Eighth Aerodynamics Prediction Challenge (APC-8)
2022/06/29

1C12

Aerodynamic Prediction of CRM-HL Using Hierarchical Cartesian Grid and Immersed Boundary Method

◯Funada Masaya, Imamura Taro
(The University of Tokyo)
Sugaya Keisuke
(JAXA)

東京大学 THE UNIVERSITY OF TOKYO

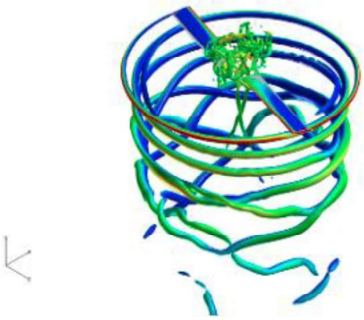
1

Agenda

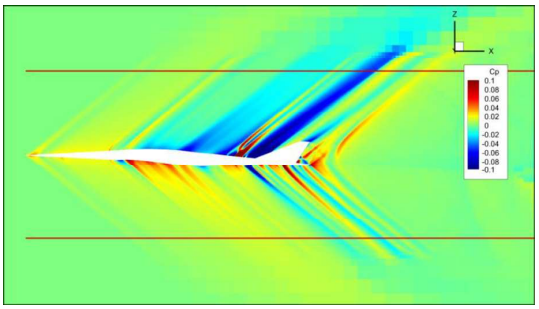
- Background
- Objective
- Numerical methods
- Case4 : 2D CRM-HL
- Case1 : 3D CRM-HL
- Conclusions

Background 1

- UTCart (The University of Tokyo Cartesian grid based automatic flow solver)
  - Unstructured hierarchical Cartesian grid
  - Automatic and robust grid generation
  - The Immersed Boundary Method with a wall function*1



菅谷, and 今村, 流力ANSS2021

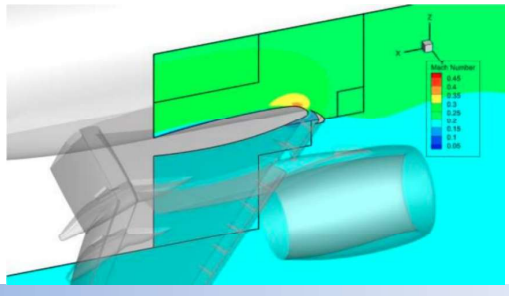


1) Tamaki, Harada, and Imamura, AIAA J., Vol 55, 2017

Background 2

- Until now, the upper limit of the number of grids in UTCart has been about 200 million
  - Some variables exceed the integer4 limit
  - Visualization software do not support integer8
- Extend the upper limit of number of grids
  - The type of some variables has been changed to integer8
  - Visualization data is output separately

→Flow simulations with about 400 million grids can now be performed

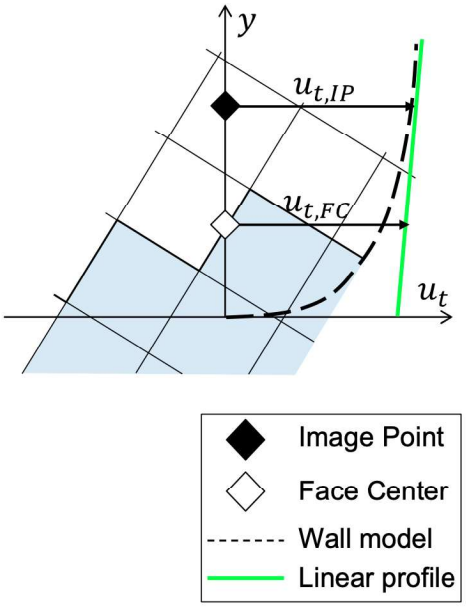


Objective

- **To evaluate the prediction accuracy of Immersed Boundary Method with a wall function for low-speed simulations of high-lift device configuration**
  - The effects of grid width are investigated
  - Steady computations
    - Case4 : 2D CRM-HL
    - Case1 : 3D CRM-HL
      - Up to 400 million grids

Immersed Boundary Method

- Flow variables are extrapolated from Image Point (IP)
- Wall function is used to determine the wall shear stress
- Assuming that tangential velocity is linear between the wall and IP



Numerical methods

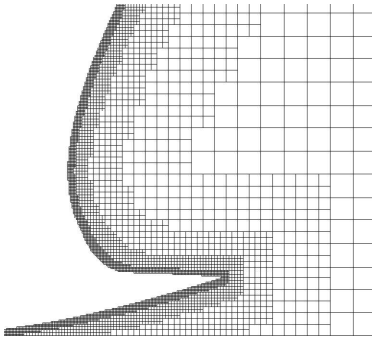
Governing Equation	RANS
Turbulence Model	SA-noft2
Inviscid Flux	SLAU+3rd-order MUSCL
Viscous Flux	2nd-order central difference
Time Integration	MFGS (Local Time Stepping)
Wall Boundary Condition	IB+SA wall model
Distance between IP and wall	$3\Delta x$
Initial Condition	Free stream

Case4
2D CRM-HL

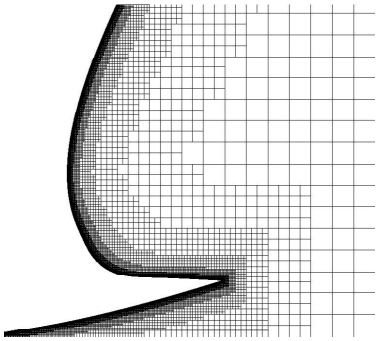
Computational grid

- CFL number is 20 in all grids

	#1	#2	#3	#4	#5	#6	#7
Minimum grid width	1.590×10^{-4}	9.538×10^{-5}	4.768×10^{-5}	2.980×10^{-5}	1.703×10^{-5}	8.515×10^{-6}	4.585×10^{-6}
Grid number	177,164	291,797	577,771	921,351	1,606,333	3,207,629	5,950,335



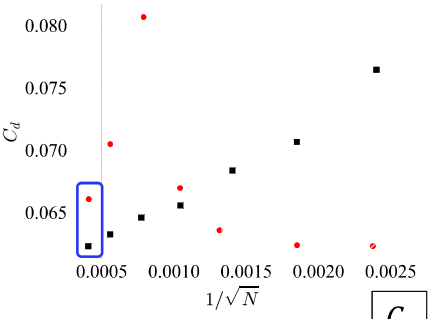
Grid #1



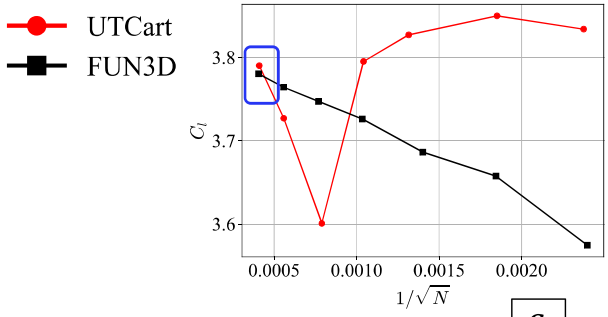
Grid #7

Aerodynamic coefficients

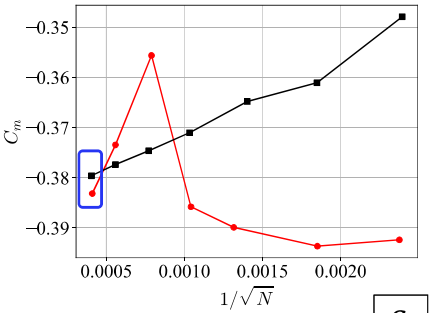
- A fair agreement between UTCart and FUN3D*1 at finest grid
- In the third finest grid, UTCart results differ from FUN3D results
  - IP is in the buffer layer (y^+_{IP} : 10~30)
- If IP is not in the buffer layer, the prediction accuracy is reasonable



C_d



C_l

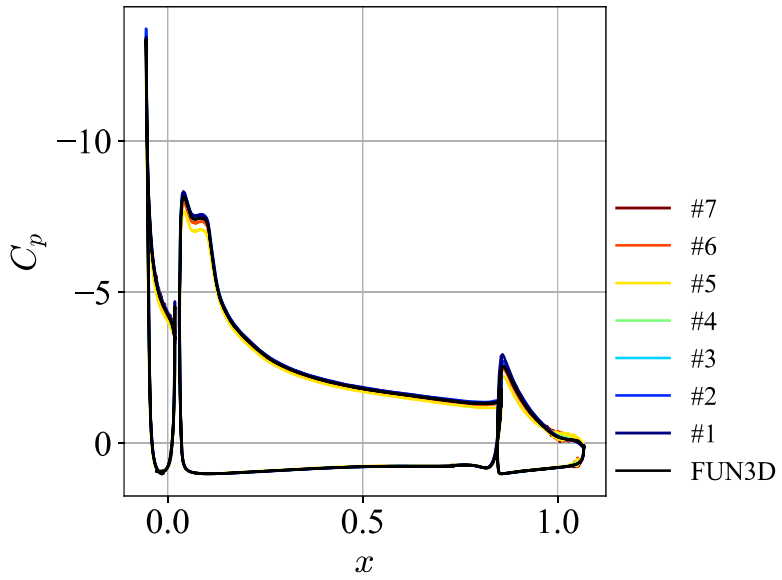


C_m

1) https://turbmodels.larc.nasa.gov/

Surface pressure coefficient

- A fair agreement with FUN3D results, except for #5-grid



Case1
3D CRM-HL

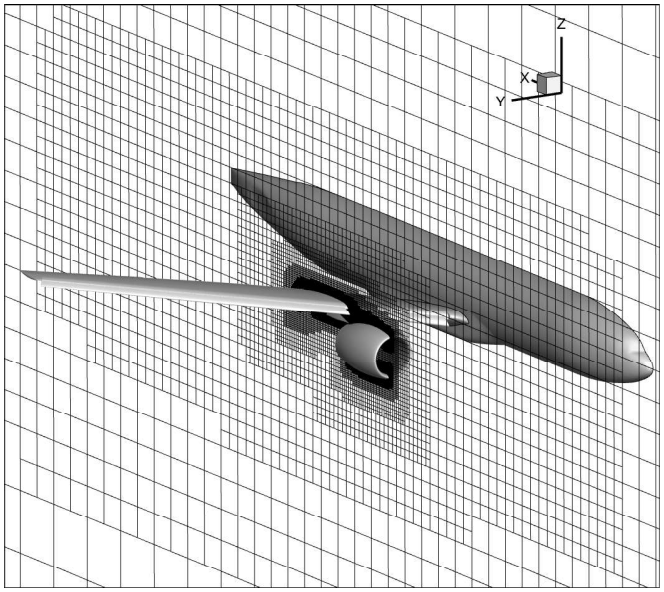
Computational grid

- Unstructured hierarchical Cartesian grid
- Three grids are used
- IP is in the log layer

	100M-grid	200M-grid	400M-grid
Number of Grids	103,640,578	194,862,769	409,626,109
Reference Grid width (Δx_{ref})	$9.537 \times 10^{-4} C_{MAC}$	$6.936 \times 10^{-4} C_{MAC}$	$4.768 \times 10^{-4} C_{MAC}$
CFL number	2	20	20

	wing	fuselage	fairing	flap	slat	nacelle	pylon
Minimum grid width	Δx_{ref}	$4\Delta x_{ref}$	$0.5\Delta x_{ref}$	Δx_{ref}	Δx_{ref}	$4\Delta x_{ref}$	$2\Delta x_{ref}$

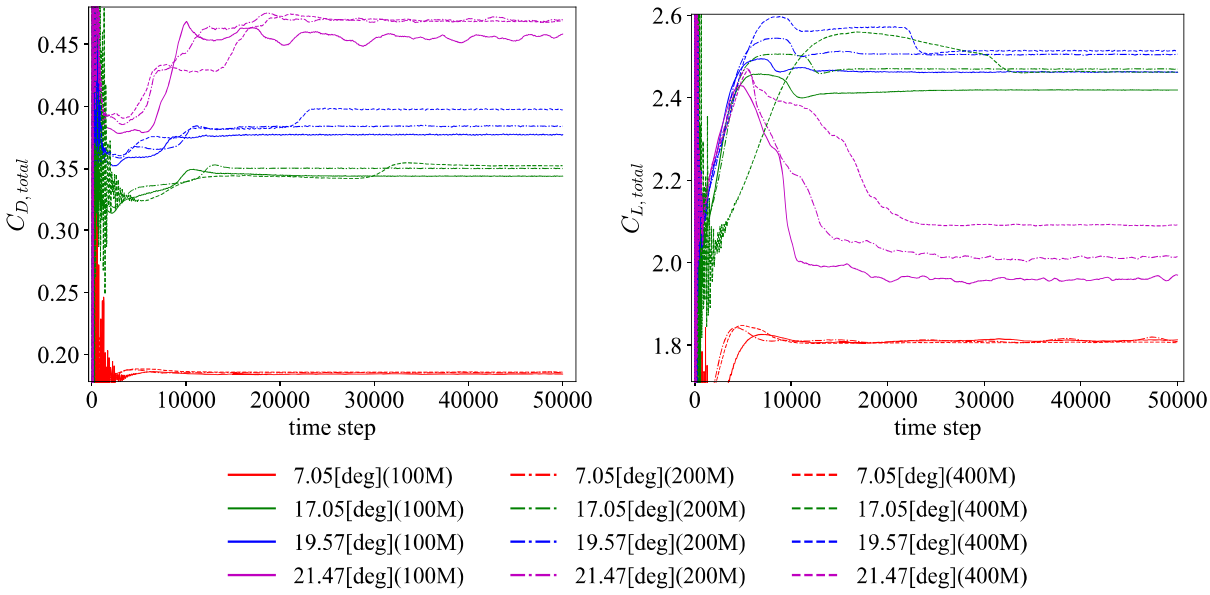
Computational grid



200M-grid

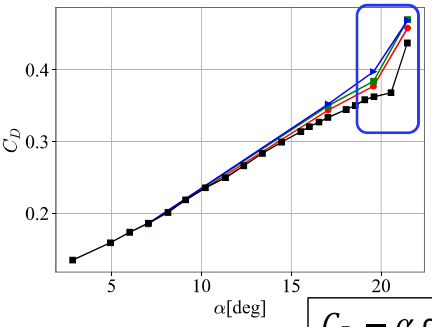
Time history

- Almost converged solutions

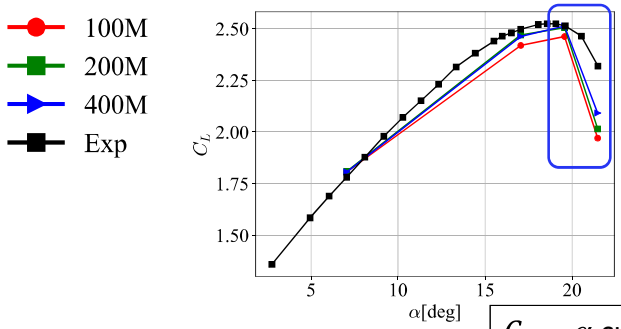


Aerodynamic coefficients

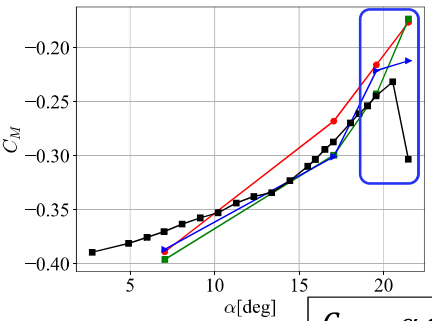
- A fair agreement between UTCart and exp. at low AoA
- Smaller C_L, larger C_D, and larger C_M of UTCart than those of exp. at high AoA
- No grid convergence in C_D and C_M at high AoA



$C_D - \alpha$ curve



$C_L - \alpha$ curve

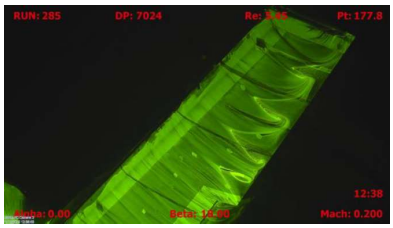


$C_M - \alpha$ curve

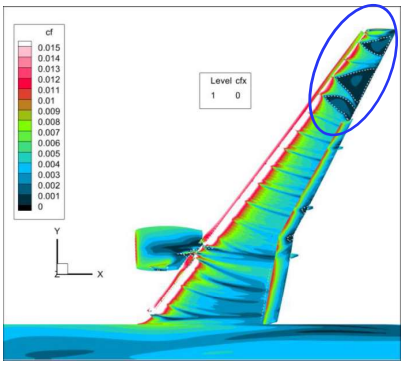
1) https://hiliftpw.larc.nasa.gov

Skin friction at $C_{L,max}$ (19.57[deg])

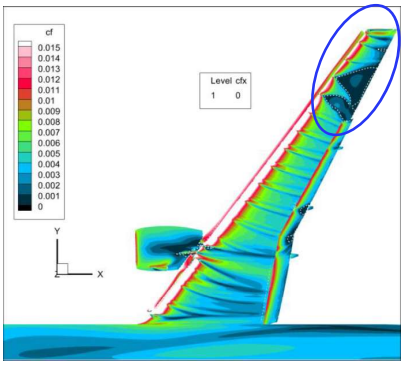
- Larger outboard separation compared to exp.
  - Smaller C_L, larger C_D, and larger C_M
  - Also reported in RANS simulations in HLPW*1
- The position of the separation area depends on the grid width



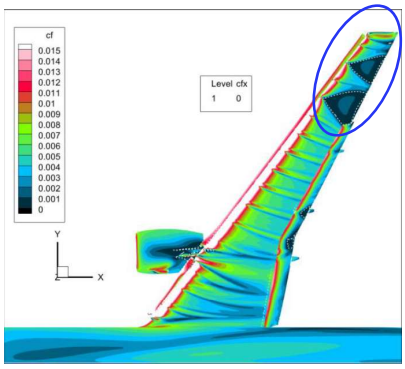
oil-flow photograph*1



100M-grid



200M-grid



400M-grid

1) https://hiliftpw.larc.nasa.gov

Conclusion

- **Steady flow simulations around CRM-HL were conducted with UTCart (IB+SA wall model)**
  - Case4 : 2D CRM-HL
    - A fair agreement between UTCart and FUN3D at finest grid
    - If IP is in the log layer, the prediction accuracy is reasonable
  - Case1 : 3D CRM-HL
    - A fair agreement to exp. at low AoA
    - Larger outboard separation compared to exp. at high AoA
    - The calculation results were dependent on grid width
    - Grid convergence was not observed in C_D and C_M at high AoA

  → IB+SA wall model can analyze high-lift device configurations with reasonable accuracy