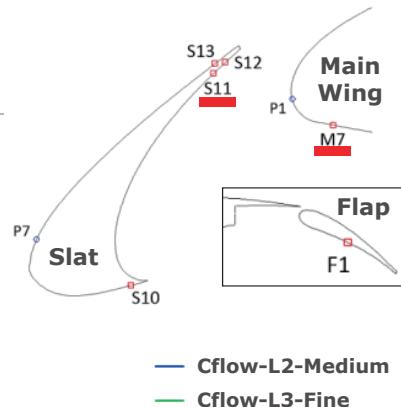
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## Grid Sensitivity at $\alpha=5.5$ deg. (Cflow L2 and L3 grids)

- Cflow格子では、格子を細かくすると全体的にレベルが小さくなる。
- Fine格子ではNBPsが弱くなっている。(Medium格子の方が風試に近い結果)
- 20kHz付近のピーク周波数はJAXA格子と同じだが、レベルは風試よりも大きい。



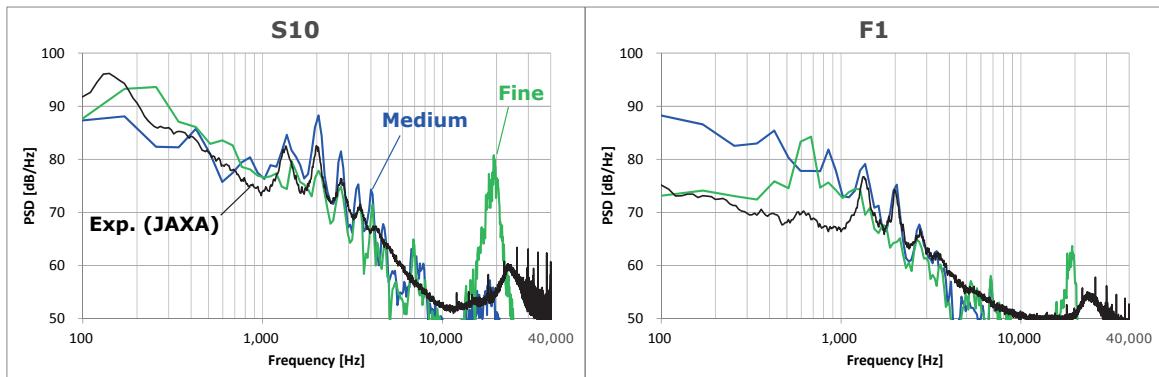
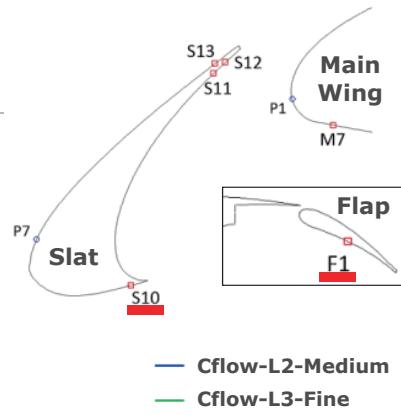
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## Grid Sensitivity at $\alpha=5.5$ deg. (Cflow L2 and L3 grids)

- 各probe点での風試の傾向を、全体的に良く捉えている。



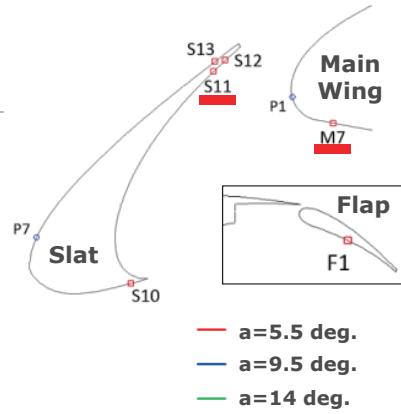
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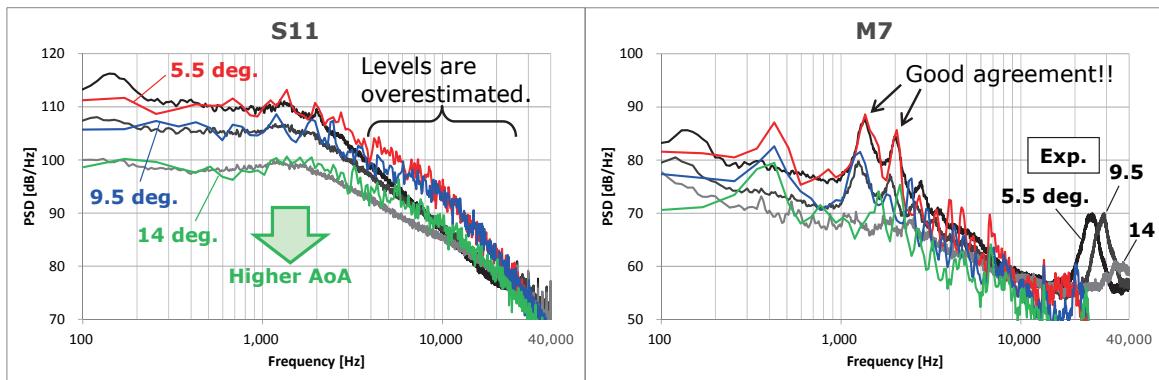
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## AoA Sensitivity (Cflow-L2-Medium grid)

- 迎角が大きくなると、レベルが小さくなるという風試の傾向を良く捉えている。
- NBPsを含めたレベルの絶対値も、概ね良く一致している。
- S11の高周波側では、風試に比べてレベルが大きい。
- 迎角が大きくなると、NBPsの周波数がやや小さくなるという傾向も一致している。
- JAXA格子での迎角依存性も、同様の傾向。(図示なし)



— a=5.5 deg.  
— a=9.5 deg.  
— a=14 deg.



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## 【課題3-2】

### 音響予測(遠方場)

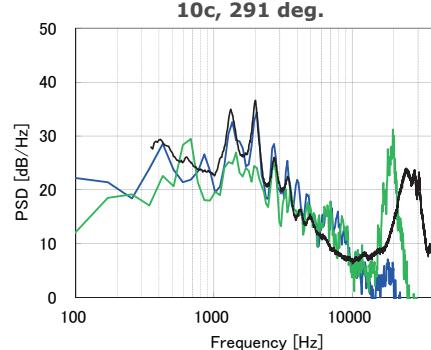
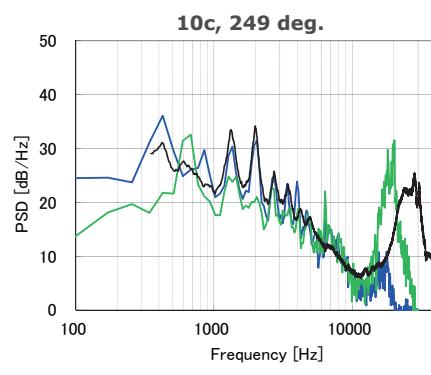
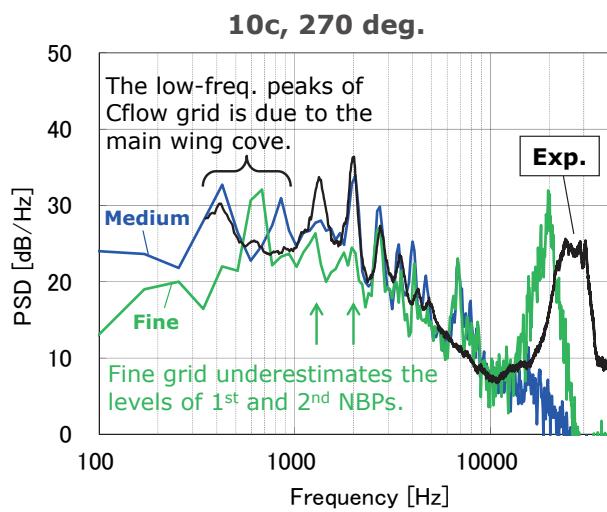
### Far-field Noise Predictions

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

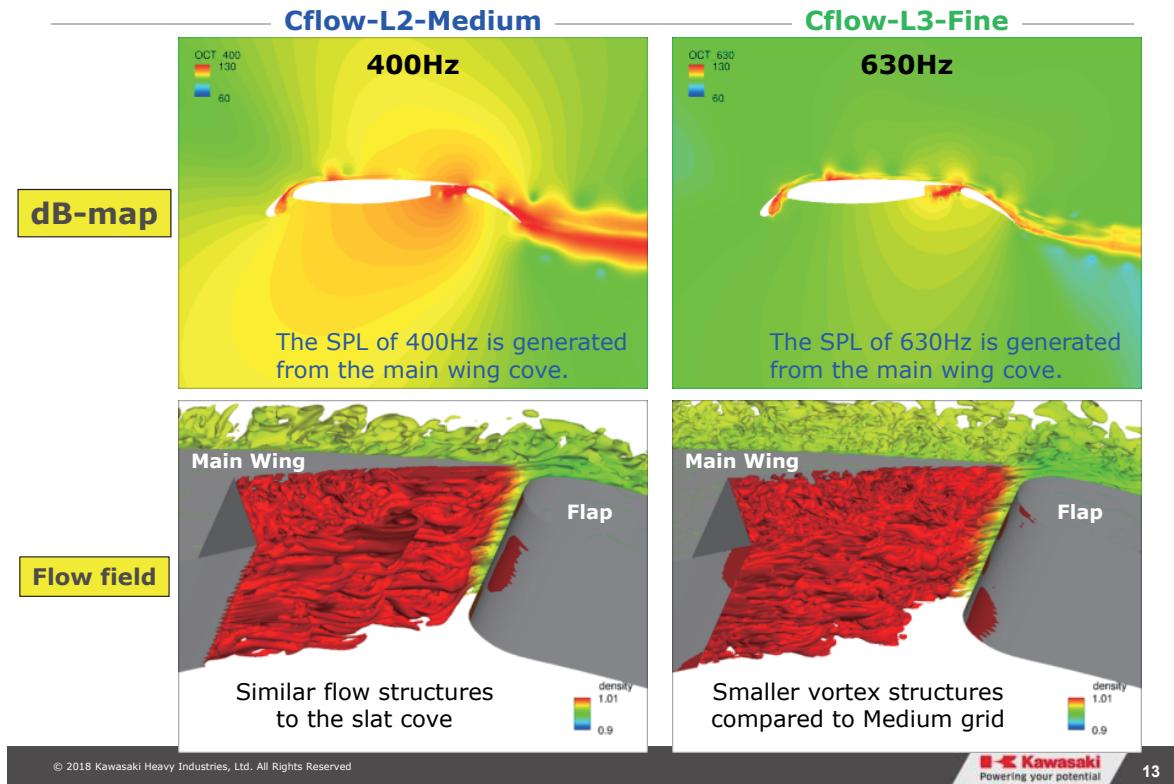
#### Grid Sensitivity at $\alpha=5.5$ deg. (Cflow L2 and L3 grids)

- 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プから発生。  
(JAXA格子では発生しない)

Cflow-L2-Medium  
Cflow-L3-Fine

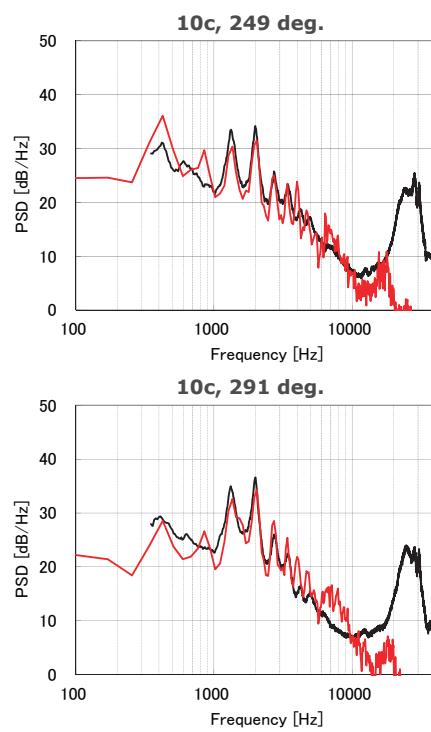
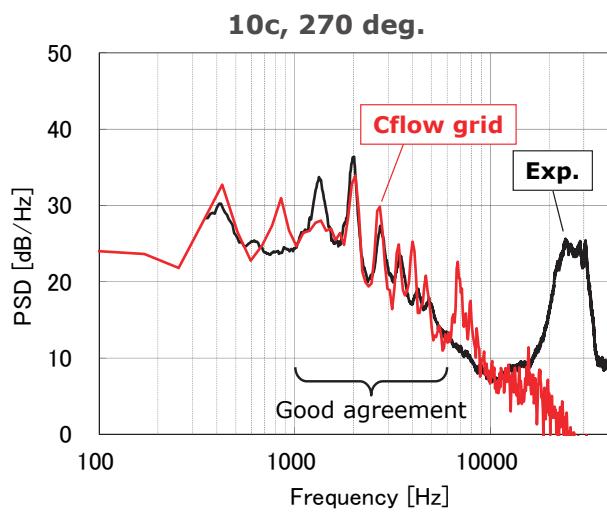


## dB-map and Main Wing Cove Flow



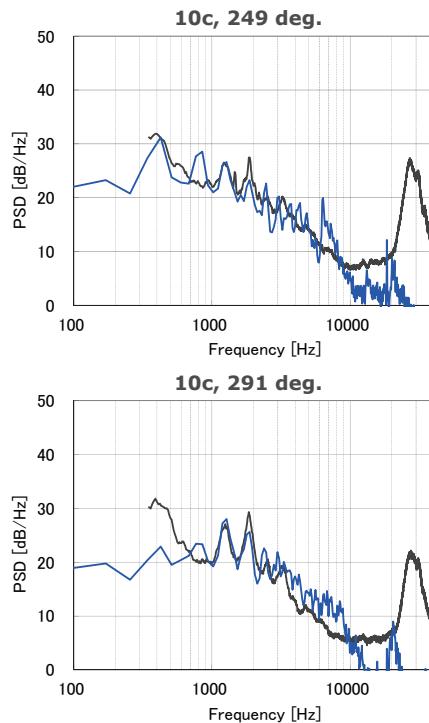
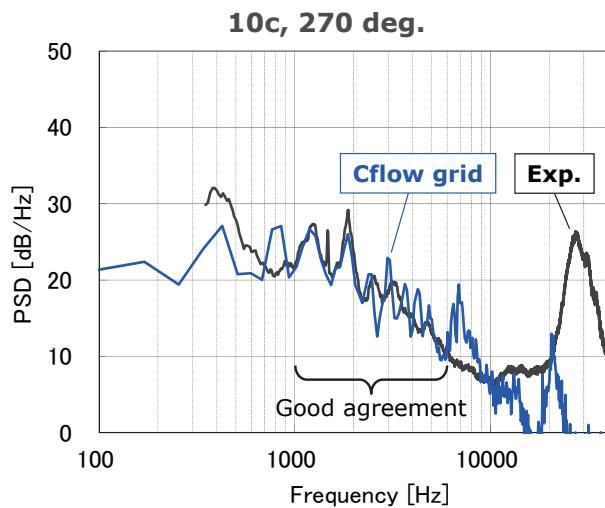
## AoA Sensitivity $a=5.5\text{deg}$ (Cflow-L2-Medium grid)

- 高周波を除いて、定量的に風試と良く一致。



## AoA Sensitivity a=9.5deg (Cflow-L2-Medium grid)

- 高周波を除いて、定量的に風試と良く一致。



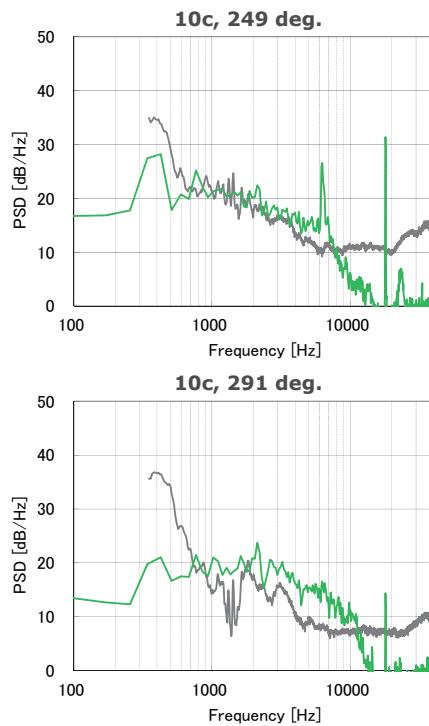
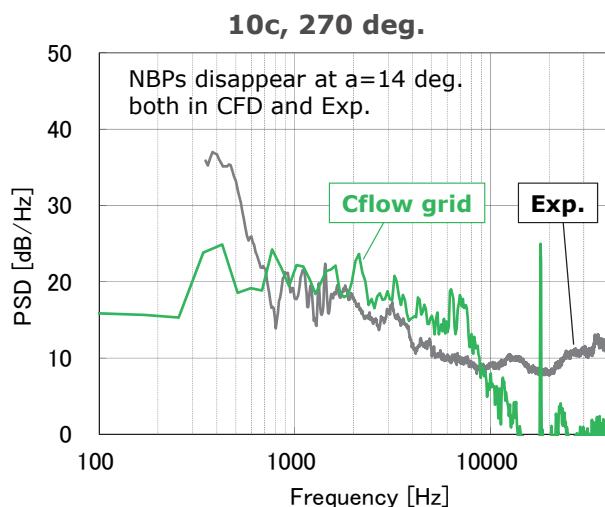
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## AoA Sensitivity a=14deg (Cflow-L2-Medium grid)

- $a=14\text{ deg.}$ でレベルが小さくなる傾向や、NBPsが消える傾向が、CFDと風試で一致。



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## まとめ Summary

### ■ Lessons Learned

正確な騒音予測のために、騒音源となる渦構造を適切に解像することが重要(格子依存性大)

- Aerodynamic noise from 30P30N consists of NBPs, slat trailing edge noise and main wing cove noise, and **it is important to resolve source vortex structures appropriately for accurate noise predictions.**
- Our SA-based DDES simulations are capable of predicting slat noise characteristics observed in the JAXA experiment at higher AoA as remarked below. **迎角依存性を捉えることができた**
  - ✓ The NBPs become weaker at AoA=9.5 deg. compared to AoA=5.5 deg. and the frequencies slightly shift lower.
  - ✓ The NBPs seem to disappear at AoA=14 deg. and the far-field noise levels are the lowest among all three AoAs.
- Quantitative noise predictions using our unsteady CFD with solid FWH method have become more reliable and reached a practical level. **非定常CFD+Solid FWHによる定量的な騒音予測の信頼性が向上し、実用的なレベルに達してきた**

### ■ Future work

- Detailed comparisons with other code (the effect of Fine grid on NBPs)
- The effect of span-wise cell size
- The effect of transition on the slat

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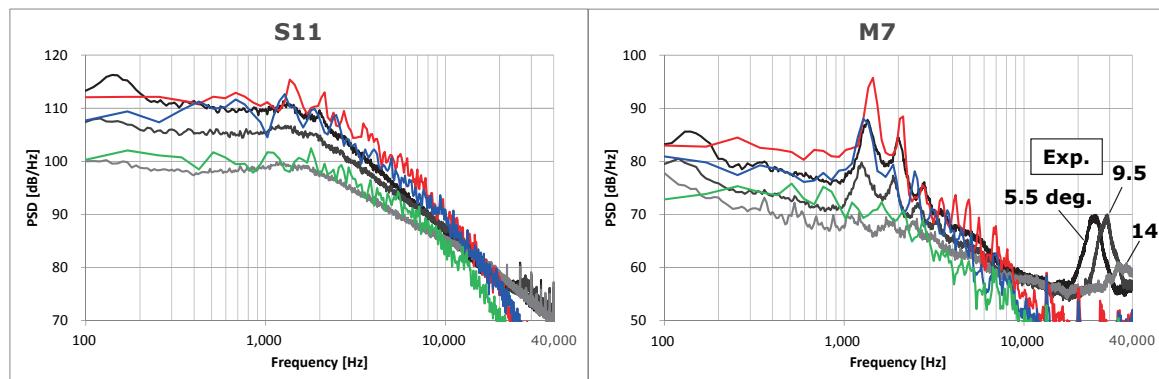
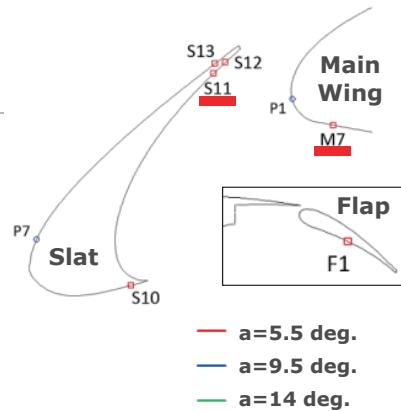
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## AoA Sensitivity (JAXA-L2-Medium grids)

- The NBP become weaker at  $\alpha=9.5$  deg. compared to  $\alpha=5.5$  deg. and the frequencies slightly shift lower.
- The NBPs seem to disappear at  $\alpha=14$  deg. and the levels are the lowest among all three angles.

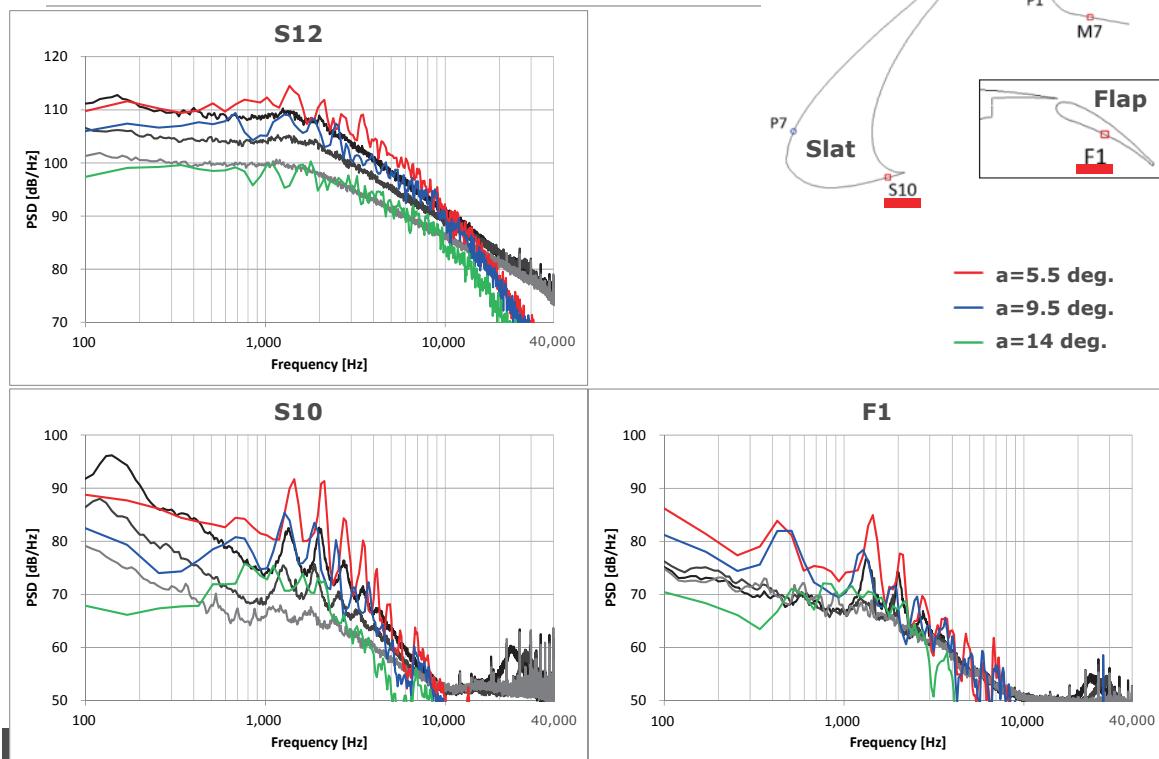


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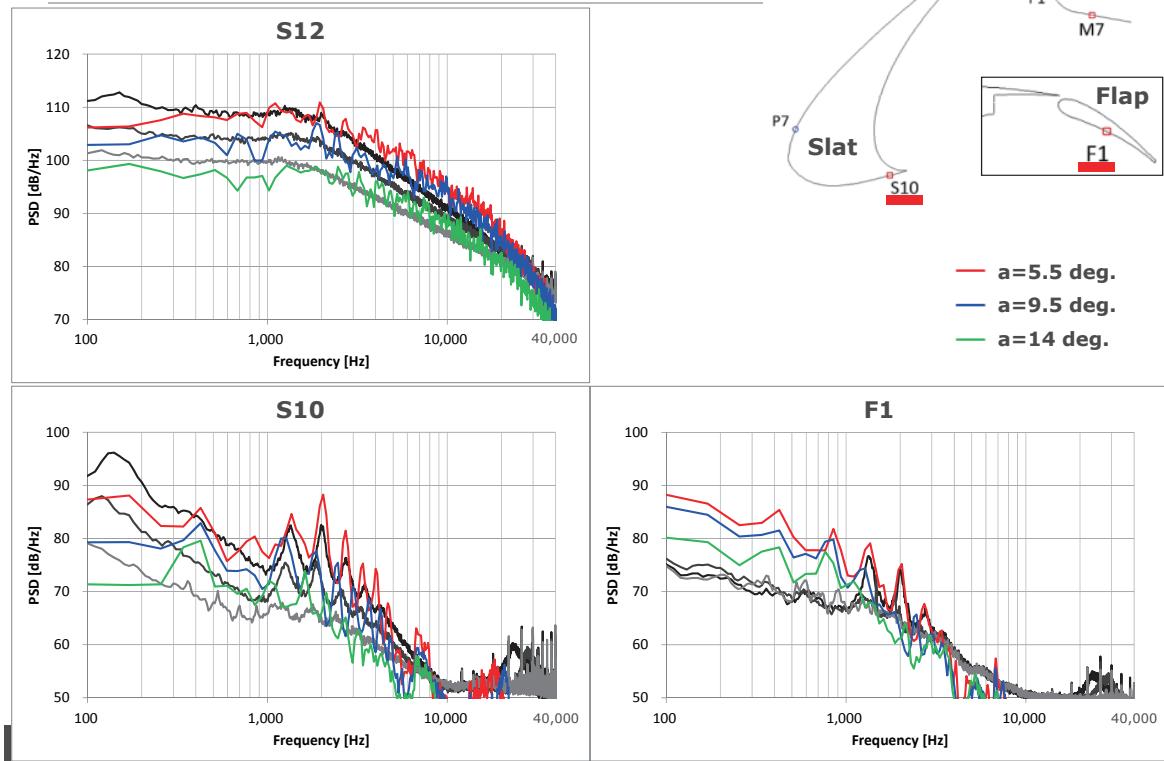
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## AoA Sensitivity (JAXA-L2-Medium grids)

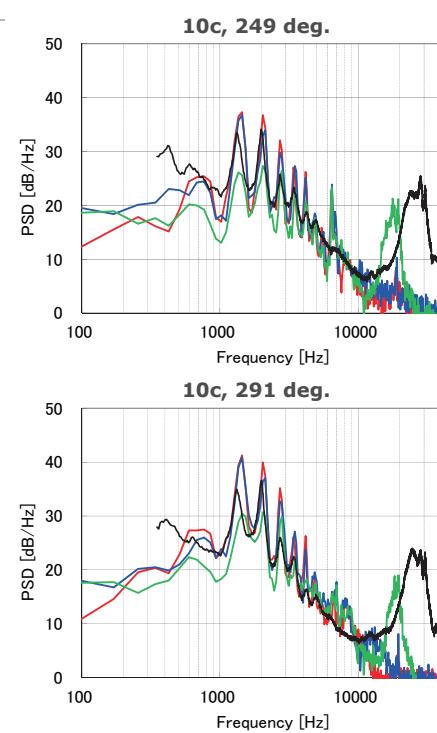
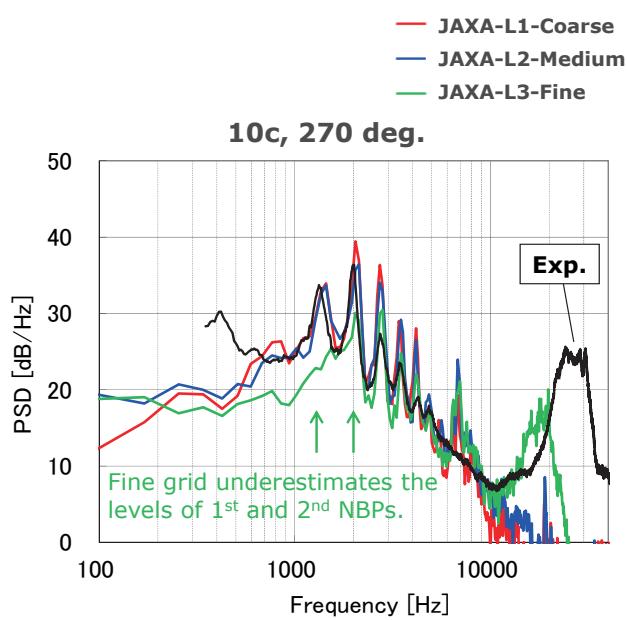


## AoA Sensitivity (Cflow-L2-Medium grids)



## Grid Sensitivity at $a=5.5$ deg. (JAXA L1, L2 and L3 grids)

- 基本的に近傍場と同じ傾向を示している。



## AoA Sensitivity (JAXA-L2-Medium)

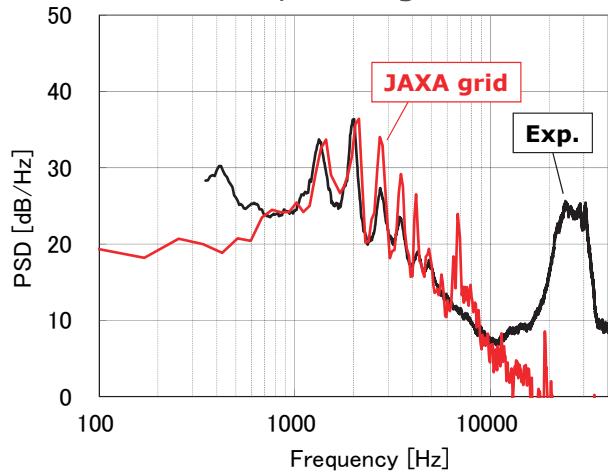
$a=5.5\text{deg}$

Far-field

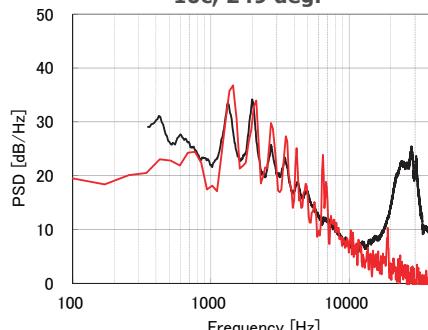
### Comparisons with Exp.

- Solver: Cflow (in-house)
- Grid: JAXA (provided)

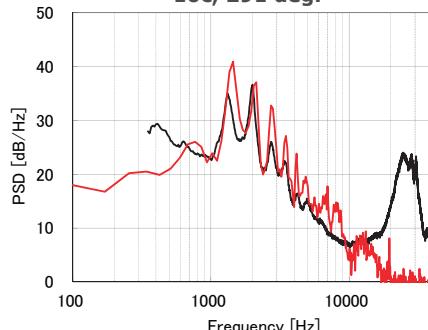
10c, 270 deg.



10c, 249 deg.



10c, 291 deg.



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## AoA Sensitivity (JAXA-L2-Medium)

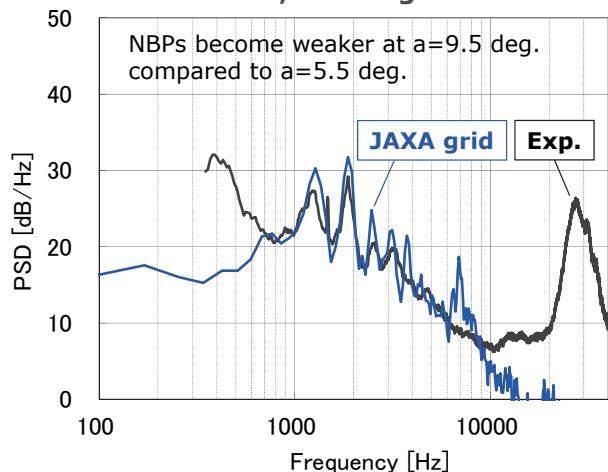
$a=9.5\text{deg}$

Far-field

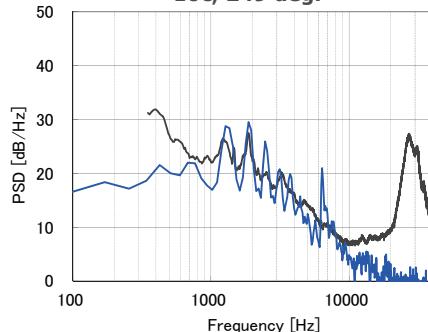
### Comparisons with Exp.

- Solver: Cflow (in-house)
- Grid: JAXA (provided)

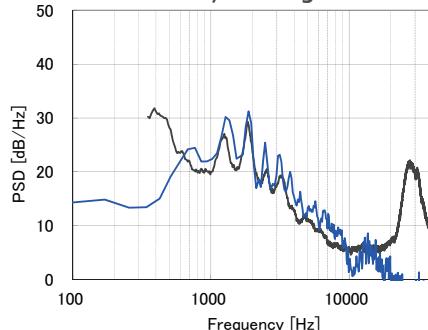
10c, 270 deg.



10c, 249 deg.



10c, 291 deg.



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## AoA Sensitivity (JAXA-L2-Medium)

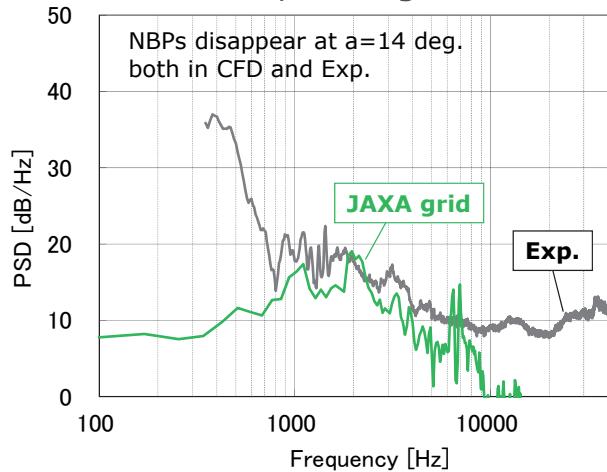
$a=14\text{deg}$

Far-field

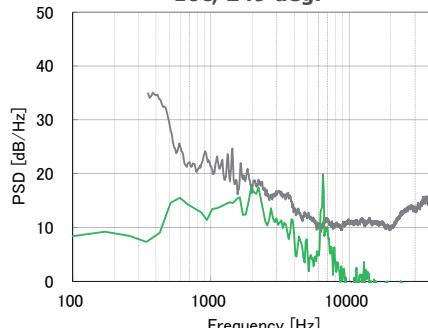
### Comparisons with Exp.

- Solver: Cflow (in-house)
- Grid: JAXA (provided)

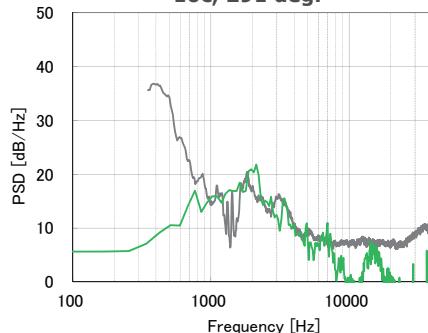
10c, 270 deg.



10c, 249 deg.



10c, 291 deg.



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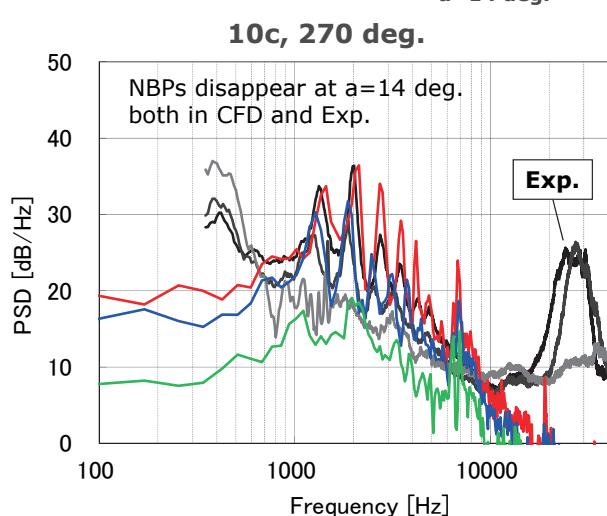
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## AoA Sensitivity (JAXA-L2-Medium)

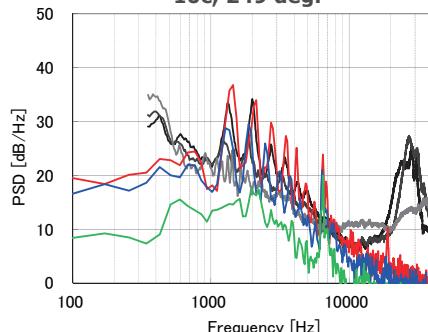
### Comparisons with Exp.

10c, 270 deg.

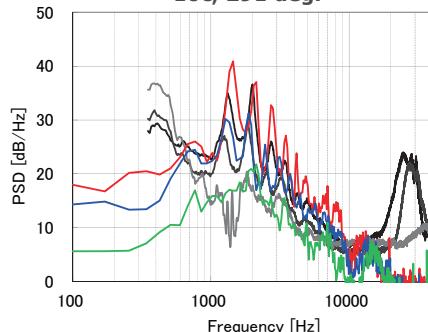


Far-field

10c, 249 deg.



10c, 291 deg.



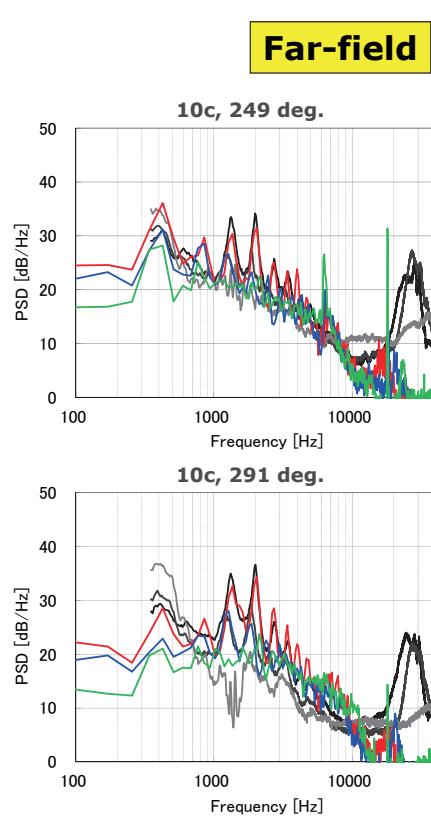
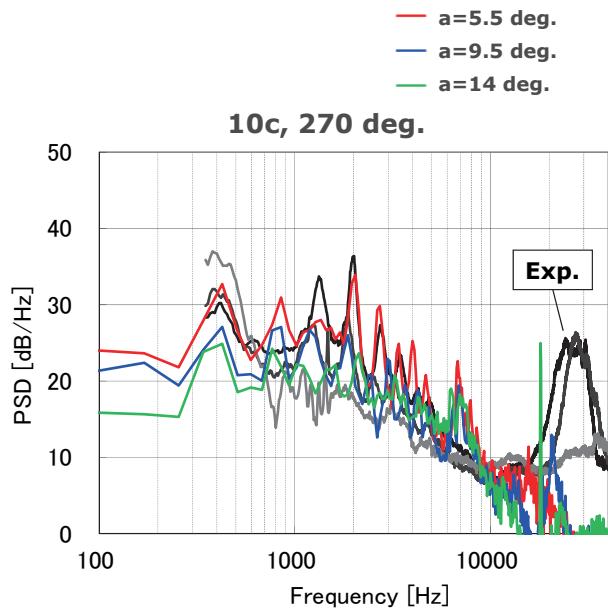
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## AoA Sensitivity (Cflow-L2-Medium)

### Comparisons with Exp.



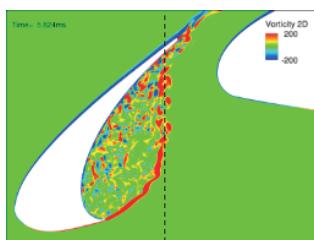
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## Flow Fields at Different AoA (Cflow-L2-Medium grid)

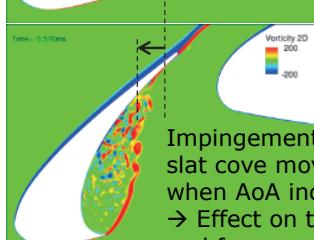
a=5.5 deg.



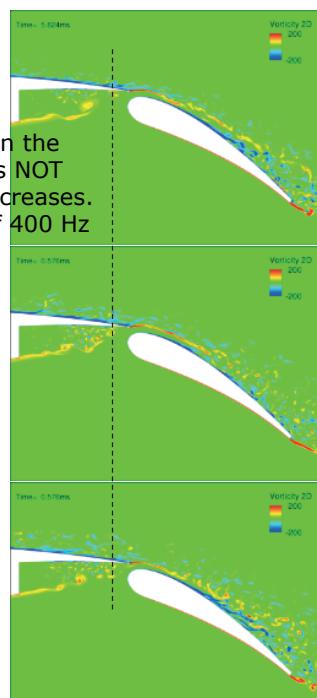
a=9.5 deg.



a=14 deg.



Impingement point in the main wing cove does not change when AoA increases.  
→ Peak frequency of 400 Hz does NOT change.



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## AoA Sensitivity      $a=5.5\text{deg}$ (Cflow-L3-Fine grid)

※途中結果(解析時間半分)

