49th Fluid Dynamics Conference/35th Aerospace Numerical Simulation Symposium

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Numerical Prediction of Aerodynamic Characteristics of NASA-CRM by **scFLOW**

Third Aerodynamics Prediction Challenge (APC-III)

Jun 28, 2017
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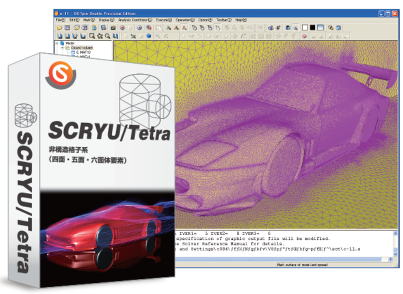
Software and Objectives

- **CFD software used in this work**
  - **scFLOW V14(RC1)**
    - **Commercial CFD software** developed by **Software Cradle**
    - Includes polyhedral mesh generation, unstructured mesh thermo-fluid solver, and visualization
    - In **V14** released in May, 2018, **density-based solver** is implemented in addition to **pressure-based solver.**

SC/Tetra(1998-)



scFLOW(2016-)

Software and Objectives

- **Background**
  - Participation in APC-I by using **SC/Tetra**
- **Objectives of this work**
  - Use two types of numerical mesh for **Case 1**
    - **HexaGrid mesh**
      - Unstructured mesh generated with **HexaGrid**, provided by APC
      - Validate the new density-based solver of **scFLOW**
      - Use **SST** turbulence model
    - **scFLOW mesh (polyhedral mesh)**
      - Unstructured polyhedral mesh generated with **scFLOW**
      - Validate both polyhedral mesh generation and solver of **scFLOW**

⇒ Investigate the **differences** in results using **two types of mesh**

Calculation Methods

- **Calculation methods of scFLOW**
  - Discretization method
    - Cell centered finite volume method
  - Inviscid flux
    - **Rotated-RHLL solver** (Nishikawa and Kitamura 2008)
      - **Robust and accurate Riemann solver** by combining the high-resolution Roe solver and the dissipative but robust HLLE solver
  - 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 skew mesh** (Jalali et al. 2014)

Calculation Methods

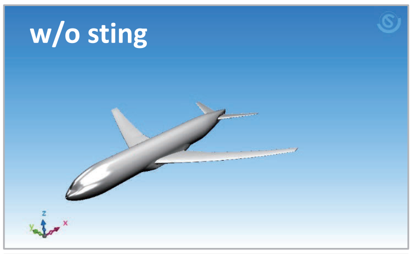
- **Calculation methods of scFLOW**
  - Accuracy of inviscid terms and limier function
    - 2nd order, van Leer-type Hishida limiter (2010)
  - Calculation method of gradients
    - Weighted least-squares method
  - Non-linear solver in a steady-state analysis
    - **Implicit defect correction method**
      - Jacobian is constructed exactly based on a compact first-order inviscid scheme and a compact viscous scheme (Nakashima et al. 2014)
      - **Expect a fast convergence for non-linear solver**
  - Turbulence model
    - **SST k-ω model** (Menter 1993)

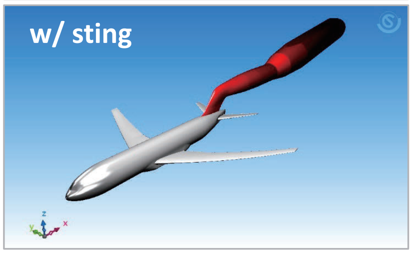
Problem Setup

- **Analysis conditions (Case 1)**
  - Transonic flow around NASA-CRM
    - **w/o** and **w/** a sting support system
    - Account for aeroelastic deflections measured by experiments

Experiments by JAXA

https://cfdws.chofu.jaxa.jp/apc/





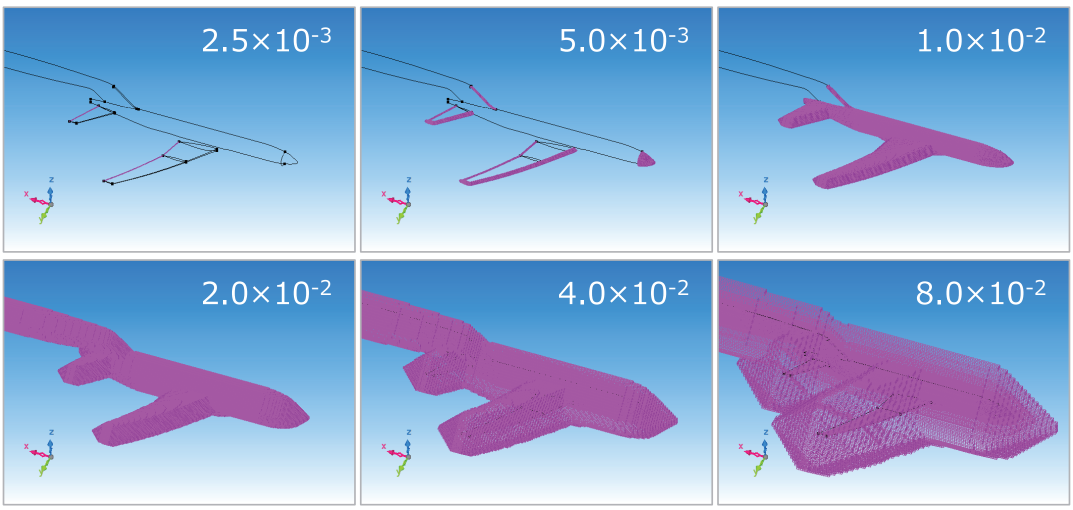
Numerical Mesh

- **Mesh used in this calculation**
  - **HexaGrid mesh**
    - Unstructured mesh generated with **HexaGrid**, provided by APC
    - Mainly **hexahedral elements**
  - **scFLOW mesh (polyhedral mesh)**
    - Unstructured polyhedral mesh generated with **scFLOW**
    - Mainly **polyhedral and hexahedral elements**

Mesh	Sting	Element	Node	Face
HexaGrid mesh	w/o	**14,992,926**	13,329,362	43,504,874
	w/	26,886,107	24,288,326	78,369,835
scFLOW mesh	w/o	**13,914,548**	29,627,823	56,129,441
	w/	19,945,934	43,397,870	81,215,399

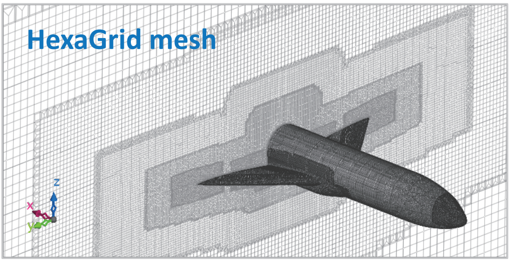
Numerical Mesh

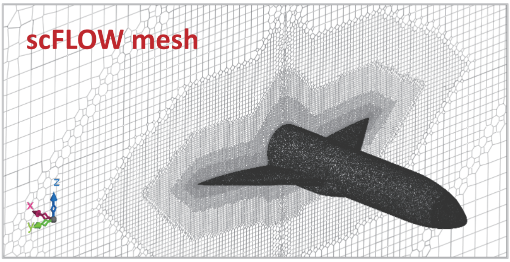
- **Mesh generation by scFLOW**
  - Definition of spatial element size by **octants**
    - Octant size : 2.5×10^{-3}(T.E. of wing)-2.56(far-field)[m]



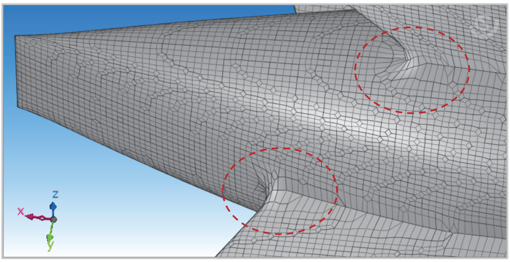
Numerical Mesh

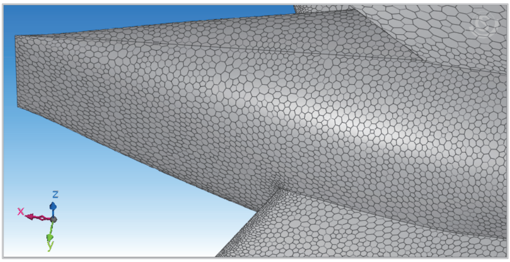
- **Comparison of meshes**
  - Cross section of volume mesh





  - Surface mesh around tail





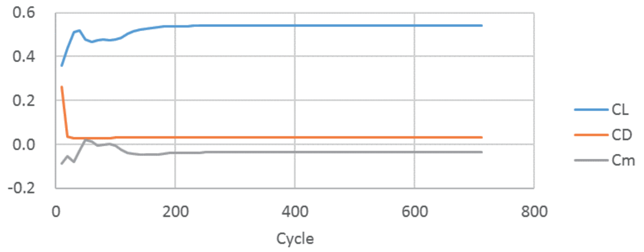
Convergence Cycle and Calculation Time

- **Convergence cycle and calculation time**
  - Averaged among all angles of attack
    - CPU: Intel Xeon E5-2695 v4 2.10GHz, 144 cores

Mesh	Sting	Convergence cycle	Calc. time[h]
HexaGrid mesh	w/o	758	0.91
	w/	929	2.09
scFLOW mesh	w/o	731	1.20
	w/	755	1.78

Less than 1,000 cycles

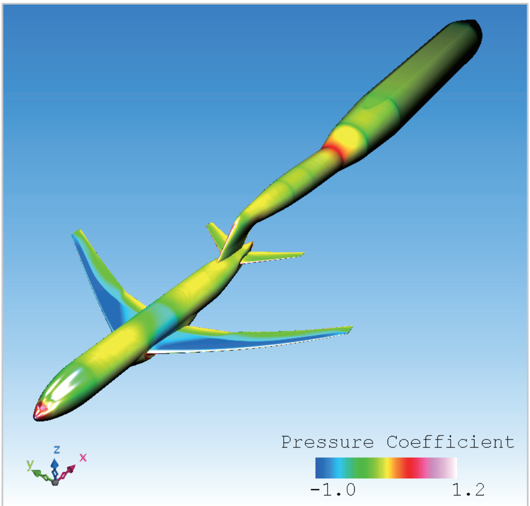
- **History of aerodynamic coefficients**
  - Ex. scFLOW mesh w/o sting, α_c=2.94 deg.



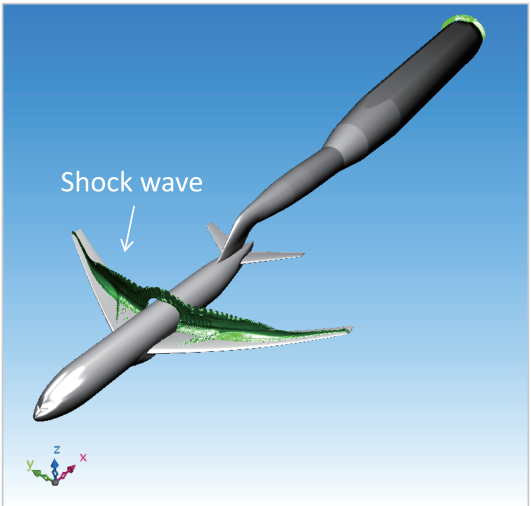
Numerical Results

- **Examples of numerical result**
  - scFLOW mesh, α_c=4.65[deg.] w/ sting

Pressure coefficient

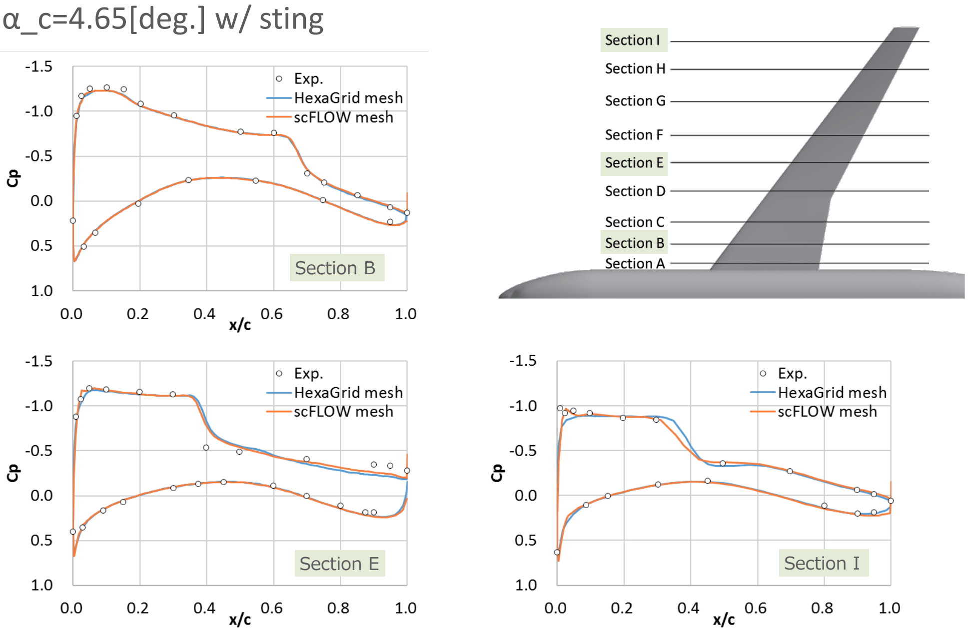


Isosurfaces of shock function
(Lovely and Haimes 1999)



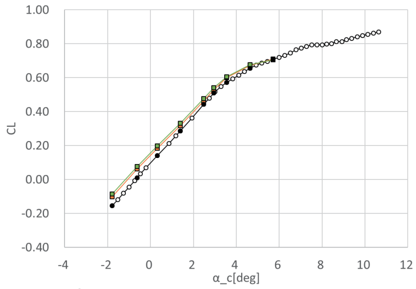
Numerical Results

- **Comparison of Cp distribution**
  - α_c=4.65[deg.] w/ sting

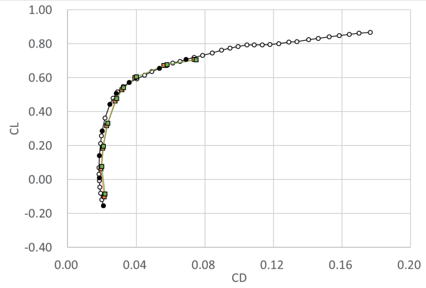


Variation of Aerodynamic Coefficients

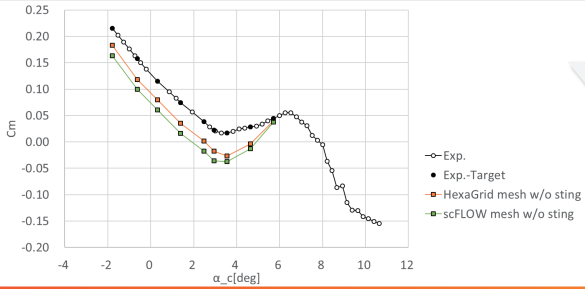
- **Aerodynamic coefficients w/o sting**
  - Lift curve



  - Drag polar



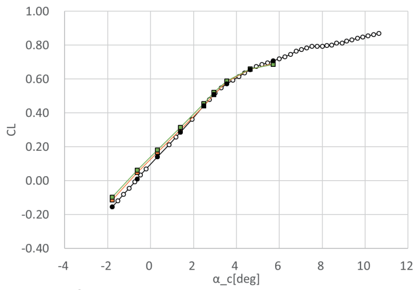
  - Pitching moment curve



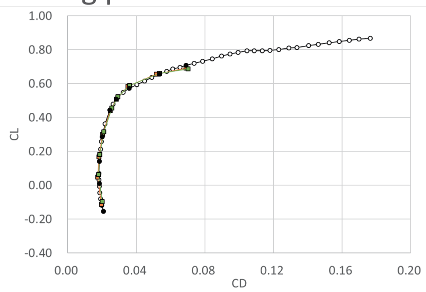
- Reasonably **good agreement** with experimental results with **SST model** on **both meshes**.

Variation of Aerodynamic Coefficients

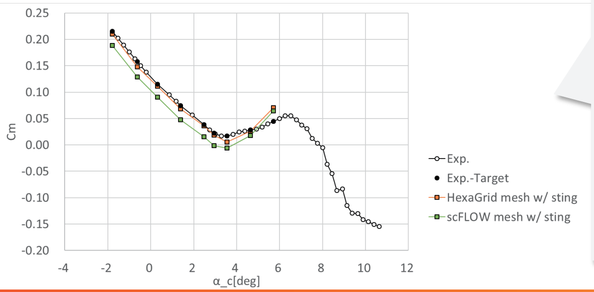
- **Aerodynamic coefficients w/ sting**
  - Lift curve



  - Drag polar



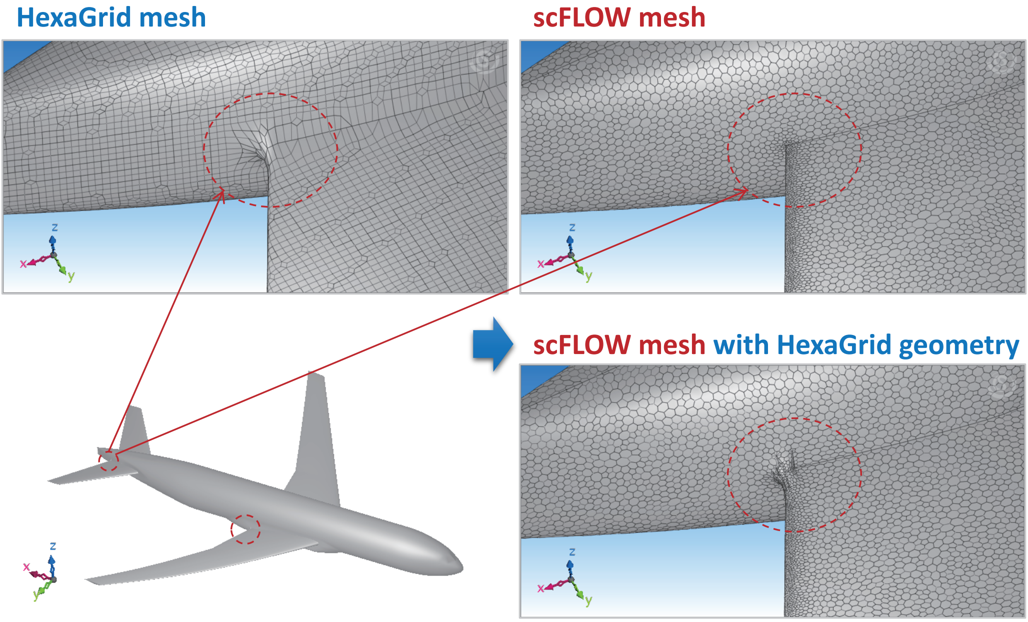
  - Pitching moment curve



- Account for the **sting geometry improves** aerodynamic coefficients, especially Cm
- As reported in **APC-II**, **HexaGrid mesh** gives results close to the experimental values

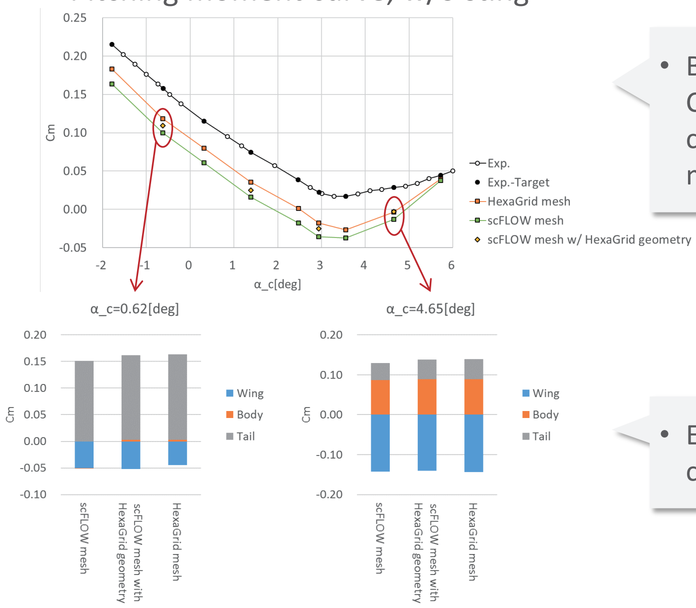
Effects of Geometry Difference

- **Match the geometry**



Variation of Aerodynamic Coefficients

- **scFLOW mesh with HexaGrid geometry**
  - Pitching moment curve, w/o sting



- By using **HexaGrid geometry**, Cm of scFLOW mesh gets close to that of HexaGrid mesh.

- Especially, **tail-wing** component of Cm is affected

Conclusions

- **Conclusions in this work**
  - By using new density-based solver of **scFLOW V14**
    - Non linear solver converged **successfully**
      - Convergence cycle less than 1,000
      - e.g., **HexaGrid mesh** w/o sting ~1 hour with 144 cores
    - **Reasonable** agreement with experiments
      - Not only **HexaGrid mesh**, but also **scFLOW mesh** generated with **scFLOW**
      - **SST k-ω model**
  - Investigate the difference in the pitching moment coefficients using two types of mesh
    - The difference is partly due to the **geometry mismatch** at the wing root.

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Thank you for your attention.