1A14

Unsteady Flow Analysis for NASA-CRM at Low-speed and High Angle-of-attack Conditions Using Flux-reconstruction Method

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Objective

- To assess the prediction capability of the state-of-the-art high-order scheme (Split-FR) and the wall-stress model for practical unsteady flows, which is realized by LS-FLOW-HO solver.

- Case 2 : Unsteady flow analysis

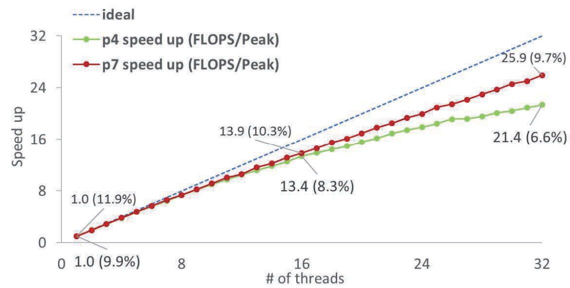
  Flow conditions: $M_\infty = 0.168$, $Re = 1.06 \times 10^6$
  Angle of attack: 11.05, 13.08 [deg]

Solver: LS-FLOW-HO

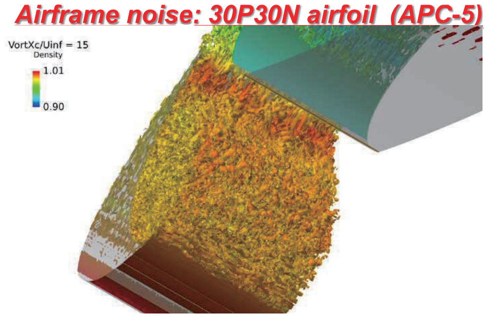
Discretization	**Split-FR (p0-15)** [1]
Inviscid Flux	SLAU
Viscous Flux	BR2 $(\eta_{BR2} = 6.0)$
SGS Model	None (Implicit LES)
Time Integration	3rd-order TVD Runge-Kutta
Shock Capturing	LAD [2] (not used in this study)
Wall Stress Model	**Equilibrium BL eqs.** [3]
Parallelism	MPI & OpenMP/OpenACC

[1] Y. Abe, et al., JCP 353 193-227 (2018)
[2] T. Haga and S. Kawai, JCP 376 534-563 (2019)
[3] T. Haga and S. Kawai, The 31st CFD symposium (2017) (in Japanese)

OpenMP Speed-up @Fujitsu FX100

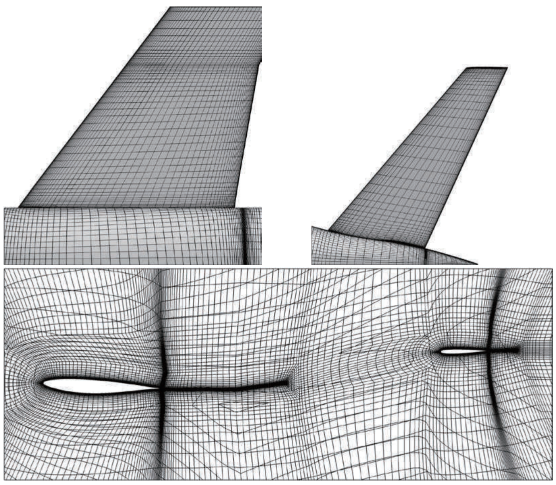


Airframe noise: 30P30N airfoil (APC-5)

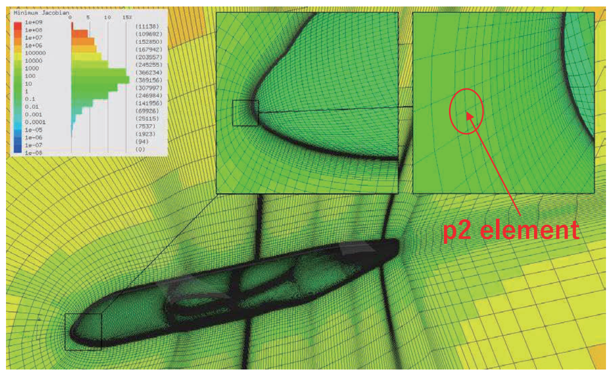


Computational Mesh

- Based on the AIAA-DPW4 mesh (JAXA-Multiblock-Coarse, 2.8 million hex) used for RANS

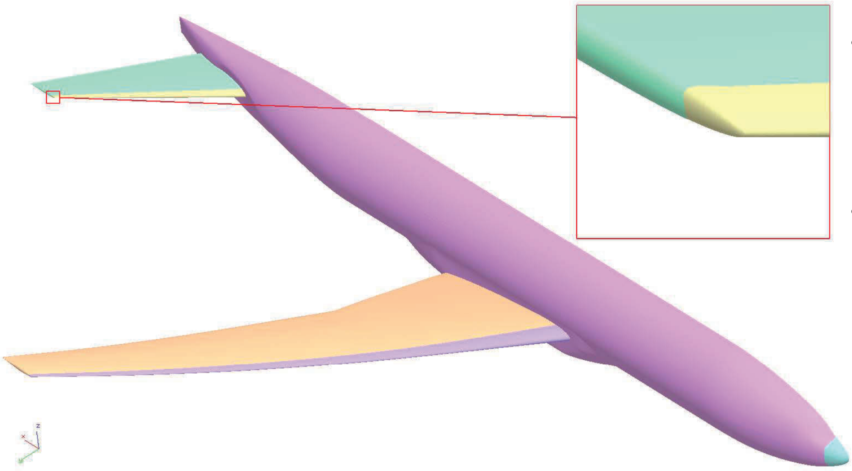


- Enlarged cell-height for WM: $\frac{\Delta h_{wall}}{c}$ =7.25e-5 (y^+<10)
- Each hex was subdivided into 8 hex by *Pointwise* Glyph script. (Feature lines are kept exactly)
- In the near wall (24 layers), the 8 hex were combined into a p2-element by *QuickMesh*.
  - ➢ p2-p1 mixed mesh in Gmsh format



Transition Treatment (Boundary Conditions)

- According to the locations of trip-dot in the wind-tunnel test, **laminar (no-slip)** or **turbulent (wall-modeled)** BCs are prescribed.



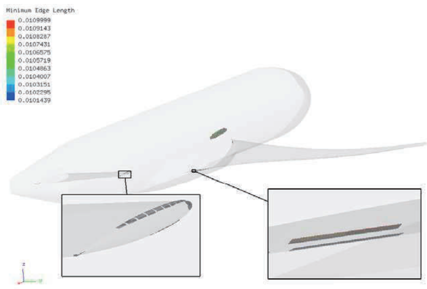
- In Exp.
  - Wings: 10% of each chord length
  - Body: 1.5% of the fuselage length
- In CFD
  - Boundary surface is split by the specified index (IJK)of the multi-block grids, which approximates the trip-dot locations.

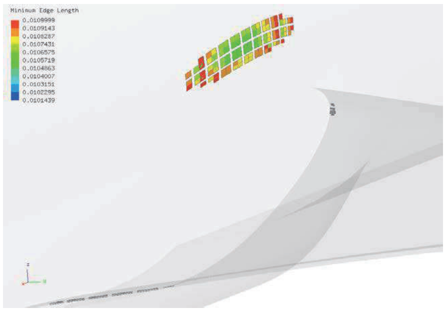
Computational Cost

JAXA 4.32% scale model: C_{ref}=0.30262 [m], Flow through time: $C_{\mathrm{ref}}/U_\infty$=0.005104 [s]

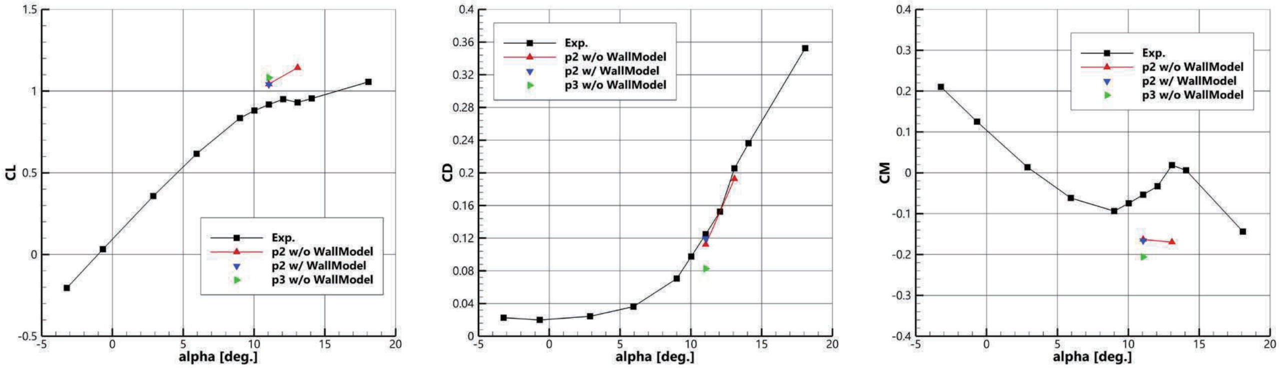
Case	$\Delta t \cdot a_\infty / C_{\mathrm{ref}}$	Timesteps for $10\, C_{\mathrm{ref}}/U_\infty$	Cores (CPUs) Fujitsu FX100	Elapse time [hours] for (X $C_{\mathrm{ref}}/U_\infty$)	Estimated elapse time [hours] for $10\, C_{\mathrm{ref}}/U_\infty$
P2 w/o WM	3.0e-6	1.98e+7	4096 (128)	185 (4.84)	381
P2 with WM	3.0e-6	1.98e+7	4096 (128)	282 (7.46)	378
P3 w/o WM	2.2e-6	2.71e+7	8192 (256)	139 (1.88)	738

Small Δt due to tiny cells:
Minimum_edge_length/MAC
=7.25e-5





Force Coefficients (Averaged)



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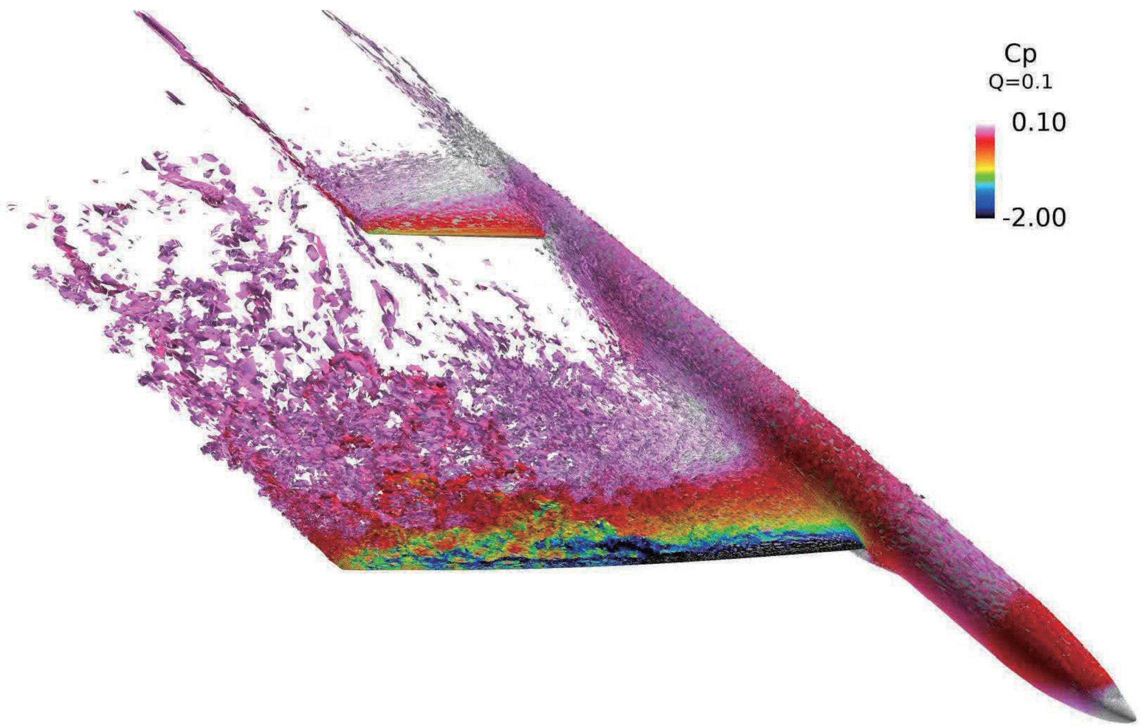
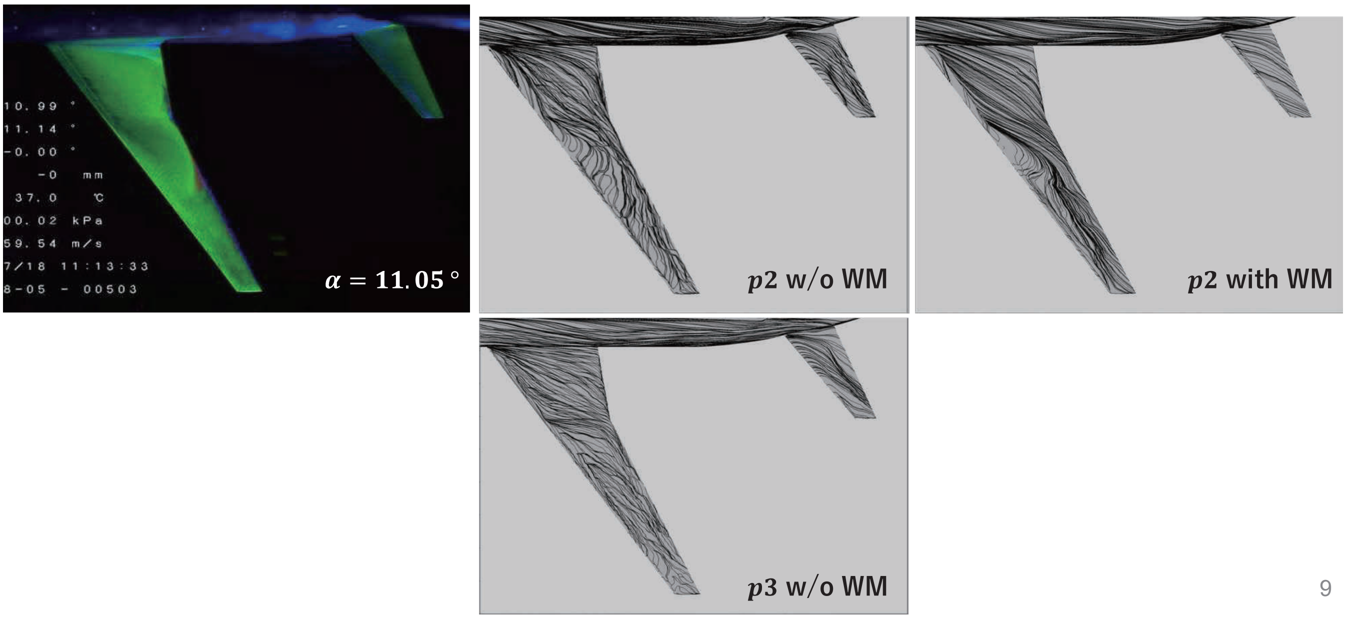


Oil Flow (Comparison with Exp.)



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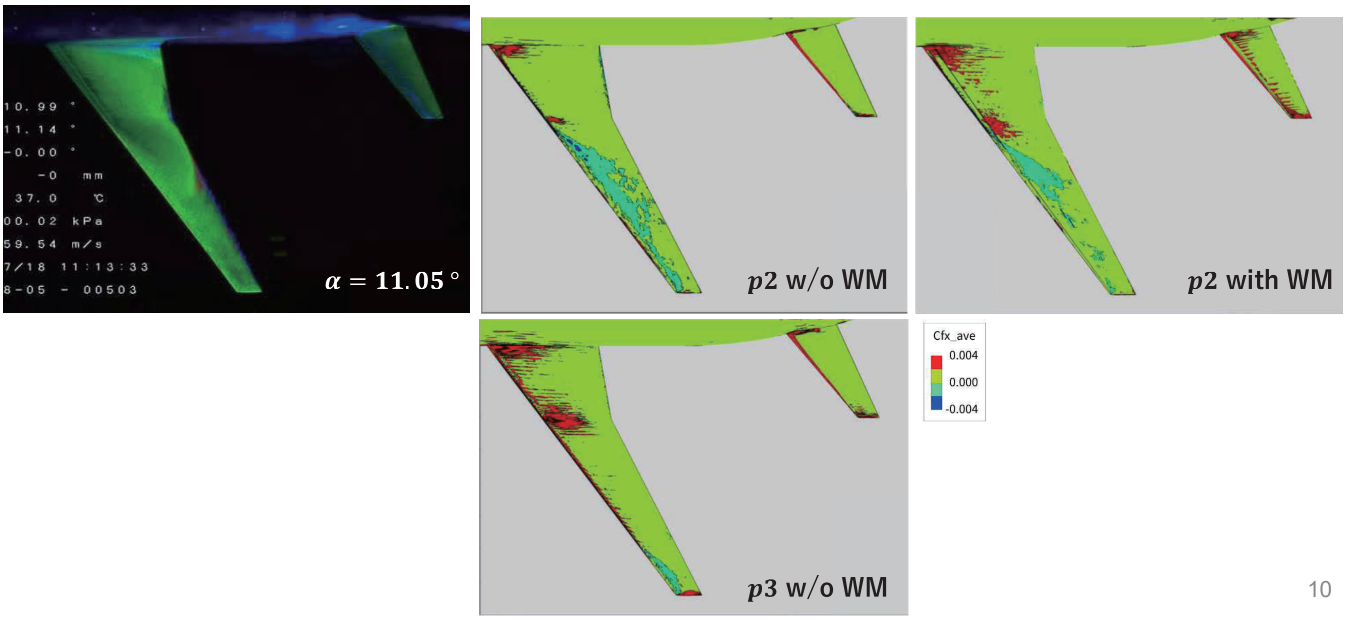
Skin Friction (Cfx)



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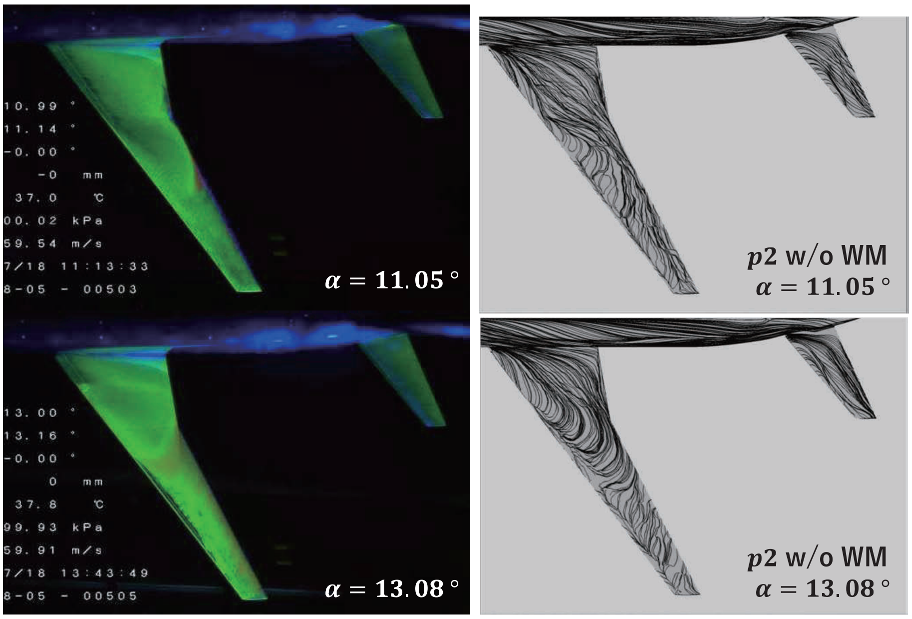
Oil Flow (Comparison with Exp.)



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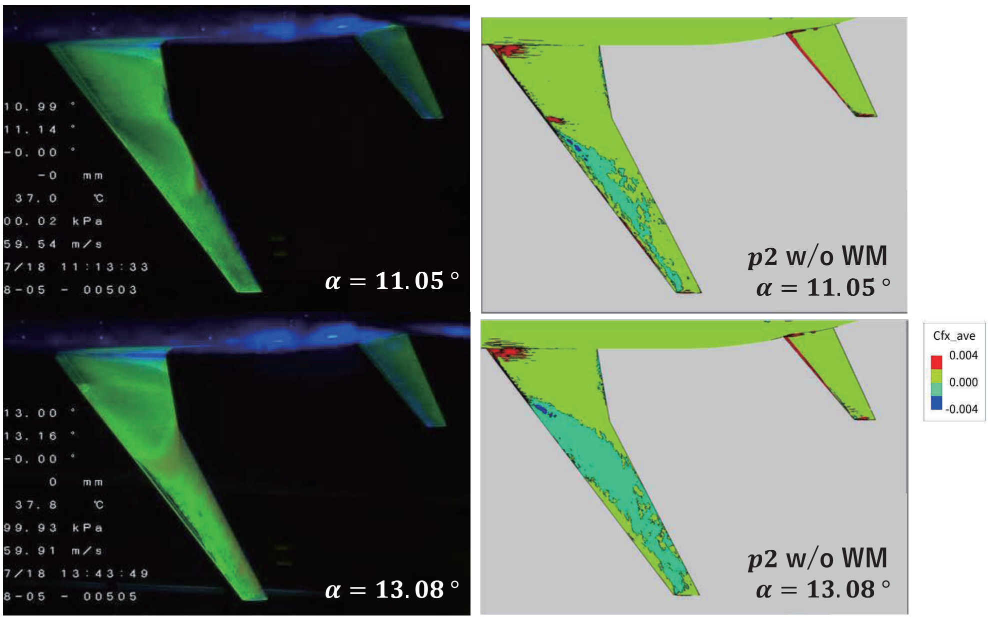
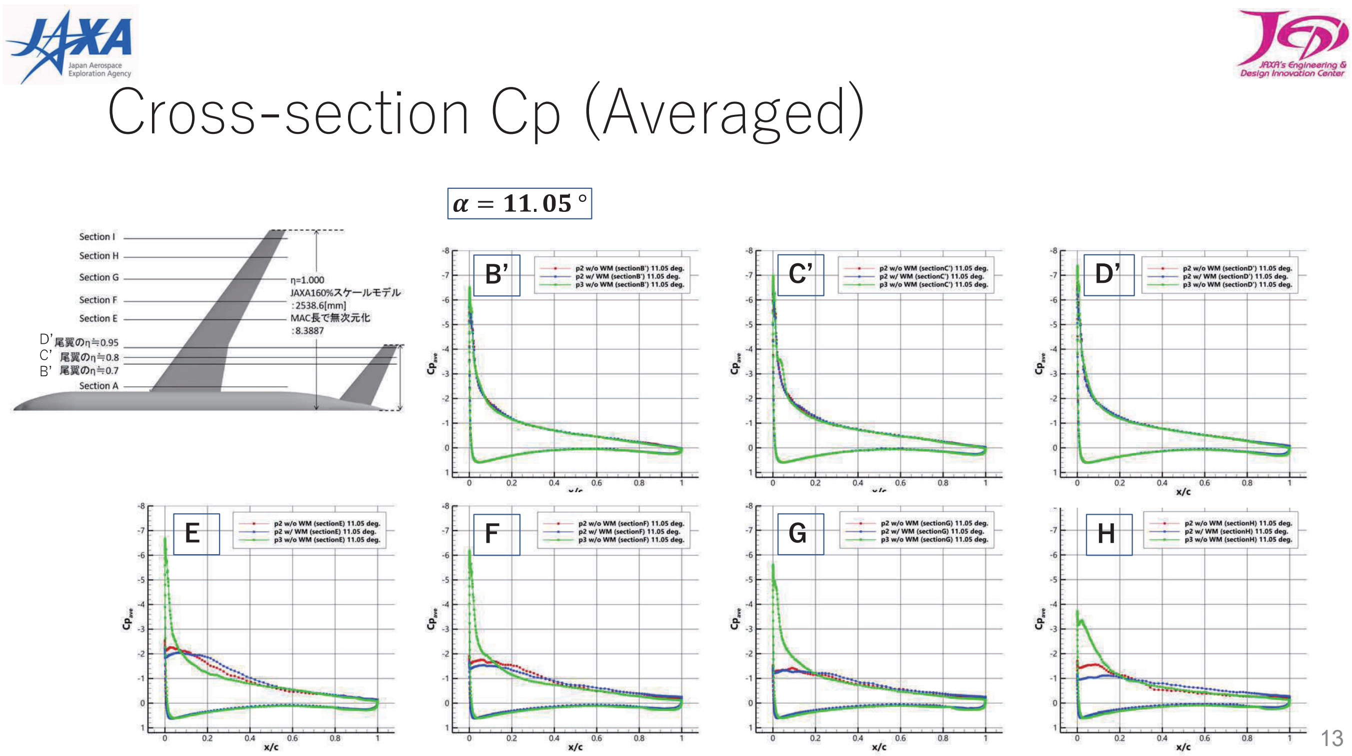
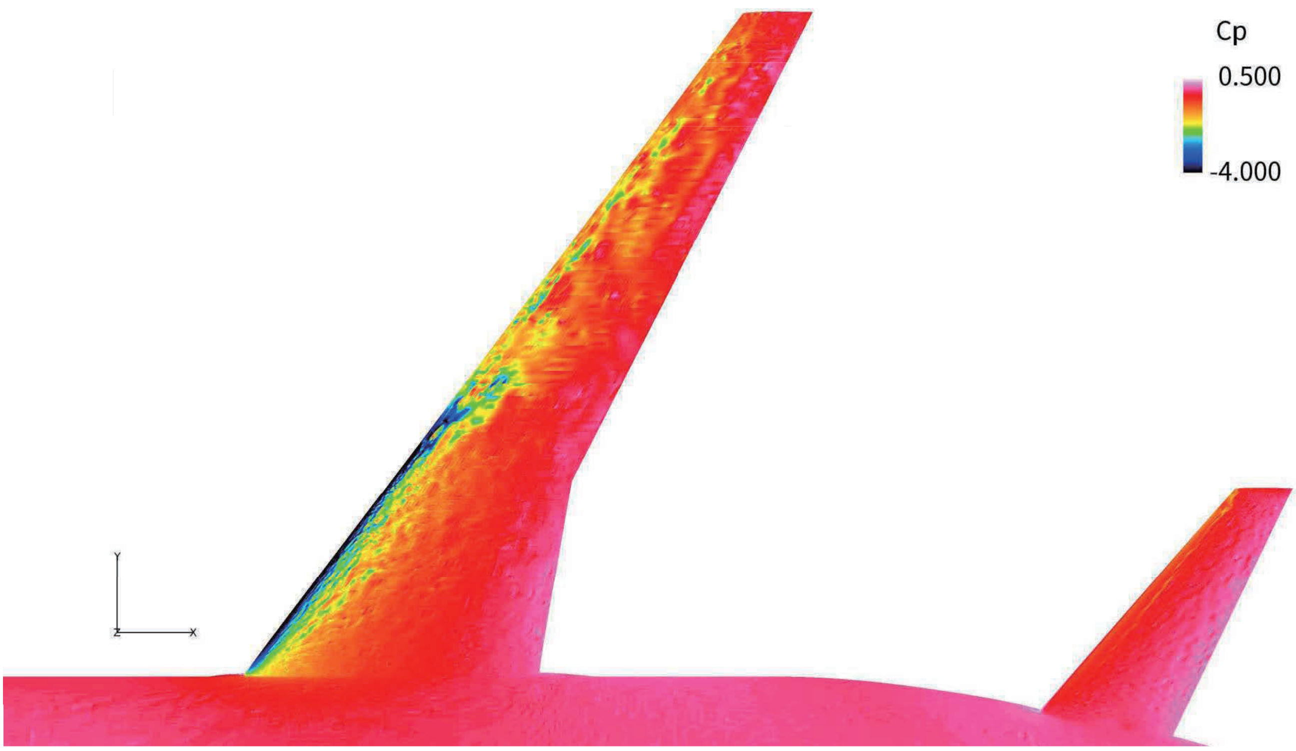
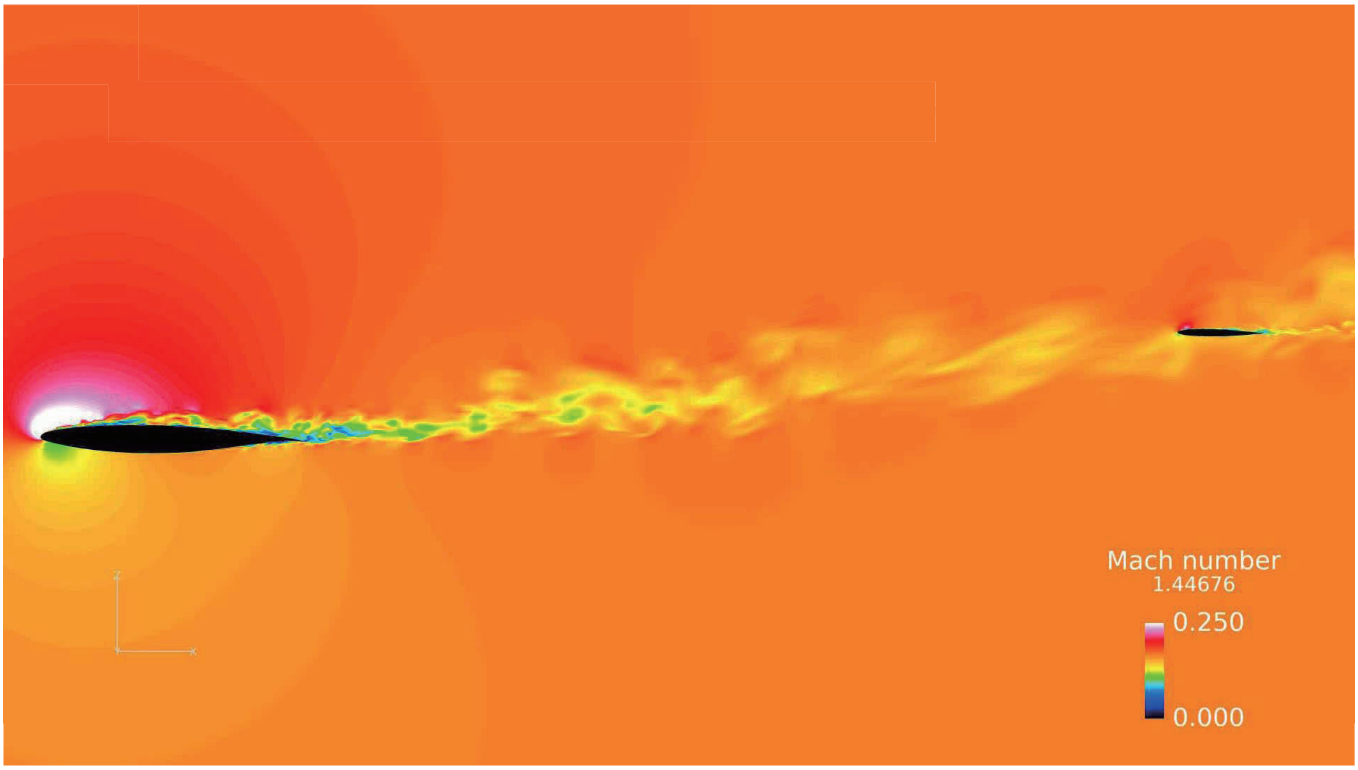



JAXA
Japan Aerospace Exploration Agency
JAXA's Engineering & Design Innovation Center
Cross-section Cp (Averaged)
$\alpha = 11.05°$
Section I
Section H
Section G
Section F
Section E
D' 尾翼のη≒0.95
C' 尾翼のη≒0.8
B' 尾翼のη≒0.7
Section A
η=1.000
JAXA160%スケールモデル
: 2538.6[mm]
MAC長で無次元化
: 8.3887
B'
C'
D'
E
F
G
H
x/c
13


Cp
0.500
-4.000
Y
X
Z



Summary

- Robustness of LS-FLOW-HO for high Re number LES around realistic geometry is demonstrated (no parameter tuning required).
- Comparable surface (oil) flow patterns to the experiment were obtained in the p2 w/o and with WM cases.
- Wall-modeled (WM) case shows some improvement in Cd. (by increased Cfx)
- p3 case predicted an overestimated Cl due to smaller separation. (resolution dependency remains)
- Open question(?): **does a wall-model help reduce the grid dependency?**
  - ➢ Further investigation is needed (use p3 with WM and a proper grid for WMLES)

- WMLES is becoming a tractable approach in terms of numerical stability and computational cost.

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Acknowledgments

- Speed-up tuning for LS-FLOW-HO was conducted by K. Tago (JAXA).
- The mixed-p HO mesh handling tool was developed by R. Kirihara (AdvanceSoft).
- JAXA Supercomputing System (JSS2) was used for the computations.