Sixth Aerodynamics Prediction Challenge (APC-6)
2020/09/28, Online

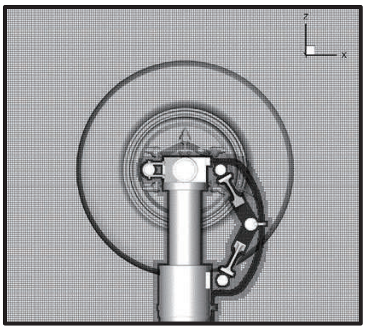
1A15
Aerodynamic prediction of NASA-CRM cruising configuration at low speed and high angle of attack using UTCart

〇Hibiki Yoshinaga, Keisuke Sugaya, Taro Imamura
(The University of Tokyo)

東京大学
THE UNIVERSITY OF TOKYO

Objective

- Low-speed and high-AoA flow predictions for NASA-CRM cruising configuration
  steady flow simulation + unsteady flow simulation
- UTCart (The University of Tokyo Cartesian grid based automatic flow solver)
  - Unstructured hierarchical Cartesian grid
  - Automatic grid generation
  - The immersed boundary method with a wall function (1)



Imamura and Tamaki, AIAA AVIATION,2020

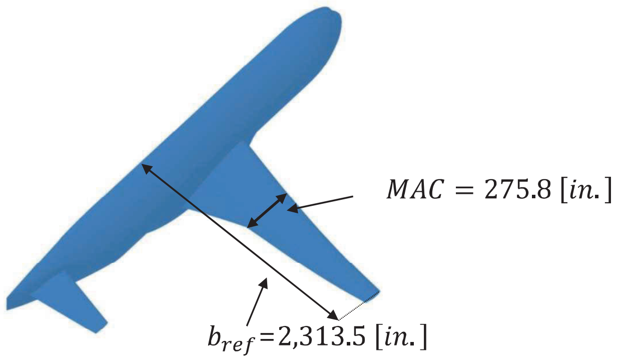
1) Tamaki, and Imamura, AIAA J., Vol 56, 2018.

This document is provided by JAXA.

Computational Condition

- NASA CRM cruising configuration

	Steady	Unsteady
Reynolds number (C_{ref} = 275.8 [in.])	1.06×10^6	
Mach number	0.168	
Reference temperature [K]	310	
Angle of attack [deg]	−3.22~18.08	13.08

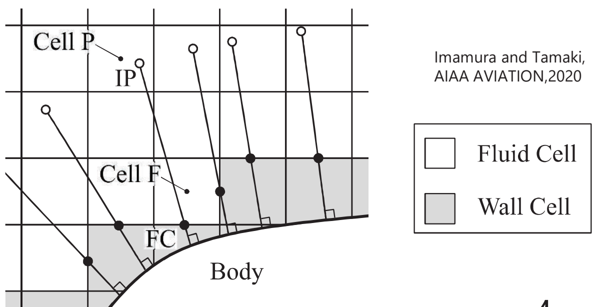


3

Numerical Methods

	Steady	Unsteady
Governing Equation	RANS	DDES(1)
Turbulence Model	SA-noft2-R(2)	
Inviscid Flux	SLAU+MUSCL(κ=1/3)	
Viscous Flux	2nd order central difference	
Time Integration	MFGS(Local Time Stepping)	MFGS(Constant dt)
Wall Boundary Condition	IB+SA wall model	
Distance between IP and wall (d_{IP})	$2\Delta x$	

1) 玉置 *et al.* ,第49期 年会講演会講演集, 2018
2) Dacles-Mariani et al, AIAA J, 1995.

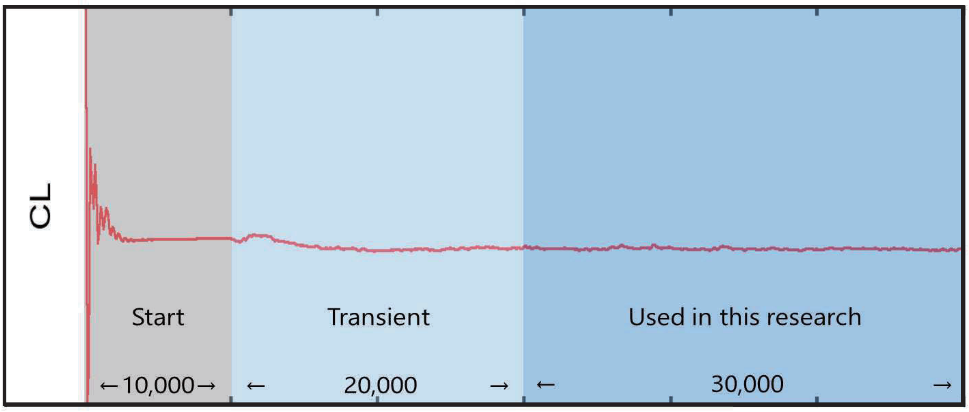


4

This document is provided by JAXA.

Time Integration(MFGS)

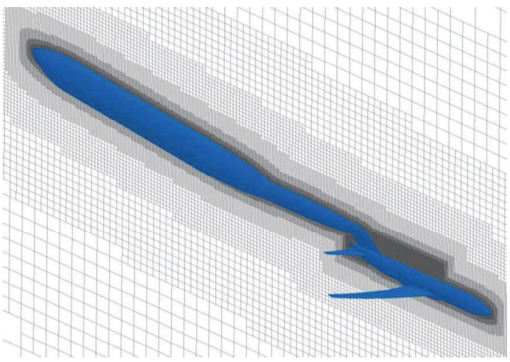
- Local time stepping
  - Local courant number : 100
- Constant dt
  - Δt : 3 [-] (about 550 steps for a uniform flow to flow through the MAC)
  - Total steps : 60,000 (Sub iterations : 5)



5

Grid Settings

	Steady w/o sting	Steady w/ sting	Unsteady	BOXFUN (reference)
Total cell number	68.5×10^6	81.4×10^6	55.2×10^6	42.5×10^6
Domain size [in.]	2.76×10^4	2.76×10^4	2.76×10^4	2.76×10^4
Minimum grid size [in.]	0.421	0.421	0.421	3.37
RB grid size [in.]	3.37	3.37	3.37	3.37
MAC / Minimum grid size (Real size scale)	655	655	655	81.8

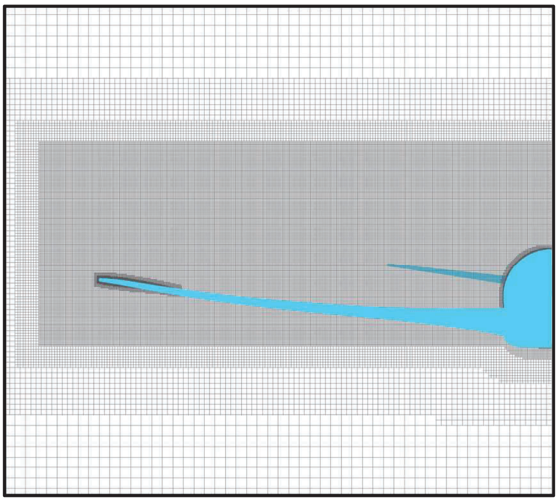


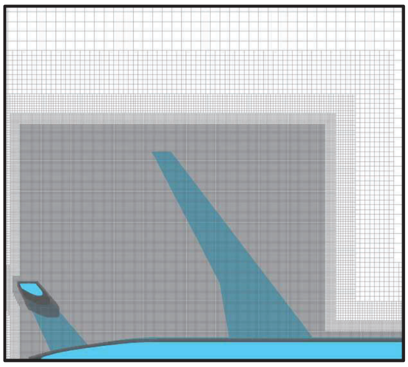
6

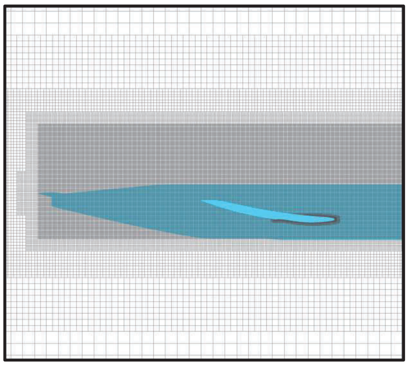
This document is provided by JAXA.

Grid Settings

- Refinement Box
  for steady flow
  based on BOXFUN



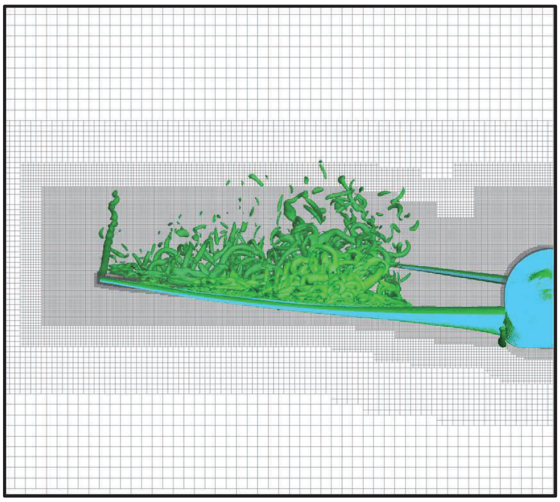


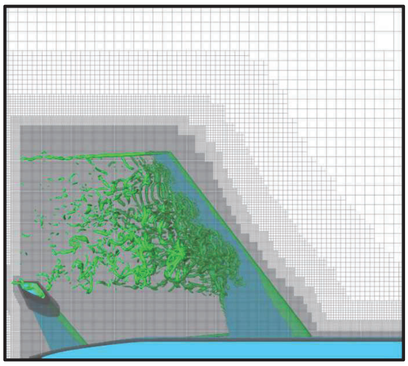


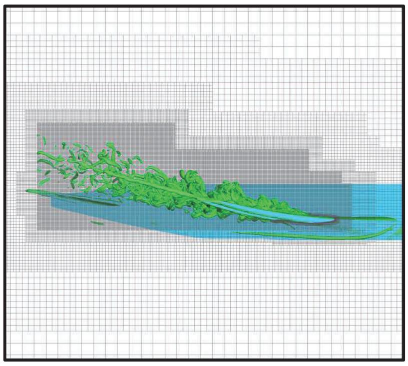
7

Grid Settings

- Refinement Boxes
  for unsteady flow
  - Total cells reduce
    from 69M to 55M







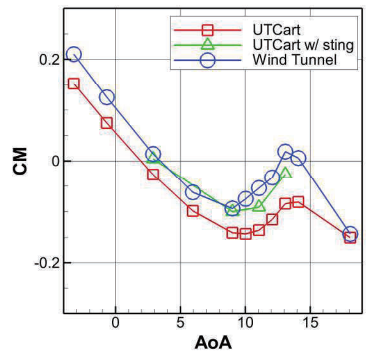
8

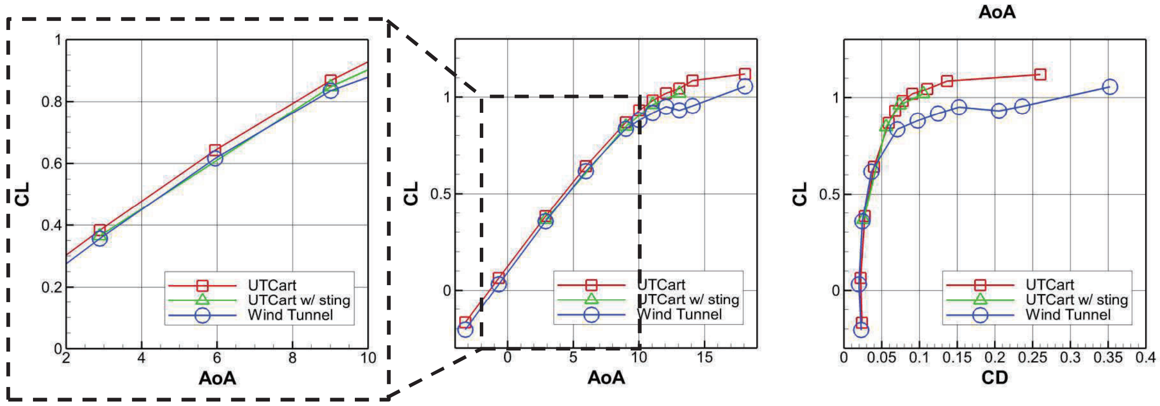
This document is provided by JAXA.

Steady simulation

α-sweep (steady flow)

- Good agreement between the results of UTCart and experiment at low AoA
  - Sting has effects on the wind tunnel experiment

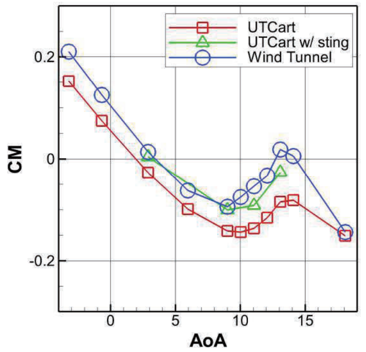


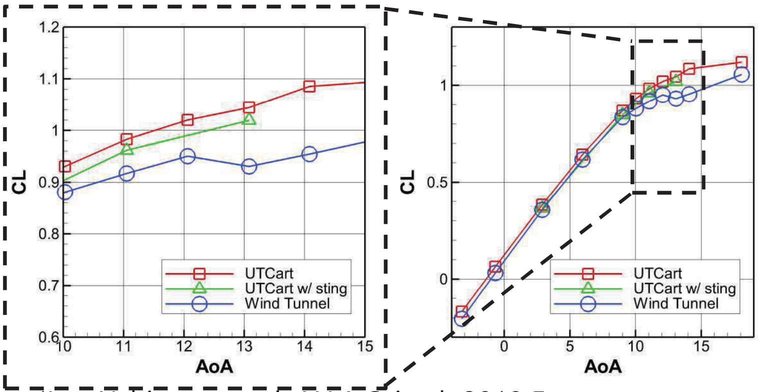


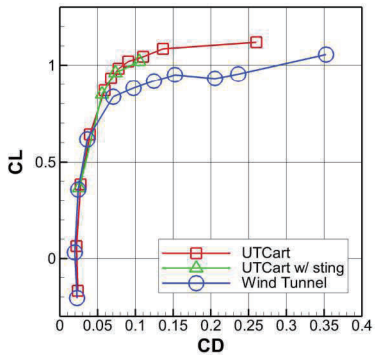
This document is provided by JAXA.

α-sweep (steady flow)

- Larger CL and smaller CM of UTCart than those of experiment at high AoA
  - separation occurs on the wingtip and trailing edge from 9.01 [deg] in the wind tunnel experiment. (1)







1) Uchiyama et al, AIAA Scitech 2019 Forum

Unsteady simulation

This document is provided by JAXA.

CL, CD, CM (unsteady flow)

- The results in unsteady simulation are closer to the ones in experiment than steady simulation.

13.08 [deg]	Experiment	Steady w/o sting	Steady w/ sting	Unsteady
CL	0.9305	1.0444	1.0196	0.9789
(error)	(0)	(11×10^{-2})	(9.0×10^{-2})	(4.8×10^{-2})
CD	0.2053	0.1103	0.1051	0.1240
(error)	(0)	(9.4×10^{-2})	(10×10^{-2})	(8.1×10^{-2})
CM	0.0186	-0.0844	-0.0262	-0.0396
(error)	(0)	(10×10^{-2})	(4.5×10^{-2})	(5.8×10^{-2})

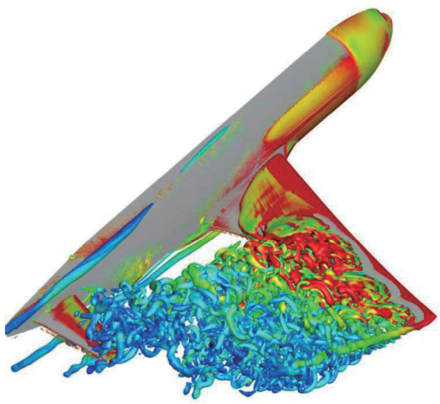
error $:= |CX_{experiment} - CX|$

13

Wake from main wing

- Separation occurs in unsteady simulation

Density Gradient Magunitude at y = 400[in.]



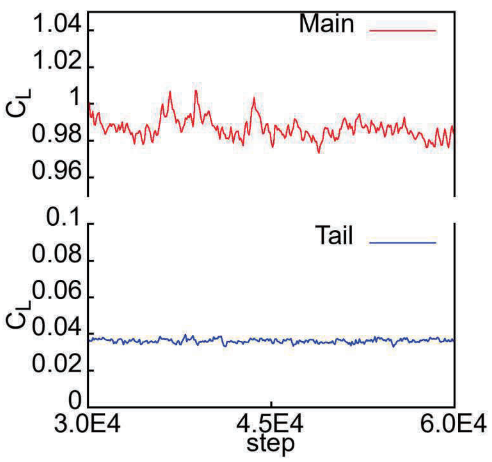
Isosurface of q-criterion = 10^{-6}, colored by density gradient.

14

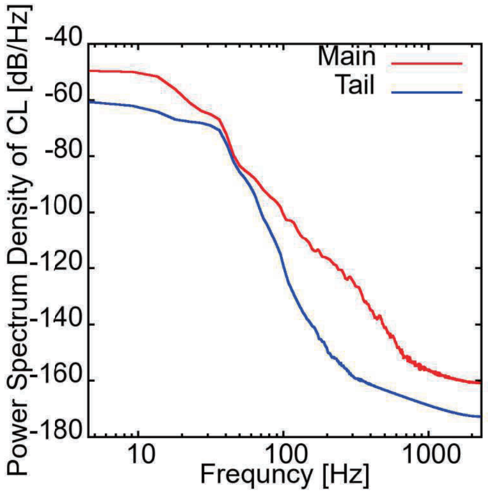
This document is provided by JAXA.

Unsteady Forces Spectrum

- Lift coefficient of main and tail wing
  - No noteworthy periodicity
    can be observed in this simulation



Signal



Spectrum

15

Conclusion

- Steady / Unsteady flow are simulated by UTCart
  - The trend of each aerodynamic coefficients is consistent with the reference experimental data at low angles of attack.
  - The results in unsteady simulation are closer to the experimental results at high angle of attack.

16

This document is provided by JAXA.