Numerical Prediction of Aerodynamic Characteristics of Multi-Element High-Lift Airfoil 30P30N by scFLOW

Fourth Aerodynamics Prediction Challenge (APC-IV)

Background

- **Our participation in APC**
  - APC-I(2015), *SC/Tetra-V12*
  - APC-III(2017), *scFLOW-V14RC1*

<table>
<thead>
<tr>
<th>Software</th>
<th>CPU</th>
<th>Calc. time [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC/Tetra</td>
<td>72</td>
<td>7.0</td>
</tr>
<tr>
<td>scFLOW</td>
<td>144</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Background

- Practical use of calculation data
  - Validation site for scFLOW

![Comparison with experiments measured by APC-III](image)

Objectives

- Objectives of this work
  - Use two types of numerical meshes
    - **Structured mesh** provided by APC-IV
      - Validate the solver in scFLOW
    - **Polyhedral mesh** generated with scFLOW
      - Validate polyhedral mesh generation for wing geometry

- Our work
  - Steady-state analysis by 2D mesh
    - **Case 1-1: 30P30N**
      - Alpha variation by using two types of meshes
      - Grid convergence for structured mesh
    - **Case 2-1: 30P35N**
      - Comparison with 30P30N by using two types of meshes
Calculation Methods

- **Calculation methods of scFLOW**
  - **Solver**
    - Density-based solver
  - **Discretization method**
    - Cell centered finite volume method
  - **Inviscid flux**
    - *Roe solver* (Roe 1981)
  - **Viscous flux**
    - **Alpha damping scheme** (Nishikawa 2010, 2011)
      - Evaluate 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 skewed mesh* (Jalali et al. 2014)

Calculation Methods

- **Calculation methods of scFLOW**
  - Accuracy of inviscid terms and limier function
    - 2nd order, van Leer-type Hishida limiter (2010)
  - **Calculation method of gradients**
    - Weighted least-squares method
  - **Non-linear solver in a steady-state analysis**
    - **Implicit defect correction method**
      - Jacobian is constructed exactly based on a compact first-order inviscid scheme and a compact viscous scheme (Nakashima et al. 2014, Nishikawa et al. 2017)
      - *Expect a fast convergence for non-linear solver*
  - **Turbulence model**
    - *Spalart-Allmaras One-Equation Model (SA)*
Problem Setup

- **Analysis conditions**
  - **Geometry**
    - Case 1-1: 30P30N
    - Case 2-1: 30P35N
  - **Flow condition**
    - Mach number: 0.17
    - Reynolds number: $1.71 \times 10^6$
    - Angle of attack (AoA): 0-26[deg]

Numerical Mesh

- **Comparison of L2(medium) meshes for 30P30N**
  - Structured mesh
  - Polyhedral mesh
Numerical Mesh

- **Polyhedral mesh generation by scFLOW**
  - Definition of spatial element size by octants
    - Octant size: $2.54 \times 10^{-5}$ (T.E. of wings) - 0.83 (far-field) [m]
    - $\sim 1.3 \times 10^{-2}$
    - $\sim 1.6 \times 10^{-3}$
    - $\sim 8.1 \times 10^{-4}$
    - $\sim 4.1 \times 10^{-4}$

- **Prism layer insertion in polyhedral mesh generation**
  - Thickness of 1st layer: $5.08 \times 10^{-6}$ [m]
  - Variation of thickness: 1.2
  - Number of layers: 20

- **L2(medium) mesh used in this calculation**
  - The number of elements

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Type</th>
<th>Elements</th>
<th>Nodes</th>
<th>Faces</th>
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<tbody>
<tr>
<td>30P30N</td>
<td>Structured</td>
<td>112,474</td>
<td>226,496</td>
<td>450,672</td>
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<td></td>
<td>Polyhedral</td>
<td>107,261</td>
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<td>502,671</td>
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<tr>
<td>30P35N</td>
<td>Structured</td>
<td>112,474</td>
<td>226,496</td>
<td>450,672</td>
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<tr>
<td></td>
<td>Polyhedral</td>
<td>106,754</td>
<td>359,698</td>
<td>500,113</td>
</tr>
</tbody>
</table>
Numerical Conditions and Calculation Time

- **Numerical conditions**
  - Initial conditions; *Uniform flow*
  - Calculates 10,000 cycles
  - Evaluate the *averaged* variables over the last 1,000 cycles

  
  Ex. Polyhedral mesh

  ![Graph](image)

- **Calculation time for L2(medium) mesh with 36cpu**

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<th>Calc. time[min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30P30N</td>
<td>Structured</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Polyhedral</td>
<td>7.2</td>
</tr>
</tbody>
</table>

  ![Table](image)

Case 1-1: Alpha Variation for 30P30N

- **Comparison of aerodynamic coefficients**
  - Cl has a reasonable agreement with the reference [AIAA 2014-2080]

  ![Graphs](image)
Case 1-1: Alpha Variation for 30P30N

- **Comparison of Cp distribution on the wing surface**
  - Good agreement with the experiments
  - AoA=5.5[deg]
  - AoA=9.5[deg]
  - AoA=14[deg]

Case 2-1: Effect of Flap Angle

- **Comparison of lift and pressure coefficients**
  - Left: Lift, Right: Pressure coefficient
  - Structured mesh
  - Polyhedral mesh

This document is provided by JAXA.
Case 2-1: Effect of Flap Angle

- Comparison of streamlines
  - Separation behavior on the flap wing is different between mesh types
    - Structured mesh
      - Polyhedral mesh

Conclusions

- Conclusions of this work
  - Case 1-1: The pressure distribution on the wing surface is reasonable agreement with experiments, not only for the structured mesh provided by APC-IV, but also for the polyhedral mesh generated with scFLOW
  - Case 2-1: Separation behavior on the flap wing is different between mesh types

- Our future work
  - Acoustic analogy of FW-H method will be released in the next version of scFLOW
    - We will try the prediction of acoustic pressure for Case 3
  - Using acoustic analysis software Actran with scFLOW
Supplement

- Co-simulation using Adams and scFLOW
  - A coupled analysis with multi-body dynamics analysis software Adams

Displacement and Euler angles
Pressure force, shear stress

Flap movement

Thank you for your attention