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Investigation of Grid Generation Strategies for Prediction of High Lift Flows

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Special Session of AIAA High Lift Prediction Workshop

June 2014

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- Results: Low Reynolds Number Study
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Simulation Details

Solver Name : CFD++ (by Metacomp Technologies)
Method : RANS Finite Volume Cell Centered Approach
Discretization : Second Order Upwind
Limiter : Minmod
Turbulence Model : Spalart Allamaras with Rotational Correction (SARC)

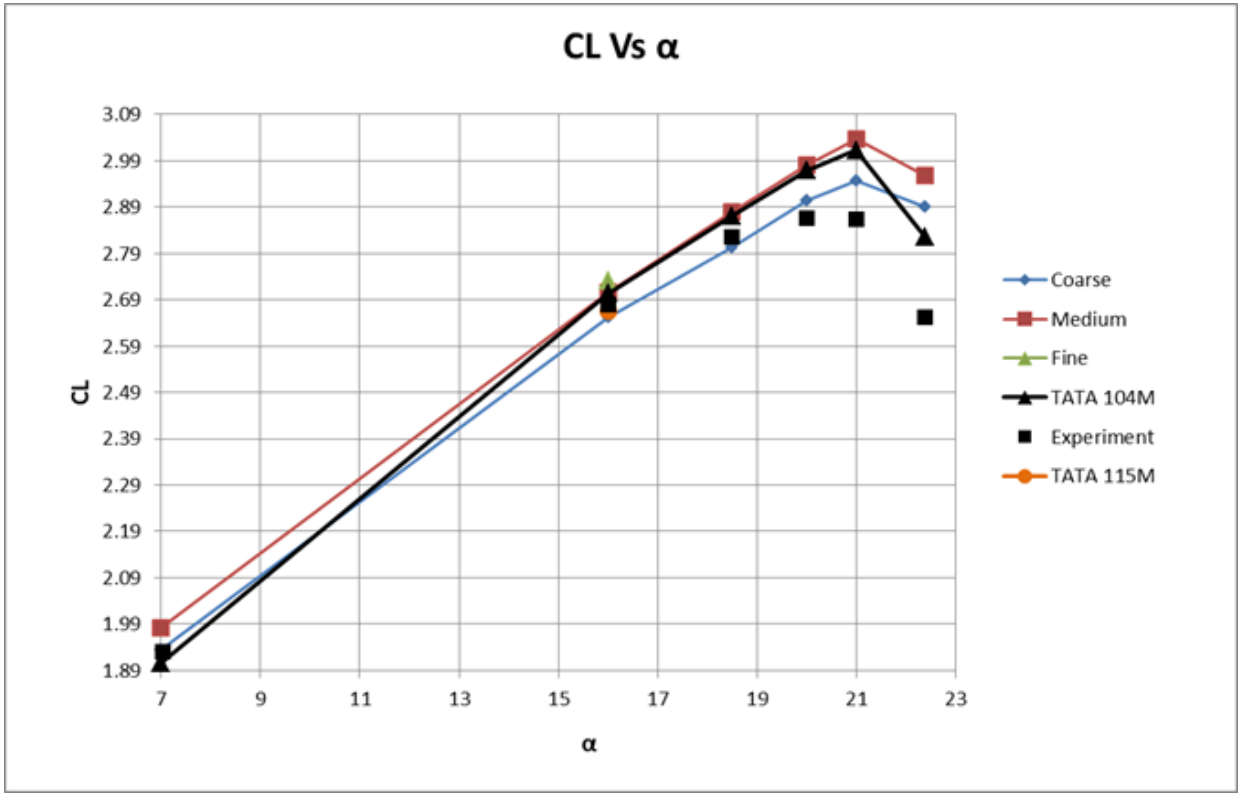
High Reynolds Number Case	
Reynolds Number	15.1M
Mach Number	0.175
Static Temperature	114K
Angles of Attack	16 - 22.4
Low Reynolds Number Case	
Reynolds Number	1.35M
Mach Number	0.175
Static Temperature	298.6K
Angles of Attack	16 - 21

Simulation Details

Config1 (No support brackets) Analysis

- Used following Mixed Unstructured Grids:
  DLR Coarse, Medium, Fine, TATA 115M and TATA 104M

- Simulated $\alpha = 7°$ to $22.4°$ at High Re Conditions

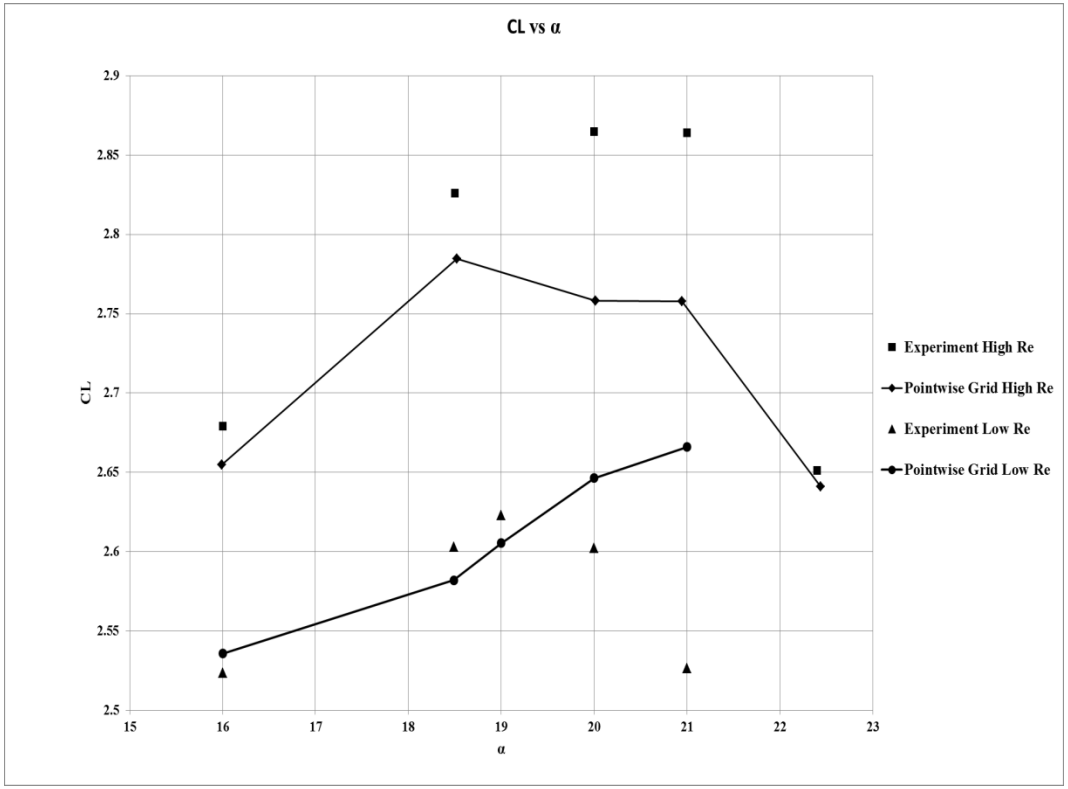


Config1 Lift Predictions

Review of work during 2nd HILIFT Prediction Workshop

Config2 (with support brackets) Analysis

- Used Pointwise Mixed Unstructured Grids provided by AIAA
- Simulated α = 16° to 22.4° at High Re and α = 16° to 21° at Low Re Conditions
- Under prediction of Stall angle and Max. CL at High Re
- Sudden Dip at α = 20°
- Stall not predicted up to α = 21° at Low Re



Config2 Lift Predictions

Focus of Current Studies

EuroLift Configuration with Support Brackets (Config2) is analyzed to:

- Investigate Surface and Volume Grid Generation Strategies to improve Lift Prediction at High Re
- Understand the reason for Dip at $\alpha = 20°$ at High Re
- Assess Applicability of High Re Grids to the Analysis of order of magnitude lower Re Case

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Grid Details

Surface Grids

Grid 1: Pointwise grid available from AIAA HiLIFTPW2

Grid 2 & Grid 3: In-house High Re grids

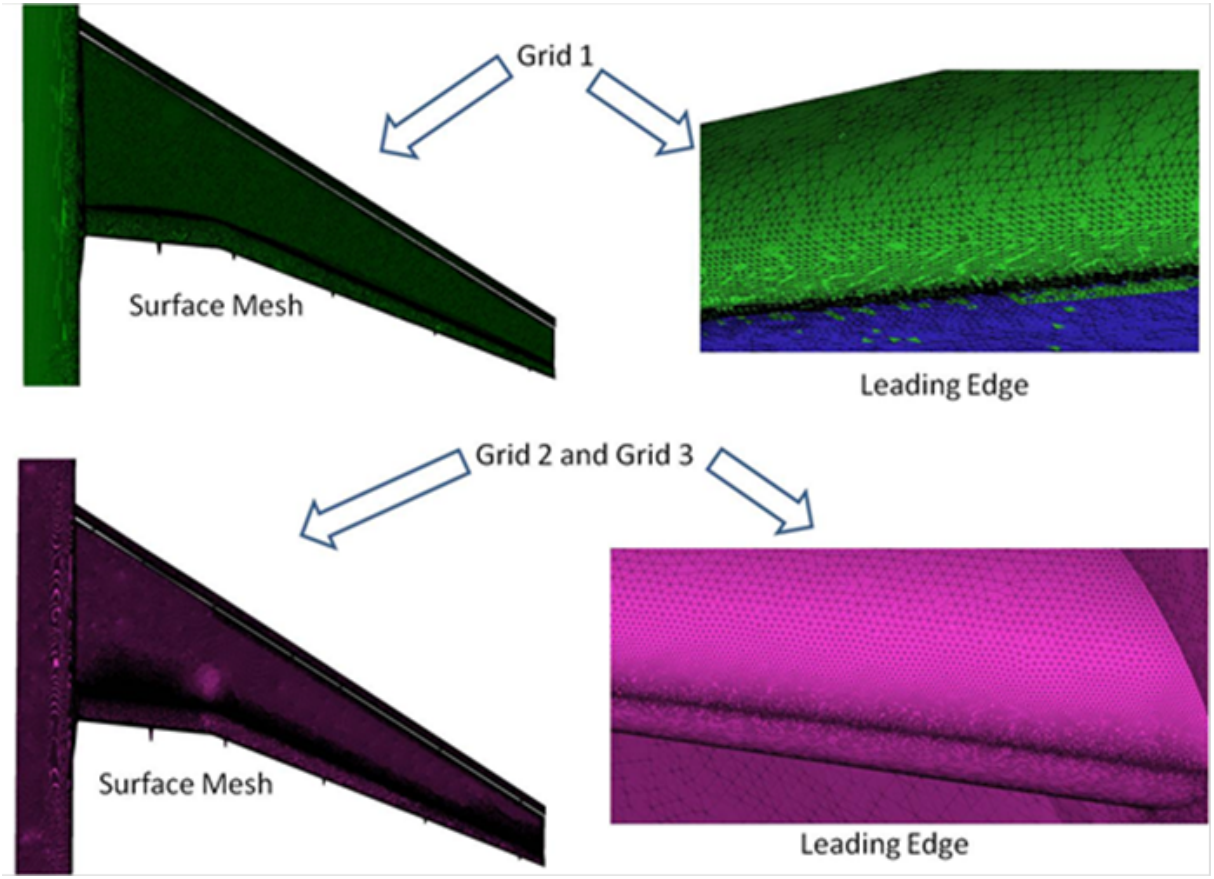
Grid 4: in-house Low Re grid

Grid 1

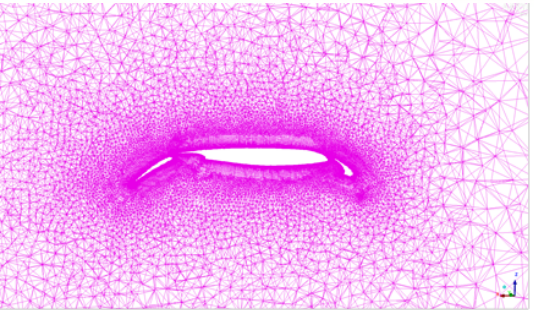
- Stretched rectangular Tri elements leading to coarser leading edge resolution
- Finer resolution of mid-chord portions of lifting elements

Grid 2, Grid 3 & Grid 4

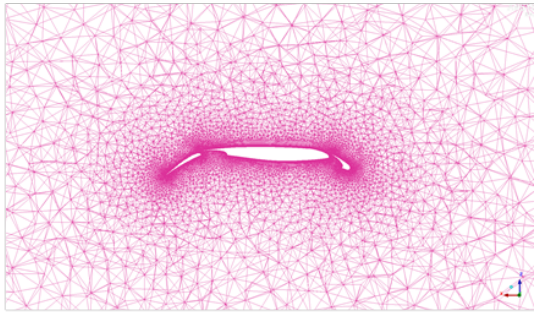
- Identical Surface Grids
- Regular Tri elements leading to finer leading edge resolution
- Coarser resolution of mid-chord portions of lifting elements



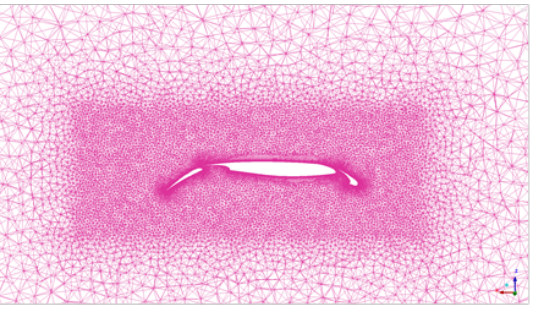
Volume Grids



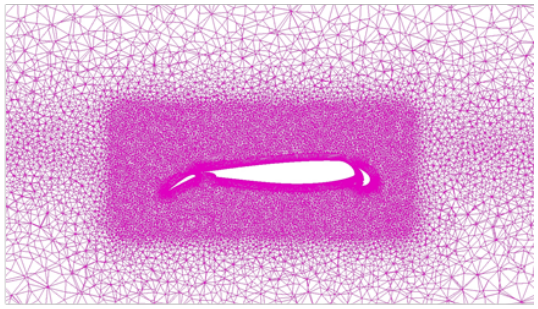
Grid 1



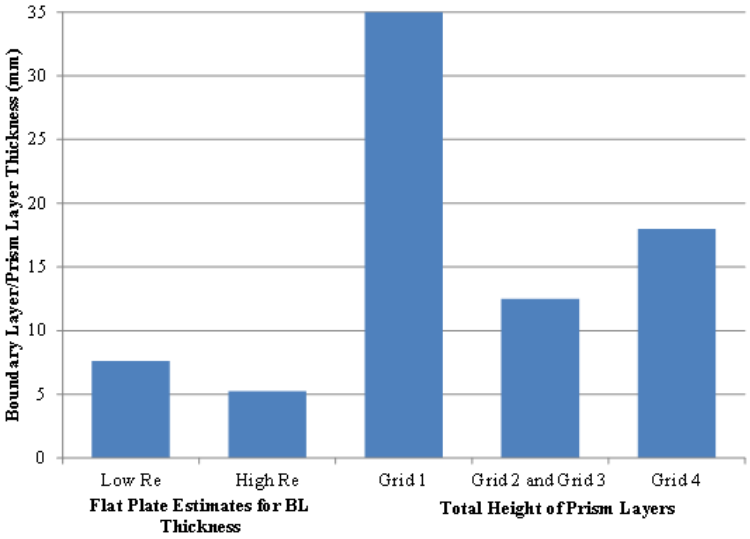
Grid 2



Grid 3



Grid 4



DETAILS OF GRIDS USED FOR THE ANALYSIS				
Grid Name	Grid 1	Grid 2	Grid 3	Grid 4
Grid Type	Tet+Prism+Pyramids	Tet+Prism+Pyramids	Tet+Prism+Pyramids	Tet+Prism+Pyramids
Grid Size	148M	156M	158M	121M
Surface Mesh Size	2.4M	3.64M	3.64M	3.64M
First Cell Height	0.00028mm	0.00055mm	0.00055mm	0.0061mm
Prism Growth Rate	1.15	1.2	1.2	1.2
No of Prism Layers	65	45	45	35
Prism Layer Height	35mm	14mm	14mm	18mm
Density Box*	No	No	Yes	Yes
Software Used	Pointwise	ICEM CFD	ICEM CFD	ICEM CFD
Created By	Pointwise Inc.	TATA	TATA	TATA

*Note: Density box is a dense region of tetrahedral elements in the vicinity of aircraft lifting surfaces.

Grid 1: Higher Prism Layer Thickness compared to other grids

Grid 2: Lower Prism Layer Thickness than Grid 1

Grid 3: Prism Layers identical to Grid 2 and also has dense Tet around Lifting elements

Grid 4: Generated for Low Re using similar strategy as Grid 3

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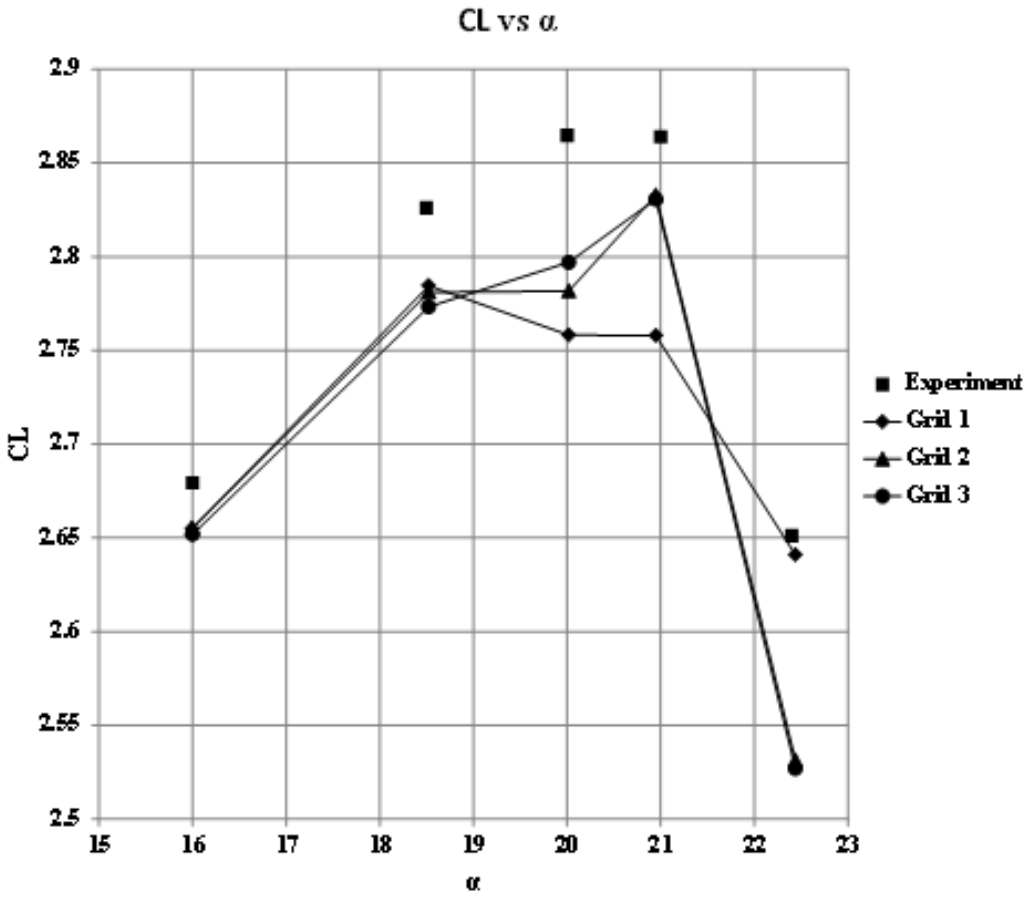
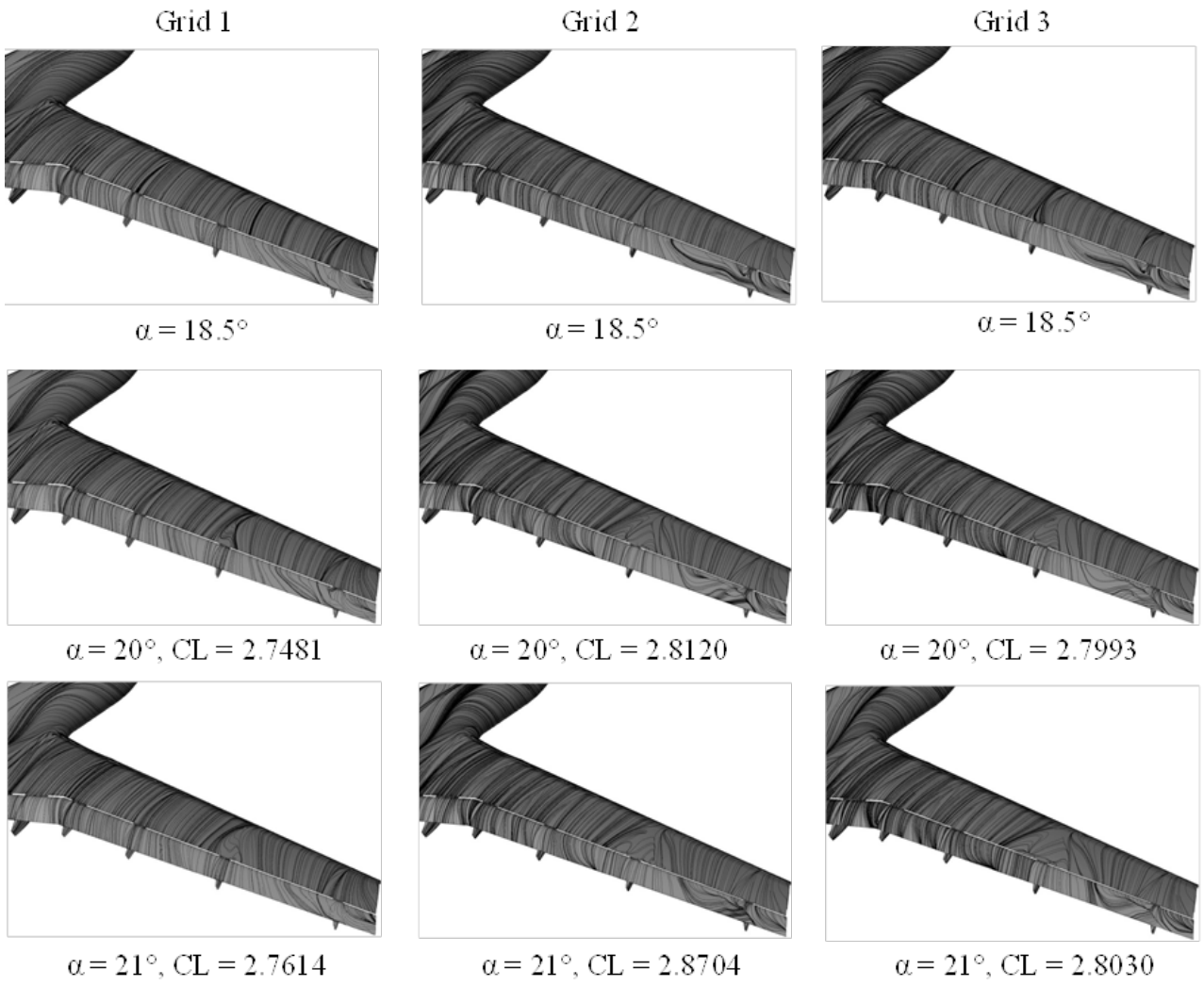
Results: High Reynolds Number Study

Lift Prediction



- Grid 2 and Grid 3 improved prediction of Stall angle and Max. CL
- Grid 3 Results demonstrated highest improvement at α =20° where CL Dip is observed
- Abrupt stall for Grid 2 and Grid 3, typical of SA model
- Grid 2 and Grid 3 indicated unsteadiness in the solution from 20° onwards

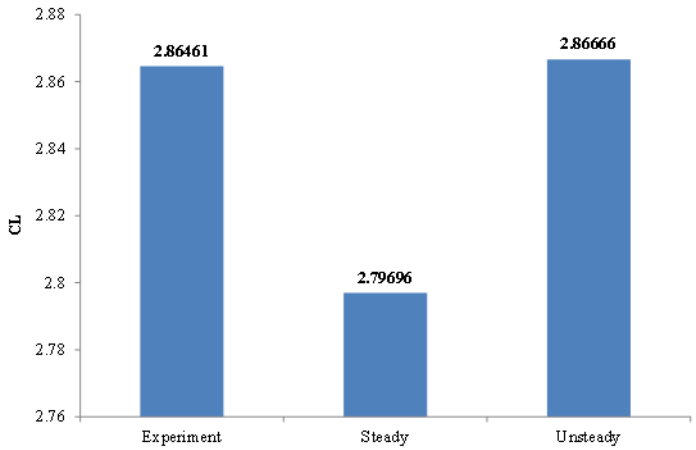
Stall Development



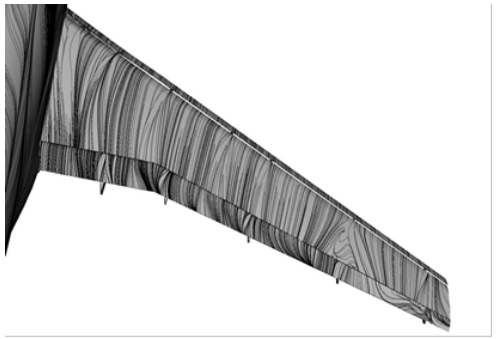
Grid 2 & Grid 3 have indicated fluctuations in Lift Coefficients and separation extent varies accordingly. The stall pattern depicted here corresponds to last iteration value which is mentioned in the figure.

Similar stall development but with varying degree of separation

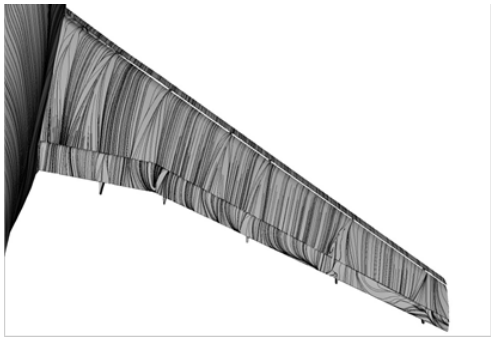
Investigation of CL dip at α = 20°



Improvement in Lift Prediction

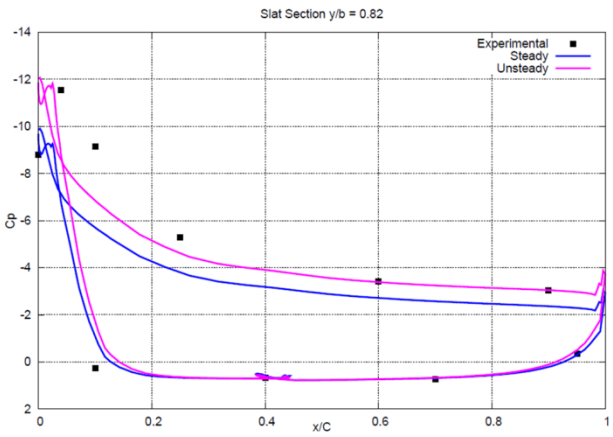


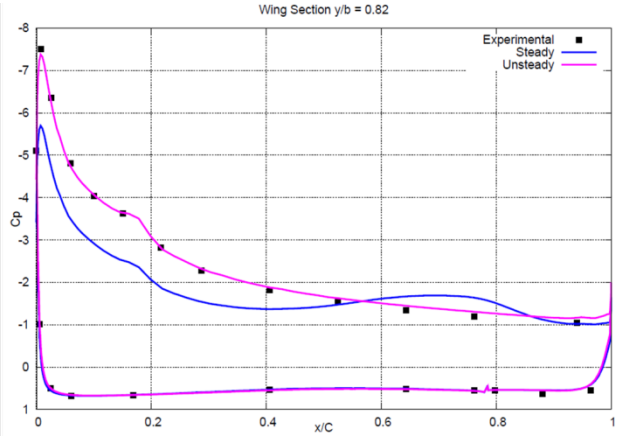
Grid 3 α = 20° Steady

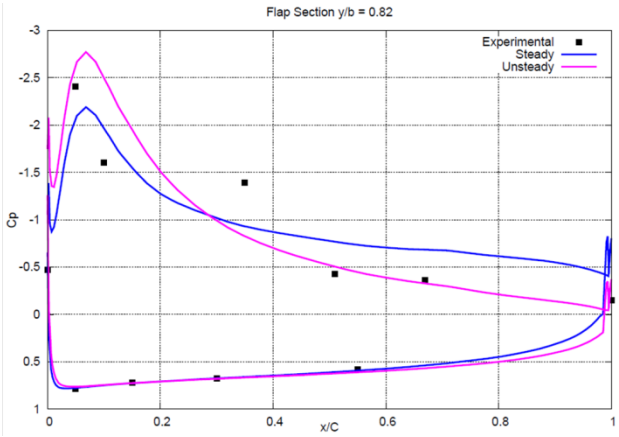


Grid 3 α = 20° Unsteady

Over prediction of Separation over Wing Surface by Steady run



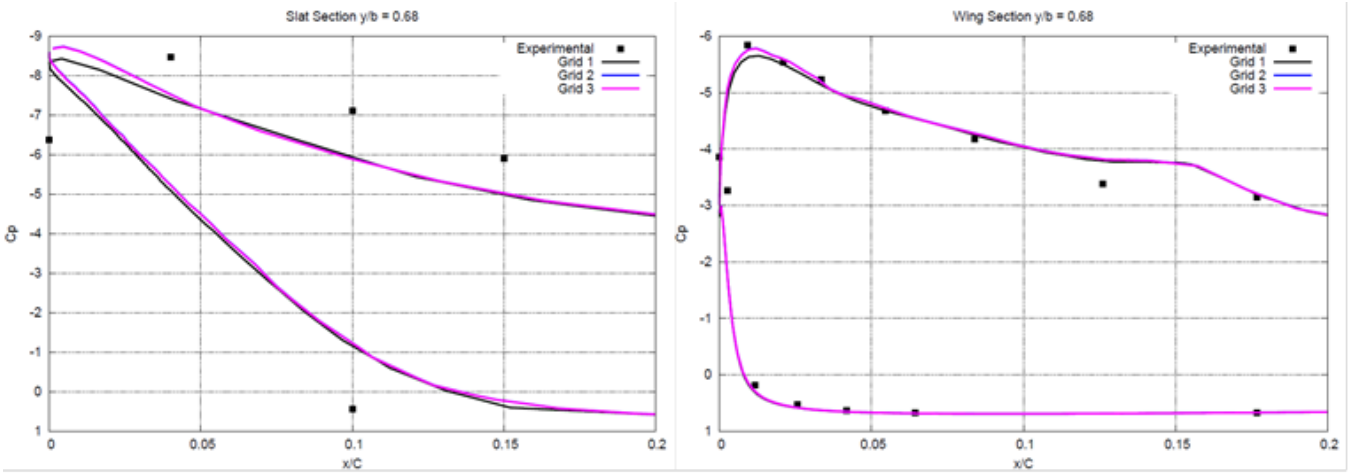


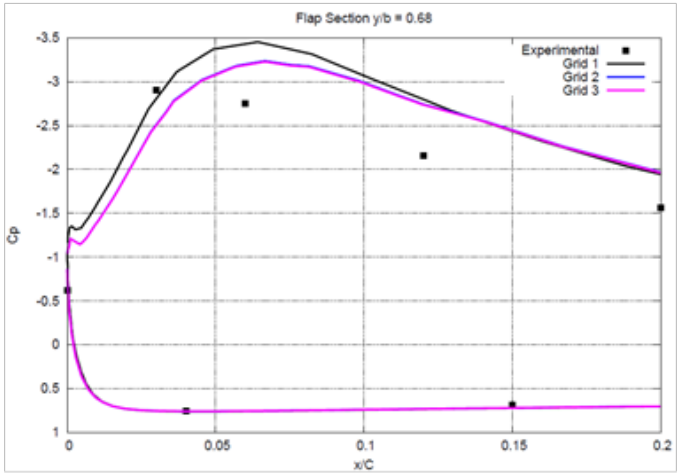


Good Agreement of surface pressures compared to Steady analysis especially on Wing followed by Slat, however Flap still needs improvement

Comparison of Surface grid generation strategies

Leading edge Pressure distribution at section y/b = 0.68, α =16°



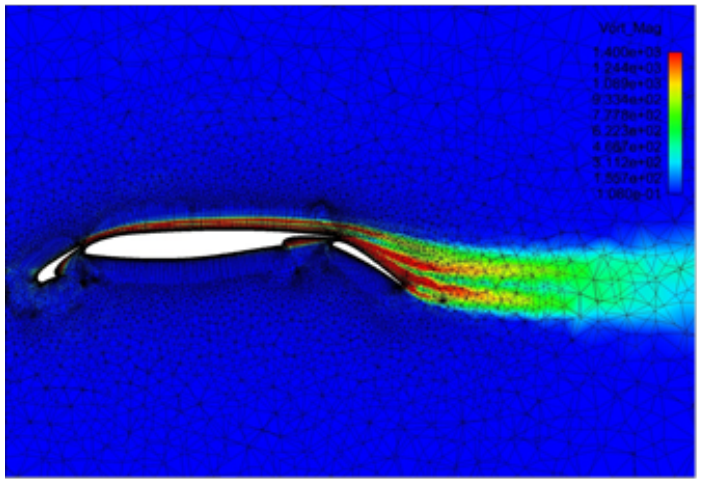


This trend consistently observed throughout the analysis

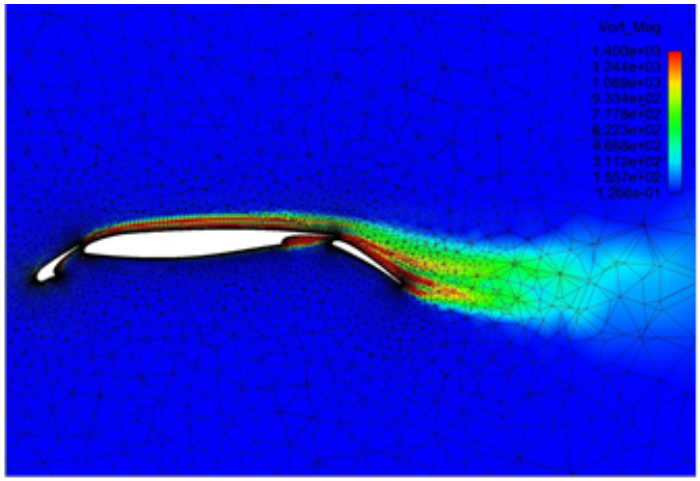
Leading edge pressure is sensitive to chord-wise and span-wise grid resolution

Comparison of Volume grid generation strategies

Vorticity Contours at section y/b = 0.68, α =16°

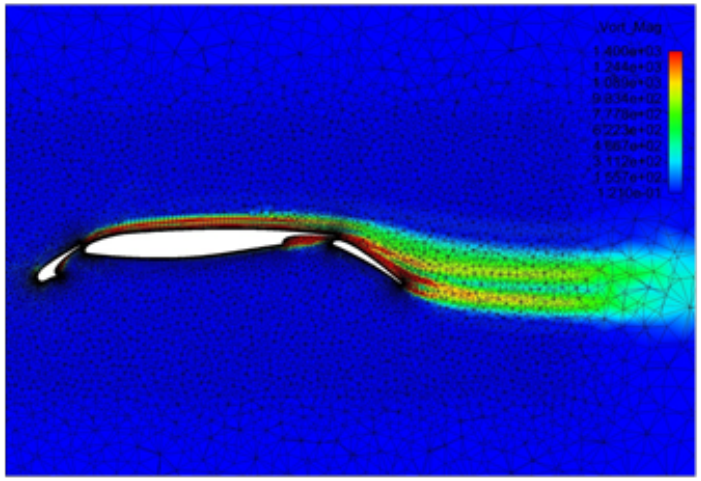


Grid 1



Grid 2

Prism most efficient in resolving wake vorticity



Grid 3

Reduction in tetrahedral size showed small improvement in the wake resolution

Trend consistent throughout the analysis

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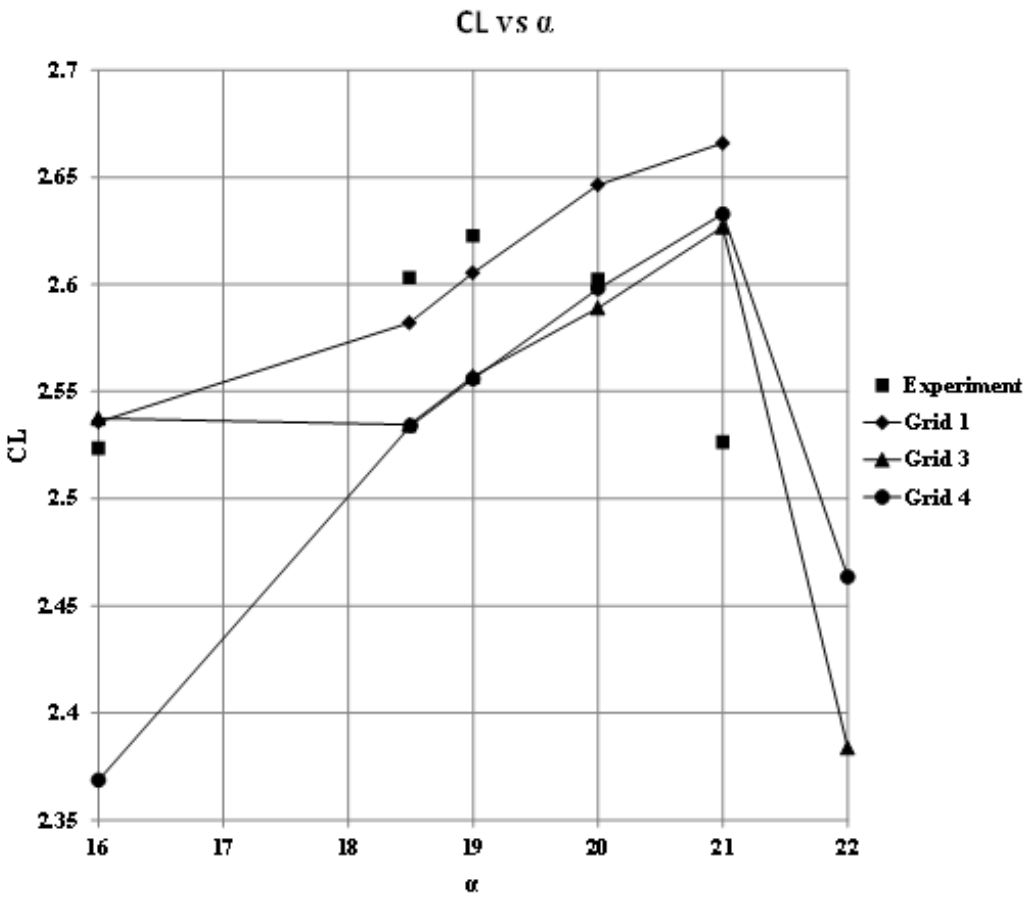
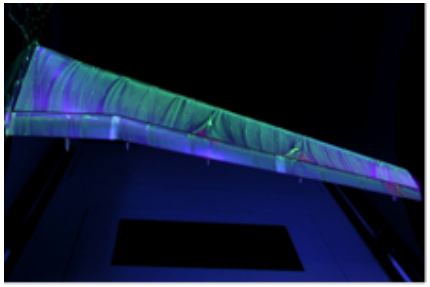
Results: Low Reynolds Number Study

Lift Prediction



- All the grids over predicted stall angle and corresponding Max. CL
- Grid 1 prediction are closer to experiment up to α = 19°
- However, over prediction of CL is higher and no stall was observed up to 21°. Further angles of attack were not simulated due to time constraints

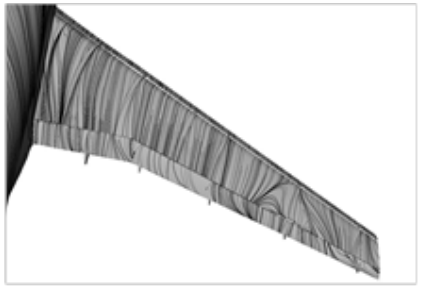
Stall Development



Wind Tunnel

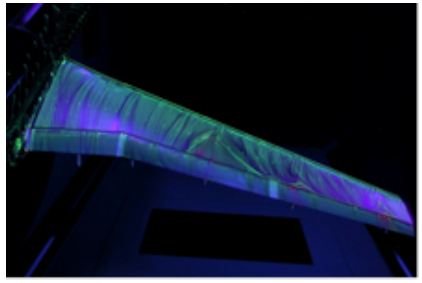
Grid 1

Grid 3



Grid 4

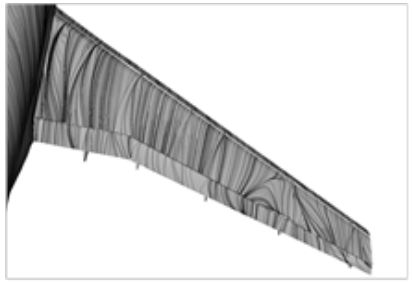
$\alpha = 18.5°$



Wind Tunnel

Grid 1

Grid 3



Grid 4

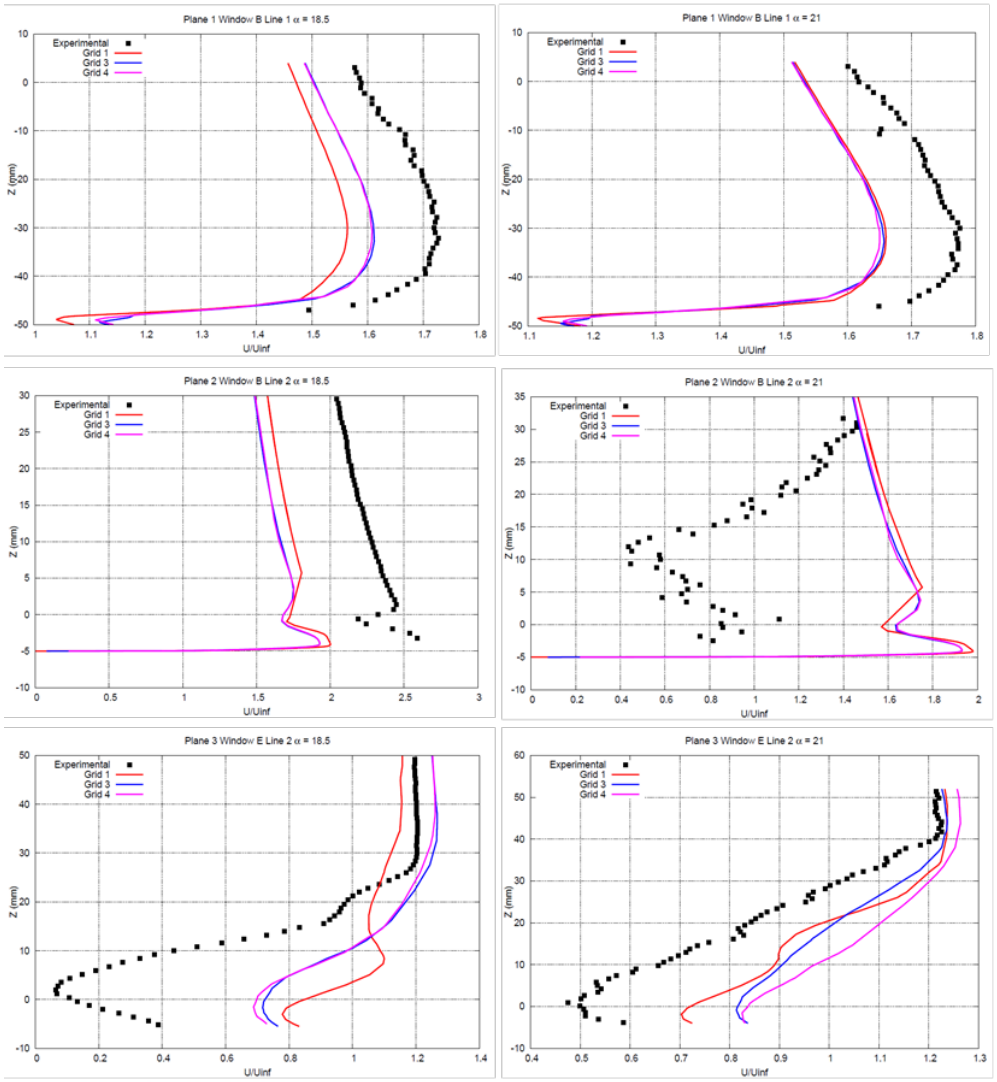
$\alpha = 21°$

CFD predicted development of single outboard separation while experiment shows two small regions of separations out of which inner one grows causing mid span stall

Comparison of Velocity Profiles

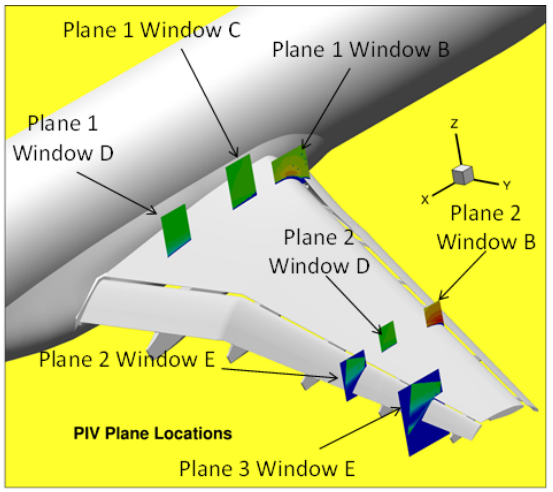
Sample Velocity Profile comparison at α = 18.5° and 21°

α = 18.5° | α = 21°



Expt. : Black
Grid 1 : Red
Grid 3 : Blue
Grid 4 : Pink

PIV Plane Locations



Overall trends for Entire Low Re analysis

- Experimental trends matched well for Plane 1 and Plane Wing Sections but agreement on flap remained poor
- Overall predictions of Grid 1 showed closer agreement to experiment at different span locations for both α = 18.5° and 21°
- No considerable difference in the predictions of Grid 3 and Grid 4
- Most probable reason for better predictions by Grid 1 is slower prism layer growth rate

Observations and Conclusion

High Reynolds Number Study

- Stall angle and CLmax prediction using Steady RANS has been satisfactory
- Unsteady analysis indicated that the cause of CL dip at $\alpha = 20°$ was over prediction of separation on Wing by Steady Analysis
- Leading edge pressure distribution indicates sensitivity to spanwise grid distribution
- Faster dissipation rate of multi-element wake vorticity observed for tetrahedral elements compared to prisms
- Vorticity dissipation rate reduced with reduction of tetrahedral size

Observations and Conclusion

Low Reynolds Number Study

- All grids predicted higher CLmax and Stall Angle than experiment
- CFD predicted outboard stall contrary to mid span stall in Wind Tunnel Tests
- All grids under-predicted fullness of velocity profiles and indicated inadequate wake resolution
- High Re grids may be usable for Low Re analysis as long as sufficient prism layer height is present to resolve wake regions
- It may be possible to improve velocity profile prediction with smaller stretching ratio but further investigations are needed in this direction

Observations Common to both studies

- Flow prediction over flap needs improvement
- Efforts in this direction can improve not only Lift but Drag Predictions as well

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Thank You