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ANSS2020 (Online)
1A11

Effects of Selected Numerical Methods on Unsteady NASA CRM Low-Speed Buffet Simulations

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and

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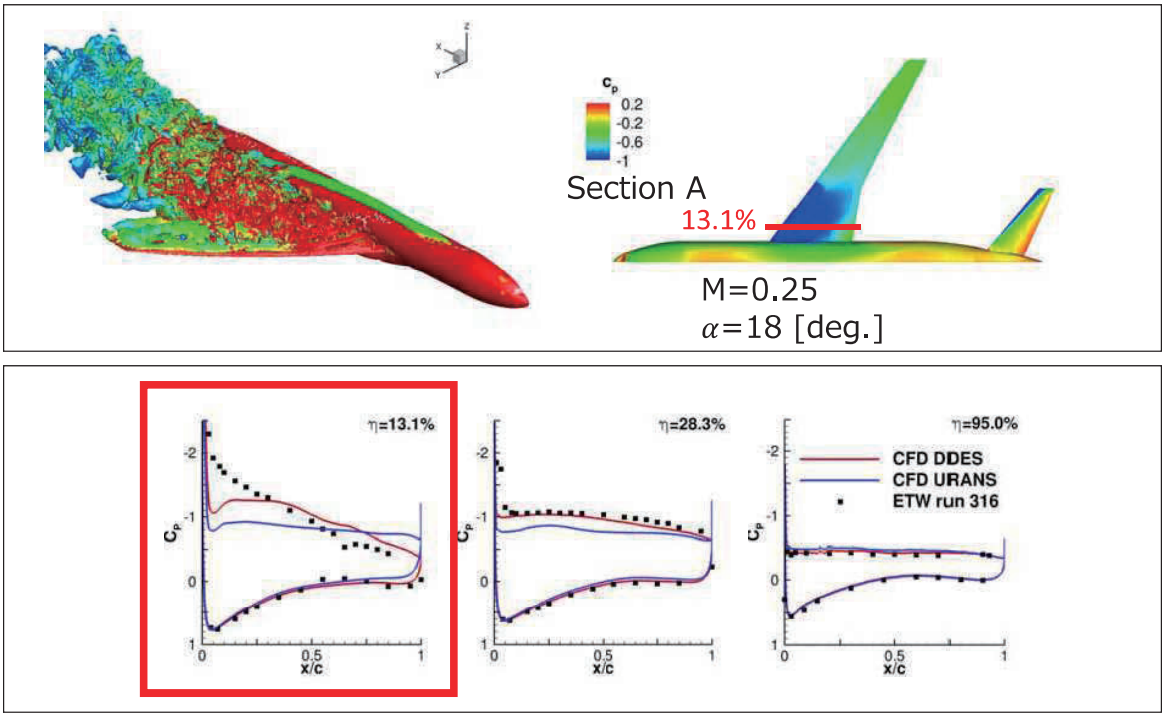
Thanks to: Alumni of Kitamura's Group
Ogawa, S., Takimoto, H., Harada, T., Takagi, Y. (YNU)

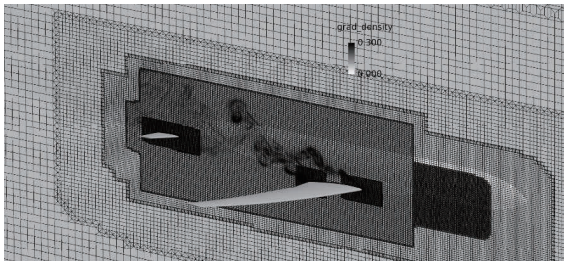
YNU YOKOHAMA National University

Low-Speed Buffet Simulations around Whole Aircraft: : NOT Good Match with Experiment



3) Waldmann, A. *et al.*, AIAA 2015-1096, 2015

Low-Speed Buffet Simulations around Whole Aircraft: Present Numerical Grid, Methods, and Conditions



22,823,905 Cells

Conditions

Mach	0.25
Re	1.16E7
AoA	18 deg.

Methods

Numerical Flux	SLAU
Turb. Model	DDES
Time Integration	LU-SGS + Backward Diff. (5 Inner-Iterations, CFL≈100,000)
Slope	Green-Gauss
Slope Limiter	Hishida (vL)

Low-Speed Buffet Simulations around Whole Aircraft: Promising Hybrid Methods, e.g., DDES

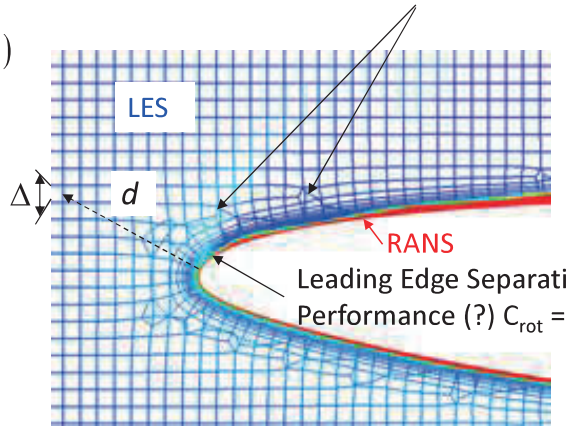
2) 0.65 is the typical choice.
Large C_{DES} : Large RANS Region
Small C_{DES} : Large LES Region

$$\tilde{d} = d - f_d \max\left(0, d - C_{DES}\Delta\right)$$

$$f_d = 1 - \tanh\left(8^3 r_d^3\right)$$

$$r_d = \frac{\tilde{\nu}}{\sqrt{u_{i,j}u_{i,j}}\kappa^2 d^2}$$

3) Dirty Cells (?)



Leading Edge Separation: 1)Depending on RANS Performance (?) C_{rot} = 1.0

Around the Leading Edge of the Main Wing.
$\tilde{d}/d$ is visualized, i.e., 0 (Blue) roughly corresponds to LES region, and 1 (Red) is RANS.

Low-Speed Buffet Simulations around Whole Aircraft: Proposed HR-DDES

2) 0.65 is the typical choice. **->0.51**

Large C_{DES} : Large RANS Region

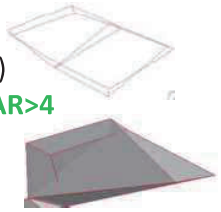
Small C_{DES} : Large LES Region

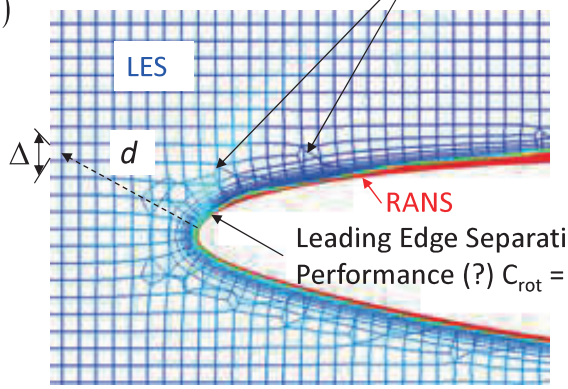
$$\tilde{d} = d - f_d \max\left(0, d - C_{DES}\Delta\right)$$

$$f_d = 1 - \tanh\left(8^3 r_d^3\right)$$

$$r_d = \frac{\tilde{\nu}}{\sqrt{u_{i,j}u_{i,j}}\kappa^2 d^2}$$

3) Dirty Cells (?) Treatment for **AR>4**





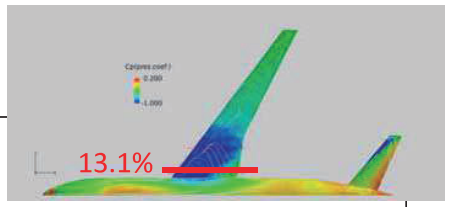
Leading Edge Separation: 1)Depending on RANS Performance (?) C_{rot} = 1.0 -> **2.0**

Around the Leading Edge of the Main Wing.

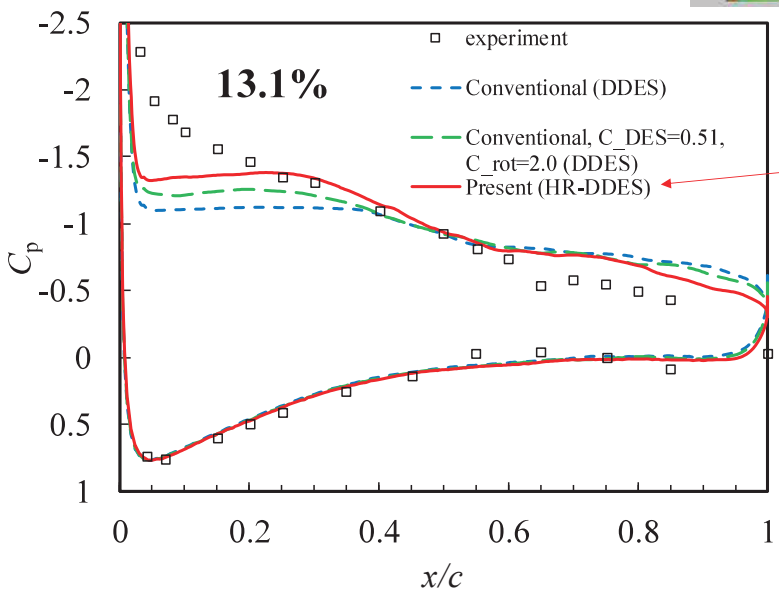
$\tilde{d}/d$ is visualized, i.e., 0 (Blue) roughly corresponds to LES region, and 1 (Red) is RANS.

Kitamura et al., "Low Speed Buffet Simulation using High-Resolution Delayed-DES with Improved LES/RANS Transition," APISAT 2019.

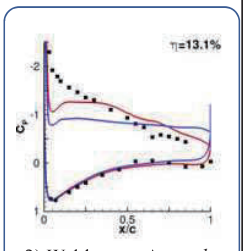
C_p Distributions



C_p Distributions over Main Wing, 13.1% Spanwise Cross-Section



Dirty-Cell Treatment (AR>4)



3) Waldmann, A. *et al.*, AIAA 2015-1096, 2015

- C_{DES}=0.51, C_{rot} = 2.0, and Dirty-Cell Treatment (AR>4): Best Match with Experiment!

Summary for HR-DDES (M=0.25)

- "HR-DDES" is proposed. This achieved:
  - ➢SA-noft2-R Coeff. C_{rot}: 1.0 -> 2.0
  - ➢DES Coeff. C_{DES}: 0.65 -> 0.51 (=Wider LES region)
  - ➢Dirty-Cell Treatment: Length Scale modification for AR>4.
- NASA-CRM Low Speed Buffet:
  - ➢Better agreement with Experiment.
- Opening the door to the "study on C_{rot} and C_{DES} in DDES"

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TASK 2: UNSTEADY SIMULATIONS

8

APC6 Task 2: Unsteady Simulations [1]

M=0.168
α=11.05, 13.08 [deg.]

APC6 (α=11.05 [deg.]) [1-1]

APC6 (α=13.08 [deg.]) [1-2]

Ref: [2]

M=0.25
α=18 [deg.]

Code	FaSTAR
Discretization	FVM
	Cell-Centered
Numerical Flux	HR-SLAU2 (2nd-order)
Slope	Green-Gauss
Time Integration	LU-SGS
Turb. Model	SA-noft2-R Delayed DES
Initial Condition	Uniform Flow

HR-DDES is used for [1] and [2]

Time Average

45,000-63,000 timesteps

Residuals

Based on our experience in [2]

M=0.25
α=18 [deg.]

(further investigations needed)

Aerodynamic Coefficients

AoA11.05

CD	CL	CM
0.16799	0.967969	0.166258

(Exp.) 0.1247 0.9172 -0.0537

AoA13.08

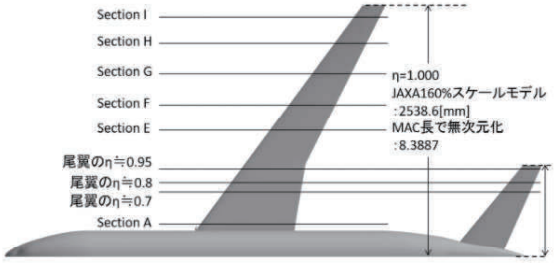
CD	CL	CM
0.191016	0.958536	-0.124039

(Exp.) 0.2053 0.9305 0.0186

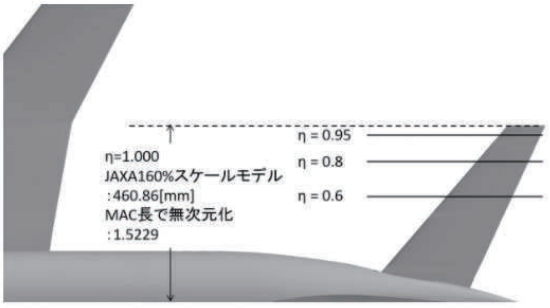
Ref:
https://cfdws.chofu.jaxa.jp/apc/exp.html

Cross-Sections

Main Wing



(Horizontal) Tail Wing

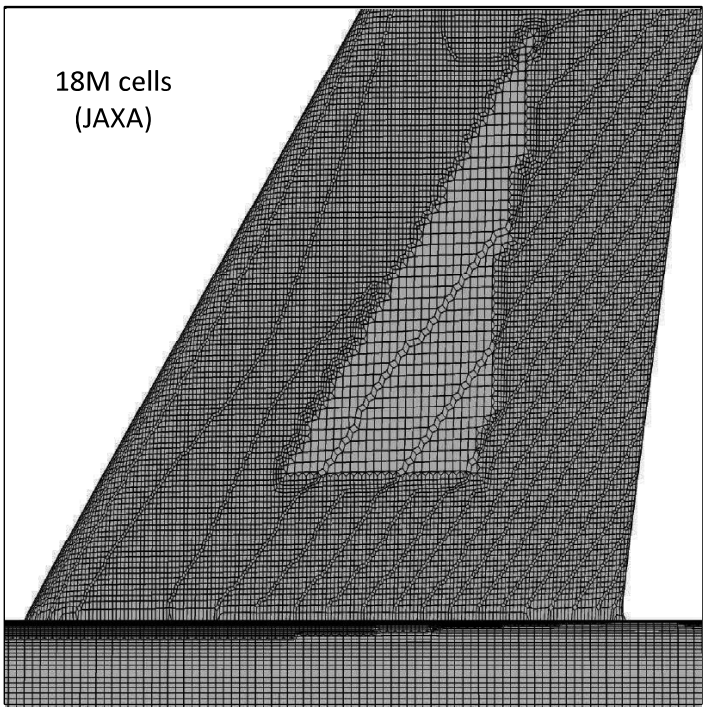


Section A	13.1%
Section B′	25.3%
Section C′	29.1%
Section D′	34%
Section E	50.2%
Section F	60.3%
Section G	72.7%
Section H	84.6%
Section I	95%

Tail Section HA	60%
Tail Section HB	80%
Tail Section HC	95%

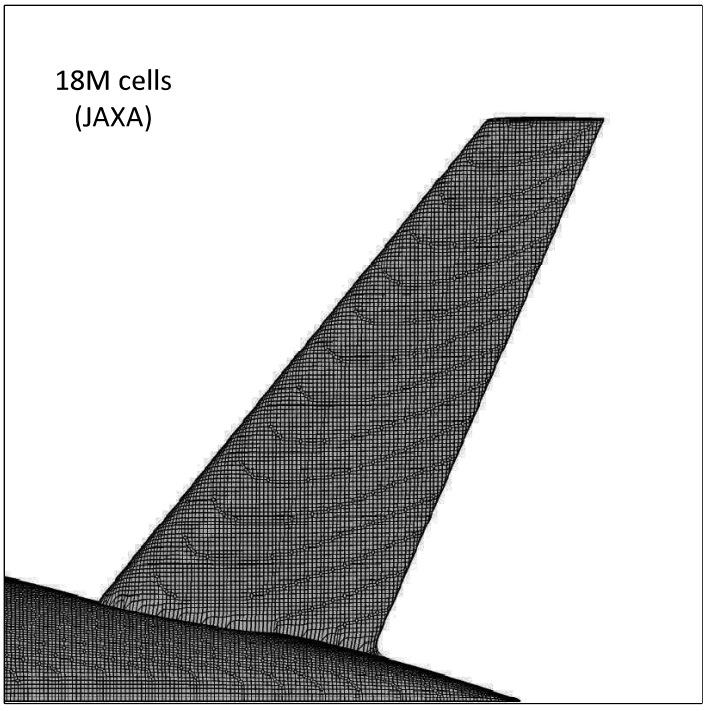
Section A: [1] and [2]
Others: [1] Only

Surface Mesh: Main-Wing Root



13

Surface Mesh: Tail-Wing



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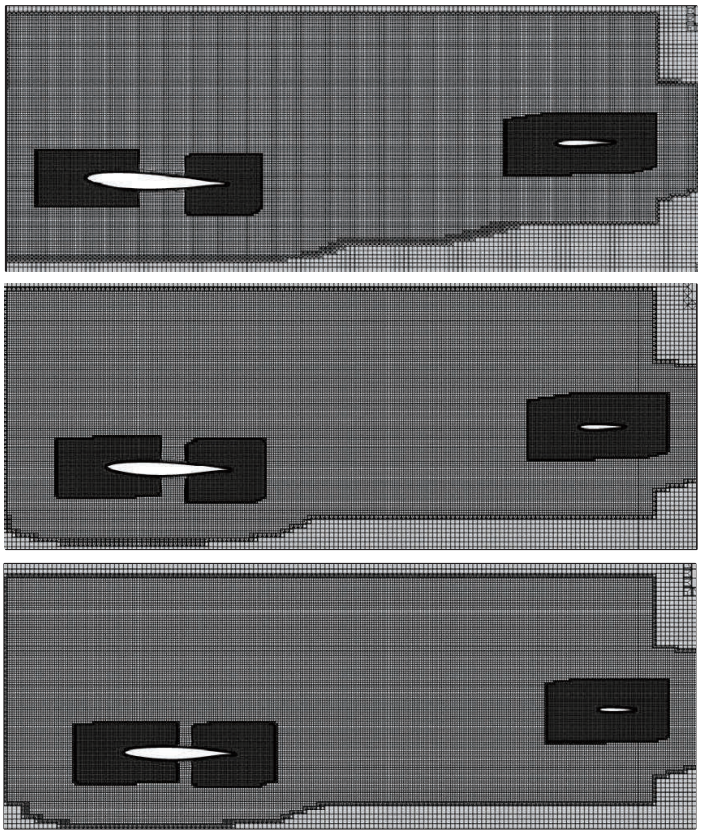
Mesh for Main Wing Wake

18M cells
(JAXA)



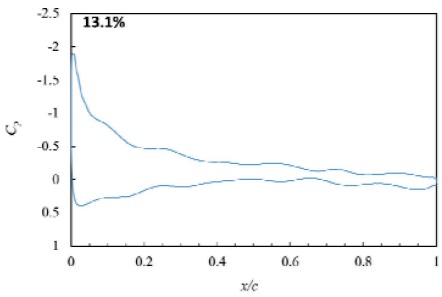
15

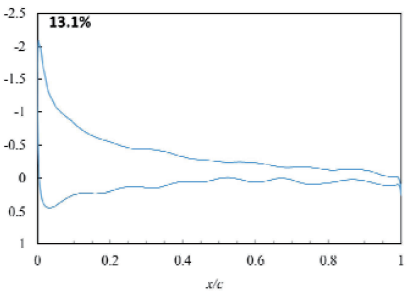
[1] APC
[2] M=0.25

Mach (Time-Averaged)

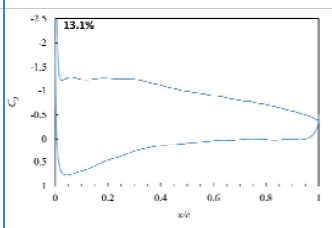
Section A	13.1%

[1] α=11.05 [deg.], 13.08 [deg.]





[2]α=18 [deg.]

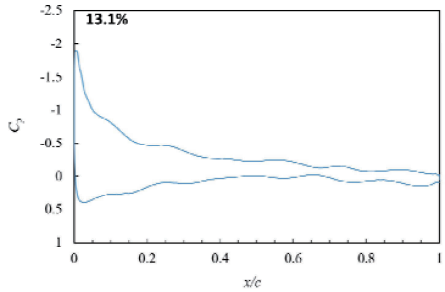


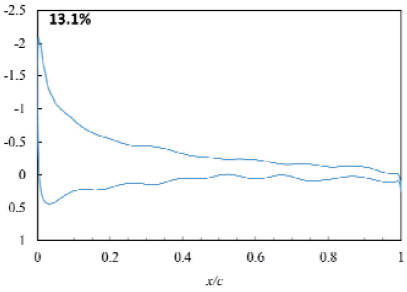
[1] APC
[2] M=0.25

Mach (Time-Averaged)

Section A	13.1%

[1] α=11.05 [deg.], 13.08 [deg.]

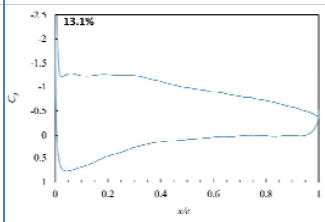




- T.E. Separation ?
- Oscillatory

➡ Needs Additional Cares for T.E. Sep., or Longer Computation?

[2]

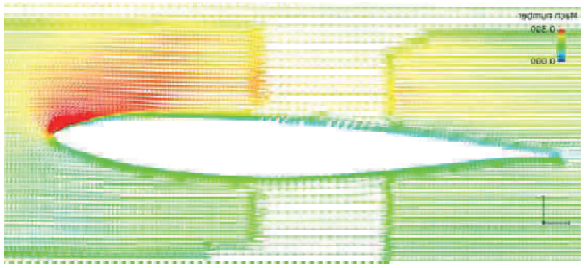


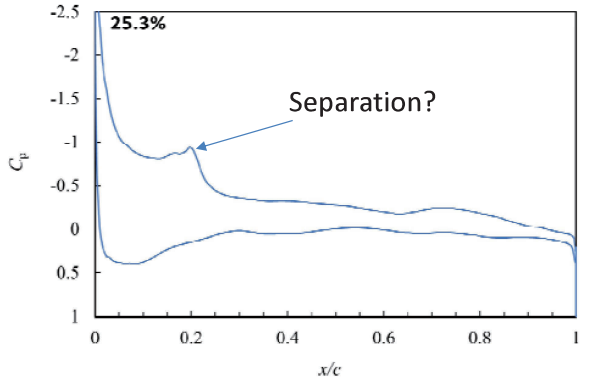
- L.E. Separation

Mach (Time-Averaged)

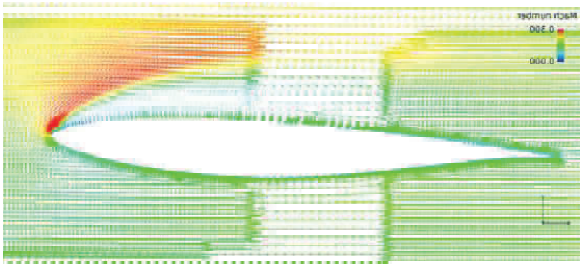
Section B’	25.3%

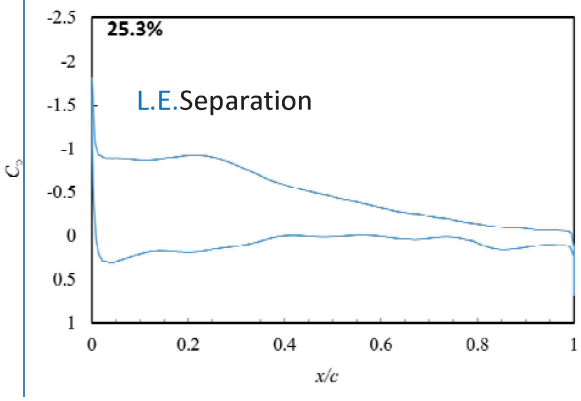
[1-1] α=11.05 [deg.]





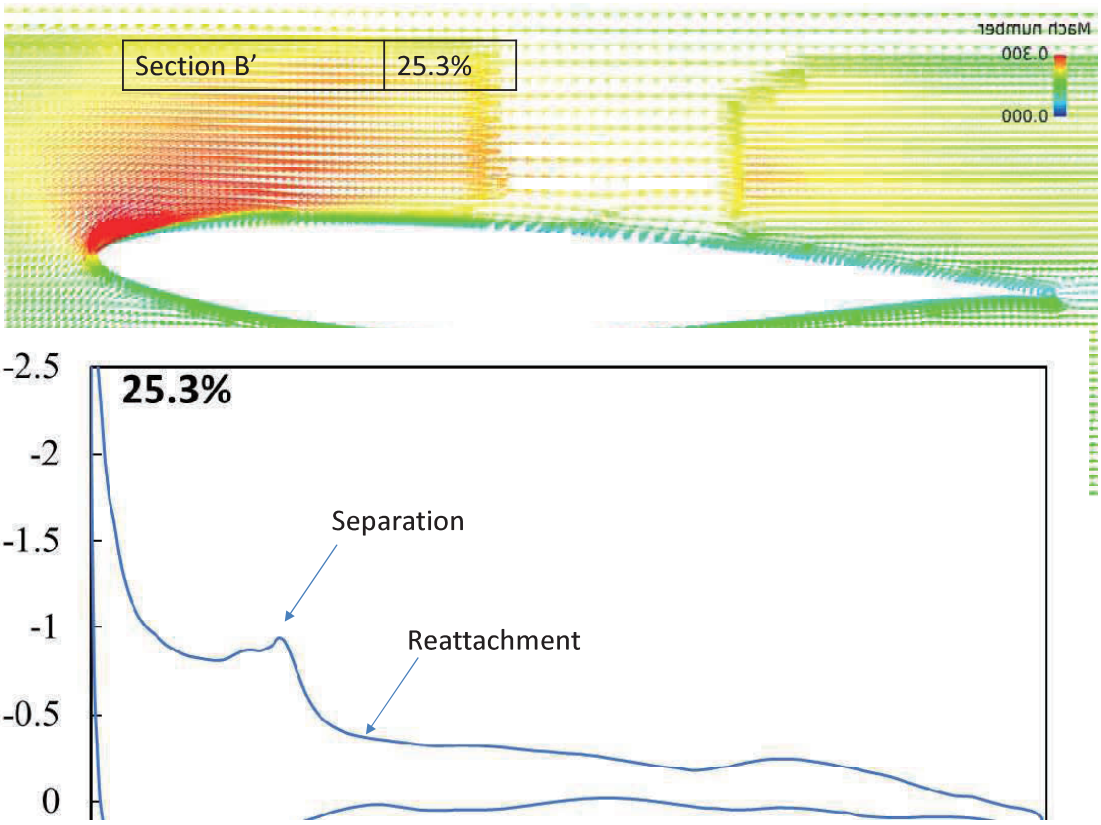
[1-2] α=13.08 [deg.]





Mach (Time-Averaged)

[1-1] α=11.05 [deg.]

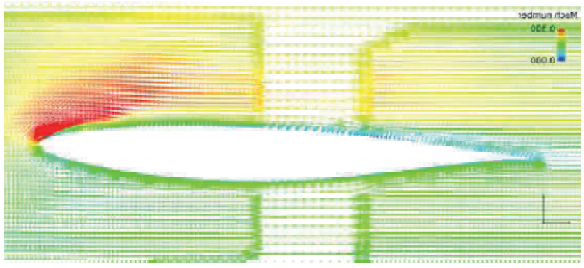


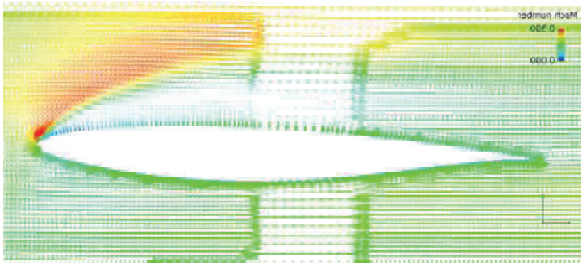
Mach (Time-Averaged)

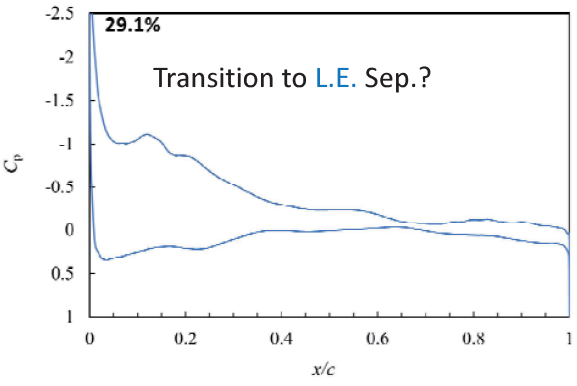
Section C'	29.1%

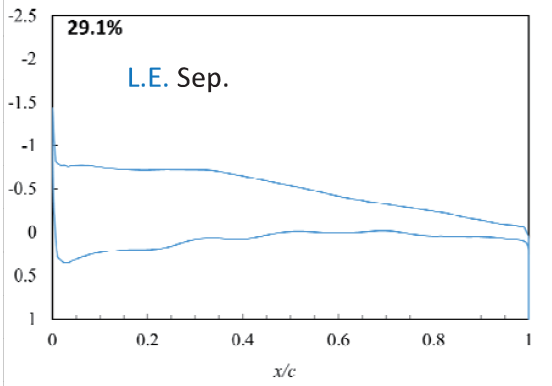
[1-1] α=11.05 [deg.]

[1-2] α=13.08 [deg.]





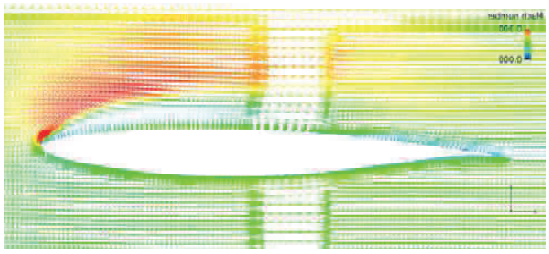


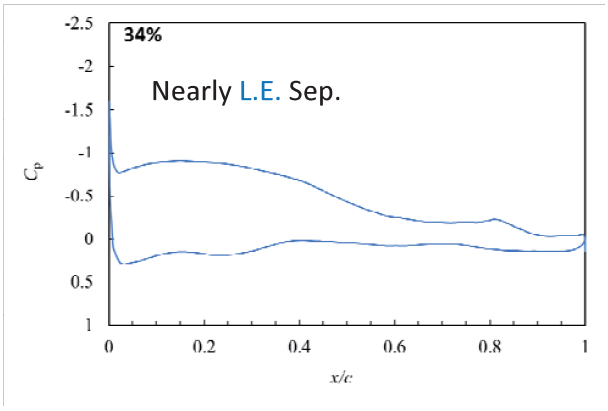


Mach (Time-Averaged)

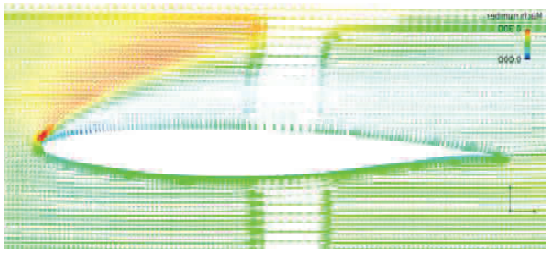
Section D’	34%

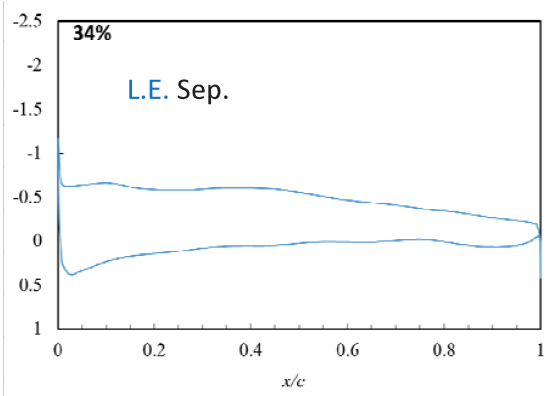
[1-1] α=11.05 [deg.]





[1-2] α=13.08 [deg.]

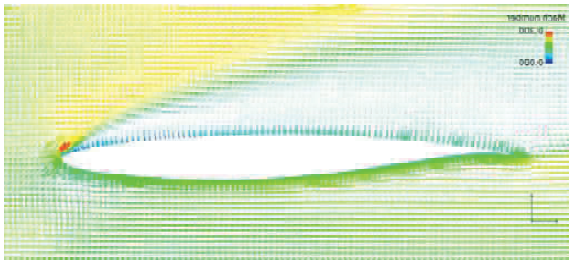


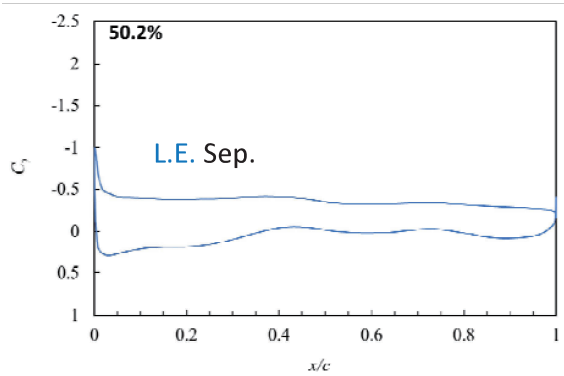


Mach (Time-Averaged)

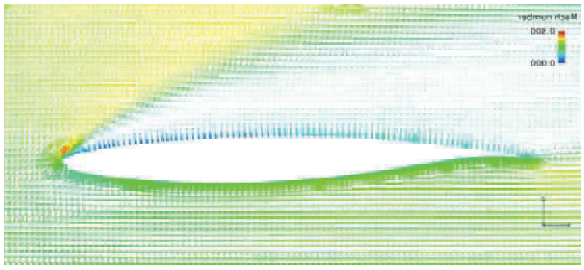
Section E	50.2%

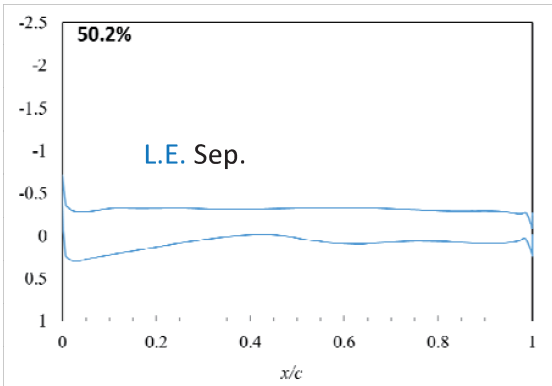
[1-1] α=11.05 [deg.]





[1-2] α=13.08 [deg.]

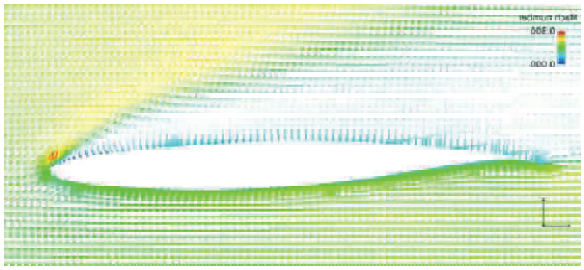


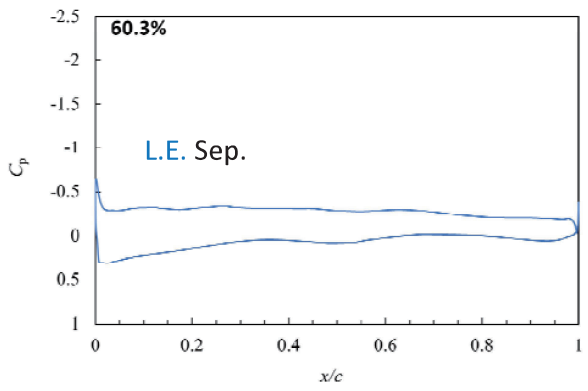


Mach (Time-Averaged)

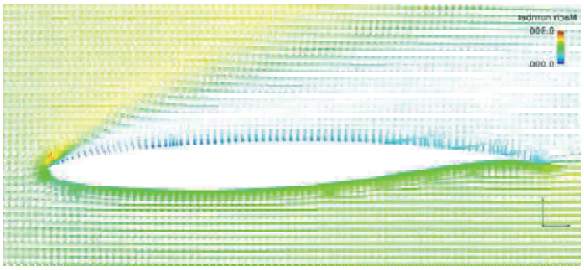
Section F	60.3%

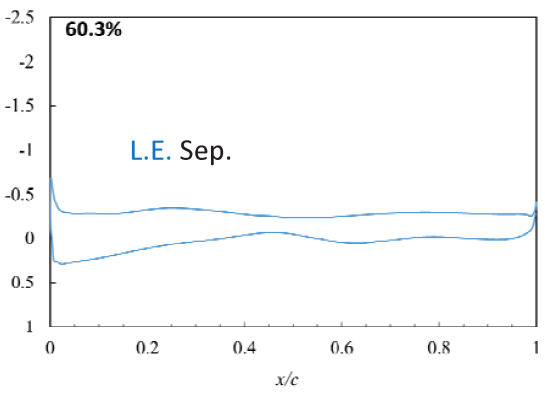
[1-1] α=11.05 [deg.]





[1-2] α=13.08 [deg.]

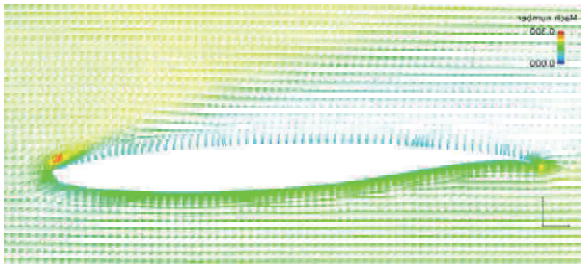


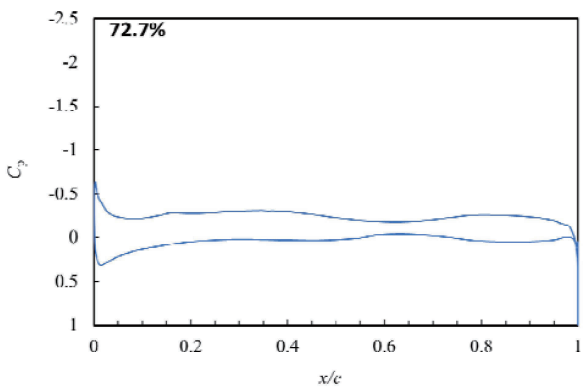


Mach (Time-Averaged)

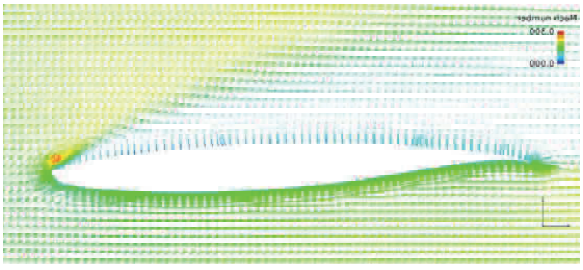
Section G	72.7%

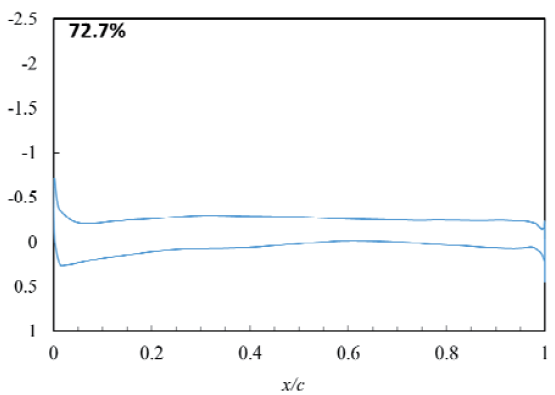
[1-1] α=11.05 [deg.]





[1-2] α=13.08 [deg.]

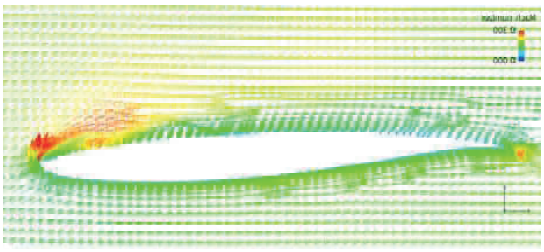


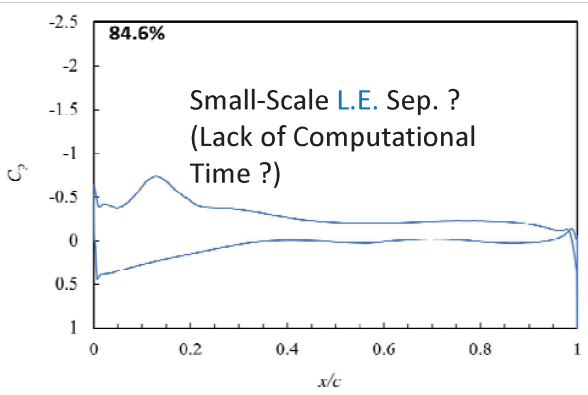


Mach (Time-Averaged)

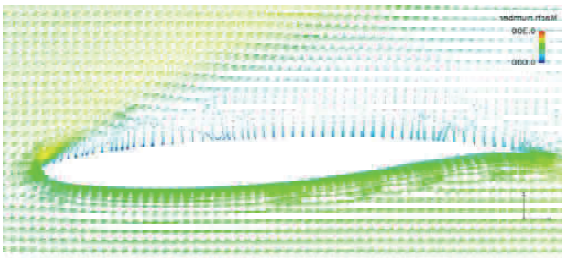
Section H	84.6%

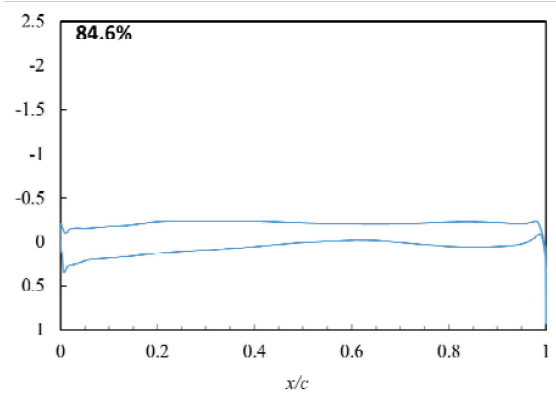
[1-1] α=11.05 [deg.]





[1-2] α=13.08 [deg.]

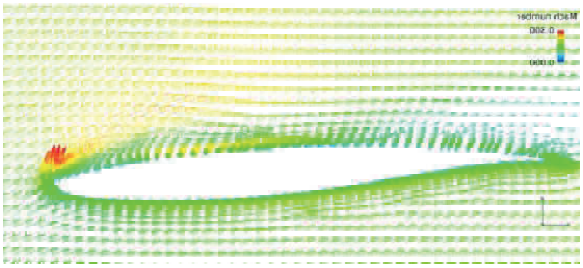


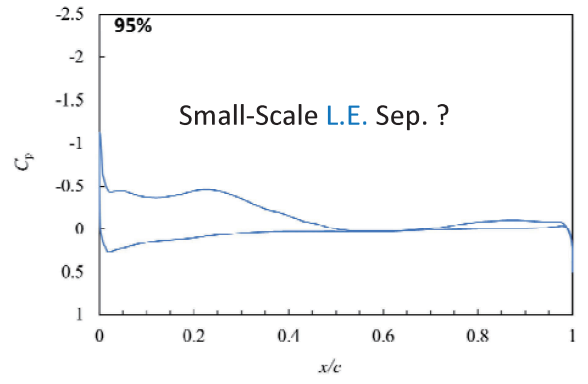


Mach (Time-Averaged)

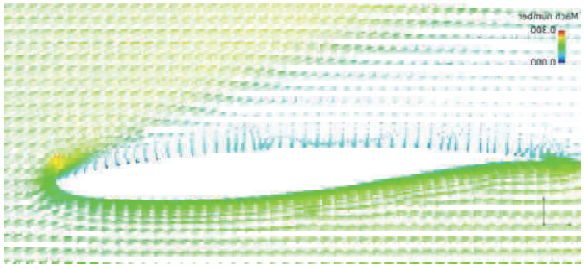
Section I	95%

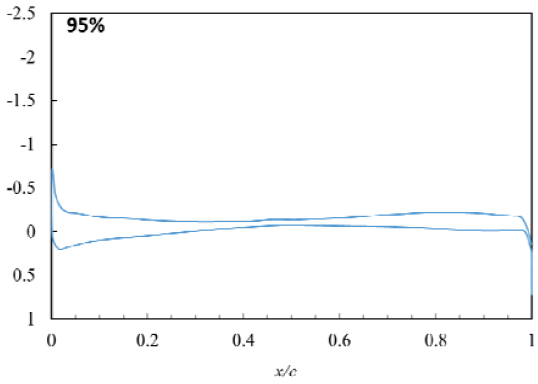
[1-1] α=11.05 [deg.]





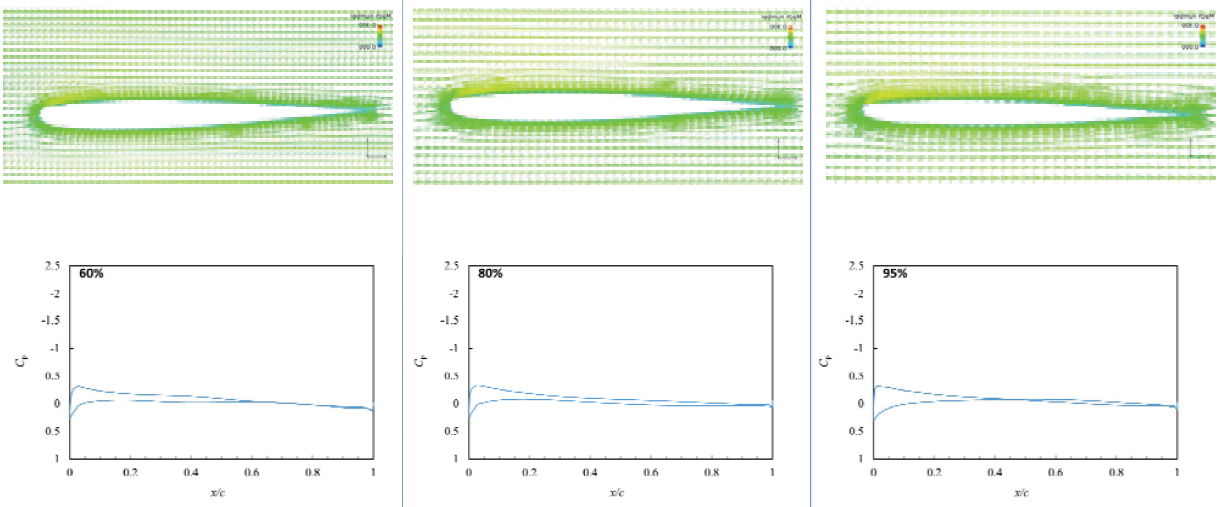
[1-2] α=13.08 [deg.]





Mach (Time-Averaged) [1-1] α=11.05 [deg.]

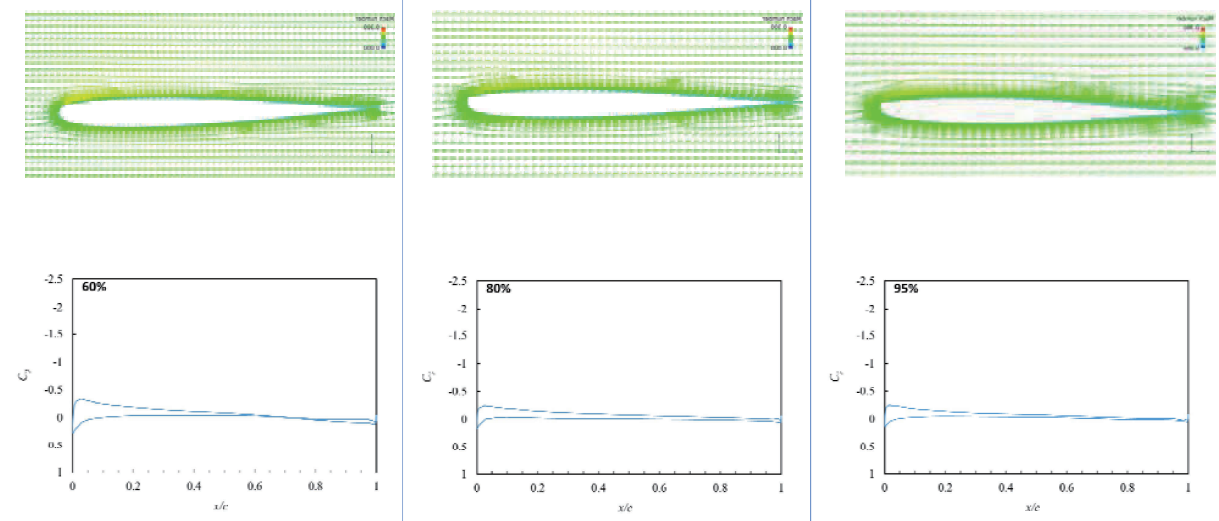
Tail Section HA	60%	Tail Section HB	80%	Tail Section HC	95%



Attached Flows

Mach (Time-Averaged) [1-2] α= 13.08 [deg.]

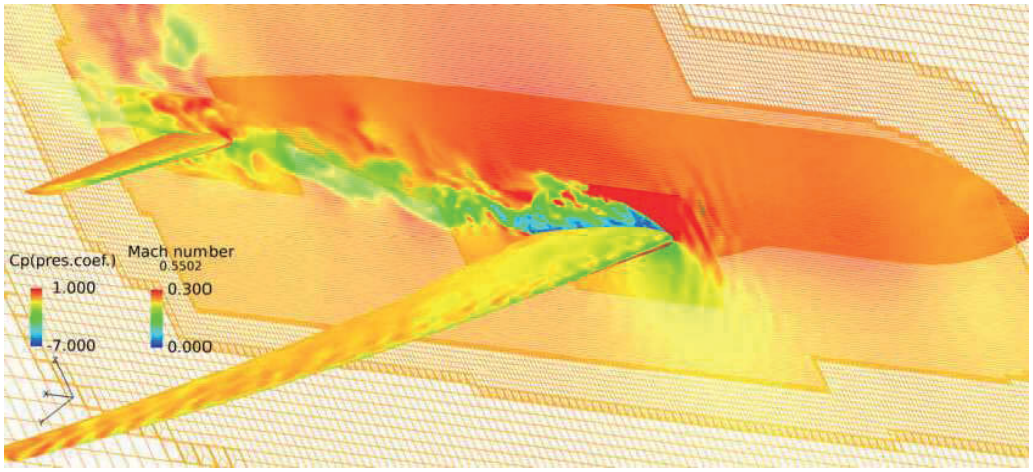
Tail Section HA	60%	Tail Section HB	80%	Tail Section HC	95%



Attached Flows

Computational Issue ?
Cp (Instantaneous)

[2] M=0.25



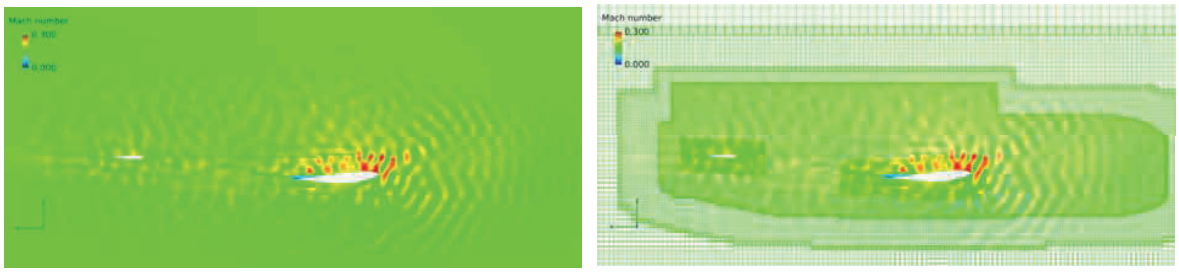
- Unsteady, Wavy Patterns observed in Cp Distributions
- Specific to the Selected Methods? Or already seen in previous computations ? (Only hardly seen?)
- **NOT easily found in Time-Averaged Field.**

13.1% Cross-sectional Mach (Instantaneous)

[1-1] APC6

- Oscillatory only near the body
- Waves disappear at cells whose sizes change abruptly

-> Mesh-dependent?

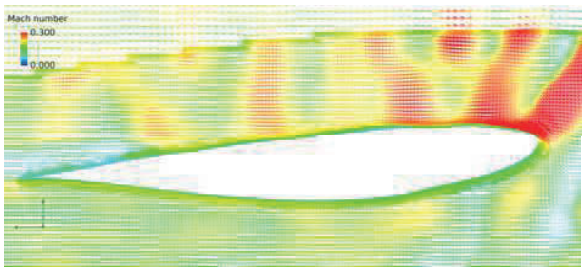


[1-1]_13.1% Cross-Section

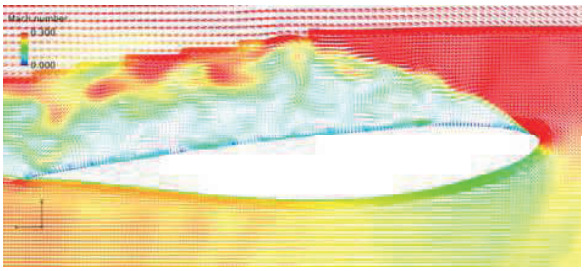
Cross-sectional Mach (Instantaneous)

[1-1] APC
[2] M=0.25

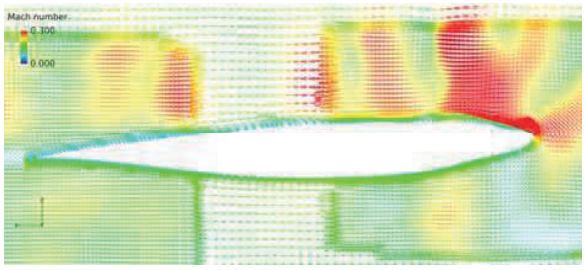
[1-1] Section A 13.1%



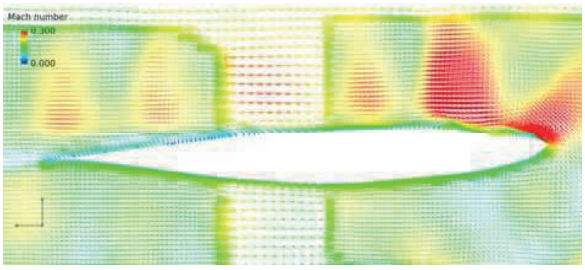
[2] Section A 13.1%



[1-1] Section B' 25.3%



[1-1] Section C' 29.1%



Summary and Future Tasks

- Unsteady Oscillations Identified (Hardly Seen in Time-Averaged Solutions), Possibly Depending on:
  Method, Mesh, Time Interval (How small should it be?),
  Time-Average Duration
- "HR-DDES" Unsteady Computations
  - "Unsteady Preconditioning" (Kim et al., AIAA J. 2018; Folkner et al., AIAA-2014-1424; Moguen, et al., J. Comput. Appl. Math. 2013)
    - May be effective
- DES Coeff. C_{DES}:
  Dynamically controlled (Dynamic DDES (DDDES))(?)
- Others: Supersonic/ Stabilization/ Grids

Acknowledgments

- The flow solver used here was **FaSTAR** developed at JAXA, as well as the mesh generators **HexaGrid** and **MEGG3D**.
- The computations were conducted using JAXA's Supercomputer System (**JSS**) 2.
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