50th Fluid Dynamics Conference/36th Aerospace Numerical Simulation Symposium

Cradle
MSC Software Company

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

Fourth Aerodynamics Prediction Challenge(APC-IV)

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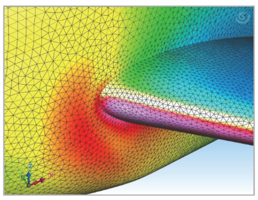
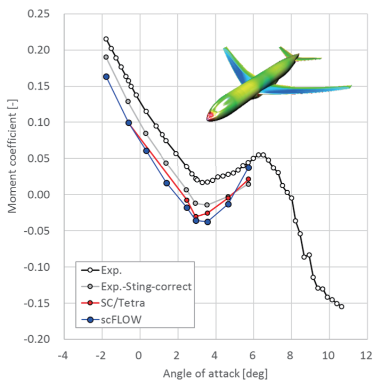
PART OF HEXAGON

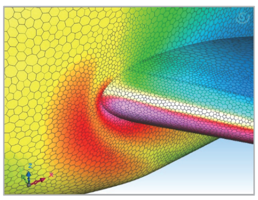
Background

- **Our participation in APC**
  - APC-I(2015), **SC/Tetra-V12**





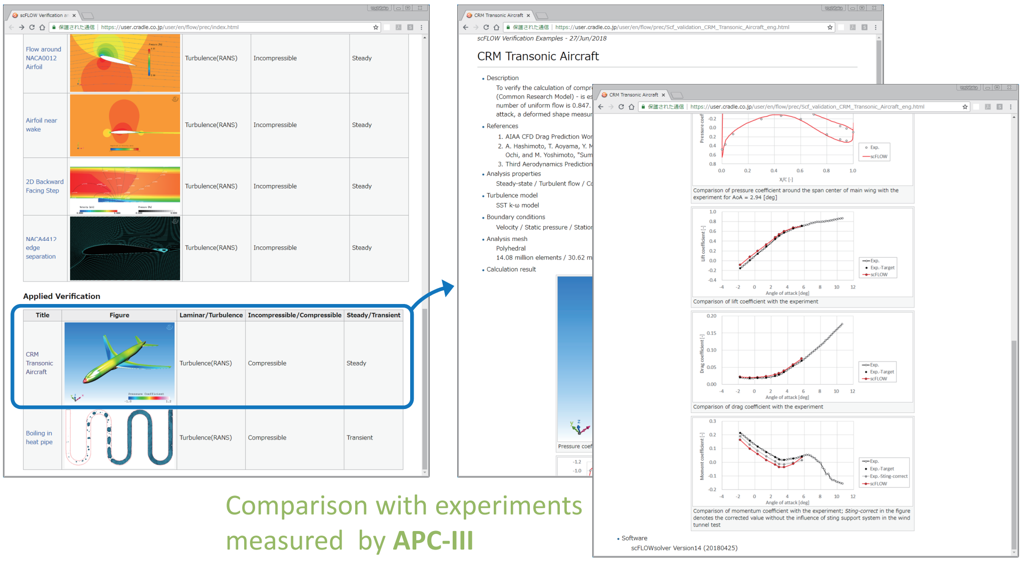
  - APC-III(2017), **scFLOW-V14RC1**



Software	CPU	Calc. time [h]
SC/Tetra	72	7.0
scFLOW	144	1.2

Background

- **Practical use of calculation data**
  - Validation site for **scFLOW**



Comparison with experiments measured by **APC-III**

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

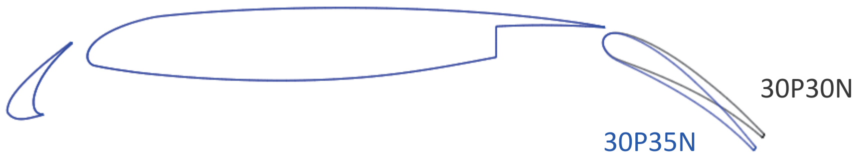
- **Calculation methods of scFLOW**
  - Solver
    - Density-based solver
  - Discretization method
    - Cell centered finite volume method
  - Inviscid flux
    - **Roe solver** (Roe 1981)
  - Viscous flux
    - **Alpha damping scheme** (Nishikawa 2010,2011)
      - Evaluate the gradient at a CV-face 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

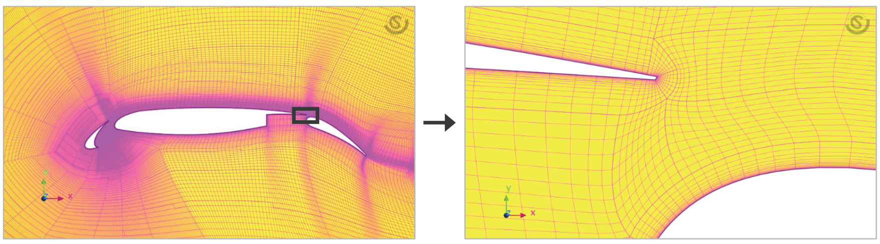
- **Analysis conditions**
  - Geometry
    - Case 1-1 : 30P30N
    - Case 2-1 : 30P35N



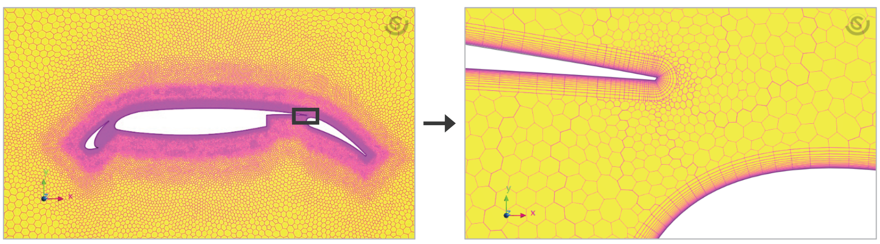
  - Flow condition
    - Mach number : 0.17
    - Reynolds number : 1.71×10^6
    - Angle of attack (AoA) : 0-26[deg]

Numerical Mesh

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



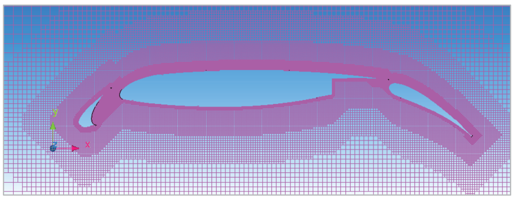
  - Polyhedral mesh



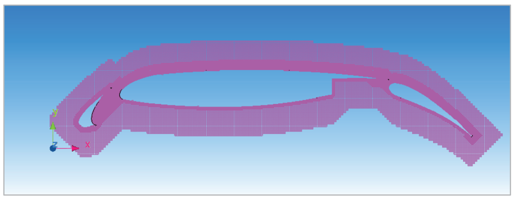
Numerical Mesh

- **Polyhedral mesh generation by scFLOW**
  - Definition of spatial element size by **octants**
    - Octant size : 2.54×10^{-5}(T.E. of wings)-0.83(far-field)[m]

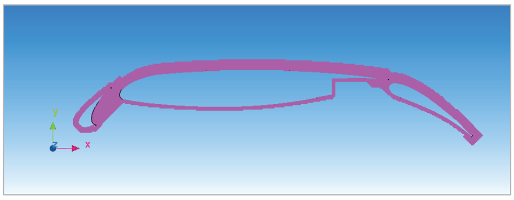
~ 1.3×10^{-2}



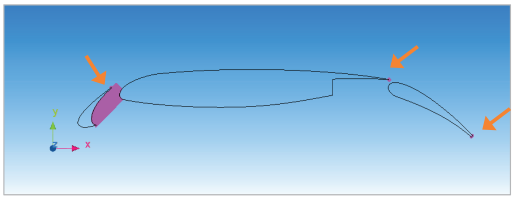
~ 1.6×10^{-3}



~ 8.1×10^{-4}



~ 4.1×10^{-4}



Numerical Mesh

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

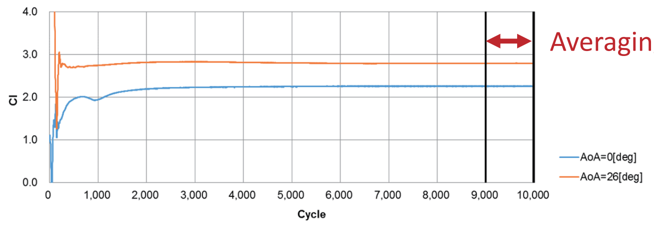
- **L2(medium) mesh used in this calculation**
  - The number of elements

Geometry	Type	Elements	Nodes	Faces
30P30N	Structured	112,474	226,496	450,672
	Polyhedral	107,261	361,772	502,671
30P35N	Structured	112,474	226,496	450,672
	Polyhedral	106,754	359,698	500,113

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



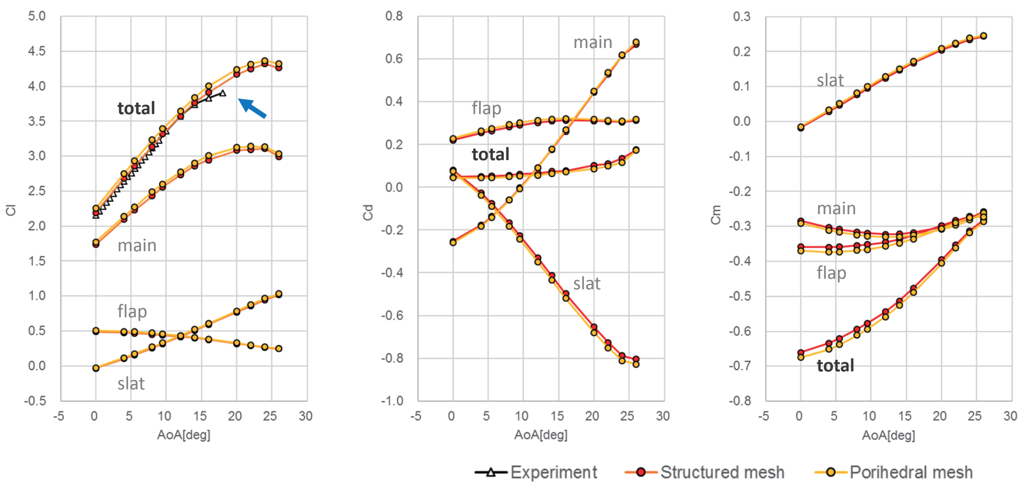
- **Calculation time for L2(medium) mesh with 36cpu**

Geometry	Type	Calc. time[min]
30P30N	Structured	7.0
	Polyhedral	7.2

Case 1-1: Alpha Variation for 30P30N

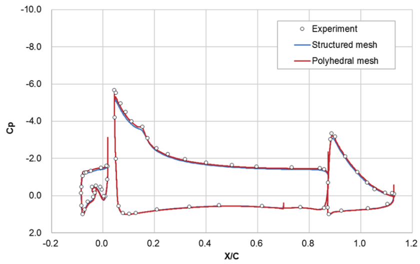
- **Comparison of aerodynamic coefficients**
  - Cl has a reasonable agreement with the reference [AIAA 2014-2080]

- Lift coefficient
- Drag coefficient
- Moment coefficient

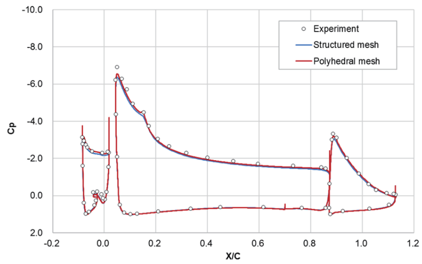


Case 1-1: Alpha Variation for 30P30N

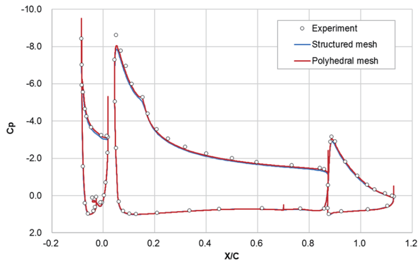
- **Comparison of Cp distribution on the wing surface**
  - Good agreement with the experiments
    - AoA=5.5[deg]



    - AoA=9.5[deg]

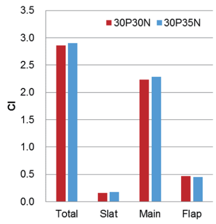


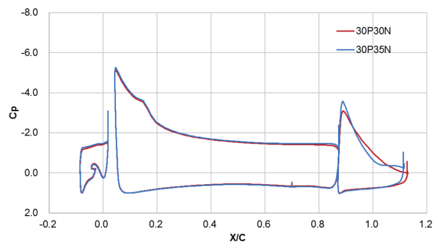
    - AoA=14[deg]



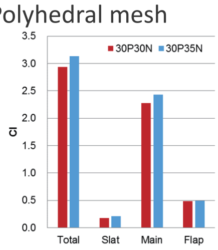
Case 2-1: Effect of Flap Angle

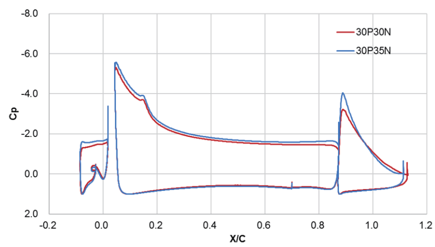
- **Comparison of lift and pressure coefficients**
  - Left: Lift, Right: Pressure coefficient
    - Structured mesh





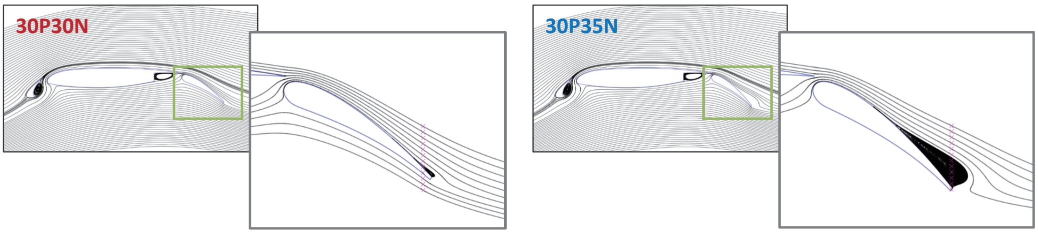
    - Polyhedral mesh



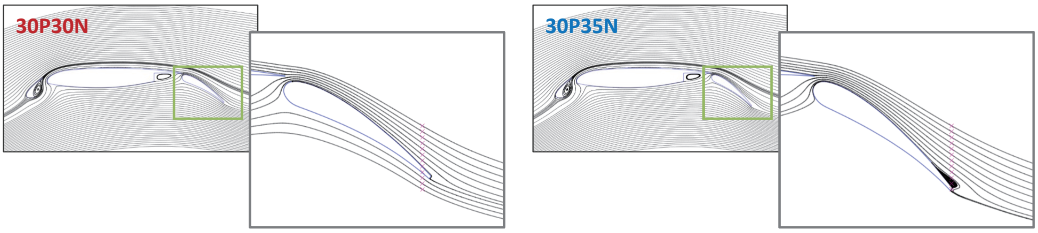


Case 2-1: Effect of Flap Angle

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



    - Polyhedral mesh



Conclusions

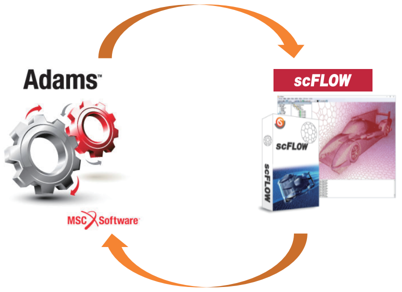
- **Conclusions of this work**
  - **Case 1-1:** The pressure distribution on the wing surface is reasonable agreement with experiments, not only for the structured mesh provided by **APC-IV**, but also for the polyhedral mesh generated with **scFLOW**
  - **Case 2-1:** Separation behavior on the flap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

scFLOW → Actran

Supplement

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

Displacement and Euler angles



Pressure force, sheer stress

- **Flap movement**

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Thank you for your attention