Fifth Aerodynamics Prediction Challenge (APC-V)
2018/07/01, Tokyo

Unsteady Aerodynamic Prediction of 30P30N Using Hierarchical Cartesian Mesh and Adaptive Mesh Refinement

○ SUGAYA Keisuke, SHU Kembun, IMAMURA Taro
(The University of Tokyo)

YOSHIHARA Tamaki
(Tohoku University)

東京大学 THE UNIVERSITY OF TOKYO

Cartesian Grid method

- UTCart (The University of Tokyo Cartesian grid based automatic flow solver)

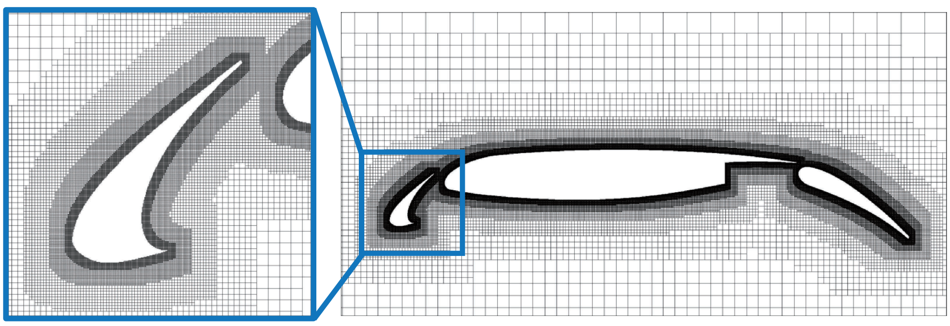
– Easy resolution control around the wall boundary.

– Controling spatial resolution is sometimes difficult.

➢Unsteady Simulation with AMR → Regenerating grids is needed.

➢Manual refinement → Empirical knowledge is needed.

⇒ New approach is needed.

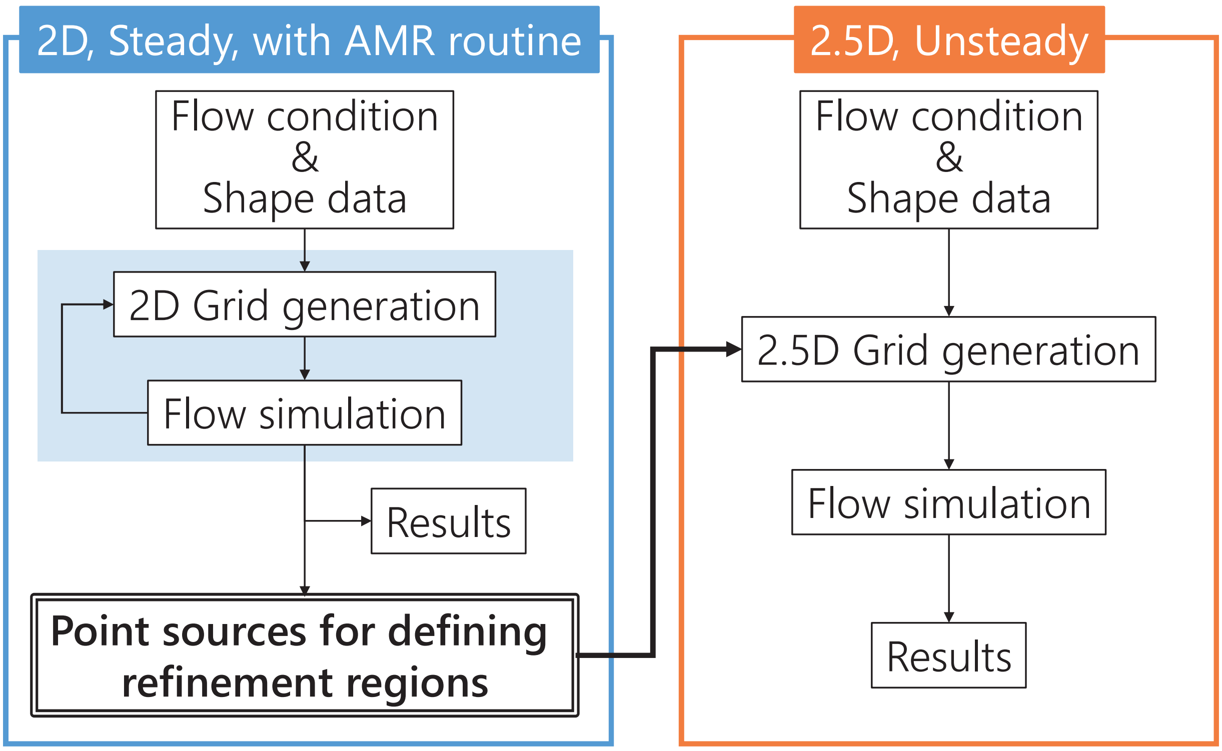


Objectives

- New workflow for unsteady flow simulation.
  - ➢**2D steady grid generation with AMR**
    + 2.5D unsteady flow simulation
    - Without grid regeneration.
    - Without empirical knowledge.
- Examine a potential capability of the proposed workflow.
- Case 1-3 (Unsteady flow), and Case 3-1 (Near field acoustics)
  - 5.5, 9.5 [deg]

3

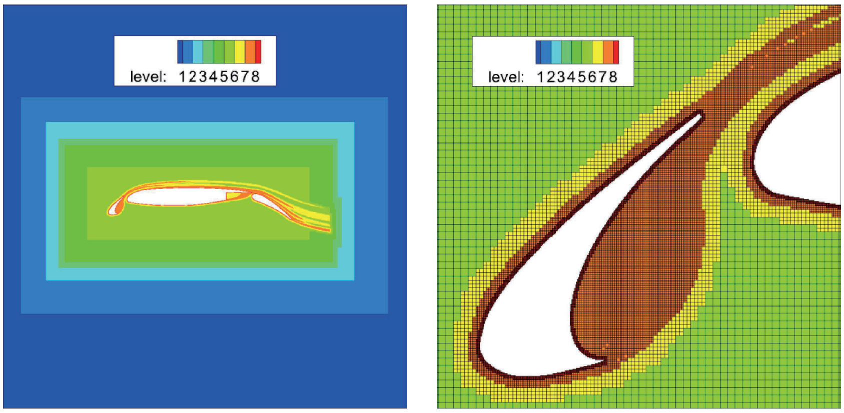
Analysis workflow



4

Computational grid

- Unstructured hierarchical Cartesian grid
  - Forest of octrees + Cell-based refinement.
  - Refinement box enclosing the airfoil
    + Solution adaptive mesh refinement.
- Domain size　　: 100 c_{ref} × 100 c_{ref} × (2/18) c_{ref}
- Total Cells　　: 18×10^6 (5.5 [deg]), 19×10^6 (9.5 [deg])
- Minimum grid size : 4.3×10^{-4} c_{ref}



Cell volume distribution
$\Delta x = \Delta x_{max} \times 1/2^{level}$

5

Numerical method

- Governing equations　: RANS (3D)
- Turbulence model　: SA-noft2-DDES-p[(1)]
  - RANS region is protected even when the stream-wise grid size is small.
- Wall boundary condition　: Immersed boundary method
  + SA wall model[(2)]
- Time integration　: 3rd order TVD Runge-Kutta
- Spatial accuracy (Inviscid) : 4th order upwind-biased scheme[(3)]
- Spatial accuracy (Viscous) : 2nd order central difference

1)　玉置 *et al.* ,第49期 年会講演会講演集, 2018
2)　Tamaki, and Imamura, AIAA J., Vol 56, 2018.
3)　玉置, and 今村, ながれ33, 2014

6

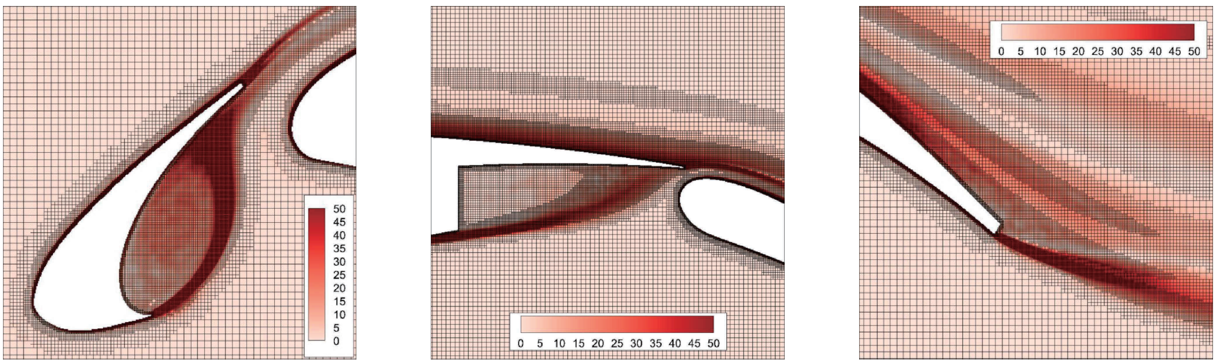
Case 1-3

Unsteady flow simulation

Time averaged flow : Vorticity

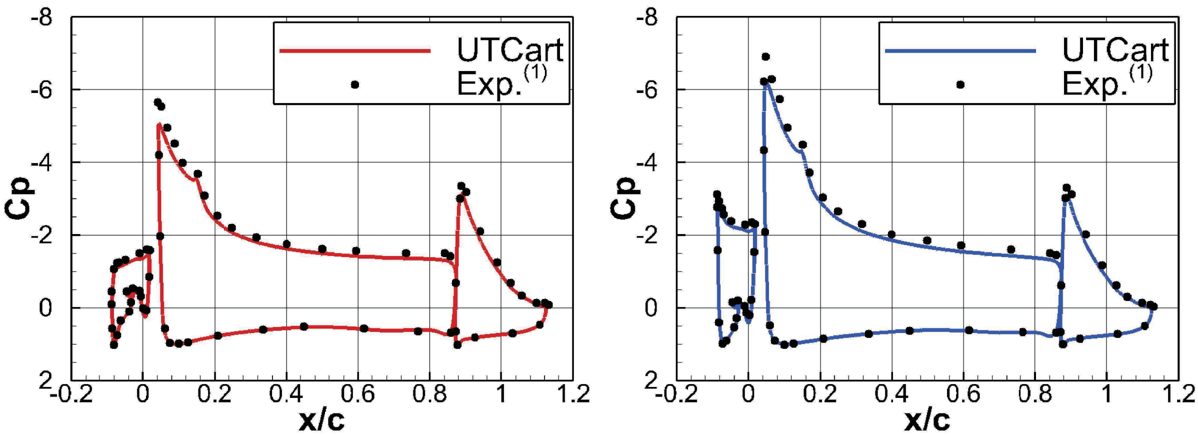
- In 2D steady AMR calculations, two indicators are used.
  - Rotation / Entropy
- In 2.5D averaged flow, refined cells are generated where the vorticity magnitude is large.

2.5D, Time averaged flow, 5.5 [deg], Vorticity magnitude



Time averaged flow : Cp

• Cp distributions agree with experimental results.



1) Murayama *et al.*, AIAA 2018-3460, 2018
2) Fourth Aerodynamics Prediction Challenge
※ CFD prediction for 5.5, 9.5 [deg] are approximately aligned with wind tunnel measurements at 7.0, 11.0 [deg], respectively.

Time averaged flow : CL

• CL of this study agree with APC-IV result reasonably.
• **Time averaged flow is well simulated.**

CL comparison (2.5D unsteady)

AoA (CFD) [deg]	5.5	9.5
Exp. (1)	2.9	3.4
Tamaki *et al.*(2)	2.82	3.23
Kojima *et al.* (2)	2.78	3.13
Burns *et al.* (2)	2.86	
Yamamoto *et al.* (2)	2.72	
This study	2.77	3.22

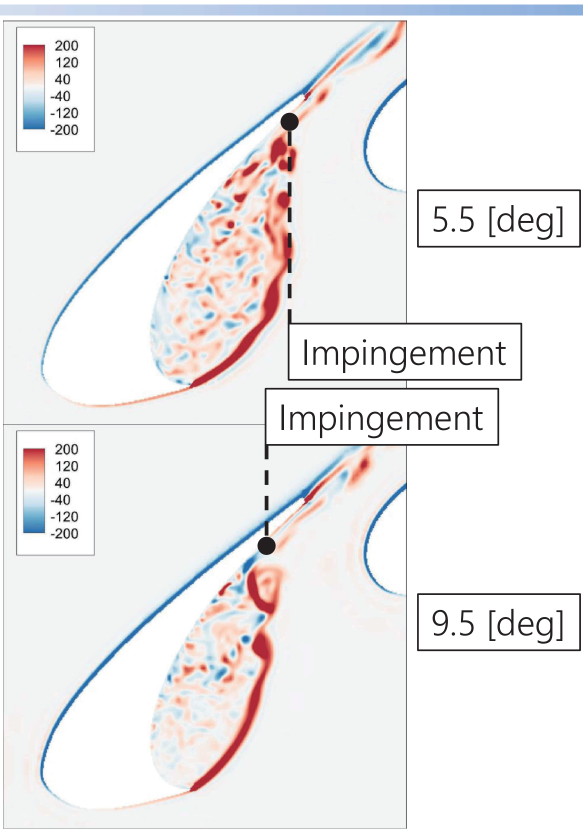
1) Murayama *et al.*, AIAA 2018-3460, 2014
2) Fourth Aerodynamics Prediction Challenge
※ CFD prediction for 5.5, 9.5 [deg] are approximately aligned with wind tunnel measurements at 7.0, 11.0 [deg], respectively.

Case 3-1

Near field acoustics

11

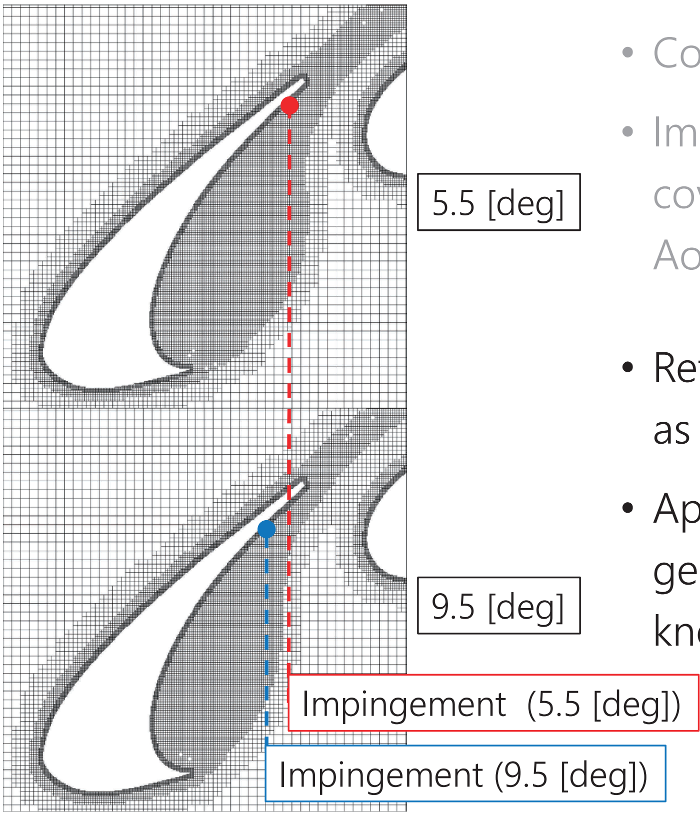
Instantaneous flow : Vorticity



- Contours of span-wise vorticity.
- Impingement point in the slat cove moves upstream when AoA increases.
- Refined cells also move as well as impingement point.
- Appropriately refined grids are generated without empirical knowledge.

12

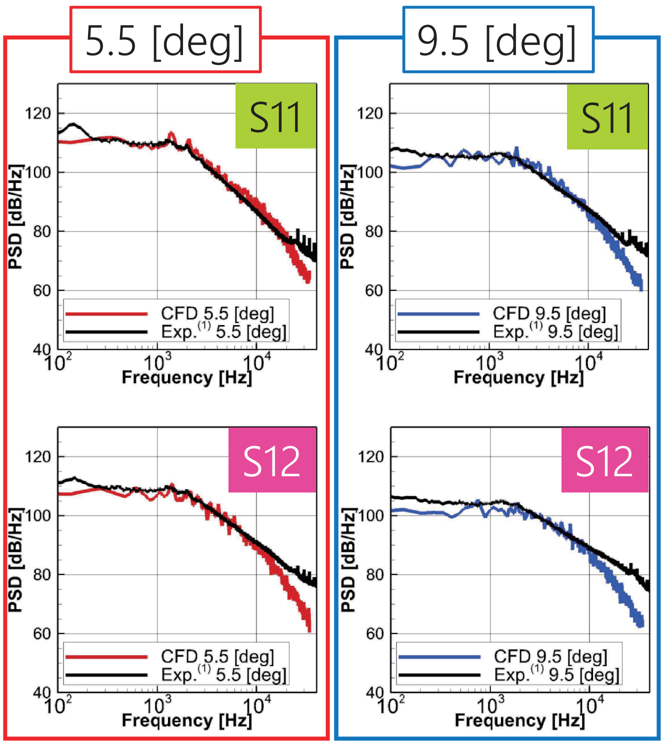
Instantaneous flow : Vorticity



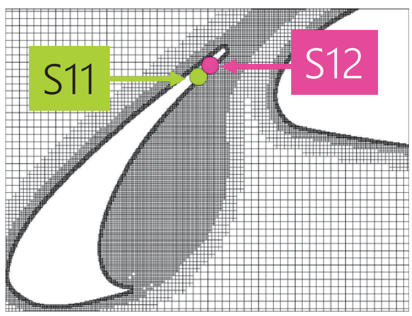
- Contours of span-wise vorticity.
- Impingement point in the slat cove moves upstream when AoA increases.
- Refined cells also move as well as impingement point.
- Appropriately refined grids are generated without empirical knowledge.

13

PSD of surface pressure : S11 and S12



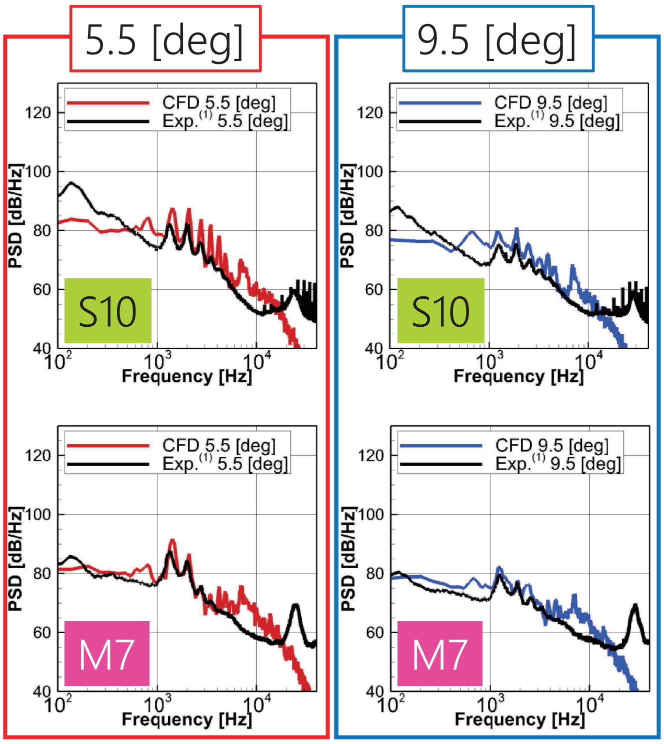
- **Good agreement with experimental results.**
- PSD levels of 9.5 [deg] are lower than those of 5.5 [deg].
  - Impingement point moves upstream.



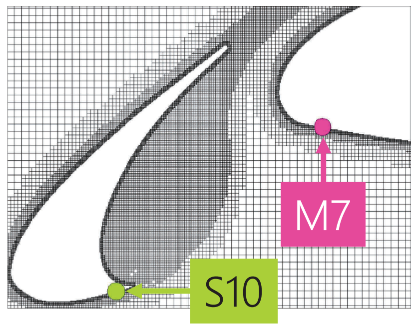
1) Murayama *et al.*, AIAA 2018-3460, 2018

14

PSD of surface pressure : S10 and M7



- CFD overestimates NBPs level (1kHz~10kHz).
  - The size of the grid is equivalent to L2 provided grid.
- Peaks around 7kHz are calculated.



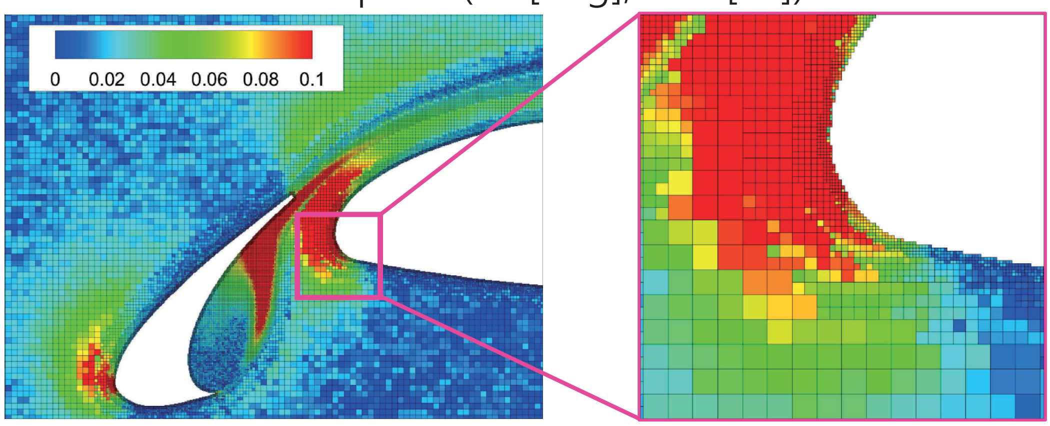
1) Murayama *et al.*, AIAA 2018-3460, 2018

15

RMS of Cp

- Cp RMS is not smooth around hanging-node.
  - Forth order accuracy in uniform region and 2nd order on hanging-node.
  - Negatively affect the PSDs prediction?
- Should be compared with the results of uniformly refined grids.

Cprms (9.5[deg], Z=1 [in.])



16

Conclusions

- Unsteady flow simulation was conducted by using UTCart.
  - 2D steady, AMR + 2.5D unsteady flow simulation.
  - Spatial resolution can be controlled automatically.
- Time averaged flow is well simulated.
  - Cp distributions agree with the experimental data.
  - CL values agree with APC-IV results.
- Necessary to compare with the results of uniformly refined grids.
  - PSDs in slat cove agree with experimental results.
  - Peaks around 7kHz are calculated at slat cusp and main wing .

17