1A20

Comparative Study on Turbulence Models and Numerical Flux Functions in NASA CRM Unsteady Low-Speed Buffet Simulations

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and
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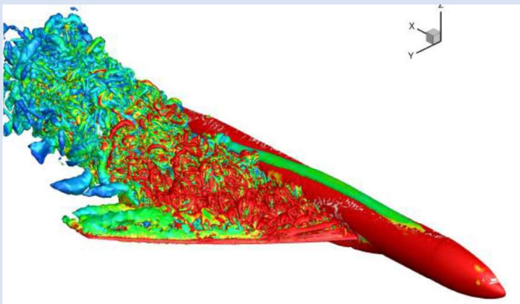
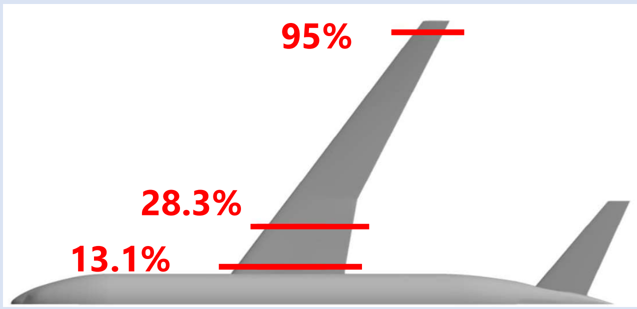
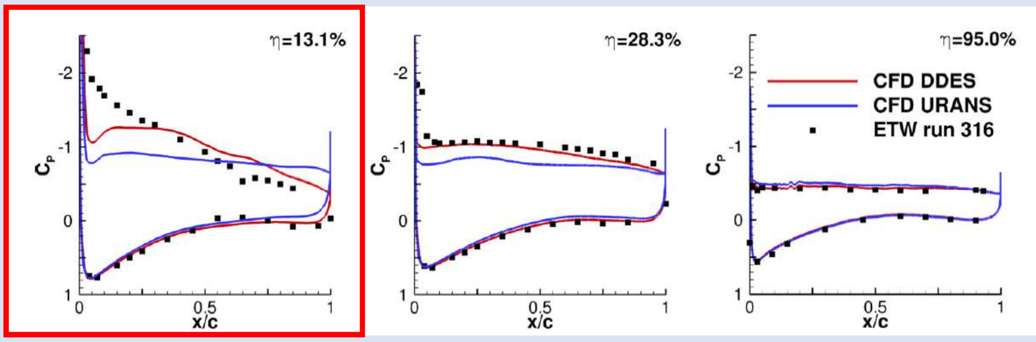
Background







[1]

➢ NOT Good Match with Experiment

[1] Andreas Waldman, Philipp Gansel, Thorsten Lutz, Ewald Kramer : Unsteady Wake Flow of an Aircraft under Low-Speed Stall Conditions in DES and PIV, 53rd AIAA Aerospace Sciences Meeting, 2015

Background

HR-DDES

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

②0.65 is the typical choice.

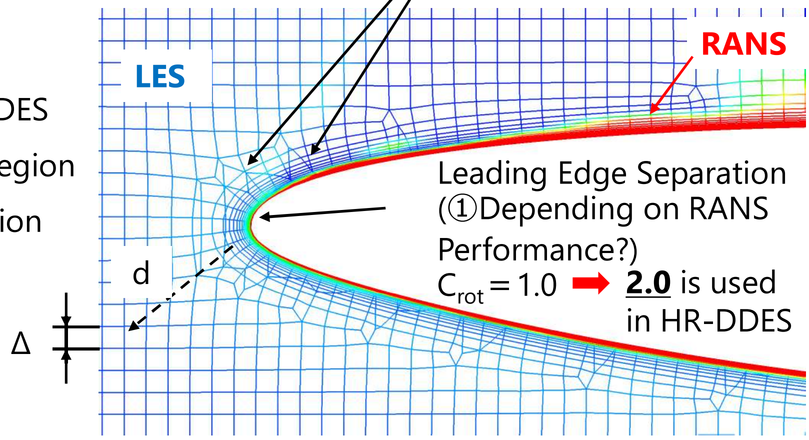
➡ **0.51** is used in HR-DDES

Large C_{DES} : **Large** RANS Region

Small C_{DES} : **Large** LES Region

③Dirty Cells ?

➡ **Deal with AR>2**



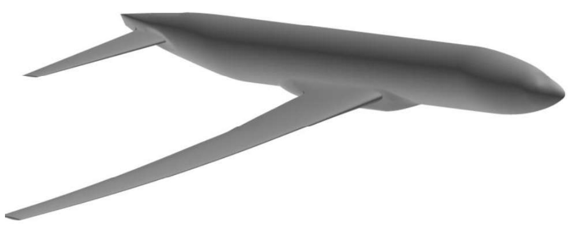
Leading Edge Separation (①Depending on RANS Performance?)

$C_{rot} = 1.0$ ➡ **2.0** is used in HR-DDES

- $\tilde{d}/d$ is visualized around the leading edge of the main wing by color counter. 0(**Blue**) roughly corresponds to **LES** region, and 1(**Red**) is **RANS** region.

Background

Previous Study (Low-Speed Buffet)[2]



NASA CRM
22,823,905 cells

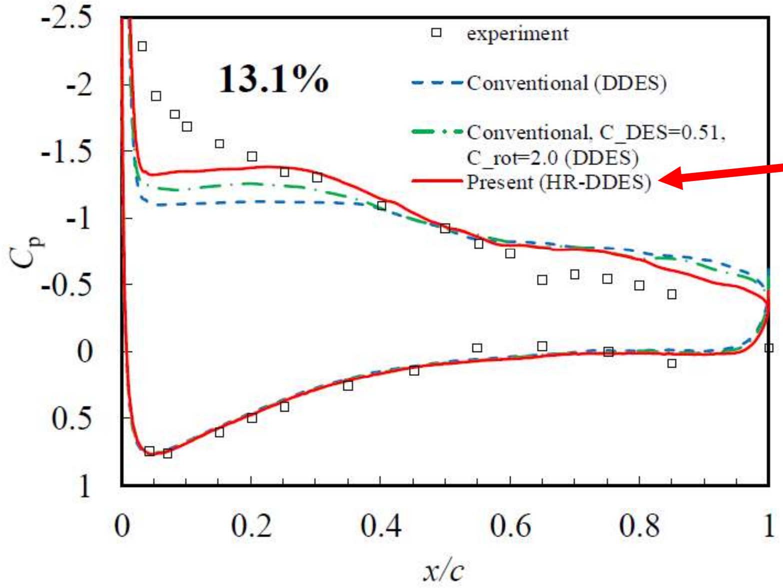
Conditions[3]		
Mach Number	:	**M = 0.25**
Reynolds Number	:	$Re = 1.16\times10^7$
Angle of Attack	:	**α = 18 [deg.]**

Methods		
Numerical Flux	:	**SLAU**
Turbulent Model	:	DDES
Time Integration	:	LU-SGS
Slope	:	Green-Gauss
Slope Limiter	:	Hishida(vL)

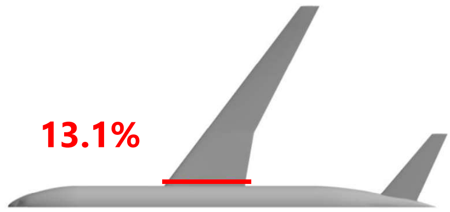
[2] Kitamura Keiichi, Ogawa Suguru, Takimoto Hiroyuki, Kanamori Masashi, Hashimoto Atsushi : High-Resolution Delayed-Detached-Eddy-Simulation(HR-DDES) on Low Speed Buffet, Proceeding of the 51st Fluid Dynamics Conference / the 37th Aerospace Numerical Simulation Symposium, 2019.
[3] Andreas Waldman, Philipp Gansel, Thorsten Lutz, Ewald Kramer : Unsteady Wake Flow of an Aircraft under Low-Speed Stall Conditions in DES and PIV, 53rd AIAA Aerospace Sciences Meeting, 2015.

Background

Previous Study (Low-Speed Buffet)[2]



Dirty Cell Treatment(AR>2)



- C_{DES}=0.51, C_{rot}=2.0 and Dirty Cell Treatment(AR>2)
  - ➡ Best Match with Experiment

[2] Kitamura Keiichi, Ogawa Suguru, Takimoto Hiroyuki, Kanamori Masashi, Hashimoto Atsushi : High-Resolution Delayed-Detached-Eddy-Simulation(HR-DDES) on Low Speed Buffet, Proceeding of the 51st Fluid Dynamics Conference / the 37th Aerospace Numerical Simulation Symposium, 2019.

Objective

- Investigate the effects of the turbulence models and numerical flux functions in Unsteady NASA CRM Low-Speed Buffet Simulations

Case		
HH	:	HR-SLAU2＆HR-DDES
HS	:	HR-SLAU2＆SA-DDES
SS	:	SLAU2＆SA-DDES

HR-DDES
C_{DES} = 0.51
C_{rot} = 2.0

SA-DDES
C_{DES} = 0.65
C_{rot} = 1.0

Conditions

- Task 2：Unsteady simulations

  Using “HexaGrid” Grid (provided by JAXA)

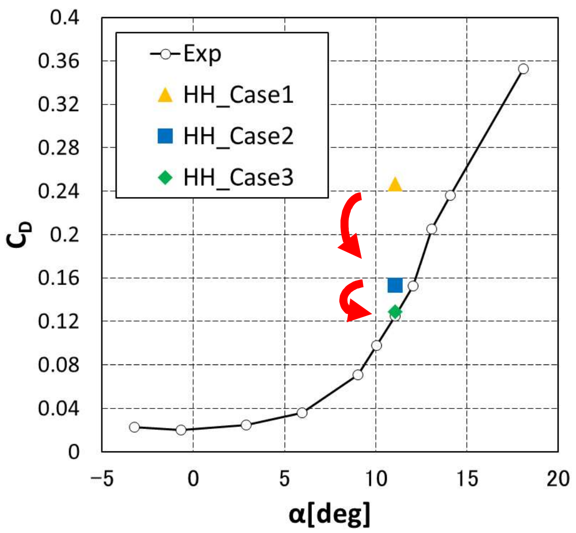
Conditions			
Mach Number	:	M	= 0.168
Reynolds Number	:	Re	$= 1.06\times10^{6}$
Angle of Attack	:	α	= 11.05, 13.08 [deg.]
Time Step	:	Δt	= 0.0125 [-]
			(2.48×10^{-4} [s])

Conditions

- Task 2：Unsteady simulations

  Using “HexaGrid” Grid (provided by JAXA)

Time Step Verification



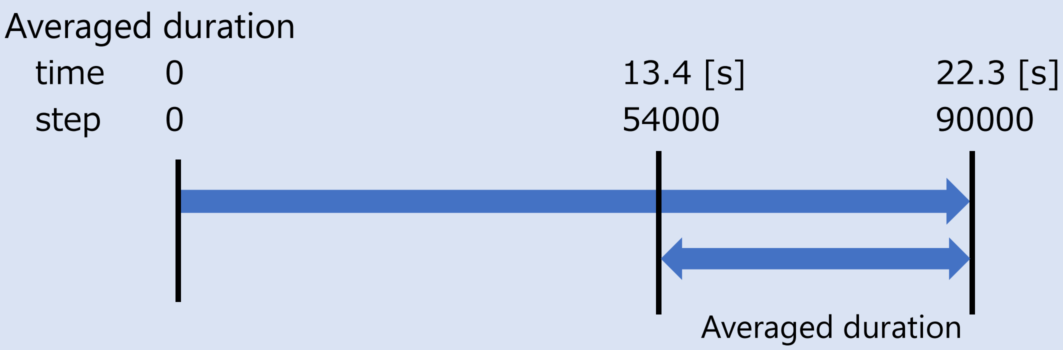
	Δt	Error [%]
HH_Case1	0.05	97.76
HH_Case2	0.025	22.81
HH_Case3	**0.0125**	**3.391**

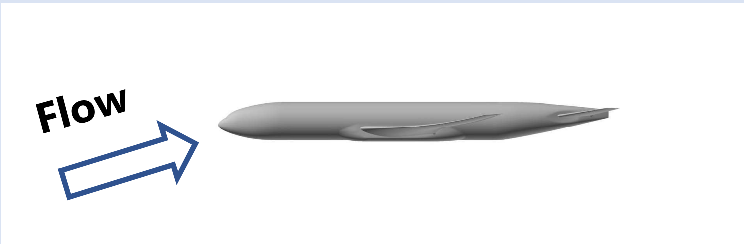
- Δt=0.0125 yielded the smallest error from Exp. data

Conditions

➢ Task 2：Unsteady simulations

Using "HexaGrid" Grid (provided by JAXA)





Methods

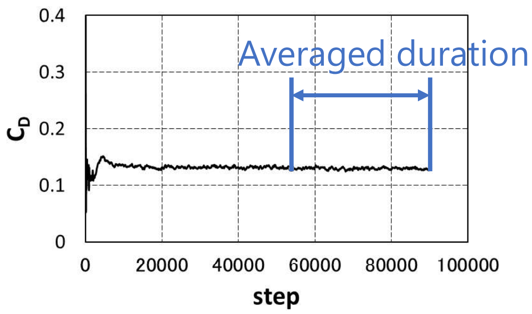
➢ Task 2：Unsteady simulations

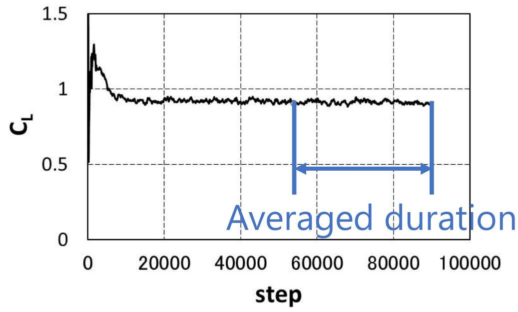
Using "HexaGrid" Grid (provided by JAXA)

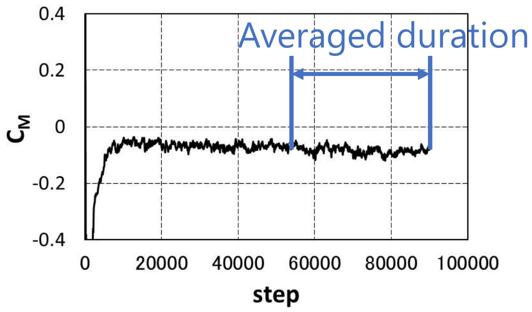
Methods		
Solver	:	FaSTAR
Numerical Flux	:	**SLAU2 or HR-SLAU2**
Turbulence Model	:	**HR-DDES or SA-DDES**
Time Integration	:	LU-SGS
Slope	:	Green-Gauss
Slope Limiter	:	Hishida(vL)

Result

Time History of Aerodynamic Coefficients (HH_AoA1105)





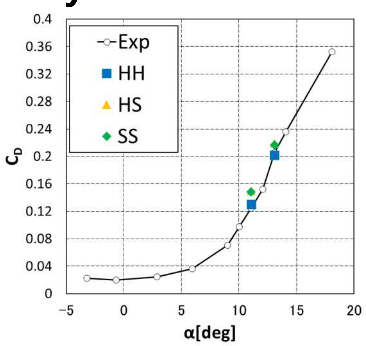


➢ The aerodynamic coefficients fully converge in the averaged duration

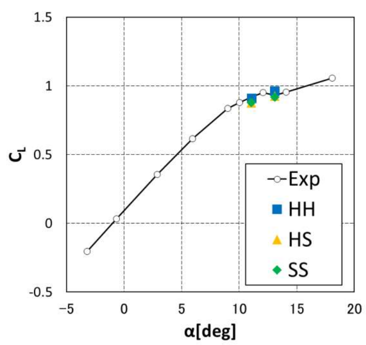
Result

Aerodynamic Coefficients

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES



	AoA11.05		AoA13.08	
	C_D Ave.	C_D Error [%]	C_D Ave.	C_D Error [%]
HH	**0.1299**	4.139	**0.2021**	1.544
HS	0.1499	20.18	0.2187	6.527
SS	0.1484	18.98	0.2168	5.626
Exp.	0.1247		0.2053	



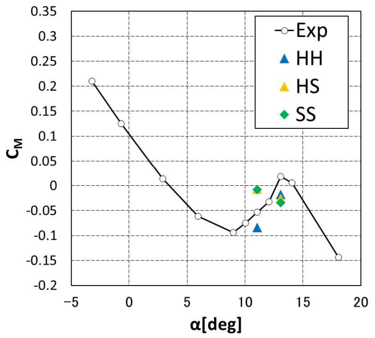
	AoA11.05		AoA13.08	
	C_L Ave.	C_L Error [%]	C_L Ave.	C_L Error [%]
HH	**0.9122**	0.5491	0.9623	3.420
HS	0.8752	4.578	**0.9238**	0.7196
SS	0.8781	4.261	0.9182	1.326
Exp.	0.9172		0.9305	

※The case closest to the Exp. is shown in **red**.

Result

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Aerodynamic Coefficients



	AoA11.05		AoA13.08	
	C_M Ave.	C_M Error [%]	C_M Ave.	C_M Error [%]
HH	**-8.435×10^{-2}**	57.08	**-1.798×10^{-2}**	196.7
HS	-7.435×10^{-3}	86.15	-2.572×10^{-2}	238.3
SS	-8.294×10^{-3}	84.55	-3.448×10^{-2}	285.3
Exp.	-5.37×10^{-2}		1.86×10^{-2}	

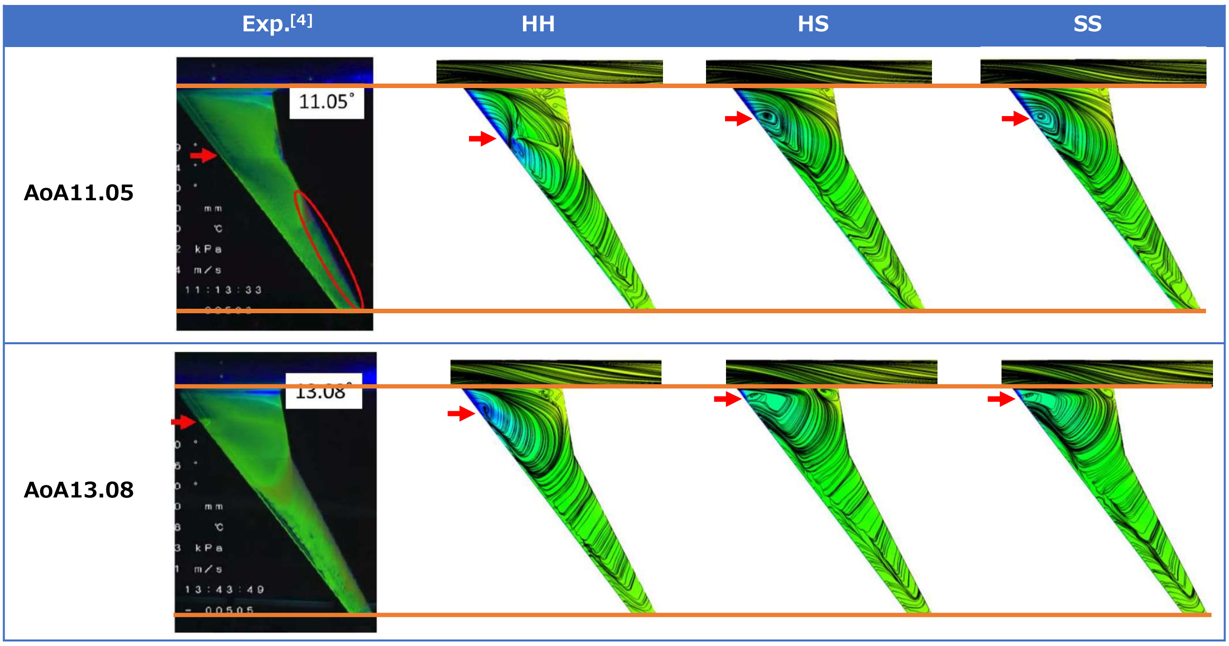
※The case closest to the Exp. is shown in **red**.

- HH showed the closest value to the Exp. for almost all the aerodynamic coefficients compared.
- C_M showed relatively large errors from Exp. regardless of the selected methods.
- Nevertheless, only HH can capture the trend of increase of C_M with increasing angle of attack.

Result

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Streamlines



- Flow separation point predicted by HH is the closest to the Exp.

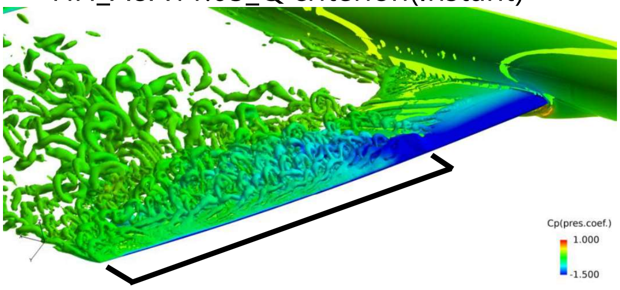
[4] Hashimoto Atsushi, Kanamori Masashi, Kirihara Ryohei, Matsuzaki Tomoaki, Nakamoto Keita, Hayashi Kenji : Steady and Unsteady computation on NASA-CRM with FaSTAR at low speeds and high angles of attack, Fluid Dynamics Conference / Aerospace Numerical Simulation Symposium 2020 Online, Sixth Aerodynamics Prediction Challenge (APC-6), 2020.

Result

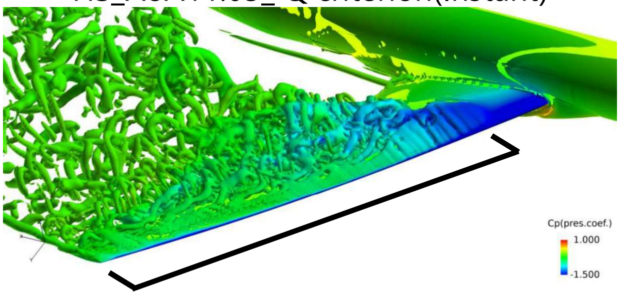
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Q Criterion

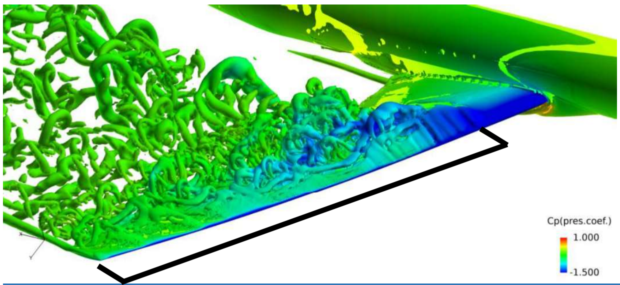
HH_AoA11.05_Q criterion(Instant)



HS_AoA11.05_ Q criterion(Instant)



SS_AoA11.05_Q criterion(Instant)



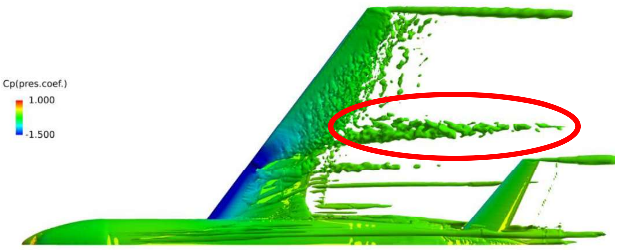
- The separation region simulated by HH is obviously different from HS and SS.

Result

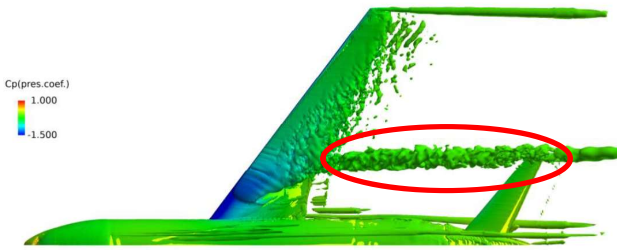
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Wake Interference with Tail

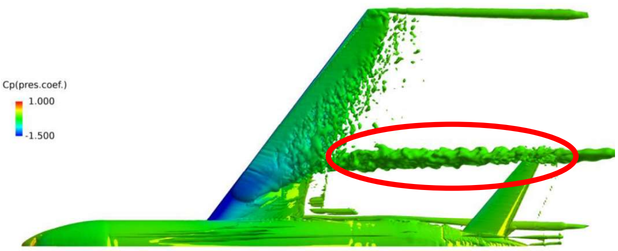
HH_AoA11.05_Q criterion(Averaged)



HS_AoA11.05_Q criterion(Averaged)



SS_AoA11.05_Q criterion(Averaged)



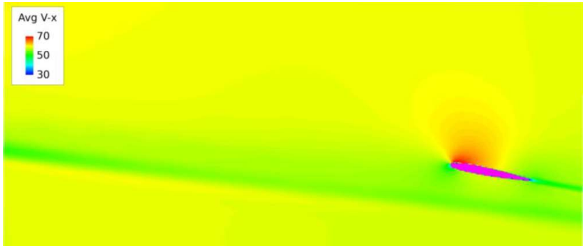
- Main wing wake is generated at the boundary between the separation and attached regions.
- In HH, the main wing wake does not interfere with the tail wing.

Result

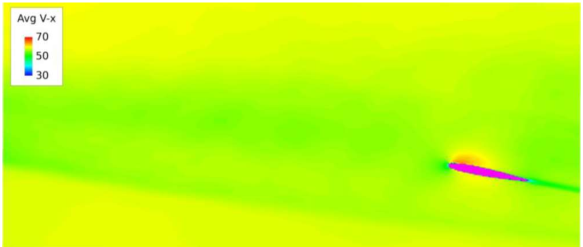
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Wake Interference with Tail

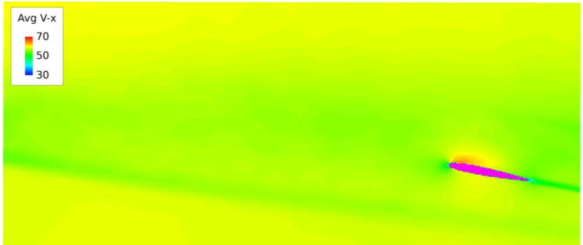
HH_AoA11.05_Section YB(Averaged)



HS_AoA11.05_Section YB (Averaged)



SS_AoA11.05_Section YB (Averaged)



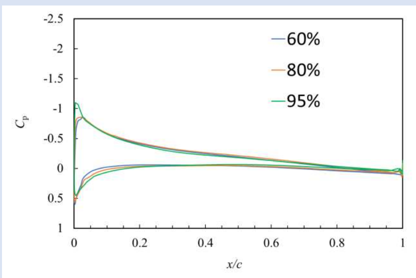
- Main wing wake is generated at the boundary between the separation and attached regions.
- In HH, the main wing wake does not interfere with the tail wing.

Result

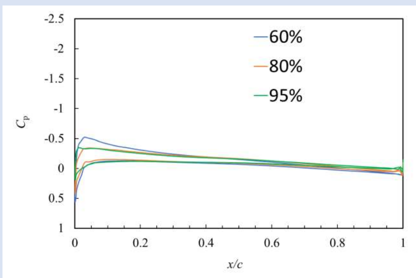
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

Wake Interference with Tail

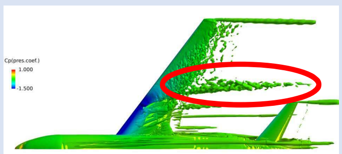
HH_Tail_Cp



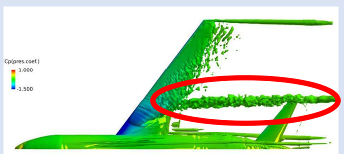
HS_Tail_Cp



HH_AoA1105



HS_AoA1105



- C_p distributions on upper surface of tail are different among cross-sections due to interference with wake. (large difference between 80% and 95%)

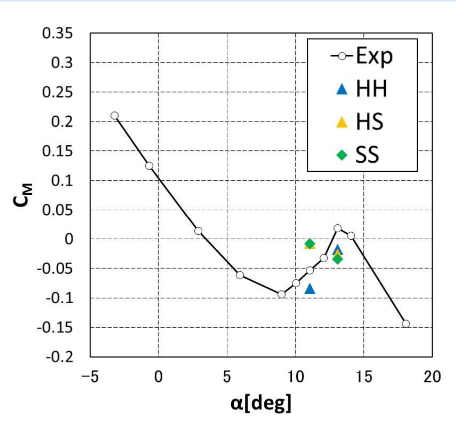
  ➡ Lift C_L is smaller in HS than in HH.

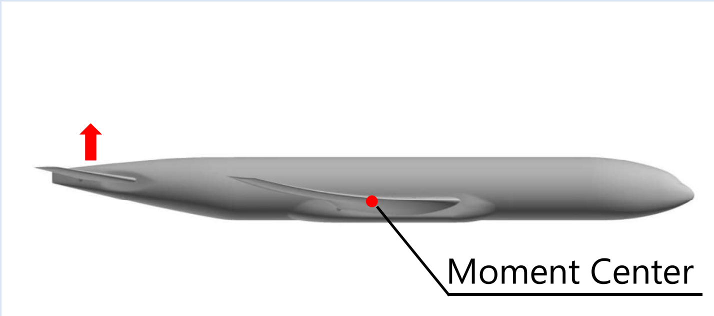
Tail C_L	
HH	HS
0.0416	0.0208

Result

Wake Interference with Tail

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES





Tail C_L	
HH	HS
0.0416	0.0208

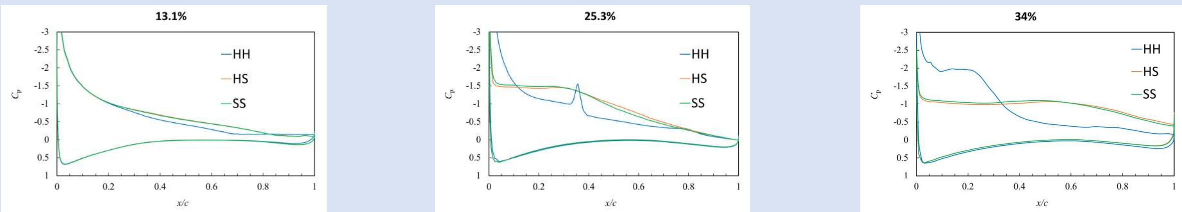
- Head-down moment is caused due to increased lift on the tail.
  - ➡ HH shows the closest value to the Exp.

Result

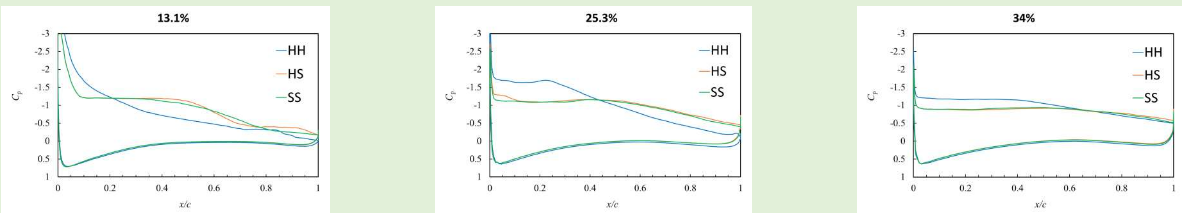
C_p Distributions

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

AoA11.05



AoA13.08

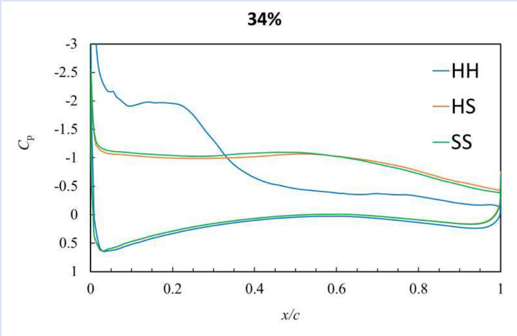


- HS and SS showed relatively similar distributions, different from HH.
- HH showed a spike of C_p around x/c = 0.35 at the 25.3% position.

Result

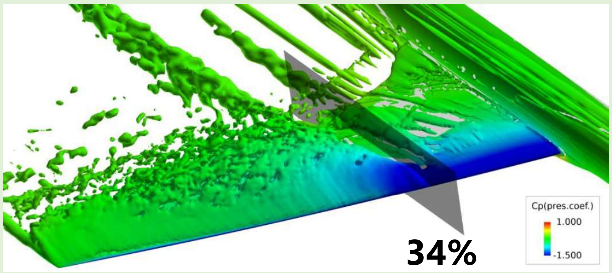
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

C_p Distributions

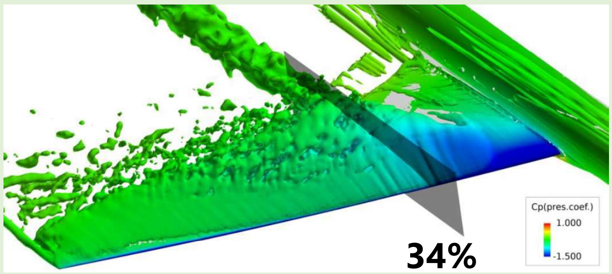


- In HH, the flow over the wing appears to begin to separate.
- In HS, the flow is completely separated.

HH_AoA11.05(Averaged)



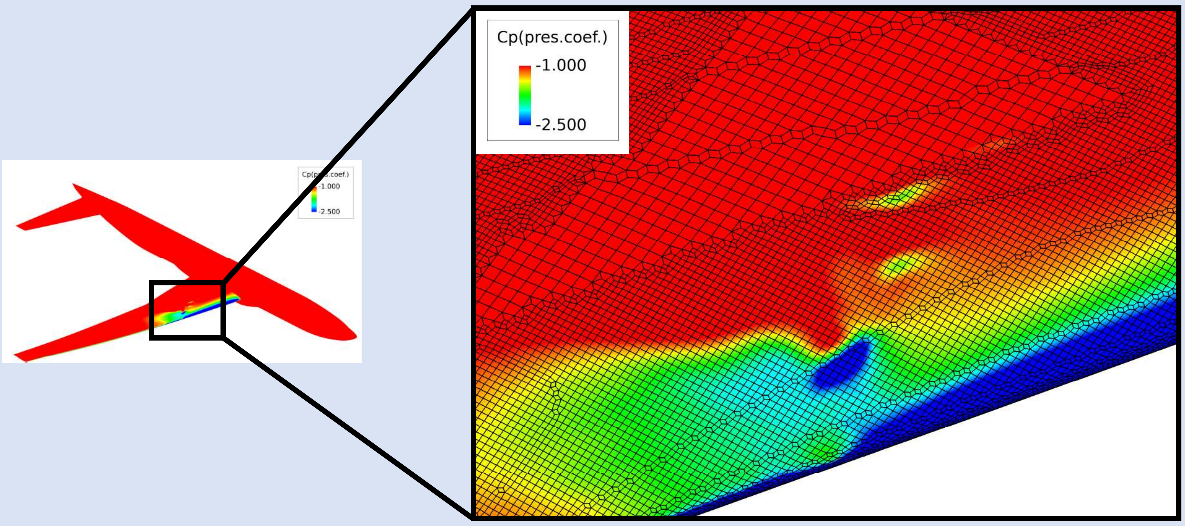
HS_AoA11.05(Averaged)



Result

Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

C_p in HH



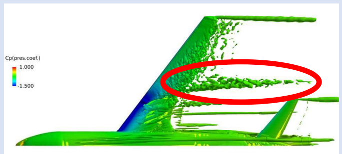
- The spike of C_p occurred at switching location of the cell sizes/geom.
- More severe cell treatment will suppress the spike?

Conclusions

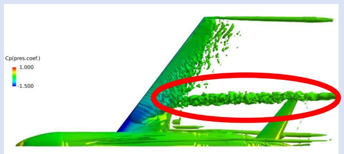
Case		
HH	:	HR-SLAU2 & HR-DDES
HS	:	HR-SLAU2 & SA-DDES
SS	:	SLAU2 & SA-DDES

- HH yielded the closest aerodynamic coefficient values to the experiment.
- HH predicted the flow separation point of the experiment.
- In HH, the main wing wake did not interfere with the tail wing. This led to lift increase of the tail and its negative pitching moment.
- HS and SS showed relatively similar C_p distributions, that were different from HH.
- HH exhibit a spike in the C_p profile, originated from the switching point of cell sizes/geometries.

HH_AoA1105



HS_AoA1105



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Acknowledgments

The flow solver used here was **FaSTAR** developed at JAXA, as well as the mesh generator **HexaGrid**.

The computations were conducted using JAXA's Supercomputer System(**JSS**) 3.

Mr. Ogawa, Suguru, **Mr. Takimoto, Hiroyuk**i, **Mr. Harada, Toshiaki** and **Mr. Takagi, Yuya** at **Yokohama National University** performed a part of numerical cases.

We appreciate their cooperation.

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