Fourth Aerodynamics Prediction Challenge (APC-IV)
2018/7/4, Miyazaki

非物体適合階層型直交格子を用いた 30P30N の空力予測

Aerodynamics Prediction of 30P30N Using Non-Body-Fitted Hierarchical Cartesian Mesh

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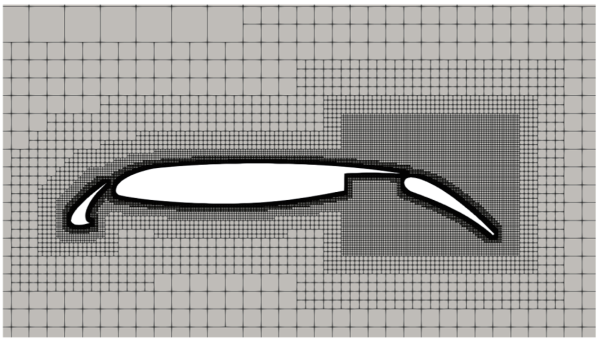
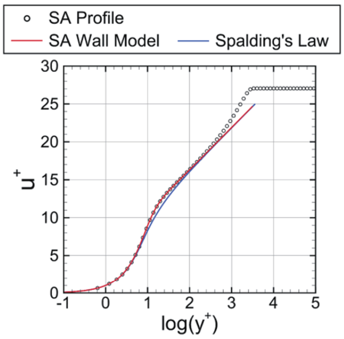
Agenda

- Background/Objective
- Computational Settings
- Results
  - Grid Convergence Study
  - Solution-Adaptive Mesh Refinement
  - α-sweep
- Conclusions

Background/Objective

- Hierarchical Cartesian Mesh (UTCart)
  - Automatic, rapid, robust grid generation
  - Easy to local refining
  - The Immersed Boundary Method with a wall function[1)]
- Research on the prediction ability of UTCart in high-lift flow
  - Especially on the grid dependency





1) Tamaki, Y. *et al.* AIAA J, 2017.

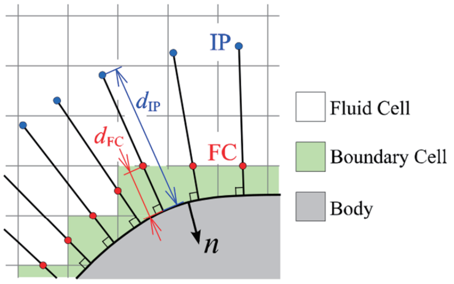
Test Cases

- 30P30N grid convergence (α-sweep)
  - Coarse, medium, fine grids
  - No local refining
- Validation of Solution-Adaptive Mesh Refinement (AMR) method
  - RAE2822, transonic flow
  - DSMA661, turbulent flow
- Case 1-1; 30P30N α-sweep applying AMR
- Reference computation
  - AIAA 2014-2080[1)]

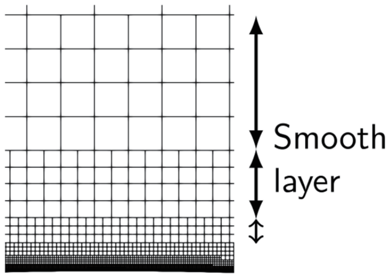
1) Murayama, M. *et al.* AIAA Paper 2014-2080.

Grid Settings

	Coarse	Medium	Fine
Total cell number	231,735	458,372	913,616
Minimum cell size (Δx, stowed chord length=1)	1.0×10^{-4}	5.0×10^{-5}	2.5×10^{-5}
Domain size		1677.7216	
d_{IP}		$3\Delta x$	
Smooth layer		3	



ref. Tamaki, *et al.*
30th CFD Symp. B03-2

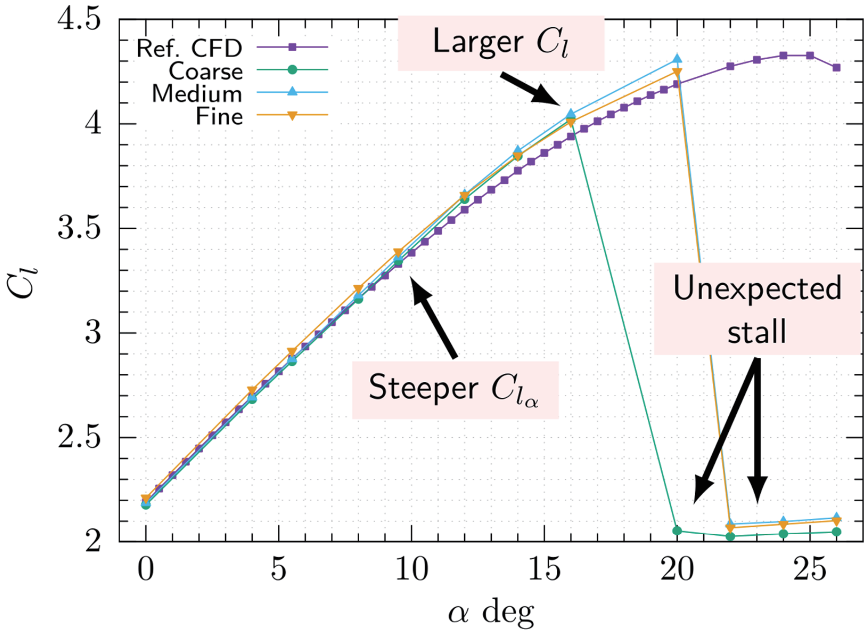


Computational Methods & Settings

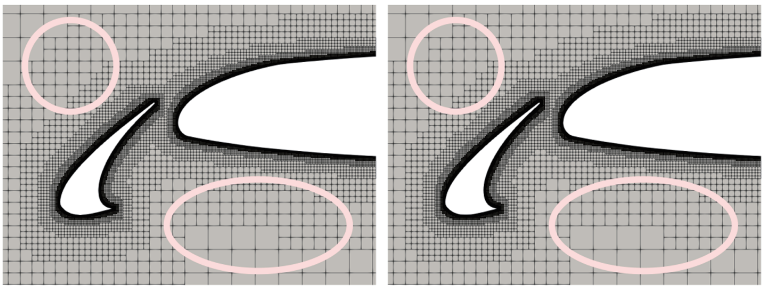
Governing Eq.	Favre-Averaged Navier–Stokes Eq.
Discretization	Cell-centerd finite volume method
Turbulence Model	SA-noft2+Wall function
Inviscid Flux	SLAU
Spatial Scheme (Inviscid Term)	3rd-Order MUSCL
Spatial Scheme (Viscous Term)	2nd-Order Central Difference
Gradient Estimatin	Weighted Least-Squares (G)
Time Integration	LU-SGS (Local Time-Stepping)
	Counrant No. $= 50$

Re	1.71×10^6 (Reference length $= 1$)
M_∞	0.17
α	$0 \to 26$ deg
T_∞	295.56 K

α-sweep (Grid Convergence)



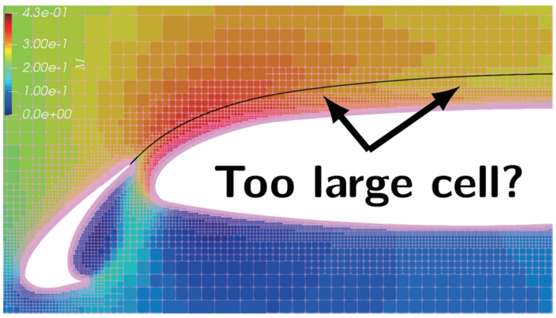
Spatial Distribution of Cell



Coarse Fine

- Only near-object region was refined
- Far-object region remains coarse

- Wake region can't be resolved by $\Delta x \to 0$



Solution-Adaptive Mesh Refinement (AMR)

Refine $\tau_i > \sigma_i$ cells where[1, 2]

$$\tau_{\mathrm{C}} = |\nabla \cdot \boldsymbol{u}| h^{3/2} \quad : \text{Compressive phenomena}$$

$$\tau_{\mathrm{R}} = |\nabla \times \boldsymbol{u}| h^{3/2} \quad : \text{Shear layer}$$

$$\tau_{\mathrm{E}} = |\nabla S| h^{3/2} \equiv \left| \nabla \frac{ds}{R} \right| h^{3/2}$$

$$= \left| \nabla \frac{1}{\gamma - 1} \ln \left[\frac{p}{p_\infty} \left(\frac{\rho_\infty}{\rho} \right)^{\gamma} \right] \right| h^{3/2} \quad : \text{Entropy gradient}$$

$$\sigma_i = \sqrt{\sum_{j=1}^{N} \frac{{\tau_{i_j}}^2}{N}} \quad (i = \mathrm{C, R, E}) \quad : \text{Standard deviation from zero}$$

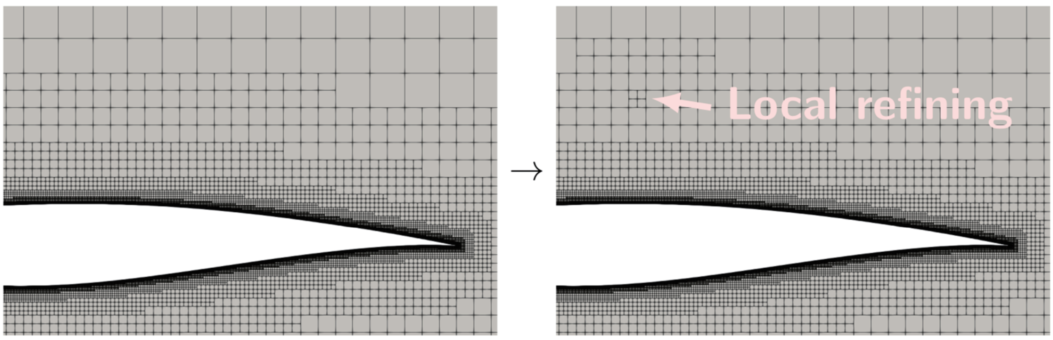
h : Local cell size, N : Total cell No.

1) De Zeeuw, D. *et al.* AIAA Paper 92-0321.

2) Hartmann, D. *et al.* Computers & Fluids, 2008.

Flowchart of AMR

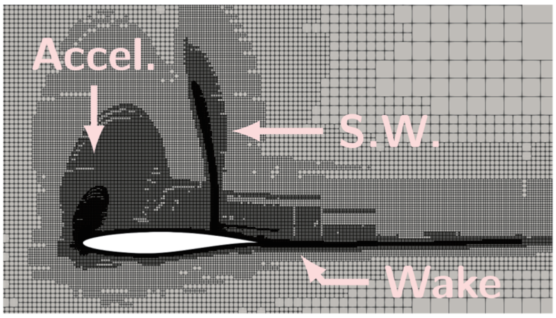
1. 1st time calculation
2. Calculate τ_i, σ_i $(i =$ C, R, E$)$
3. Obtain $h > \Delta x$ and $\tau_i > \sigma_i$ cell
4. Output setting file to refine obtained cell by 1 level
5. 2nd time Calculation
6. Do until total cell No. ∼600k (around 5–6 loops) for 30P30N



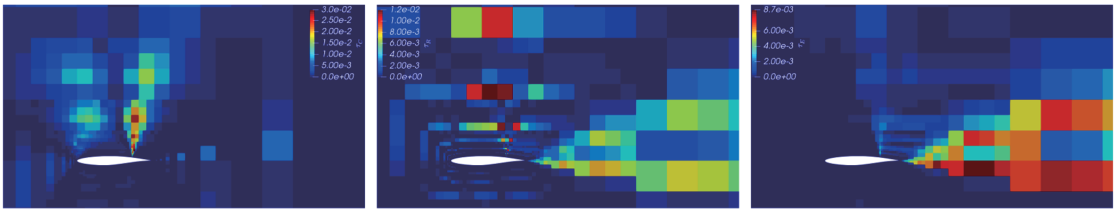
Validation of AMR Method; Transonic Flow

Transonic Flow around an RAE2822

Governing Eq.	Euler
Limiter	vanAlbada
Δx	2.0×10^{-4}
α	3 deg
M	0.75
T_∞	295.56 K



Level 7 Adapted Grid with 189,078 Cells

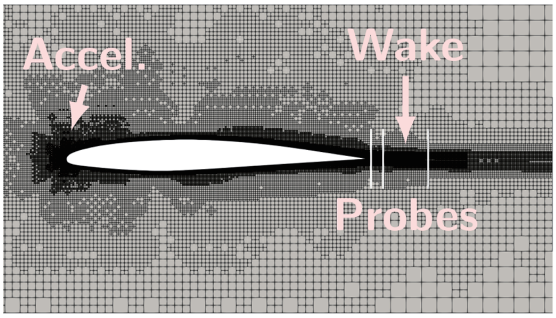


τ_C τ_R τ_E for 1st Grid

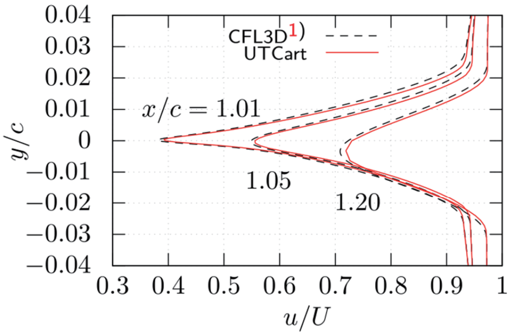
Validation of AMR Method; Turbulent Flow

Turbulent Flow around a DSMA661[1)]

Governing Eq.	RANS
Δx	2.0×10^{-4}
Re	1.2×10^{6}
α	0 deg
M	0.088
T_∞	300 K



Level 6 Adapted Grid with 277,315 Cells

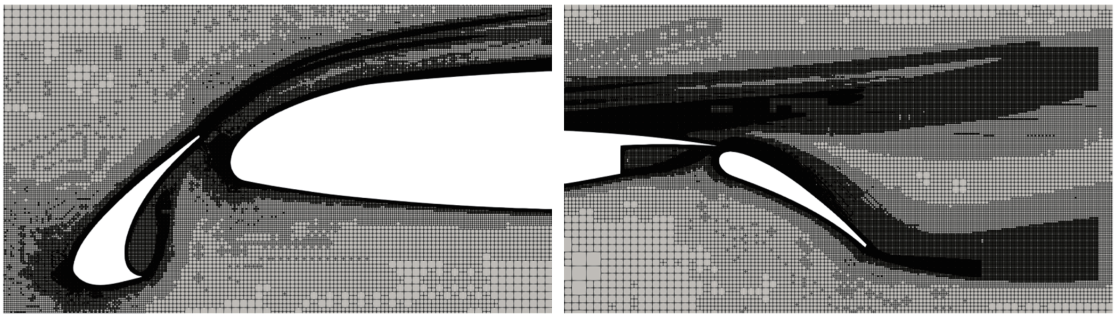


- UTCart can resolve wake as CFL3D

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

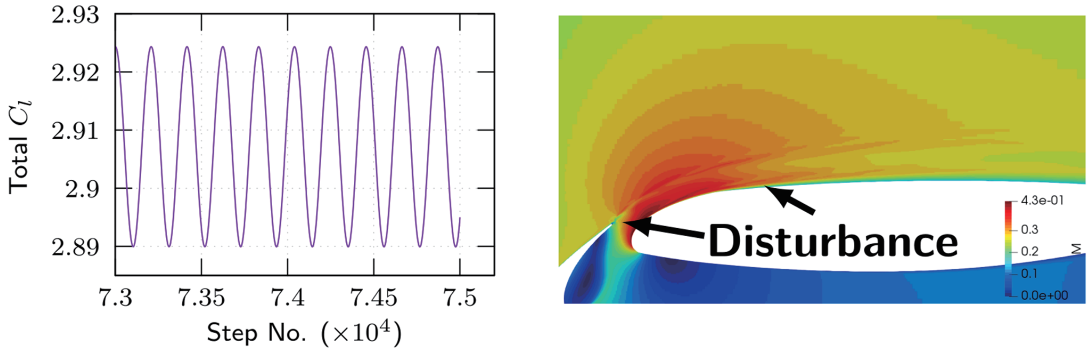
Apply AMR to 30P30N; Example of Refined Grid

- Wake region is refined



$\alpha = 20$ deg, Level 6 Adapted Grid with 703,128 Cells

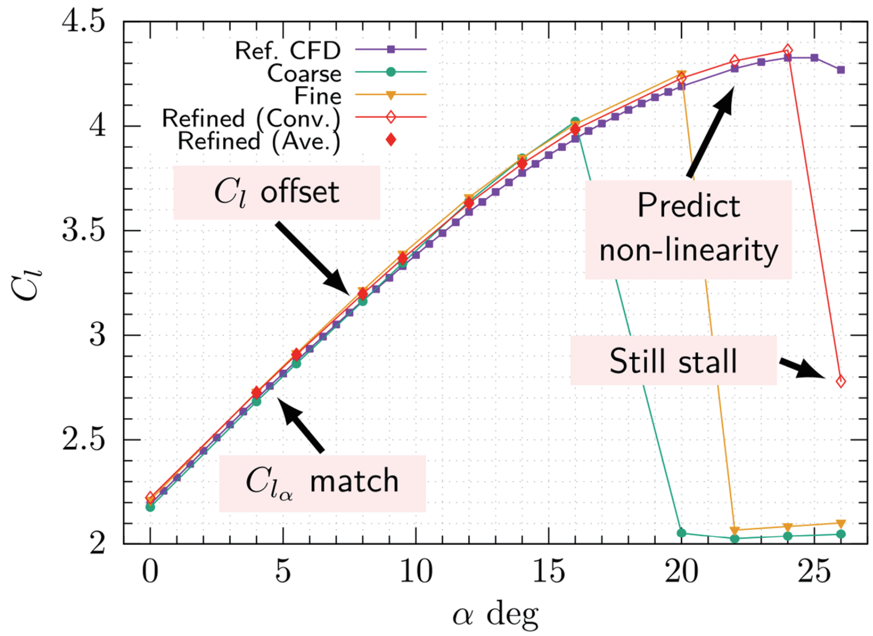
Apply AMR to 30P30N; Unsteadiness of Flow



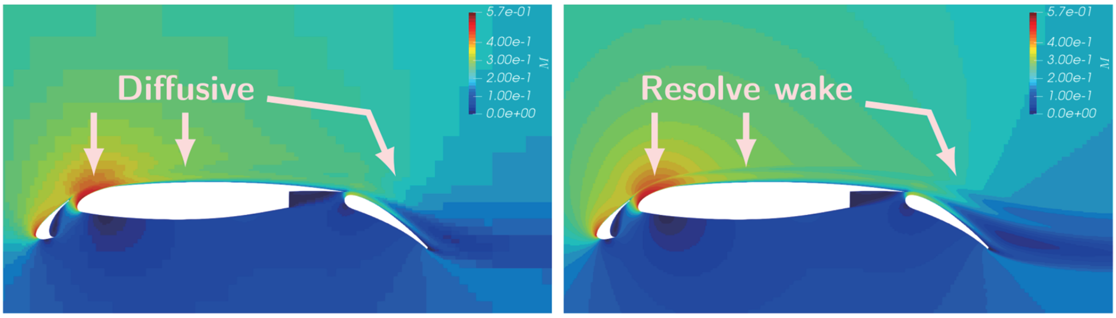
Total C_l and M Distribution for $\alpha = 5.5$ deg, Level 5 Adapted Grid

- Refined grid causes unsteadiness of force and flowfield despite assuming stedy flow calculation
- Take step-average of force and flowfield for visualization $\longrightarrow$

C_l–α Plot (Refined Grid)



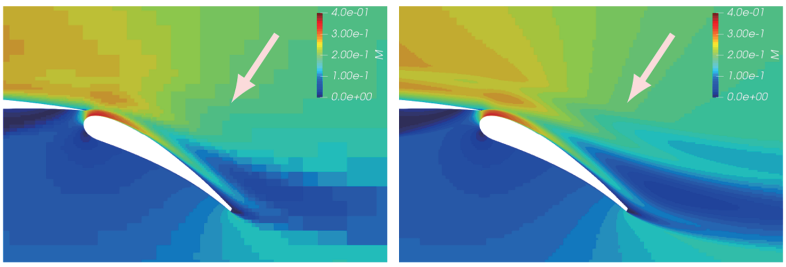
Flowfield Visualization ($\alpha = 14$ deg)



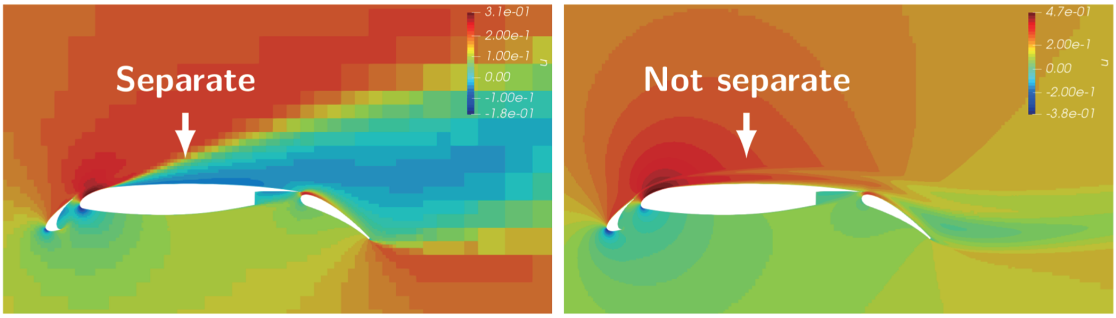
Coarse Refined

M Distribution (Ave.) at $\alpha = 14$ deg, Level 5 Adapted Grid with 680,562 Cells

- Slat wake is well resolved



Flowfield Visualization ($\alpha = 20$ deg)

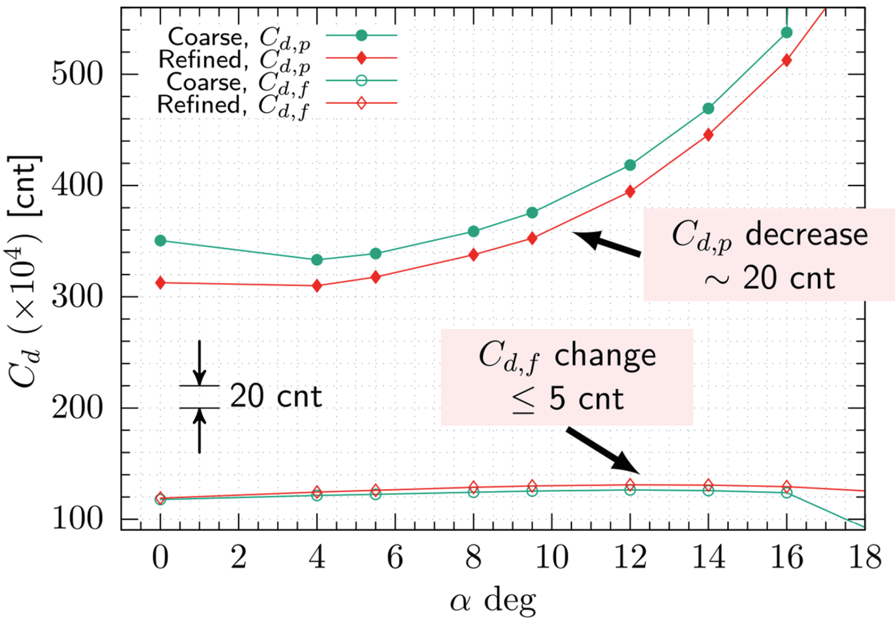


Coarse Refined

u Distribution (Conv.) at $\alpha = 20$ deg, Level 6 Adapted Grid with 703,128 Cells

- Unexpected separation disappeared by spatial grid refining

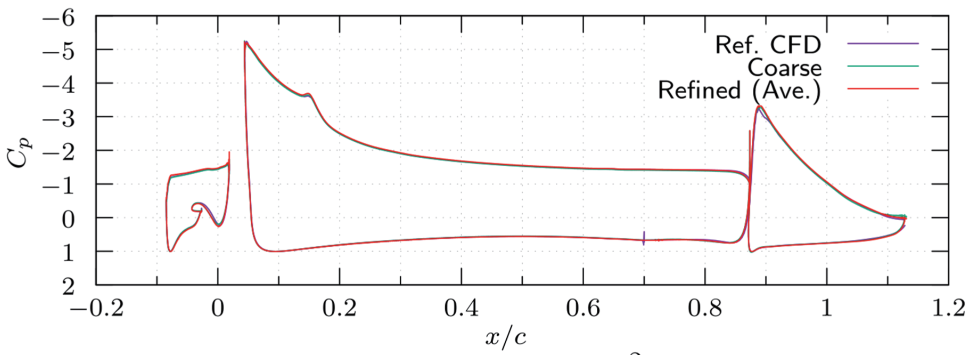
C_d–α Plot (Refined Grid)



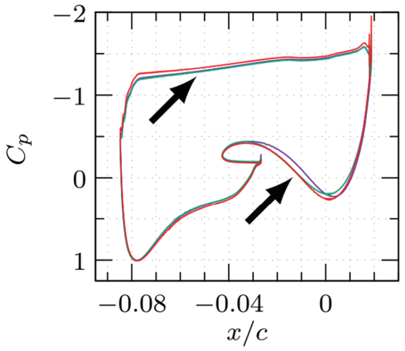
Conclusion

- Grid convergence of α-sweep was examined
  - Stall α predicted by UTCart differed from that of reference CFD data
- Solution-Adaptive Mesh Refinement method was validated
  - Shock wave and wake region were refined
- Refined grid could avoid unexpected stall
  - Stall at $\alpha = 26$ deg can't be avoided with current method
  - Cause of the C_l offset should be investigated further
- Spatial grid refining decreased $C_{d,p}$ by 20×10^{-4}

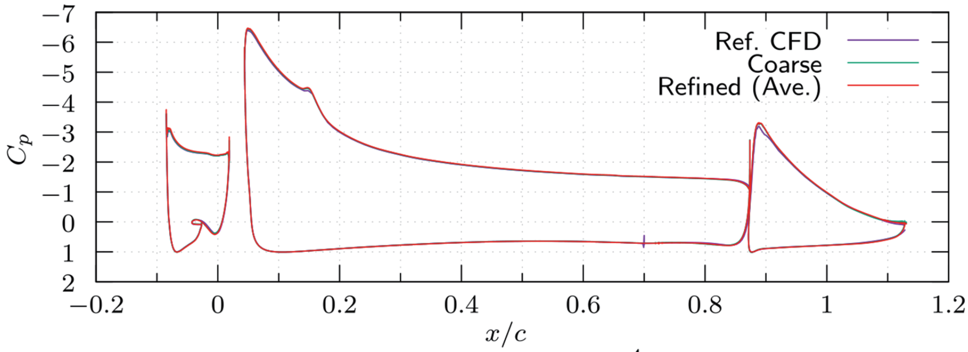
Appendix; Surface C_p ($\alpha = 5.5$ deg)



- Mismatch at slat upper surface and slat cove



Appendix; Surface C_p ($\alpha = 9.5$ deg)



- Mismatch at slat upper surface and slat cove