CFD computations for NASA TRAP WING using the code HiFUN

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Outline

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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.

Introduction continued

Tools employed continued

- Post-processing is carried out using TECPLOT 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.

Features of code HiFUN

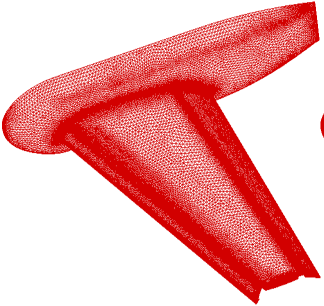
HiFUN: **HI**gh Resolution **F**low Solver on **UN**structured Meshes

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.

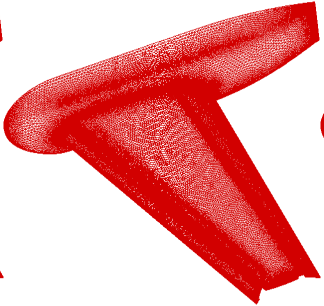
Outline

Config 1: Surface grids



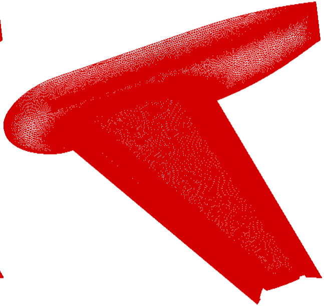
Coarse

Field cells: 7695034



Medium

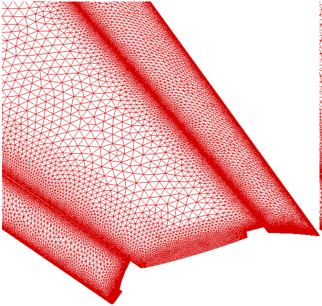
21903245



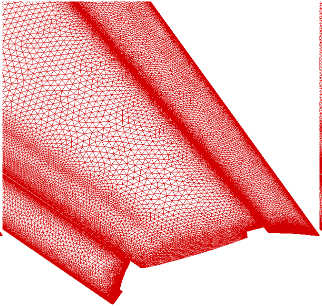
Fine

63305904

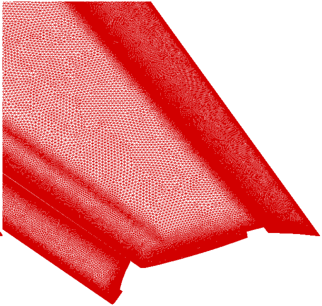
Config 1: Surface grids, tip zoomed view



Coarse



Medium



Fine

Configuration 1: Grid details

Grid details

Grid Type	Coarse	Medium	Fine
Field Nodes	3088347	8188411	22419724
Field Cells	7695034	21903245	63305904
Boundary Nodes	135004	236077	527552
Boundary Faces	263557	459285	1035372
BL 1^{st}–Cell (in)	0.00020	0.00013	0.00009
BL Cells	21	31	36

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

Computational details continued

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 our experience in SPICES–09)

Outline

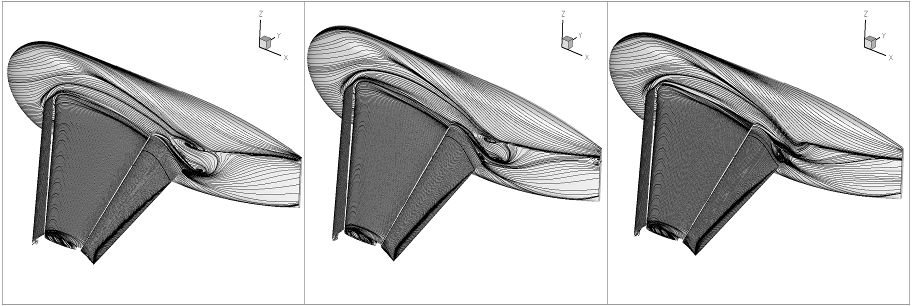
Outline

3 Results: Case 1–Grid convergence

- Streamlines: $\alpha = 13^o$
- Streamlines: $\alpha = 28^o$
- Cp comparison: $\alpha = 13^o$
- Cp comparison: $\alpha = 28^o$
- Integrated coefficients comparison
- Typical convergence histories

Config 1 streamlines: Overall view

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

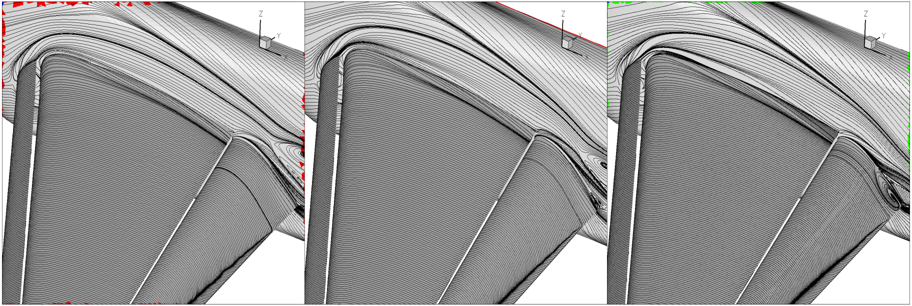


Coarse Medium Fine

- With grid refinement, a significant difference in separation pattern can be seen on the body pod above the flap.

Config 1 streamlines: Main element

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

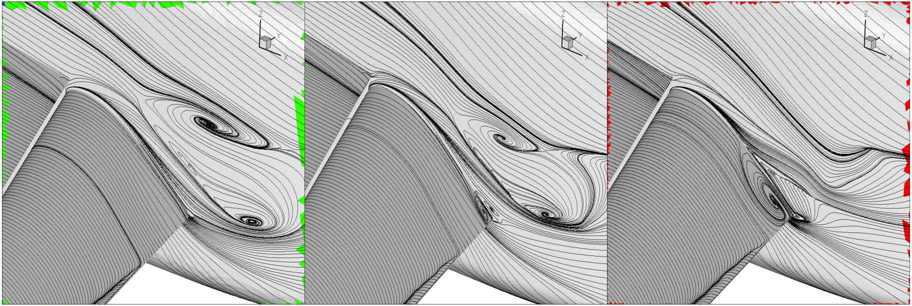


Coarse Medium Fine

- Flow on main element is predominantly chord–wise.

Config 1 streamlines: Flap–body pod

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

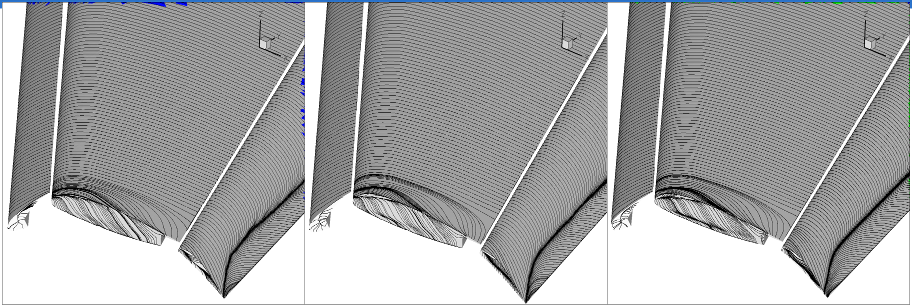


Coarse Medium Fine

- The bubble at flap–body pod junction grows in size with grid refinement.

Config 1 streamlines: Tip region

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



Coarse Medium Fine

- The span-wise extent and chord-wise position of separation line on the flap upper surface does not change with grid refinement.

Outline

3 Results: Case 1–Grid convergence

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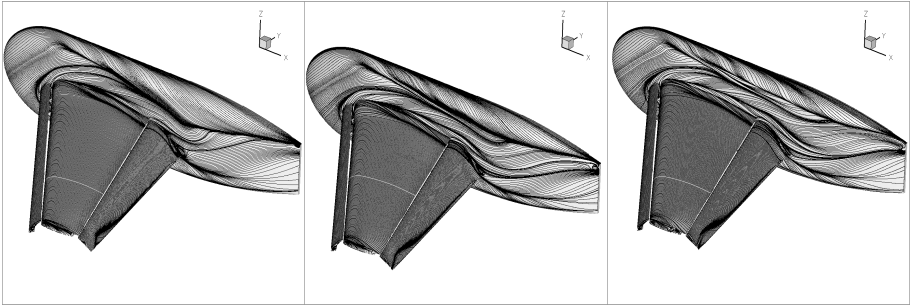
Config 1 streamlines: Overall view

$M_\infty = 0.2, Re_\infty = 4.3\ million, \alpha = 28^o$

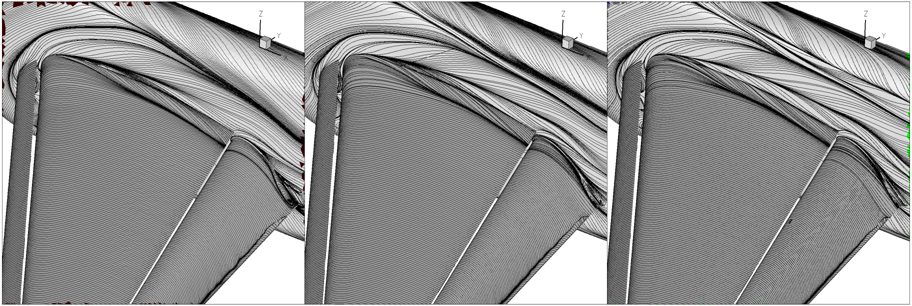


Coarse Medium Fine

- The complex flow over body pod exhibits multiple separation and re-attachment lines.

Config 1 streamlines: Main element

$M_\infty = 0.2$, $Re_\infty = 4.3$ *million*, $\alpha = 28^o$

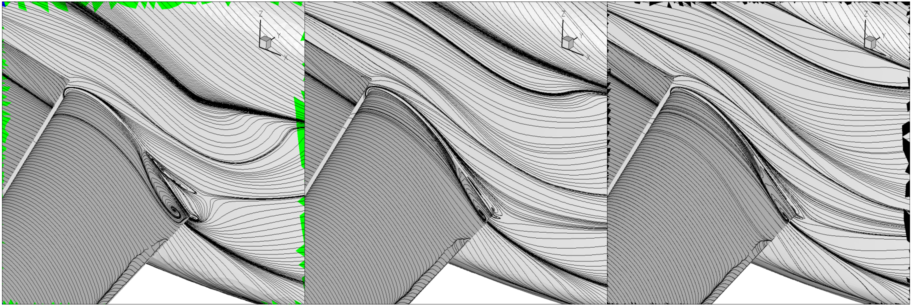


Coarse Medium Fine

- Flow on main element is predominantly chord–wise.

Config 1 streamlines: Flap–body pod

$M_\infty = 0.2$, $Re_\infty = 4.3$ *million*, $\alpha = 28^o$

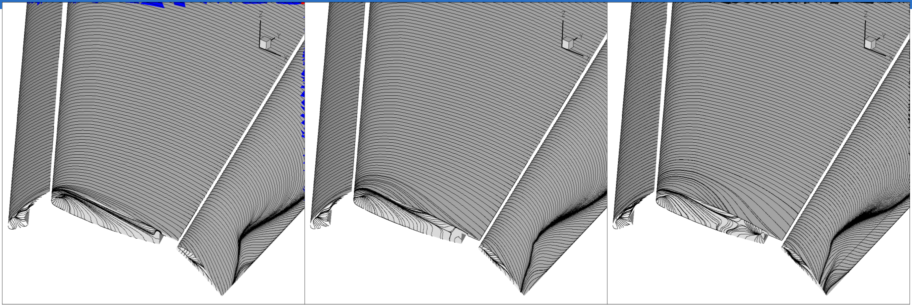


Coarse Medium Fine

- The separation bubble size at flap–body pod junction is unaffected with grid refinement (unlike for $\alpha = 13^o$ case).

Config 1 streamlines: Tip region

$M_\infty = 0.2, Re_\infty = 4.3$ *million*, $\alpha = 28^o$



Coarse Medium Fine

- The span-wise extent and chord-wise position of separation line on the flap upper surface does not change with grid refinement (also for $\alpha = 13^o$ case).

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3 Results: Case 1–Grid convergence

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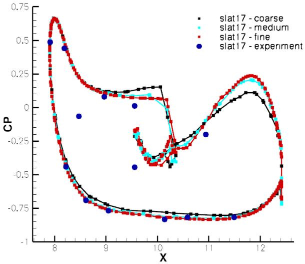
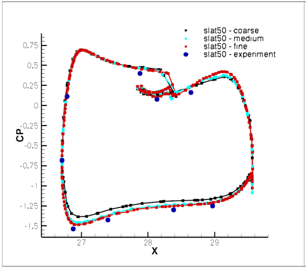
Config 1: Cp comparison on slat

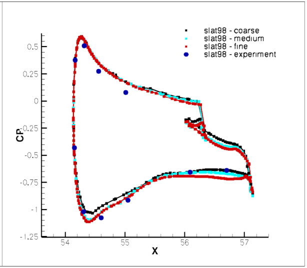
$M_\infty = 0.2, Re_\infty = 4.30 \ million, \alpha = 13^o$



17 %



50 %

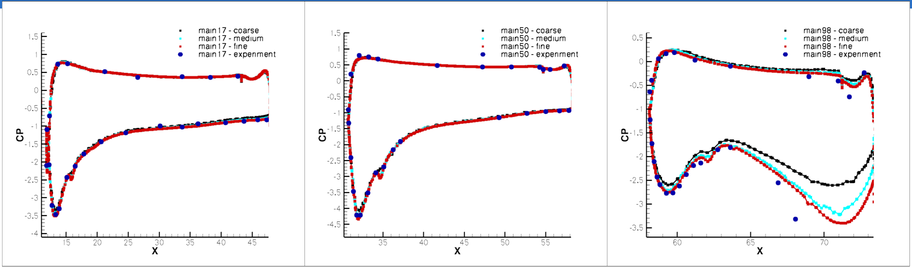


98 %

- 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*, $\alpha = 13^o$

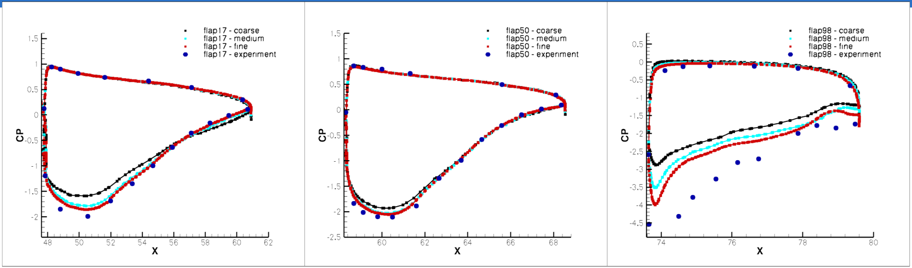


17 % 50 % 98 %

- 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 mid–chord location on upper surface at 98 % station.

Config 1: Cp comparison on flap

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



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 on upper surface at 98 % station.

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- Streamlines: $\alpha = 13^o$
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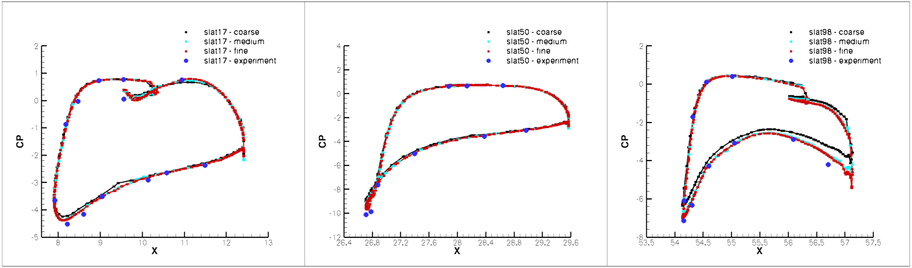
Config 1: Cp comparison on slat

$M_\infty = 0.2, Re_\infty = 4.30\ million, \alpha = 28^o$

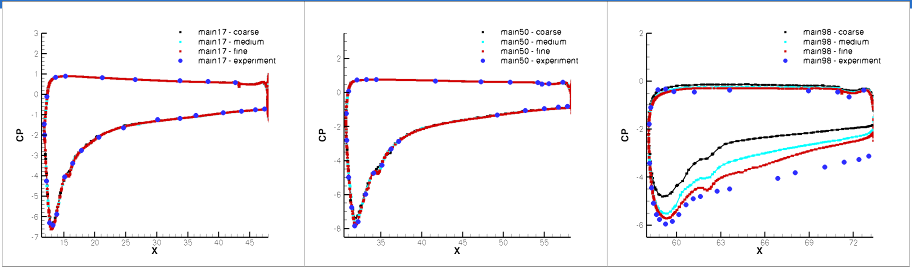


17 % 50 % 98 %

- 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

$M_\infty = 0.2, Re_\infty = 4.30$ *million*, $\alpha = 28^o$

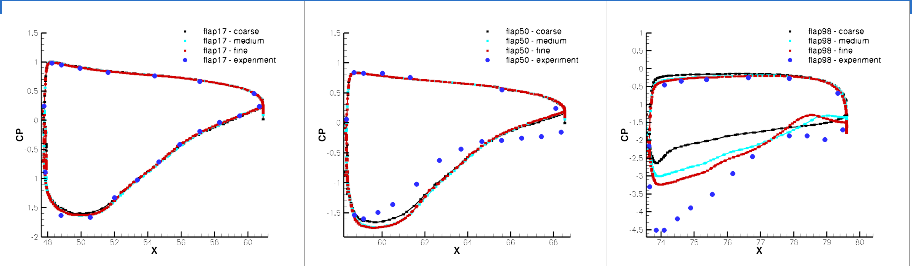


17 % 50 % 98 %

- 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

$M_\infty = 0.2, Re_\infty = 4.30\ million, \alpha = 28^o$



17 % 50 % 98 %

- Good Cp comparison at 17 % station.
- 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.

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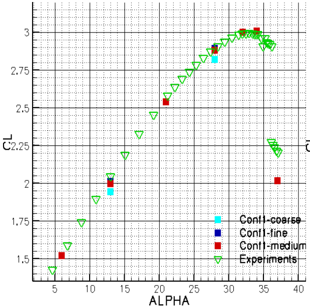
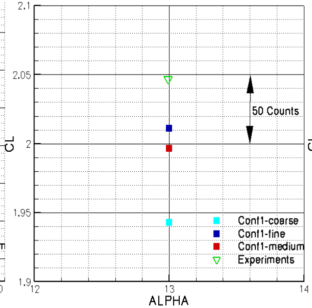
Comparison of Lift coefficient

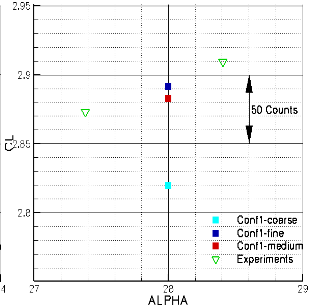
$M_\infty = 0.2, Re_\infty = 4.3$ *million*



Overall view



Zoom:$\alpha = 13^o$

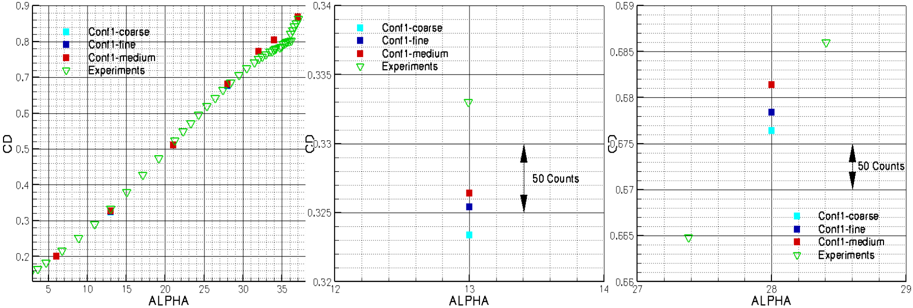


Zoom:$\alpha = 28^o$

- With grid refinement, the computed lift coefficients for $\alpha = 13^o$ and $\alpha = 28^o$ are tending to the experimental values.

Comparison of Drag coefficient

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

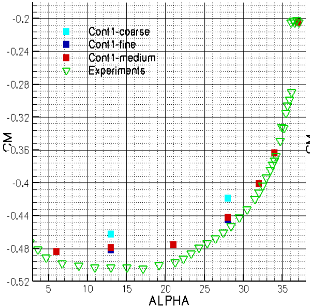


Overall view   Zoom:$\alpha = 13^o$ Zoom:$\alpha = 28^o$

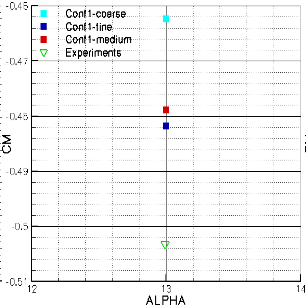
- With grid refinement, the computed drag coefficient for $\alpha = 28^o$ is tending to the experimental value.

Comparison of Moment coefficient

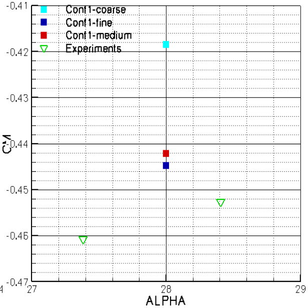
$M_\infty = 0.2, Re_\infty = 4.3$ *million*



Overall view



Zoom:$\alpha = 13^o$



Zoom:$\alpha = 28^o$

- With grid refinement, the computed moment coefficients for $\alpha = 13^o$ and $\alpha = 28^o$ are tending to the experimental values.

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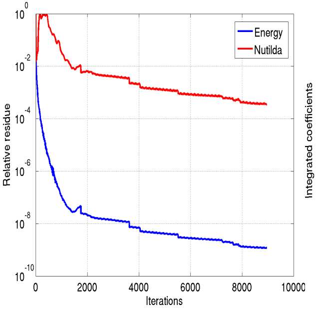
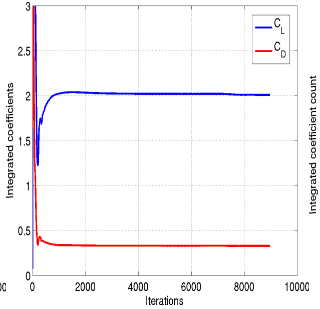
Convergence history: Fine grid, $\alpha = 13^0$

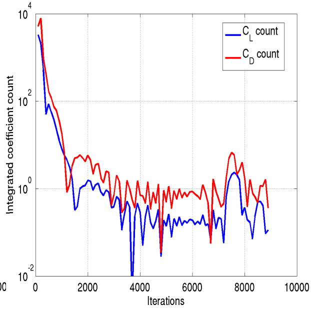
Fine grid: $M_\infty = 0.2$, $Re_\infty = 4.3$ *million*



Relative Residue



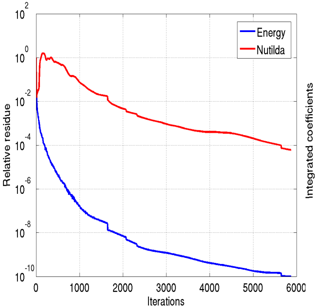
C_L, C_D evolution



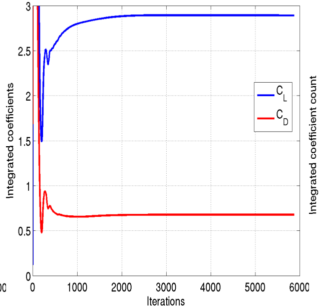
$\Delta C_L, \Delta C_D$ counts

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

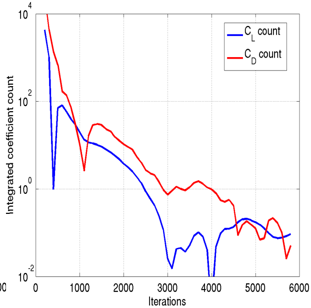
Fine grid: $M_\infty = 0.2$, $Re_\infty = 4.3$ *million*



Relative Residue



C_L, C_D evolution



$\Delta C_L, \Delta C_D$ counts

Outline

Concluding remarks

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: $\alpha = 13^o$ and $\alpha = 28^o$

- Separation bubble is seen at flap–body pod junction for both angles of attack.
- At $\alpha = 13^o$, 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: $\alpha = 13^o$ and $\alpha = 28^o$

- 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 ($\alpha = 28^o$) on the slat lower surface is indicative of better flow alignment at higher incidences resulting in subdued separation activity.

Concluding remarks

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

- 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.

Acknowledgments

Authors wish to thank

- Prof. Govindarajan, Chairman, Supercomputer Education and Research Centre (SERC), IISc for the use of IBM Blue Gene.
- Mr. Satish Regode for his help in post-processing the results.
- Dr. P. R. Viswanath (Boeing, India) for his useful comments on the work.
- Dr. Mori Mani (Boeing) for kindly agreeing to make this presentation on their behalf.

Thank you

Thank you

- Thank you

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