CFD computations for NASA TRAP WING using the code HiFUN

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Outline

1. Introduction
2. Typical grids
3. Results: Case 1–Grid convergence
4. Conclusions
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1. Introduction
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3. Results: Case 1–Grid convergence
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Introduction

Tools employed

- Grid generation for NASA TRAP WING is carried out using GAMBIT and TGRID, commercial grid generators from ANSYS available at Supercomputer Education and Research Centre (SERC), IISc.

- Flow computations for TRAP WING are performed using the code HiFUN, a commercial flow solver from Simulation and Innovation Engineering Solutions (SandI) available at CAd Lab, Department of Aerospace Engineering, IISc.
Tools employed continued

- Post-processing is carried out using TECPLLOT available at SERC, IISc.
- The compute platform used in the present study is IBM Blue Gene available at SERC, IISc. Hardware details of Blue Gene are as follows:
  - 4096 2-way SMP nodes (8192 processors)
  - IBM PowerPC 440x5 processors operating at 700 Mhz 32-bit
  - 1 GB main memory per node with a total of 4 TB for the cluster
  - Gigabit network with Cisco 6500 Gigabit switch.
Algorithmic features

- Unstructured cell centre finite volume methodology.
- Higher order accuracy: linear reconstruction procedure.
- Flux limiting: Venkatakrishnan Limiter.
- Inviscid flux computation: Roe scheme.
- Convergence acceleration: matrix free symmetric Gauss-Seidel relaxation procedure.
- The viscous flux discretization: Green–Gauss theorem based diamond path reconstruction.
- Eddy viscosity computation: Spalart Allmaras TM.
- Parallelization: MPI.
Config 1: Surface grids

Coarse
Field cells: 7695034

Medium
21903245

Fine
63305904
Config 1: Surface grids, tip zoomed view

Coarse

Medium

Fine
## Configuration 1: Grid details

<table>
<thead>
<tr>
<th>Grid details</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid Type</strong></td>
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<tr>
<td><strong>Field Nodes</strong></td>
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<td><strong>Field Cells</strong></td>
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<td>63305904</td>
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<td><strong>Boundary Nodes</strong></td>
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<td><strong>Boundary Faces</strong></td>
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<td>459285</td>
<td>1035372</td>
</tr>
<tr>
<td><strong>BL 1st – Cell (in)</strong></td>
<td>0.00020</td>
<td>0.00013</td>
<td>0.00009</td>
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<tr>
<td><strong>BL Cells</strong></td>
<td>21</td>
<td>31</td>
<td>36</td>
</tr>
</tbody>
</table>

**Note**

Boundary layer is grown using aspect ratio based algorithm.
Computational details

Resource details

- Grid: Medium grid for configuration 1 with about 21 million field cells
- Computer Platform: Blue Gene with IBM PowerPC processors
- Operating system: Unix
- Compiler: XL FORTRAN 90
Resource details continued

- Number of processors: 128
- Memory requirement of HiFUN: Approximately 800 MB per million of grid size
- Convergence criterion: 9–10 decades fall in energy residue with change in drag count over 100 iterations to be less than 1
- Number of iterations: Typically 6000–8000
- Run time Wall clock: 60–80 hours
- Expected run time on 128 nodes of a Xeon based cluster: 15–20 hours (based on our experience in SPICES–09)
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3 Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- Cp comparison: $\alpha = 13^\circ$
- Cp comparison: $\alpha = 28^\circ$
- Integrated coefficients comparison
- Typical convergence histories
Config 1 streamlines: Overall view

$M_\infty = 0.2$, $Re_\infty = 4.3$ million, $\alpha = 13^\circ$

With grid refinement, a significant difference in separation pattern can be seen on the body pod above the flap.
Config 1 streamlines: Main element

$M_\infty = 0.2$, $Re_\infty = 4.3 \text{ million}$, $\alpha = 13^\circ$

Flow on main element is predominantly chord–wise.
Config 1 streamlines: Flap–body pod

$M_\infty = 0.2$, $Re_\infty = 4.3$ million, $\alpha = 13^\circ$

The bubble at flap–body pod junction grows in size with grid refinement.
**Config 1 streamlines: Tip region**

\[ \infty = 0.2, \ \text{Re}_\infty = 4.3 \text{ million}, \ \alpha = 13^\circ \]

The span-wise extent and chord-wise position of separation line on the flap upper surface does not change with grid refinement.
3 Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- Cp comparison: $\alpha = 13^\circ$
- Cp comparison: $\alpha = 28^\circ$
- Integrated coefficients comparison
- Typical convergence histories
Config 1 streamlines: Overall view

$M_\infty = 0.2, \quad Re_\infty = 4.3 \text{ million}, \quad \alpha = 28^\circ$

The complex flow over body pod exhibits multiple separation and re-attachment lines.
Config 1 streamlines: Main element

$M_{\infty} = 0.2$, $Re_{\infty} = 4.3 \text{ million}$, $\alpha = 28^\circ$

Flow on main element is predominantly chord–wise.
Config 1 streamlines: Flap–body pod

\[ M_\infty = 0.2, \quad Re_\infty = 4.3 \text{ million}, \quad \alpha = 28^\circ \]

The separation bubble size at flap–body pod junction is unaffected with grid refinement (unlike for \( \alpha = 13^\circ \) case).
Config 1 streamlines: Tip region

\( M_\infty = 0.2, \ Re_\infty = 4.3 \ million, \ \alpha = 28^\circ \)

The span-wise extent and chord-wise position of separation line on the flap upper surface does not change with grid refinement (also for \( \alpha = 13^\circ \) case).
Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- Cp comparison: $\alpha = 13^\circ$
- Cp comparison: $\alpha = 28^\circ$
- Integrated coefficients comparison
- Typical convergence histories
Config 1: Cp comparison on slat

\[ M_\infty = 0.2, \, Re_\infty = 4.30 \text{ million}, \, \alpha = 13^\circ \]

- Good Cp comparison on upper surface at each station.
- Poor Cp comparison on lower surface involving underbelly bubble: limitation of turbulence model.
Config 1: Cp comparison on main element

$M_\infty = 0.2, \ Re_\infty = 4.30 \ million, \ \alpha = 13^\circ$

- Good Cp comparison at 17 % & 50 % stations.
- Inadequate grid resolution to capture tip vortices (even) on fine grid has resulted in not-so-good Cp comparison beyond mid-chord location on upper surface at 98 % station.
**Config 1: Cp comparison on flap**

\[ M_\infty = 0.2, \quad Re_\infty = 4.30 \text{ million}, \quad \alpha = 13^\circ \]

- **17 %**
  - Good Cp comparison at 17 % & 50 % stations.

- **50 %**
  - Inadequate grid resolution to capture tip vortices (even) on fine grid has resulted in not–so–good Cp comparison on upper surface at 98 % station.

- **98 %**
Introduction  Typical grids  Results: Case 1–Grid convergence  Conclusions

Outline

3 Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- $C_p$ comparison: $\alpha = 13^\circ$
- $C_p$ comparison: $\alpha = 28^\circ$
- Integrated coefficients comparison
- Typical convergence histories
Config 1: Cp comparison on slat

\( M_\infty = 0.2, \ Re_\infty = 4.30 \ \text{million}, \ \alpha = 28^\circ \)

- Good Cp comparison on upper surface at all stations.
- Reduction in (disappearance of) separation on lower surface has led to good Cp prediction at all stations.
Config 1: Cp comparison on main element

$M_\infty = 0.2, \text{Re}_\infty = 4.30 \text{ million, } \alpha = 28^\circ$

- 17%
- 50%
- 98%

- Good Cp comparison at 17% & 50% stations.
- Inadequate grid resolution to capture tip vortices (even) on fine grid has resulted in not-so-good Cp comparison beyond quarter-chord location on upper surface at 98% station.
Config 1: Cp comparison on flap

\( M_\infty = 0.2, \, Re_\infty = 4.30 \text{ million}, \, \alpha = 28^\circ \)

- **17 %**
  - Good Cp comparison at 17 % station.

- **50 %**
  - Severe adverse pressure gradient on the flap leading to a possible flow separation not captured in the numerics; compounded by inadequate resolution of tip vortices leading to not-so-good Cp comparison at 50 % and 98 % stations.

- **98 %**
3 Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- Cp comparison: $\alpha = 13^\circ$
- Cp comparison: $\alpha = 28^\circ$

- Integrated coefficients comparison
- Typical convergence histories
Comparison of Lift coefficient

\[ M_\infty = 0.2, \quad Re_\infty = 4.3 \text{ million} \]

With grid refinement, the computed lift coefficients for \( \alpha = 13^\circ \) and \( \alpha = 28^\circ \) are tending to the experimental values.
Introduction  Typical grids  Results: Case 1–Grid convergence  Conclusions

Comparison of Drag coefficient

$M_\infty = 0.2$, $Re_\infty = 4.3$ million

Overall view  Zoom: $\alpha = 13^\circ$  Zoom: $\alpha = 28^\circ$

- With grid refinement, the computed drag coefficient for $\alpha = 28^\circ$ is tending to the experimental value.
Comparison of Moment coefficient

$M_\infty = 0.2, \text{Re}_\infty = 4.3 \text{ million}$

With grid refinement, the computed moment coefficients for $\alpha = 13^\circ$ and $\alpha = 28^\circ$ are tending to the experimental values.
Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^\circ$
- Streamlines: $\alpha = 28^\circ$
- Cp comparison: $\alpha = 13^\circ$
- Cp comparison: $\alpha = 28^\circ$
- Integrated coefficients comparison
- Typical convergence histories
Convergence history: Fine grid, \( \alpha = 13^0 \)

Fine grid: \( M_\infty = 0.2, \, Re_\infty = 4.3 \) million

Relative Residue

\( C_L, C_D \) evolution

\( \Delta C_L, \Delta C_D \) counts
Introduction

Convergence history: Fine grid, $\alpha = 28^0$

Fine grid: $M_\infty = 0.2$, $Re_\infty = 4.3$ million

Relative Residue  $C_L, C_D$ evolution  $\Delta C_L, \Delta C_D$ counts
Outline

1 Introduction

2 Typical grids

3 Results: Case 1–Grid convergence

4 Conclusions
Conclusions

- In the present work, results of RANS computations for NASA TRAP WING using the code HiFUN are presented.
- During grid generation the guidelines provided by workshop committee are followed, except for the number of field cells.
Concluding remarks

Grid convergence study: $\alpha = 13^\circ$ and $\alpha = 28^\circ$

- Separation bubble is seen at flap–body pod junction for both angles of attack.
- At $\alpha = 13^\circ$, separation bubble becomes more pronounced with grid refinement.
- Separation line is seen on upper surface of flap for both angles of attack.
- The chord-wise location and span-wise extent of the separation line does not change with grid refinement.
Concluding remarks

Grid convergence study: $\alpha = 13^\circ$ and $\alpha = 28^\circ$

- An overall good comparison of computed and experimental Cp distributions can be seen on upper surfaces of slat, main element and flap.
- Cp comparison on the lower surface of slat in the underbelly separation region is poor owing to the limitation of turbulence model.
- Better prediction of Cp for higher incidence ($\alpha = 28^\circ$) on the slat lower surface is indicative of better flow alignment at higher incidences resulting in subdued separation activity.
Concluding remarks

Grid convergence study: $\alpha = 13^\circ$ and $\alpha = 28^\circ$

- Cp comparison near the tips of main element and flap is not-so-good owing to inadequate grid resolution in capturing vortices and can be improved with further grid refinement.

- With grid refinement, lift, drag and moment coefficients tend towards experimental values.
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Thank you

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