UTCart Contribution to HiLiftPW-3

The University of Tokyo

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### 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>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>no</td>
<td>no</td>
<td>no</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>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a (no nacelle)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2b (no nacelle w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2c (with nacelle)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2d (with nacelle w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- UTCart (The University of Tokyo Cartesian grid based automatic flow solver) is developed as a platform for aerodynamic designing
  - The immersed boundary method with a wall function is used for the wall boundary condition
  - UTCart has been validated in simple 2D turbulent problems\(^1\) and simulation of NASA-CRM\(^2\)
- Validation in more complex problem is desirable to check the **accuracy** and **robustness** of UTCart

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1) Tamaki, Y. et al, AIAA J, 2017 (accepted)
2) Tamaki, Y. et al, AVIATION 2017, APA-41 (Thursday, 3:30PM)
Overview of UTCart

- **Grid generation**
  - Automatic generation by oct-tree structure

- **Domain partitioning**
  - METIS

- **Flow calculation**
  - Compressible flow solver parallelized by MPI
  - Immersed boundary method for wall boundary

<table>
<thead>
<tr>
<th>Turbulence Model</th>
<th>SA-noft2-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inviscid Flux</td>
<td>SLAU (AUSM-type all speed)</td>
</tr>
<tr>
<td>Spatial Scheme</td>
<td>Fourth-order upwind-biased$^3$)</td>
</tr>
<tr>
<td>(Inviscid Term)</td>
<td></td>
</tr>
<tr>
<td>Limiter</td>
<td>N/A</td>
</tr>
<tr>
<td>Time Integration</td>
<td>Matrix-free Gauss-Seidel</td>
</tr>
</tbody>
</table>

3) Tamaki & Imamura, Comp. & Fluids, 2017.
Verification study (case3)

Wake velocity profile

Grid 4 (Finest, 103,790 cells)

CFL3D
Verification study (case3)

- Near-field profile is difficult to be predicted
  - Resolution of Cartesian grid around sharp edge

- Far-field profile is relatively accurate even on coarse grid

<table>
<thead>
<tr>
<th></th>
<th>Grid 1</th>
<th>Grid 2</th>
<th>Grid 3</th>
<th>Grid 4</th>
<th>CFL3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min($u/U_\infty$) at x/c=1.01</td>
<td>0.4784</td>
<td>0.4503</td>
<td>0.4209</td>
<td>0.3791</td>
<td>0.3815</td>
</tr>
<tr>
<td>Min($u/U_\infty$) at x/c=1.8</td>
<td>0.8409</td>
<td>0.8455</td>
<td>0.8458</td>
<td>0.8493</td>
<td>0.8472</td>
</tr>
</tbody>
</table>
Computational grids around JSM

- Grid size on the wall is variable to save the cell number
- More than 1000 cells in local chord (MAC=529.2mm)
Computational grids around JSM

- Nacelle off: 114,466,104 cells
- Nacelle on: 123,077,385 cells
Computational grids around JSM

Local refinement (level 1)
Computational grids around JSM

- 400 cells / flap chord
- 20 cells / slat support width
Computational grids around JSM (A-A)
Computational resources

For nacelle-off configuration (117M cells)

- Grid generation
  - Workstation, Xeon E5-2643 v3 @ 3.4GHz, 1 core
  - 1 h 40 min, 120 GB

- Flow calculation
  - Reedbush-U supercomputer (UTokyo), Xeon E5-2697 v4 @ 2.1 GHz, 144 cores (pure MPI)
  - 56 h (30,000 steps), 150 GB

(oscillation graph)
Aerodynamic coefficients

- Fair agreement with experiment at low angles of attack
- 10% low $CL_{\text{max}}$
Nacelle increment

- Delta CD is relatively accurate
- Delta CL at high angles of attack is difficult to be predicted (due to separation?)
Surface streamline (Nacelle off)

- TE separation on flap

4.36 deg Nacelle off

14.54 deg Nacelle off
Surface pressure (Nacelle off, $\alpha=14.54$ deg)

A-A

H-H

E-E
Surface streamline (Nacelle off)

- Separation at wake of slat support

18.58 deg Nacelle off

20.57 deg Nacelle off
Surface pressure (Nacelle off, $\alpha=18.58$ deg)
Surface streamline (Nacelle on)

- Separation become large compared with case 2a
### Sensitivity study (Nacelle off, \( \alpha = 18.58 \) deg)

<table>
<thead>
<tr>
<th>Grid</th>
<th>Grid 1 (117M)</th>
<th>Grid 2 (140M)</th>
<th>Grid 1 (117M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inviscid term</td>
<td>Fourth-order</td>
<td>Fourth-order</td>
<td>Second-order</td>
</tr>
<tr>
<td>CL</td>
<td>2.494</td>
<td><strong>2.516</strong></td>
<td>2.409</td>
</tr>
</tbody>
</table>

- **Grid 1:**
  - \( \Delta x_{\text{min}} = 0.250 \) mm
- **Grid 2:**
  - \( \Delta x_{\text{min}} = 0.225 \) mm

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**Diagram:**

- **Grid 1**
  - Fourth-order
  - \( cfx \) values range from 0 to 0.02

- **Grid 2**
  - Fourth-order
  - \( cfx \) values range from 0 to 0.02
Summary

- JAXA Standard Model is simulated using UTCart
  - Oct-tree Cartesian grid and Immersed boundary method with a wall function is used

- Possibility and challenge of the Cartesian grid are confirmed
  - Grid is generated in a robust way, and the small features (e.g. gaps) are reproduced
  - Flow feature (e.g. surface pressure) at low angles of attack ($\alpha \leq 14.54$ deg) is accurately predicted
  - Flow unsteadiness remains
  - $C_{L_{\text{max}}}$ is 10% lower than experimental data
    - High-order scheme is effective
    - Further grid convergence should be examined
Surface Pressure (Nacelle on, $\alpha=18.58$ deg)
Computational grid (H-H)
Computational grid (N-N)
Surface Streamline (Nacelle on)

Nacelle on AoA=4.36

Nacelle on AoA=10.47
Surface Streamline (Nacelle on)
Surface Streamline (Nacelle on)