54th Fluid Dynamics Conference/40th Aerospace Numerical Simulation Symposium
Eighth Aerodynamics Prediction Challenge（APC-8）

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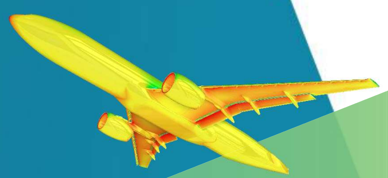

scFLOWによるCRM-HLの低速高迎角条件における空力特性予測

Numerical Prediction of Aerodynamic Characteristics of CRM-HL at Low Speed and High Angles of Attack by scFLOW

June 29th, 2022

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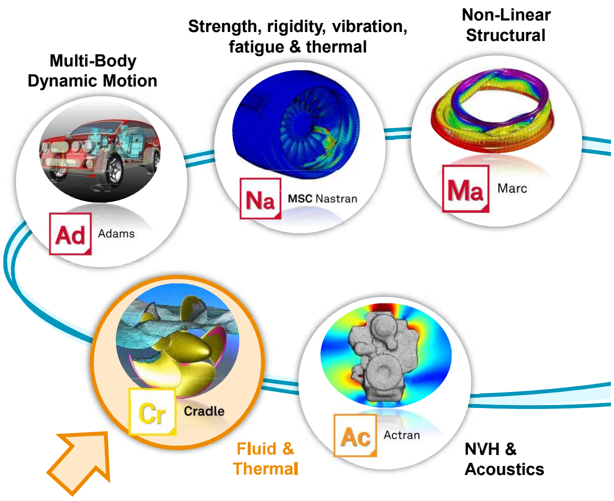
CFD Centre of Excellence
／Software Cradle

Background and Objectives

About scFLOW

- **What is scFLOW?**
  - A part of commercial CFD package “Cradle CFD” developed by Hexagon
    - **User-friendly GUI**
    - A comprehensive package
      - **Pre-processor:** Polyhedral mesh generator
      - **Solver:** Unstructured polyhedral mesh thermo-fluid solver
        - **Incompressible to hypersonic flows**
        - Multi-phase flows
        - Granular flows
      - **Post-processor:** Visualization
    - Multiphysics
      - Co-simulation among **MSC Nastran, Marc, Adams, Actran.**



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Background and Objectives

About scFLOW

- **What is scFLOW?**
  - scFLOW has recently been ported to the Fugaku A64FX system and become available on **Fugaku**.


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Press Release

For immediate distribution

23 June 2021

Hexagon adopts the supercomputer Fugaku to revolutionise the use of simulations in product innovation

Partnership with Fujitsu means Cradle CFD customers can complete previously unfeasible simulations faster than ever before

Hexagon has demonstrated how innovation can be accelerated by opening up the possibility of completing complex CFD (computational fluid dynamics) simulations that were previously too time consuming and expensive using the world's fastest

https://www.mscsoftware.com/news/hexagon-adopts-supercomputer-fugaku-revolutionise-use-simulations-product-innovation

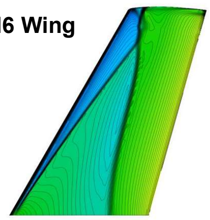
https://asia.nikkei.com/Business/Technology/Japan-s-Fugaku-keeps-position-as-world-s-fastest-supercomputer

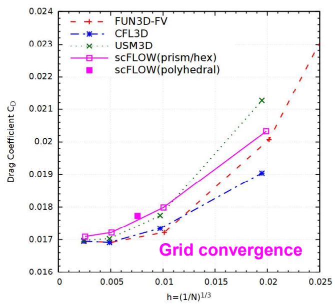
Background and Objectives

Validation Works and Objectives

- **Validation of scFLOW on aerospace applications**
  - **AIAA 2020-3029**
    - Hemisphere-cylinder (HC) and ONERA M6 (OM6) wing in NASA's turbulence model resource (TMR).
    - Good agreement with those obtained by NASA's government codes (FUN3D, CFL3D, USM3D).
  - **AIAA 2022-3522**
    - Validate scFLOW on models used at **4th AIAA CFD High Lift Prediction Workshop** (HLPW4).
    - Demonstrate the parallel efficiency on Fugaku.
- **Objectives of this work**
  - Further verification study for low speed & high AoA flows of CRM-HL with scFLOW
    - Steady RANS
      - **Iterative convergence characteristics** of aerodynamic coefficient
      - Comparison with **experimental measurement**
      - Research on the **aerodynamic hysteresis** around the stall angle
    - Transient analysis
      - Shows preliminary results

ONERA M6 Wing



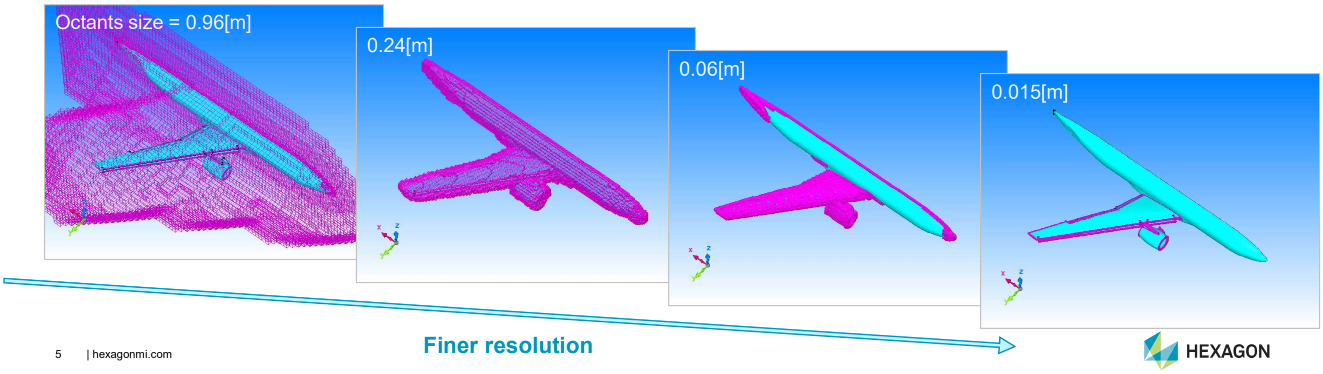


Numerical Methods

Numerical Mesh

- **Mesh generation by scFLOW**
  - For the **boundary layer elements,** the recommended values of Level-C in Mesh Generation Guidelines on the workshop website were used for the initial thickness and boundary layer growth rate.
  - For this work, Octants are simply refined around the walls, especially at the edges.

Example of Octants specification



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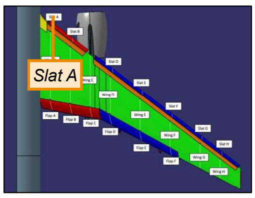
Numerical Methods

Numerical Mesh

- **Comparison with provided mesh, ANSA103**

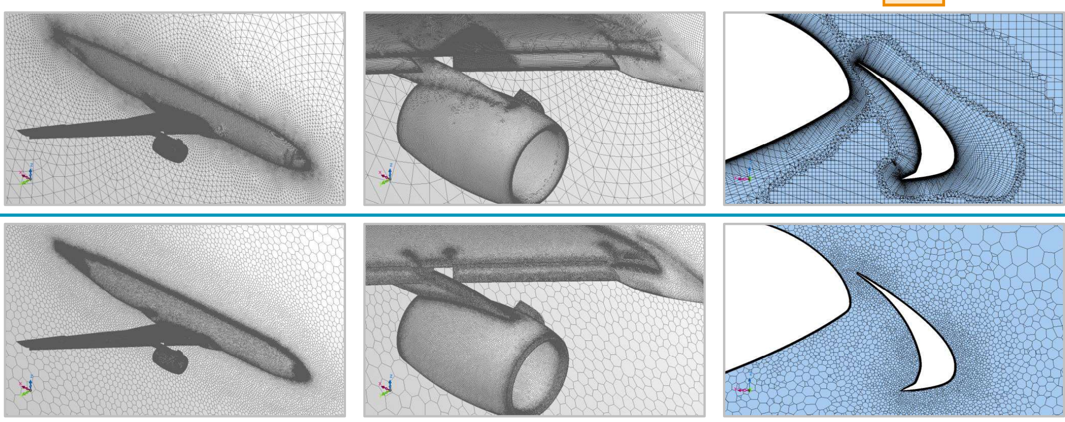
Mesh	Elements	Faces
ANSA 103, Level C	276,096,145	764,761,128
Polyhedral Mesh	62,124,074	294,876,783



Surface mesh | Around the nacelle | Cross-section at *Slat A*

ANSA 103, Level C

Polyhedral Mesh



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Numerical Methods

Numerical Procedure

- Discretization method
  - Cell-centered finite volume method, **unstructured polyhedral**, density-based solver
- Inviscid flux
  - **Roe flux**
- Reconstruction
  - **Linearity-preserving U-MUSCL (Nishikawa 2020)**
    - Recovers the accuracy of U-MUSCL even when the mesh is in bad condition
    - κ for the meanflow equations
      - Polyhedral Mesh : κ=0.5
      - ANSA 103 : κ=0.0(more stable but less accurate)
- Viscous flux
  - **Alpha damping scheme (Nishikawa 2010)**
    - Evaluates the gradient at a CV-face by using high-frequency damping term with the parameter alpha in addition to the arithmetic mean of elemental gradients
    - Stable and accurate even for skew mesh (Jalali et al. 2014)

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Numerical Methods

Numerical Procedure

- Calculation method of gradients
  - Polyhedral Mesh : Weighted least squares
  - ANSA 103 : Green-Gauss(more stable but less accurate)
- Non-linear solver in a steady-state analysis
  - Implicit defect correction solver with the residual Jacobian derived exactly from a lower-order discretization with a local pseudo-time step
- Turbulence model
  - **Steady : SA-neg**
  - **Transient : SST-SAS**
- Initial field & calculated AoA
  - **Steady**
    - Uniform Flow : 2.78, 7.05, 11.29, 17.05, 19.57, 20.55, 21.47°
    - AoA Increasing : 17.05 → 19.57 → 20.55 → 21.47°
    - AoA Decreasing : 11.29 ← 17.05 ← 19.57 ← 20.55 ← 21.47°
  - **Transient**
    - Steady results : 7.05, 17.05, 19.57, 21.47°

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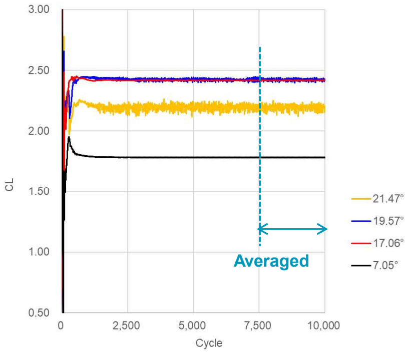
Numerical Results

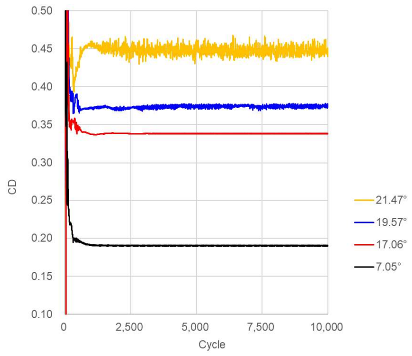
Convergence Histories

- Calculation histories of aerodynamic coefficients, CL, CD, and CM, **Polyhedral Mesh**
  - **Evaluate the averaged flow-field in the last 2,500 cycles**

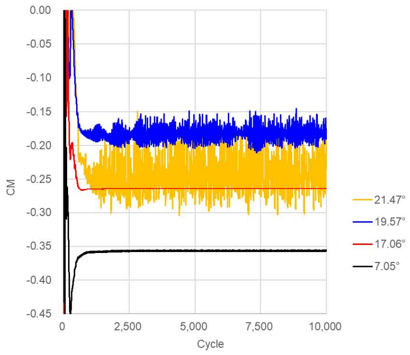
Lift coefficient



Drag coefficient



Momentum coefficient



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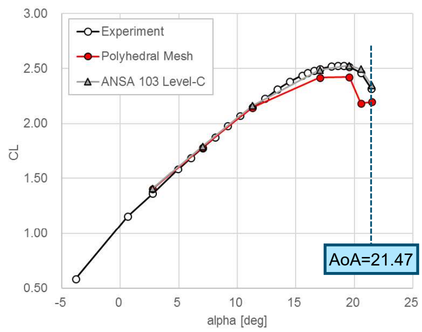
Numerical Results

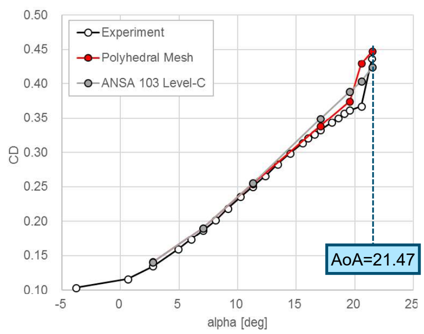
AoA Sweep

- Comparison of the aerodynamic coefficients, CL, CD, and CM
  - It has been said that around the stall angle is difficult with the steady RANS, but these results are relatively good.

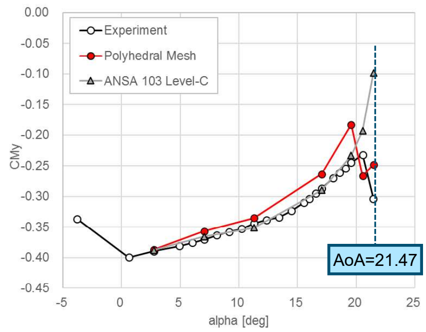
Lift coefficient



Drag coefficient



Momentum coefficient



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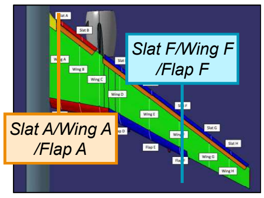
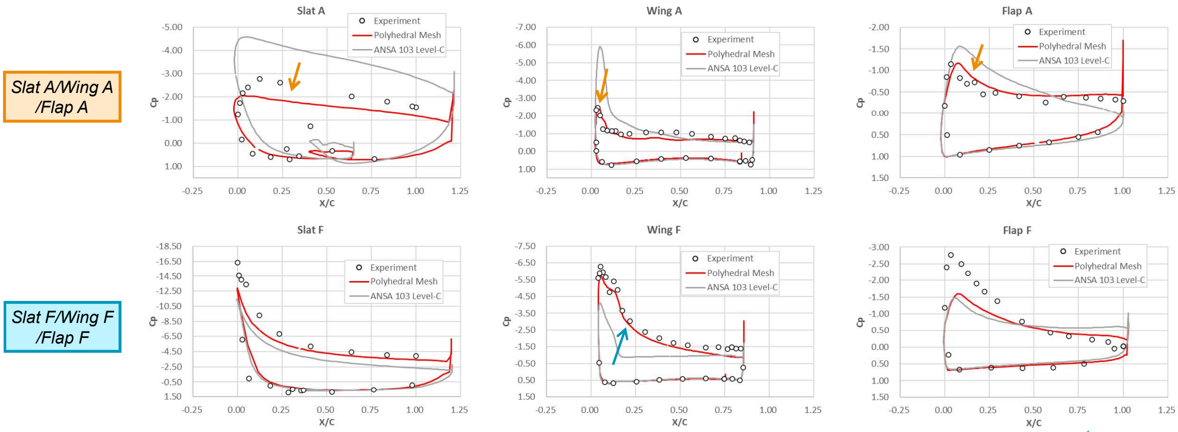
Numerical Results

AoA Sweep

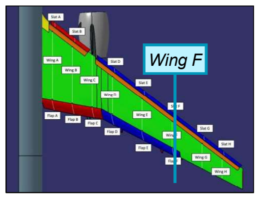


- Comparison of the pressure coefficients, Cp, at AoA=21.47°
  - In terms of the pressure distribution on the wing surface, **Polyhedral Mesh** gives better results.

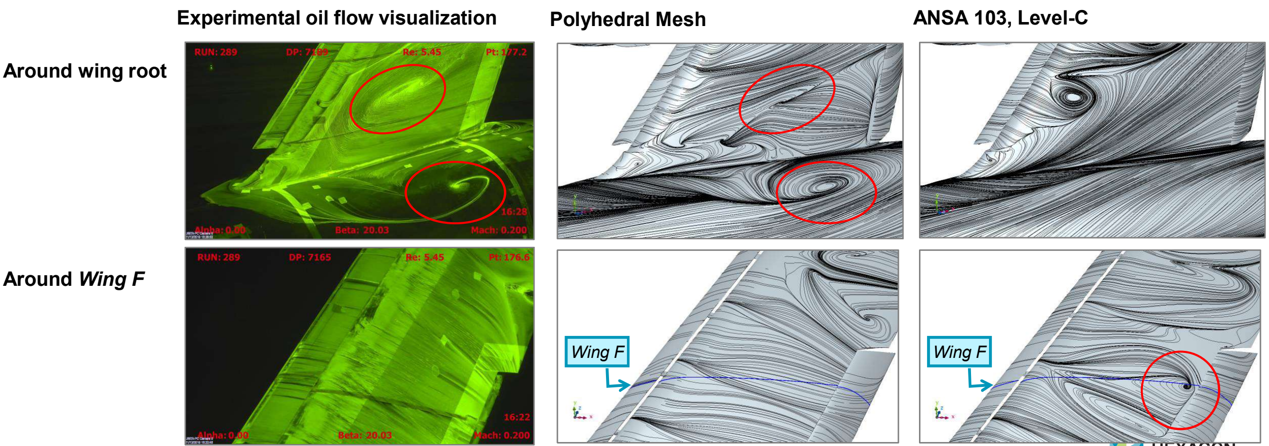


Numerical Results

AoA Sweep



- Comparison of the oil flow visualization at AoA=21.47°
  - Polyhedral Mesh predicts well the flow separation around the wing root and attached flow around the section *Wing F*.

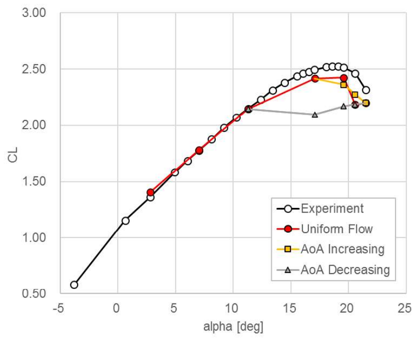


Numerical Results

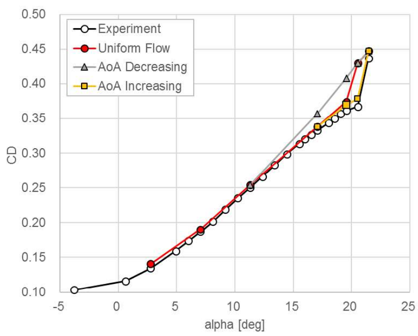
Aerodynamic Hysteresis

- Comparison of the aerodynamic coefficients, CL, CD, and CM, among 3 sets of initial conditions: a uniform flow (Uniform Flow), the result at a lower AoA (AoA Increasing), and the result at a higher AoA (AoA Decreasing)

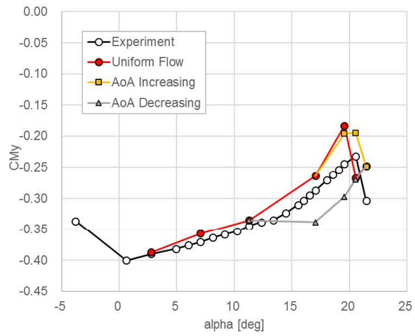
Lift coefficient



Drag coefficient



Momentum coefficient



Numerical Results

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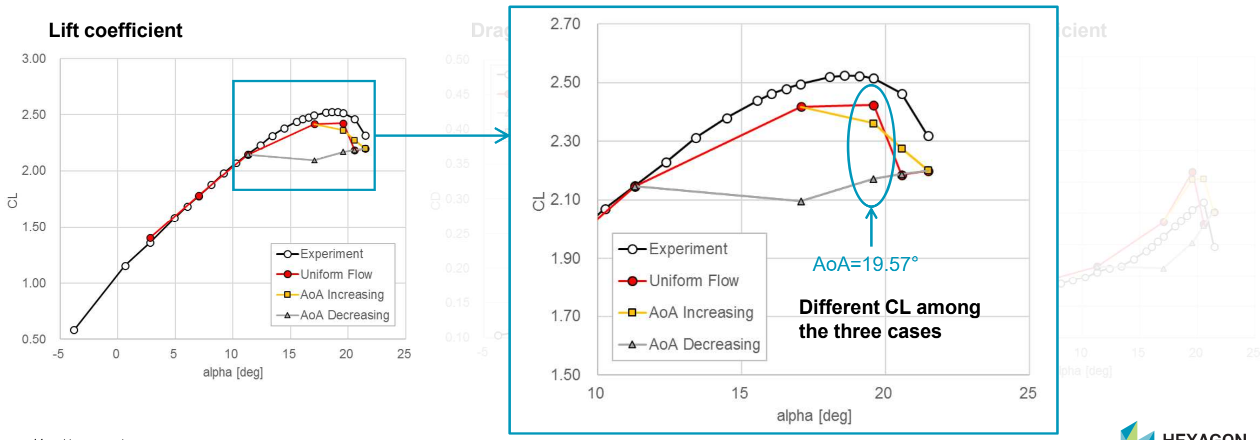
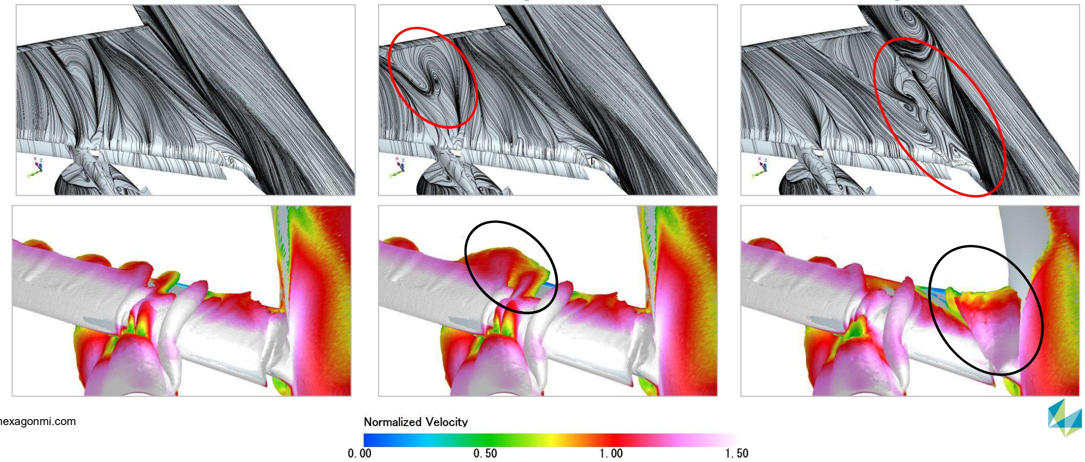


Numerical Results

Aerodynamic Hysteresis

- Comparison of oil flow and iso-surfaces of the vorticity, AoA=19.57°
  - **Separation behind the nacelle or at the wing root** occurs depend on the initial field

Uniform Flow **AoA Increasing** **AoA Decreasing**



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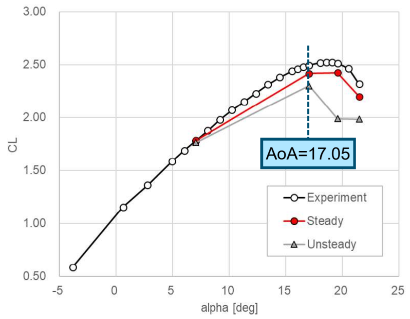
Numerical Results

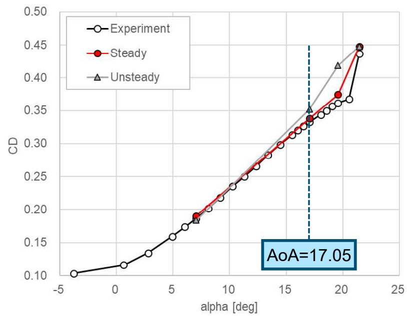
Transient Analysis

- Comparison of the aerodynamic coefficients, CL, CD, and CM
  - Preliminary calculation of transient analysis **can not improve** the steady RANS results.

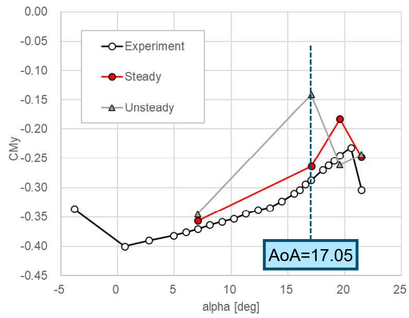
Lift coefficient



Drag coefficient



Momentum coefficient



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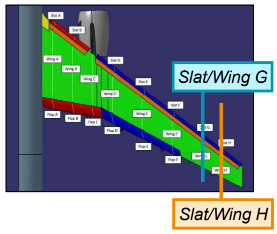
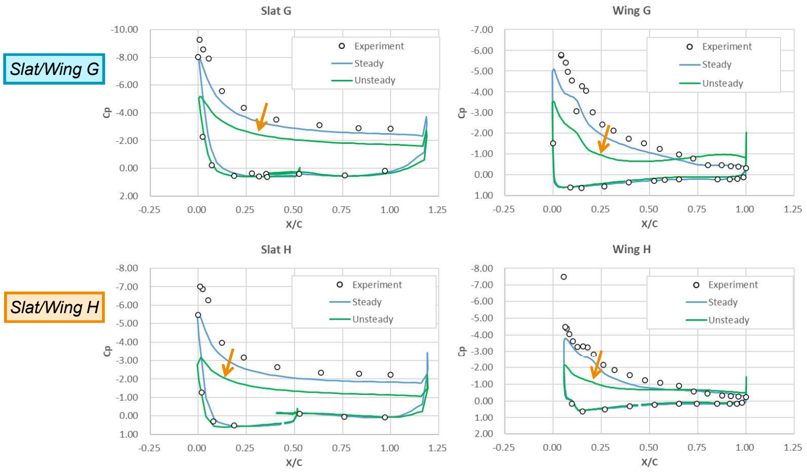
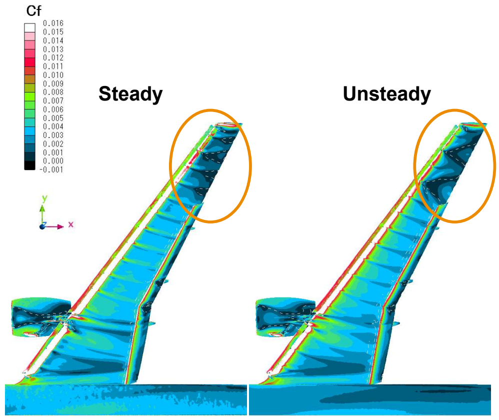
Numerical Results

Transient Analysis



- Comparison of the pressure coefficients, Cp, and wall shear stress at AoA=17.05°





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Conclusions & Future Work

Conclusions & Future work

- **Conclusions**
  - Verification study of CRM-HL with a polyhedral finite-volume turbulent-flow solver, scFLOW was performed.
    - **Steady results** were successfully obtained.
    - The coefficients CL, CD, and CM are relatively good agreement with those of experiment. Especially, prediction at a higher AoA after the stall is difficult. However, Polyhedral Mesh got better results in terms of surface pressure by **capturing the separation accurately**.
    - **Aerodynamic hysteresis** is observed: especially for AoA=19.55°, steady-state results are different among the three cases of angle-increase, decrease, and uniform flow start.
    - Preliminary calculation of transient analysis could not improve the steady RANS results.
- **Future work**
  - Study the **transient analysis** and **adaptive mesh refinement approach** to capture the separation phenomena more accurately and improve the resulting aerodynamic coefficient prediction.

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