The analysis of wing-body configuration by Building-Cube Method （ BCMによる翼胴形態解析の現状）

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Cases

• APC-III Case 1
  NASA-CRM aerodynamic prediction at cruise and high AoA
  → BCM-TAS coupling solver

• APC-I Case2
  Wake of NASA-CRM wing-body configuration
  → BCM solver
Flow solver

• BCM (Building Cube Method)
  - Cartesian mesh based solver

- Pros
  • Easy parallel computation
  • Easy grid generation for complex shapes
  • High-order spatial accuracy

- Cons
  • Shape reproducibility
  • Difficulty in resolving boundary layer

Near wall treatment

• BCM-TAS coupling solver
  • Efficient analysis near the wall: TAS*
  • Sufficient resolution in the far field: BCM

*TAS (Tohoku university Aerodynamic Simulation)
  - Unstructured mesh solver
Case 1: Numerical methods

Solver: BCM-TAS coupling

<table>
<thead>
<tr>
<th></th>
<th>TAS</th>
<th>BCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governing Eq.</td>
<td>Compressible NS Eq.</td>
<td>Compressible Euler Eq.</td>
</tr>
<tr>
<td>Discretization</td>
<td>Cell-vertex finite volume</td>
<td>Cell-centered finite volume</td>
</tr>
<tr>
<td>Inviscid Flux</td>
<td>HLLEW</td>
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</tr>
<tr>
<td>Time integration</td>
<td>LU-SGS</td>
<td>LU-SGS</td>
</tr>
<tr>
<td>Turbulence model</td>
<td>SA-noft2</td>
<td>-</td>
</tr>
</tbody>
</table>

Grid: MEGG3D Medium mesh + BCM mesh

Linear interpolation between BCM and TAS
Case 1: Results

- Wake of NASA-CRM wing-body configuration
  - $M = 0.85$, $Re_c = 2.26\times10^6$, $T_{ref} = 284$ K
  - $\text{AoA} : 3.07, 4.84\deg$
  - Wing deformation considered

$C_m$ : BCM-TAS is similar to FaSTAR-Hexagrid (A1-H)
$C_D$ : BCM-TAS estimates about 20 counts larger $C_D$ than other solvers
→ To be investigated in the future
   (Turbulence model, grid, interpolation between TAS-BCM)

APC-I Case 2

Wake of NASA-CRM wing-body configuration
- $M = 0.85$, $Re_c = 2.26\times10^6$, $T_{ref} = 284$ K
- $\text{AoA} : 3.07, 4.84\deg$
- Wing deformation considered
APC-I Case 2

Wake of NASA-CRM wing-body configuration
- $M = 0.85$, $Re_c = 2.26 \times 10^6$, $T_{ref} = 284$ K
- $AoA : 3.07, 4.84^\text{deg}$
- Wing deformation considered

Validation of wake prediction by BCM
Compare the results of BCM-TAS coupling solver and the experiment

APC-I Case 2: Numerical methods

<table>
<thead>
<tr>
<th>Governing Eq.</th>
<th>BCM-NS</th>
<th>BCM-Euler</th>
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</tr>
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<td>SA-noft2-R</td>
<td>-</td>
</tr>
</tbody>
</table>

Wall boundary treatment
- Immersed boundary method (Ghost cell approach)
  - Density & pressure $\rightarrow$ Zeroth-order interpolation
  - Velocity $\rightarrow$ Linear interpolation
APC-I  Case 2: Computed cases

- Solvers
  - BCM-RANS : NS solver / nonslip condition
  - BCM-RANS-SLIP : NS solver / slip condition
  - BCM-Euler : Euler solver
  - Coupling-Euler : TAS(SA) / BCM Euler
  - Coupling-DES : TAS(SA) / BCM (Lagrangian SGS)

- Grid

<table>
<thead>
<tr>
<th></th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum grid size</td>
<td>0.0061035 (0.92mm)</td>
<td>0.0030518 (0.46mm)</td>
<td>0.0015259 (0.23mm)</td>
</tr>
<tr>
<td>Total cell number</td>
<td>253,468,672</td>
<td>1,425,592,320</td>
<td>1,459,552,256</td>
</tr>
</tbody>
</table>

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APC-I  Case 2 : Result (u)

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<tr>
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</tr>
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<tbody>
<tr>
<td>RANS</td>
<td>Wing tip vortex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RANS-SLIP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euler</td>
<td></td>
<td>body</td>
<td></td>
</tr>
<tr>
<td>EXPERIMENT</td>
<td>inboard wing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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APC-I Case 2 : Result ($C_p$)

- The result of RANS does not have sufficient negative pressure to generate wing tip vortex
APC-I Case 2: Result \((w)\)

- Velocity profile along the horizontal line passing through wing-tip vortex center

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## Conclusion

We analyzed APC-III Case 1 and APC-I Case 2 by BCM

- **APC-III Case 1 (BCM-TAS coupling solver)**
  - Good agreement with the experiment and other CFD solver for $C_L$ and $C_m$
  - $C_D$ appears larger than other solvers
    → Turbulence model? grid? interpolation between BCM-TAS?

- **APC-I Case 2 (BCM solver)**
  - The RANS solver did not generate a wing-tip vortex
  - BCM result could not capture separation around kink
    → It is necessary to properly resolve the surface of the object
  - Peak tangential velocity is overestimated in the BCM-Euler, and vortex core appears too large in the BCM-RANS-SLIP