008 - KHI Contribution to HiLiftPW-3

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Outline

- Summary of cases completed
- Introduction of “Cflow”
- Overview of grid systems and numerical methods
- Results of HL-CRM
- Results of JSM
- Summary and future works
## Summary of cases completed

<table>
<thead>
<tr>
<th>Case</th>
<th>Alpha=8, Fully turb, grid study</th>
<th>Alpha=16, Fully turb, grid study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a (full gap)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1b (full gap w adaption)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1c (partial seal)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1d (partial seal w adaption)</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>Polar, Fully turb</th>
<th>Polar, specified transition</th>
<th>Polar, w transition prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a (no nacelle)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2b (no nacelle w adaption)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2c (with nacelle)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2d (with nacelle w adaption)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>2D Verification study</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>yes</td>
</tr>
</tbody>
</table>

**Topics of this presentation**

- HL-CRM
- JSM
- DSMA661 Airfoil
Introduction of “Cflow”

Kawasaki original CFD tool

\[ \text{Cflow} = \text{Grid Generator} + \text{Flow Solver} \]

- Non-orthogonal Octree AMR
- Layered grid

- Highly complicated
- Unsteady
- Large-scale

- Cflow has been validated in various workshops.

2010-2016
BANC I-IV

2013
HiLift-PW2

2016
DPW6

Unsteady flow

Steady flow
# Overview of grid systems

<table>
<thead>
<tr>
<th>Case</th>
<th>Grid System</th>
<th>Solver</th>
<th>Comment</th>
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<tr>
<td>1a, 1c</td>
<td>B3-HLCRM-UnstrHexPrismPyrTet_PW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b, 1d</td>
<td>Cflow Grid (Unstructured Hexahedra)</td>
<td>Cflow</td>
<td>Single grid is applied to all AoA.</td>
</tr>
<tr>
<td>2a, 2c</td>
<td>D-JSM_UnstrMixed_JAXA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b, 2d</td>
<td>Cflow Grid (Unstructured Hexahedra)</td>
<td></td>
<td>Single grid is applied to all AoA.</td>
</tr>
</tbody>
</table>

Details about Cflow Grid were presented in GMGW-1.

[Cflow Grid (HL-CRM full gap)]

- Non-orthogonal Octree
- Flow Adapted
- Boundary-fitted Layer
- Sectional Grid
  - HL-CRM full gap, eta=0.552, AoA=8[deg]
## Summary of code and numerics used

<table>
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<tr>
<th>Governing Equations</th>
<th><strong>Cflow</strong> Solver methods</th>
</tr>
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<td><strong>RANS</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Spatial Discretization</th>
<th>Cell-centered finite volume method with 2nd-order accurate reconstruction based on MUSCL</th>
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<tbody>
<tr>
<td>Inviscid Flux</td>
<td><strong>SLAU</strong> (Simple Low-dissipation AUSM scheme)</td>
</tr>
<tr>
<td>Viscous Flux</td>
<td>2nd-order accurate central difference</td>
</tr>
<tr>
<td>Time Integration</td>
<td>MFGS implicit method with local time stepping</td>
</tr>
<tr>
<td>Turbulence Model</td>
<td><strong>SA-noft2</strong></td>
</tr>
</tbody>
</table>

### Reference for **Cflow** details

Case 1a, 1b – HL-CRM (full gap)

Grid Convergence
Grid size

- 3 sizes of grid is computed for both B3 and Cflow Grid.

![Graph showing number of cells for coarse, medium, and fine grids for Cflow and B3.]

Cflow Grid is flow-adapted.

Sectional Grid @ $\eta=0.552$

Coarse | Medium | Fine

Cflow

B3
Grid convergence – CD-CDi, CL

CD-CDi

* CDi = CL2/(πAe), A = 9.0, e = 1

CL

CflowGrid has lower drag and higher lift than B3.

Discrepancy between B3 and Cflow seems to come from pressure drag (next page).
Grid convergence – CDv, CDp

- Friction drag coefficient (CDv) and pressure drag coefficient (CDp).

Difference between B3 and Cflow on skin friction (CDv) is small relative to that of pressure drag.

CDv

CDp-CDi

Difference of CDp - CDi is dominant to the discrepancy of CD-CDi.
Surface streamlines @ AoA=16[deg]

Surface Grid

B3 (Fine)
Separation near flap gap and outer flap edge is larger than Cflow.

Cflow (Coarse)
Wing surface mesh density is similar to each other.
Case 2a-2d
– JSM (Nacelle ON/OFF)
Computational mesh

JAXA Grid

Cflow Grid

Unstructure Mixed Unstructure Hexahedra
Lift curve

Mach 0.172
Re[-] 1.93 x 10^6

JAXA Grid

Cflow Grid

CL of CflowGrid drops earlier than JAXA grid.
Surface flow  \( \text{AoA}=10.47[\text{deg}] \)

**Skin friction coefficient \( C_f \)**

- **JAXA Grid**
- **Cflow Grid**

Separation at downstream side of #8 bracket.
Surface flow  AoA=18.58[deg]

Skin friction coefficient Cf

JAXA Grid

Cflow Grid

Largely separated at downstream side of #6 bracket.
Wing surface mesh density is similar to JAXA Grid.

Surface mesh is finer than JAXA Grid around wing LE.
Total pressure ratio @ No.6 bracket

- JAXA Grid: Total pressure ratio
  - 0.999
  - 0.97

- Cflow Grid: Volume mesh density is finer than JAXA Grid.

Volume mesh density is finer than JAXA Grid.
Effects of initial condition

- Effects of initial condition were investigated at AoA greater than 18.54[deg].
  - Two results are compared.
    - Impulsive start
    - start from the results of AoA=14.54[deg].

JAXA Grid (Impulsive)

Cflow Grid (Impulsive)

JAXA Grid (start from AoA=14.54[deg])

Cflow Grid (start from AoA=14.54[deg])

JAXA Grid CL was greatly improved.

Cflow Grid CL was much lower than impulsive start.
Effects of initial condition on surface flow

Impulsive Start

Separation was suppressed in JAXA Grid.

Start from AoA=14.54[deg]

Flow was separated at another bracket in Cflow Grid.
Summary and Future Works

- HL-CRM full gap (Grid convergence) case
  - Results of *Cflow Solver* using B3 Grid and *Cflow Grid* were presented.
  - Grid convergence was obtained in both grids.
  - B3 grid had higher drag than *Cflow*. Lower grid density of B3 near flap gap and outer flap edge might induce flow separation.

- JSM case
  - Results of *Cflow Solver* using JAXA Grid and *Cflow Grid* for both Nacelle-ON/OFF configurations were presented.
  - CL of *Cflow* Grid dropped earlier than experiment. This was caused by separation near wing tip.
  - Effects of initial condition was investigated. Starting lower AoA result improved flow field in JAXA Grid but not in Cflow Grid.
  - The separation issue seems to be grid dependency. This detail causes will be investigated in future work.
Kawasaki, working as one for the good of the planet

“Global Kawasaki”
Case 1a,b – HL-CRM

Grid Convergence
Grid Convergence – CL, Cm

CL

Cm

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KHI proprietary
Grid Convergence – CD, CD-CDi

CD

1/(N^2/3)

CD-CDi

* CDi=CL2/(πAe), A=9.0, e=1

AoA=16[deg]

AoA=8[deg]

Cflow B3

HL-CRM full gap

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KHI proprietary
Total Pressure Ratio @ AoA=16[deg]

- **Cflow**
  - Artificial total pressure loss decreases in finer mesh.

- **B3**
  - Separation at wing root seems large relative to Cflow Grid.

**HL-CRM full gap**

KHI proprietary
Surface streamlines with $C_p$ @ AoA=16[deg]

Coarse  ➔  Medium  ➔  Fine

Cflow

B3
Surface streamlines with $C_f$ @ $AoA=16[\text{deg}]$
Total Pressure Ratio @ $\alpha = 16^\circ$

(CflowGrid, Medium)

eta = 0.552
Total Pressure Ratio @ $\alpha = 16^\circ$
(B3, Medium)

Wake seems to be dissipated around the flap upper surface.

$\eta = 0.552$
Surface Cp around Flap Gap (Medium)
Surface Cp around Root Gap (Medium)

B3

CflowGrid
Case 1c,d – HL-CRM

Partially Sealed Flap
\( \Delta = \text{(Cflow Grid)} - \text{(B3 Grid)}, \text{Medium} \)

\[ \begin{align*}
\Delta C_L & = \Delta \text{(gapped)} - \Delta \text{(sealed)} \\
\Delta C_m & = \Delta \text{(gapped)} - \Delta \text{(sealed)} \\
\end{align*} \]
\[ \Delta = (\text{gapped-flaps}) - (\text{sealed-flaps}), \text{ Medium} \]
Case 2a-d JSM
CL - Cm

Mach 0.172
Re[-] 1.93 x 10^6

D-JSM_UnstrMixed_JAXA

CflowGrid

CL vs Cm graphs for WTT (Nacelle ON) - corrected, WTT (Nacelle OFF) - corrected, CFD (Nacelle-ON), and CFD (Nacelle-OFF)
Case 3 – 2D Verification Case
Grid Convergence – Cl, Cd

**Cl**

- Cflow
- CFL3D
- FUN3D

**Cd**

- Cflow
- 5 counts

**Cdp**

- Cflow
- 5 counts

**CdV**

- Cflow
- 1 count
Wake (U-velocity)

5th Finest

4th Finest

3rd Finest

2nd Finest

Finest

All CFL3D results are Finest Grid.