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

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Outline

Outline

Scope

Scope

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

Outline

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
- 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

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

Configurations

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

Grids

Config	Grid code	NC (million)	Comment
1	UG1	11.85	SPICES09
	UG2	38.60	SPICES09
	CG	7.7	HiLiftPW1
	MG	21.9	HiLiftPW1
	FG	63.3	HiLiftPW1
	AG1	23.95	AdaptedCG
	AG2	50.15	AdaptedAG1
1–WB	CGB	11.26	Recent
	MGB	28.86	Recent
8	MG8	21.41	HiLiftPW1

Outline

1 Scope

2 Solver and Methodology

3 Results

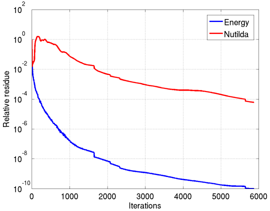
4 Conclusions

Outline

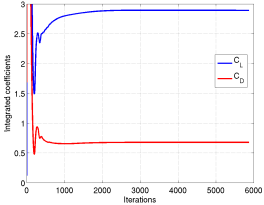
3 Results
- Results summary
- Adaptive calculations
- Bracket effect
- Unsteady computations

Solution convergence criterion

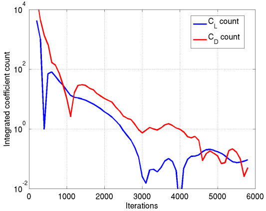
Fine grid (FG) at $\alpha = 28^o$



Residue



Coefficients

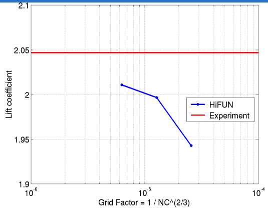


Coefficients count

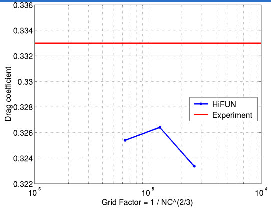
- Residue fall in energy 10 decades
- Lift/Drag coefficients convergence: less than 0.1 count in 100 iterations

Grid convergence study at $\alpha = 13^o$

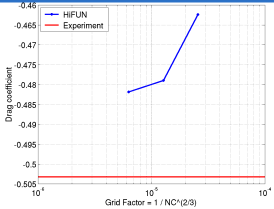
Grids: CG, MG and FG



C_L convergence



C_D convergence



C_M convergence

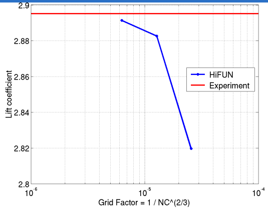
- C_L and C_M converge monotonically to experimental values
- C_D convergence is non-monotonous

Between Coarse to Fine grids

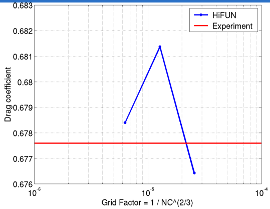
- Changes in lift, drag and moment counts are 67, 20 and 19 respectively

Grid convergence study at $\alpha = 28^o$

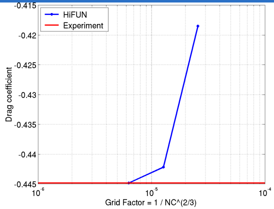
Grids: CG, MG and FG



C_L convergence



C_D convergence



C_M convergence

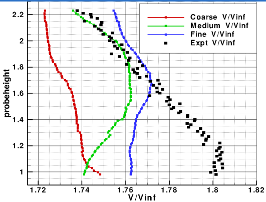
- C_L and C_M converge monotonically to experimental values
- C_D converges non-monotonically to experimental value

Between Coarse to Fine grids

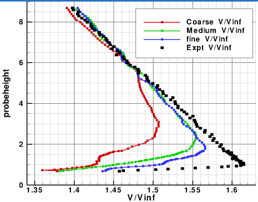
- Changes in lift, drag and moment counts are 71, 19 and 26 respectively

Grid convergence study: Velocity profiles

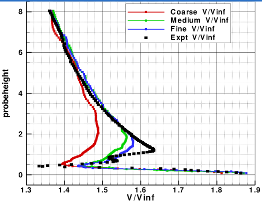
CG, MG and FG: $\alpha = 28^o$



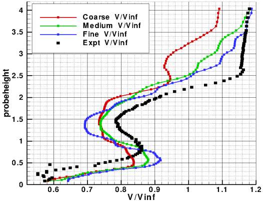
Main, $\eta = 15\%$



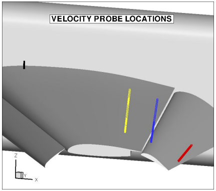
Main, $\eta = 83\%$



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



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



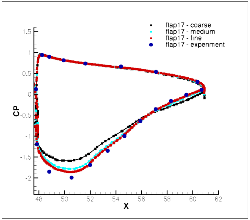
Probe locations

Effect of grid resolution on drag

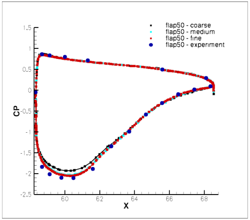
α^o	Grid code	C_{DP}	C_{DV}	C_D	ΔC_{DP}	ΔC_{DV}	ΔC_D
13	CG	0.31280	0.01056	0.32336	...	...	...
	MG	0.31533	0.01107	0.32640	0.00253	0.00052	0.00304
	FG	0.31378	0.01161	0.32540	-0.00155	0.00054	-0.00101
28	CG	0.66631	0.01013	0.67643	...	...	...
	MG	0.67053	0.01084	0.68138	0.00423	0.00072	0.00494
	FG	0.66666	0.01174	0.67840	-0.00387	0.00090	-0.00297

- Pressure drag shows greater dependency on grid refinement than viscous drag

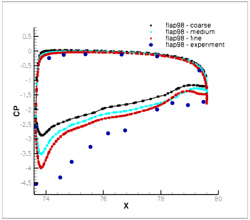
C_p distribution - Flap, $\alpha = 13^o$



17% span



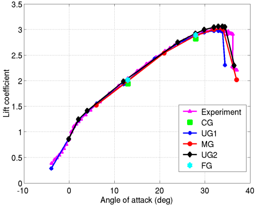
50% span



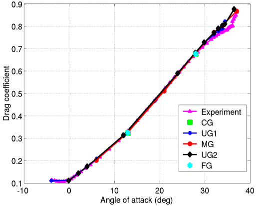
98% span

- 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

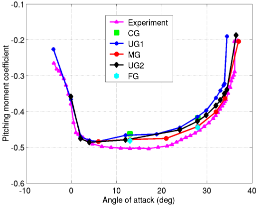
α sweep study



Lift



Drag



Moment

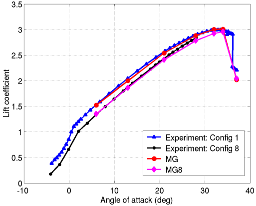
- Computed lift and drag coefficients show excellent comparison with experiments
- Computed pitching moment coefficient curve shows deviation from experimental results
  - Lack of grid resolution in tip region?
  - Effect of brackets?

Maximum lift coefficient

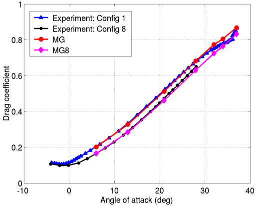
	α_{max}	CL_{max}
UG1	32	2.9735
UG2	33	3.0565
Experiment	32.993	3.0306

- Excellent comparisons can be seen for α_{max} and CL_{max} with experimental values

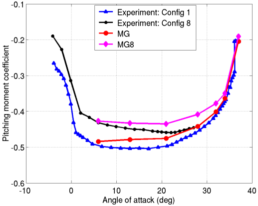
Flap setting study



Lift

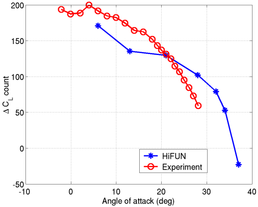


Drag

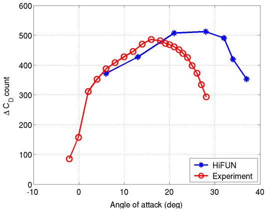


Moment

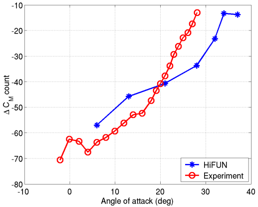
ΔC_L, ΔC_D and ΔC_M count



ΔC_L count



ΔC_D count



ΔC_M count

$$\Delta(.) = (.)_{config1} - (.)_{config8}$$

Outline

3 Results

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

Adaptive calculations

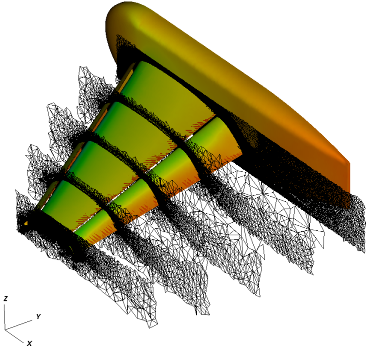
Solution based adaptation

- 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

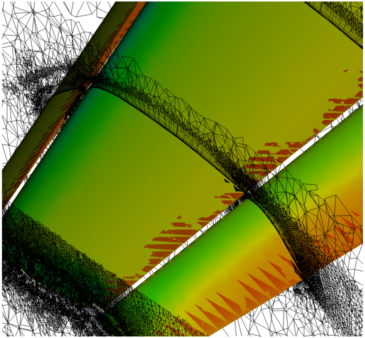
Reference: R–parameter

Ganesh N., N. V. Shende, N. Balakrishnan, "'R–parameter: A local truncation error based adaptive framework for finite volume compressible flow solvers", Computers & Fluids, Volume 38, Number 9, October 2009, pp. 1799–1822.

Adapted grids

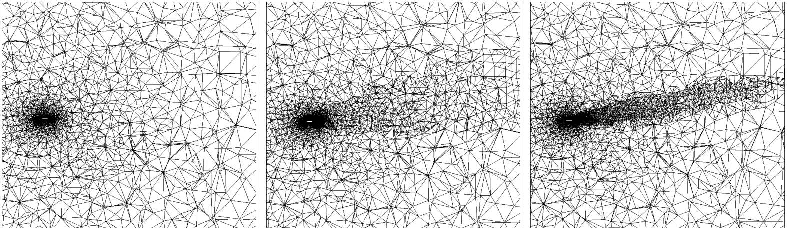


Adapted grid AG2



Zoom view of grid AG2

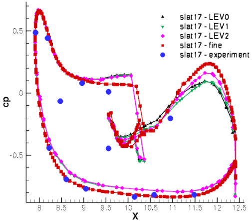
Grid cut views



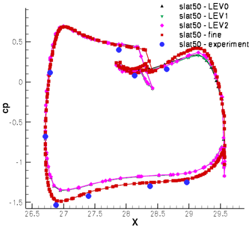
Level 0 Level 1 Level 2

Grid sections at 98% wingspan for various adaption levels

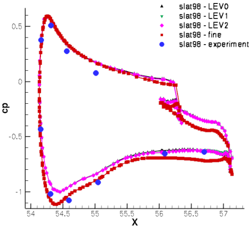
Adapted grids - C_P distribution (Slat)



17% span



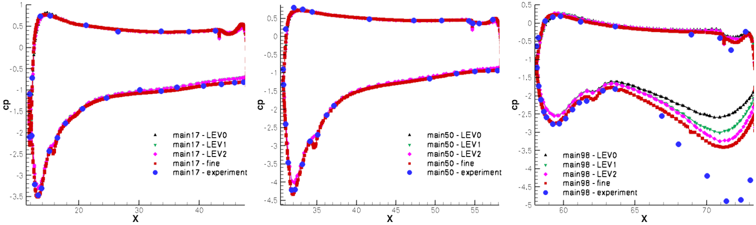
50% span



98% span

- No significant effect of adaptation in slat region

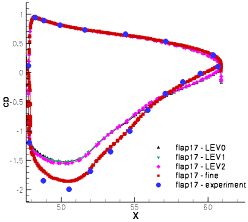
Adapted grids - C_P distribution (Main)



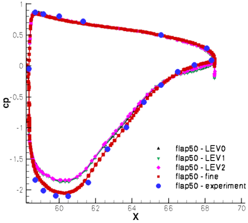
17% span 50% span 98% span

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

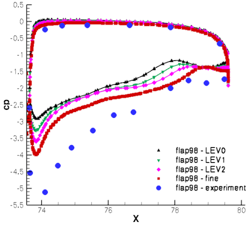
Adapted grids - C_P distribution (Flap)



17% span



50% span



98% span

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

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3 Results
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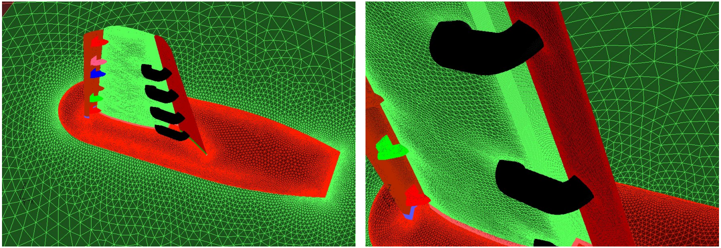
- Adaptive calculations
- Bracket effect
- Unsteady computations

Bracket effect



Surface grid with brackets

Bracket effect

Configuration	Grid code	C_L	C_D	C_M
1 without brackets	CG	1.9429	0.3237	-0.4623
1 with brackets	CGB	1.9714	0.3261	-0.4668
1 without brackets	MG	1.9967	0.3264	-0.4789
1 with brackets	MGB	2.0008	0.3283	-0.4774
1 with brackets	Experiments	2.0468	0.3330	-0.5032

$\alpha = 13^o$

- 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

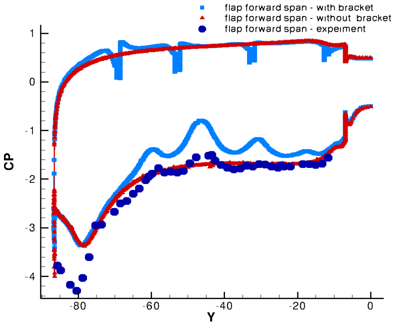
Configuration	Grid code	C_L	C_D	C_M
1 without brackets	CG	2.8197	0.6764	-0.4185
1 with brackets	CGB	2.2987	0.6295	-0.3427
1 without brackets	MG	2.8826	0.6814	-0.4421
1 with brackets	MGB	2.7638	0.6476	-0.4095
1 with brackets	Experiments	2.8952	0.6776	-0.4559

$\alpha = 28^o$

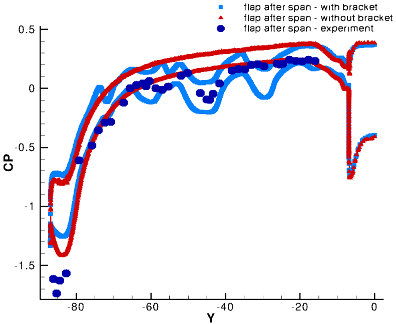
- C_L, C_D and C_M computed without the bracket show better match with the experiments

Bracket effect: C_P distribution

Spanwise flap pressure distribution, $\alpha = 28^o$



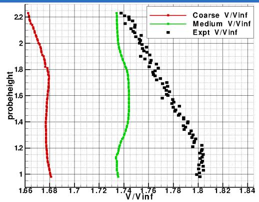
Forward chord location



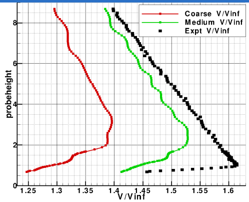
Aft chord location

Bracket effect: Velocity profiles

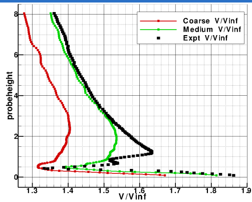
CGB and MGB: $\alpha = 28^o$



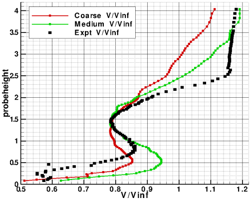
Main, $\eta = 15\%$



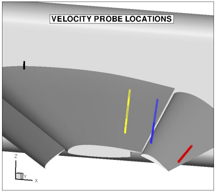
Main, $\eta = 83\%$



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



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



Probe locations

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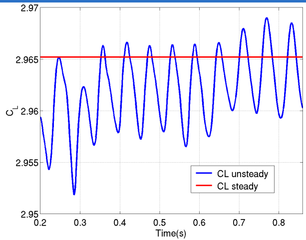
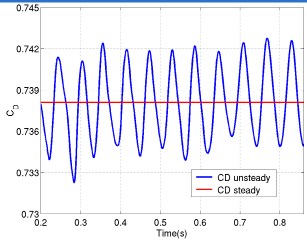
Unsteady computations, $\alpha = 30.44^o$



Evolution of C_L

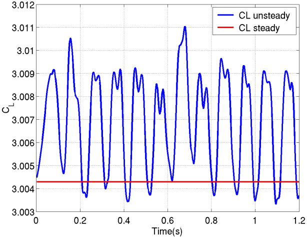


Evolution of C_D

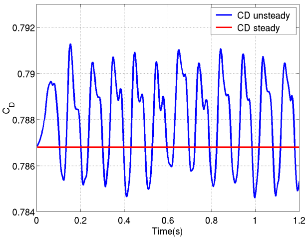
α^o	Physical time step	Strouhal number
30.440	0.0025	0.2362

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

Unsteady computations, $\alpha = 32.942^o$



Evolution of C_L



Evolution of C_D

α^o	Physical time step	Strouhal number
32.942	0.0025	0.1554

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

Outline

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

Acknowledgments

- Gopalakrishna N. (CAd Lab): Bracket study
- Partha Mondal (CAd Lab): Unsteady study, presentation
- Parthiban A. (SandI): Grids for Configuration 1 with brackets

Thank you

Thank you

- Thank you