Unstructured adaptive mesh calculations for NASA TRAP WING using the code HiFUN

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Outline

1. Scope
2. Solver and Methodology
3. Results
4. Conclusions
1 Scope
2 Solver and Methodology
3 Results
4 Conclusions
Scope

- Results summary
  - Grid convergence study
  - Flap setting study
- Adaptive mesh refinement
- Effect of brackets
- Unsteady effects near stall
Outline

1. Scope
2. Solver and Methodology
3. Results
4. Conclusions
Algorithmic features

- Unstructured cell centre finite volume methodology
- Higher order accuracy: linear reconstruction procedure
- Higher order time accuracy by dual time method
- Flux limiting: Venkatakrishnan Limiter
- Inviscid flux computation: Roe scheme
- Convergence acceleration: matrix free SGS relaxation procedure
- The viscous flux discretization: Green–Gauss procedure
- Eddy viscosity computation: Spalart Allmaras TM
- Parallelization: MPI
Grid strategy

- Unstructured hybrid grids
  - Prismatic elements in the viscous padding
  - Tetrahedral elements outside the viscous padding
- Far field is placed 150 chords away from wing
- Most of the grids are generated adhering to the guidelines provided by the technical committee of CFD HiLiftPW-1
Configurations

- Configuration 1 - Slat 30, Flap 25 full span
- Configuration 1 with brackets
- Configuration 8 - Slat 30, Flap 20 full span
## Grids

<table>
<thead>
<tr>
<th>Config</th>
<th>Grid code</th>
<th>$NC$ (million)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UG1</td>
<td>11.85</td>
<td>SPICES09</td>
</tr>
<tr>
<td></td>
<td>UG2</td>
<td>38.60</td>
<td>SPICES09</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>7.7</td>
<td>HiLiftPW1</td>
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<tr>
<td></td>
<td>MG</td>
<td>21.9</td>
<td>HiLiftPW1</td>
</tr>
<tr>
<td></td>
<td>FG</td>
<td>63.3</td>
<td>HiLiftPW1</td>
</tr>
<tr>
<td></td>
<td>AG1</td>
<td>23.95</td>
<td>AdaptedCG</td>
</tr>
<tr>
<td></td>
<td>AG2</td>
<td>50.15</td>
<td>AdaptedAG1</td>
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<tr>
<td>1–WB</td>
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<td>Recent</td>
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<td>8</td>
<td>MG8</td>
<td>21.41</td>
<td>HiLiftPW1</td>
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</table>

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1. Scope

2. Solver and Methodology

3. Results

4. Conclusions
3 Results

- Results summary
- Adaptive calculations
- Bracket effect
- Unsteady computations
Solution convergence criterion

Fine grid (FG) at $\alpha = 28^\circ$

- Residue fall in energy 10 decades
- Lift/Drag coefficients convergence: less than 0.1 count in 100 iterations
Grid convergence study at $\alpha = 13^\circ$

Grids: CG, MG and FG

- $C_L$ convergence
- $C_D$ convergence
- $C_M$ convergence

- $C_L$ and $C_M$ converge monotonically to experimental values
- $C_D$ convergence is non-monotonous

Between Coarse to Fine grids

- Changes in lift, drag and moment counts are 67, 20 and 19 respectively
Grid convergence study at $\alpha = 28^\circ$

Grids: CG, MG and FG

$C_L$ convergence, $C_D$ convergence, $C_M$ convergence

- $C_L$ and $C_M$ converge monotonically to experimental values
- $C_D$ converges non-monotonically to experimental value

Between Coarse to Fine grids

- Changes in lift, drag and moment counts are 71, 19 and 26 respectively
Grid convergence study: Velocity profiles
CG, MG and FG: $\alpha = 28^\circ$

Main, $\eta = 15\%$  
Main, $\eta = 83\%$  
Flap, $\eta = 83\%$(front)

Flap, $\eta = 83\%$(aft)  
Probe locations
Effect of grid resolution on drag

<table>
<thead>
<tr>
<th>$\alpha^\circ$</th>
<th>Grid code</th>
<th>$C_{DP}$</th>
<th>$C_{DV}$</th>
<th>$C_D$</th>
<th>$\Delta C_{DP}$</th>
<th>$\Delta C_{DV}$</th>
<th>$\Delta C_D$</th>
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</thead>
<tbody>
<tr>
<td>13</td>
<td>CG</td>
<td>0.31280</td>
<td>0.01056</td>
<td>0.32336</td>
<td>...</td>
<td>...</td>
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<tr>
<td></td>
<td>MG</td>
<td>0.31533</td>
<td>0.01107</td>
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<td>FG</td>
<td>0.31378</td>
<td>0.01161</td>
<td>0.32540</td>
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<td>-0.00101</td>
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<tr>
<td>28</td>
<td>CG</td>
<td>0.66631</td>
<td>0.01013</td>
<td>0.67643</td>
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<td>...</td>
<td>...</td>
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<tr>
<td></td>
<td>MG</td>
<td>0.67053</td>
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Pressure drag shows greater dependency on grid refinement than viscous drag
Scope \ Solver and Methodology \ Results \ Conclusions

\[ C_p \text{ distribution - Flap, } \alpha = 13^\circ \]

- With grid refinement, pressure distribution moves towards experimental results
- Even fine grid resolution near wing tip is inadequate to capture accurate pressure gradients due to vortical flow
Compared with experiments, the computed lift and drag coefficients show excellent
similarity. However, the pitching moment coefficient curve presents a noticeable
deviation from the experimental results. This could be due to:
- Lack of grid resolution in the tip region?
- Effect of brackets?
Excellent comparisons can be seen for $\alpha_{max}$ and $CL_{max}$ with experimental values.

<table>
<thead>
<tr>
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<th>$\alpha_{max}$</th>
<th>$CL_{max}$</th>
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<tr>
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<td>UG2</td>
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<td>3.0565</td>
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<td>Experiment</td>
<td>32.993</td>
<td>3.0306</td>
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Flap setting study

Lift

Drag

Moment
\[ \Delta C_L, \Delta C_D \text{ and } \Delta C_M \text{ count} \]

\[ \Delta(\cdot) = (\cdot)_{\text{config}1} - (\cdot)_{\text{config}8} \]
3 Results

- Results summary
- Adaptive calculations
- Bracket effect
- Unsteady computations
Adaptive calculations

Solution based adaptation

- Hybrid
- R–parameter + divergence / curl
- Adaptation effected outside viscous padding
  - Pressure drag sensitive to flow curvatures
  - Viscous drag depends on boundary layer padding
  - Use fine viscous padding and effect adaptation outside padding

Reference: R–parameter

Adapted grids

Adapted grid AG2

Zoom view of grid AG2
Grid cut views

Level 0
Level 1
Level 2
Grid sections at 98% wingspan for various adaption levels
Adapted grids - $C_P$ distribution (Slat)

- No significant effect of adaptation in slat region

17% span

50% span

98% span
Adapted grids - $C_P$ distribution (Main)

17% span

- Pressure distribution becomes progressively better with adaptation

- Still grid resolution in not sufficient near tip region
Adapted grids - $C_p$ distribution (Flap)

- Pressure distribution becomes progressively better with adaptation
- Still grid resolution is not sufficient near tip region

17% span

50% span

98% span
3 Results

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Bracket effect

Surface grid with brackets
## Bracket effect

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Grid code</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$C_M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 without brackets</td>
<td>CG</td>
<td>1.9429</td>
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<tr>
<td>1 with brackets</td>
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<td>0.3261</td>
<td>-0.4668</td>
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<tr>
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<td>MG</td>
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<td>0.3264</td>
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<td>1 with brackets</td>
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<tr>
<td>1 with brackets</td>
<td>Experiments</td>
<td>2.0468</td>
<td>0.3330</td>
<td>-0.5032</td>
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</tbody>
</table>

$\alpha = 13^\circ$

- $C_L$ and $C_D$ computed with the bracket show better match with the experiments
- Computations without the bracket show better performance in terms of $C_M$ prediction
## Bracket effect

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Grid code</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$C_M$</th>
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<tbody>
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<td>2.8197</td>
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<td>0.6476</td>
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<tr>
<td>1 with brackets</td>
<td>Experiments</td>
<td>2.8952</td>
<td>0.6776</td>
<td>-0.4559</td>
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</tbody>
</table>

$\alpha = 28^\circ$

- $C_L$, $C_D$ and $C_M$ computed without the bracket show better match with the experiments.
Bracket effect: $C_P$ distribution
Spanwise flap pressure distribution, $\alpha = 28^\circ$
Bracket effect: Velocity profiles

CGB and MGB: $\alpha = 28^\circ$

Main, $\eta = 15\%$

Main, $\eta = 83\%$

Flap, $\eta = 83\%$(front)

Flap, $\eta = 83\%$(aft)

Probe locations
3 Results

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Unsteady computations, $\alpha = 30.44^\circ$

- Evolution of $C_L$
- Evolution of $C_D$

<table>
<thead>
<tr>
<th>$\alpha^\circ$</th>
<th>Physical time step</th>
<th>Strouhal number</th>
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<tbody>
<tr>
<td>30.440</td>
<td>0.0025</td>
<td>0.2362</td>
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- Lift and drag coefficients vary by about 5 and 50 counts respectively

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Unsteady computations, $\alpha = 32.942^\circ$

<table>
<thead>
<tr>
<th>$\alpha^\circ$</th>
<th>Physical time step</th>
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</tr>
</thead>
<tbody>
<tr>
<td>32.942</td>
<td>0.0025</td>
<td>0.1554</td>
</tr>
</tbody>
</table>

- Lift and drag coefficients vary by about 5 and 50 counts respectively
Outline

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Concluding remarks

Conclusions

- High lift computations for configurations 1 and 8 of NASA Trap Wing on various hybrid unstructured grids using flow solver HiFUN are presented.

- The ability of code HiFUN to accurately predict integrated force coefficients has been demonstrated.

- Though the solution adaptive grids show promise in terms of capturing more accurate pressure distribution compared to the base grid, further analysis is needed to understand their ability to predict accurate integrated force and moment coefficients.
Concluding remarks

Conclusions continued

- Inclusion of brackets does not seem to enhance the accuracy of prediction of integrated coefficients.
- Unsteady computations reveal that the flow is grossly steady even at higher incidences near maximum lift coefficient.
Gopalakrishna N. (CAd Lab): Bracket study
Partha Mondal (CAd Lab): Unsteady study, presentation
Parthiban A. (SandI): Grids for Configuration 1 with brackets
Thank you