# EFFECT OF TRAILING EDGE REFINEMENT ON FORCE CONVERGENCE AND ACCURACY FOR FLOW OVER BLUNT TRAILING EDGE AIRFOIL

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## ABSTRACT

*This paper presents the study of effect of trailing edge refinement on force, residual convergence and accuracy of blunt trailing edge airfoil using In-house parallel 3D RANS code (AVFL - Aero Viscous Flow). Present study is carried out for incompressible flow over ADE high lift cambered airfoil at M=0.15, AOA = 0 & 10 deg. Medium type Structured O-grid was generated over the airfoil using IGG Numeca grid generation software with two additional sections along span wise direction to use 3D RANS code with second order discretization scheme (MUSCL)[1]. Basic grid of size 233×105×3 with and without refinement at Trailing edge was used for CFD simulation. Three type mesh were generated for CFD study. They are 1. mesh-1 without Trailing edge refinement, 2. mesh-2 with Trailing edge refinement only at both end and 3. mesh-3 with Trailing edge refinement at both end & midpoint. This code uses cell-centered FVM based discretization method and R-K Multi stage-second order scheme with explicit time integration. Roe Fluxdifference-splitting scheme with local time step was used for convective flux calculation. The viscous flux calculation were carried out using gradient calculation by Gauss-divergence theorem on a shifted control volume. Also Spalart-Allmaras turbulence model was used for turbulent viscosity calculation [3][4][5]. At the far field boundaries, Riemann characteristics boundary condition was applied. From the CFD study, it was found that mesh refinement at trailing edge of airfoil improves the force and residual convergence and also captures flow near the trailing edge i.e. base flow behaviour. CFD study with multigrid algorithm to accelerate the solution convergence further is under progress. it will be shown in the final paper.*

**Keywords**: AVFL 3D Code, Trailing Edge Refinement, ADELS-E2 Airfoil, force & residual convergence.

## NOMENCLATURE

| | |
|---|---|
| M | = Mach number |
| P | = Static Pressure |
| T | = Static Temperature |
| α | = Angle of Attack |
| $C_L$ | = Coefficient of lift |
| $C_D$ | = Coefficient of drag |
| $C_P$ | = Coefficient of pressure |

## INTRODUCTION

Today Computational Fluid Dynamics plays important role in the design of any aerospace vehicle. It significantly reduces the time & cost involved in design phase by limiting wind tunnel study to few test cases. Also today Parallelized CFD solver with high performance cluster nodes can handle larger grid and can do aerodynamic calculations accurately in less time for even a complete aircraft configuration. The main advantage of in-house code development activity is that the code can be customized to tackle complex flow phenomenon where commercial CFD packages cannot be used and also understand the physics of the flow governing equation such as continuity, momentum & energy equations...etc. The resultant code has to be validated first to check the stability, convergence and accuracy of the solution at different flow regimes before employing it for actual applications. AVFL 3D code has already been validated for low subsonic to supersonic flow regime application using explicit time integration. In this work the low subsonic flow over ADE cambered airfoil with trailing edge refinement on force and residual convergence and accuracy of results have been studied using in-house parallel 3D RANS code.

## GEOMETRY AND GRID GENERATION DETAILS ON RAE2822 AIRFOIL

The numerical simulation is carried out on medium O-type grids, 233×105×3 (Fig.1). An enlarged view of the mesh-1 without Trailing edge refinement is shown in Fig.1a, mesh-2 with Trailing edge refinement only at both end and mesh-3 with Trailing edge refinement at both end & mid-point are shown in refinement is shown in Fig.1b & Fig.1c respectively. Trailing edge refinement was carried out without changing the total mesh size. There are 233 points were distributed in chord-wise direction (i), 105 points were distributed in radial direction (j) which is normal to the surface and 3 points are taken along the span direction (k). The grid points are clustered around the airfoil (wall) where the gradients normal to the airfoil surface are much greater than that of tangential gradients except near the leading/trailing edges. Consequently the cells nearest to the surface have very high aspect rations. The first cell height from the surface is 0.0000085m i.e. $y^+ = 1$.

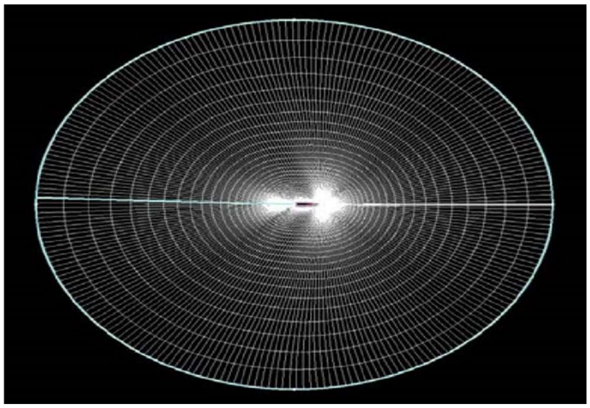

**FIGURE 1:** STRUCTURED O GRID ON ADE AIRFOIL

(233 ×3×105 )

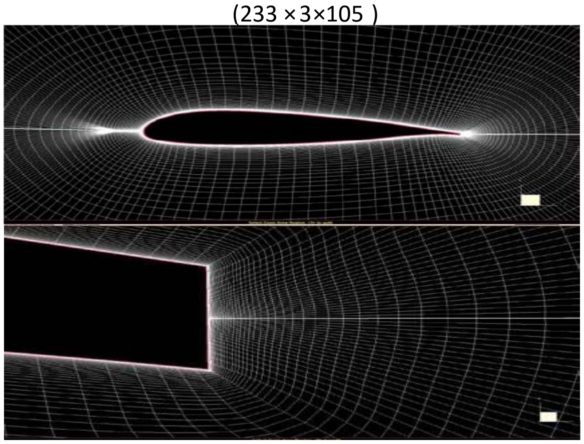

**FIGURE 1a**: ENLARGED VIEW MESH-1 WITHOUT TRAILING EDGE REFINEMENT

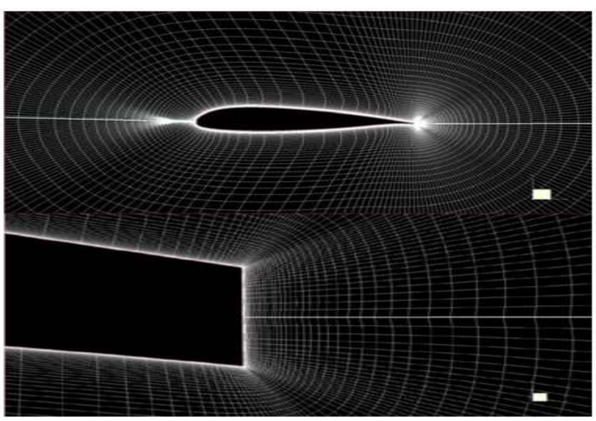

**FIGURE 1b:** ENLARGED VIEW MESH-2 TRAILING EDGE REFINEMENT ONLY AT BOTH END

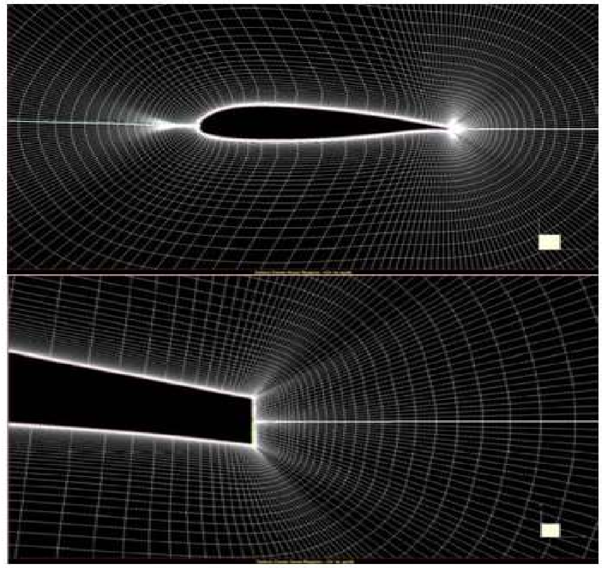

**FIGURE 1c:** ENLARGED VIEW MESH-2 TRAILING EDGE REFINEMENT AT BOTH END & MID POINT

## FLOW CONDITIONS

| | |
|---|---|
| M | 0.15(V = 52.34m/sec) |
| Static Pressure | 101325 Pa |
| Static Temperature | 303 K |
| Angle of attack | 0º and 10º |
| CFL Number (explicit) | 1.0 |

**TABLE 1:** FREE-STREAM FLOW CONDITIONS

## BOUNDARYCONDITIONS

No-slip boundary condition was applied at airfoil surface (wall) which is $j_1$ boundary. Riemann characteristics boundary condition was applied at $j_{max}$ boundary which uses 1-D characteristics theory to set far-filed conditions. Cyclic/connecting boundaries were specified at $i_1$ & $i_{max}$ planes and symmetry boundary conditions were applied at $k_1$ and $k_{max}$ planes.

## RESULTS & DISCUSSION

Mach contour for mesh-1 and mesh-2 are shown in Fig.2a, 2b, 2c and 2d respectively. It shows that the mesh with trailing edge refinement captures base flow behavior accurately. Fig.5 and Fig. 9 the density residual plot in log scale for $\alpha = 0°$ & $10°$ shows that the density residual has reduced from $10^{-3}$ to $10^{-6}$ for mesh-1 and from $10^{-3}$ to $10^{-7}$ for mesh-2 for the number of same iteration. The reduction in force & density residual with refinement will decrease the computational time for CFD studies. $C_L$ and $C_D$ vs. iteration plot (Fig.3 & 4 for $\alpha = 0°$ and Fig 7 & 8 for $\alpha = 10°$) shows that the solution becomes stable after 12000 iterations for mesh-2 but minor oscillation are observed for mesh-1 till 15000 iterations. The chord wise $C_P$ distribution comparison plot (Fig.9) shows that the mesh-2 captures the base flow behavior better than mesh-1. There is not much difference observed between mesh-2 and mesh-3 results. Hence for 10 deg angle of attack comparison of results only done for mesh-

1 and mesh-2 (shown in Fig-7, 8, 9 and 10). The comparison of force convergence, residual level and $C_P$ plot between mesh-1 and mesh-2 shows that mesh with trailing edge refinement will improve solution convergence and accuracy. Also due to better resolution of flow at blunt trailing edge, the base drag is computed accurately resulting in better prediction of overall drag. To validate the code data, Cp plot comparison between code and Experimental [18] data (Fig.6 & Fig.10) was done. Code data matches reasonably well with experimental data. CFD study with multigrid algorithm to accelerate the solution convergence further is under progress. It will be shown in the final paper.

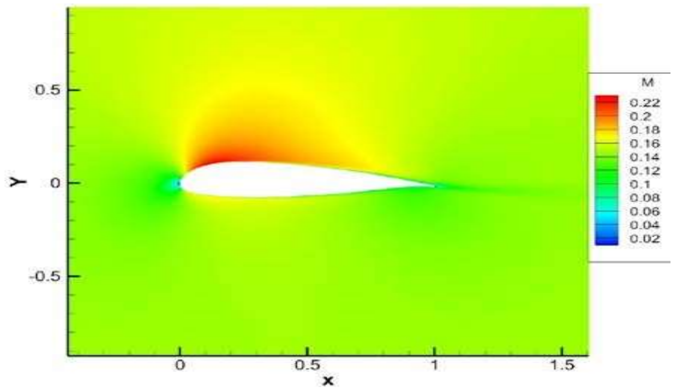


**FIGURE 2a:** ENLARGED VIEW WITHOUT MESH (MESH-1)

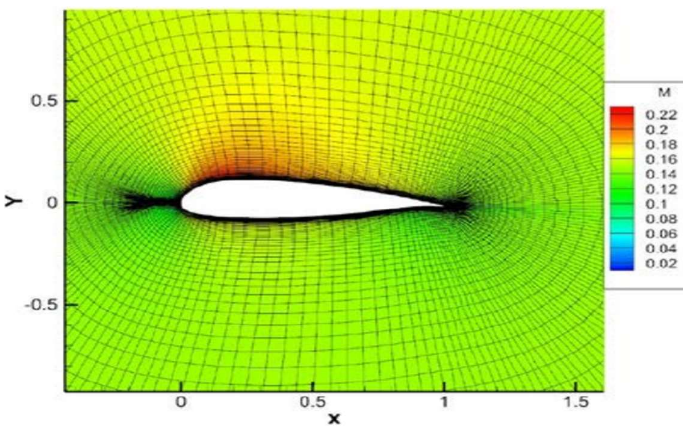


**FIGURE 2b:** ENLARGED VIEW WITH MESH (MESH-1)

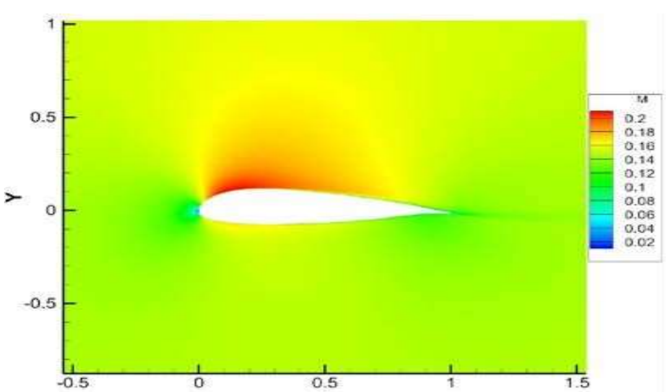


**FIGURE 2c:** ENLARGED VIEW WITHOUT MESH (MESH-2)

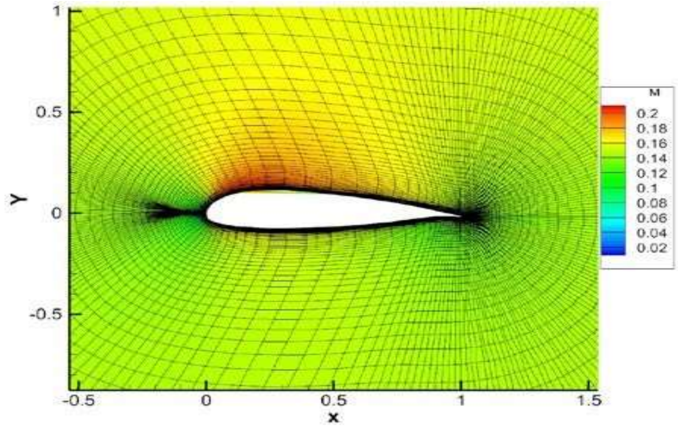


**FIGURE 2d:** ENLARGED VIEW WITH MESH (MESH-2)

**FIGURE 2:** MACH CONTOUR ON ADELS-E2 AIRFOIL OF GRID SIZE 233 X 3 X 105 AT A = 0º

## I. PLOTS

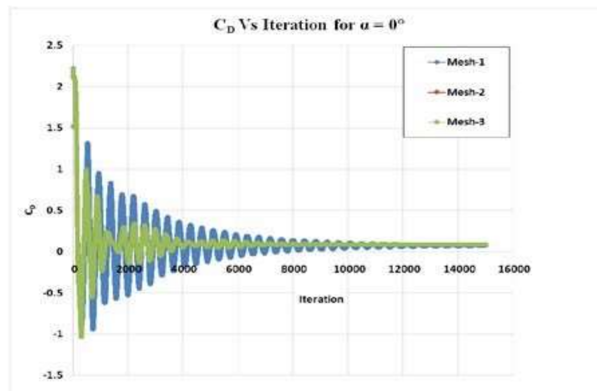


**FIGURE 3**: $C_L$ vs. ITERATION COMPARISON AT $\alpha = 0°$.

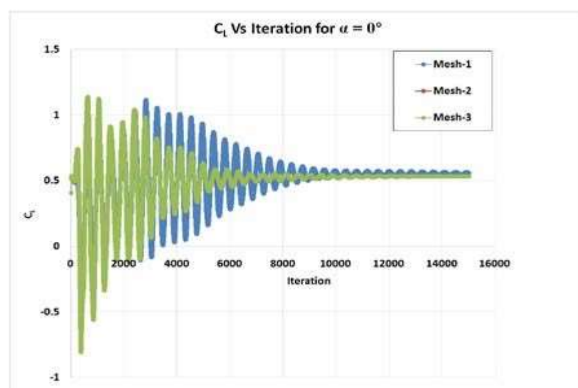


**FIGURE 4:** $C_D$ vs. ITERATION COMPARISON AT $\alpha = 0°$.

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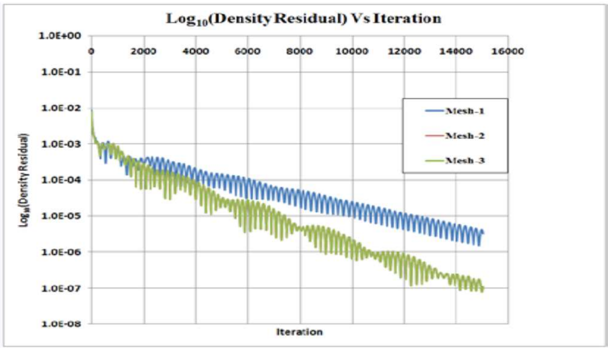



**FIGURE 5:** DENSITY RESIDUAL VS ITERATIONS AT α = 0°.

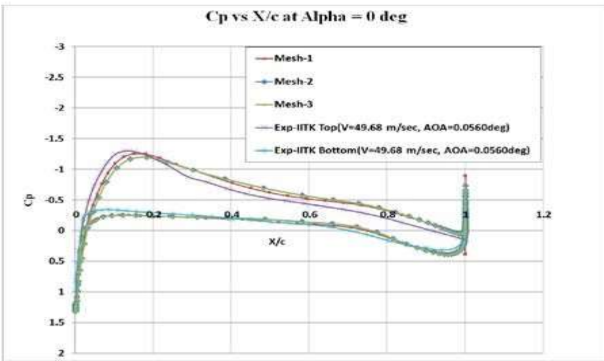



**FIGURE 6:** Cp PLOT COMPARISON BETWEEN THE MESH AT α = 0°.

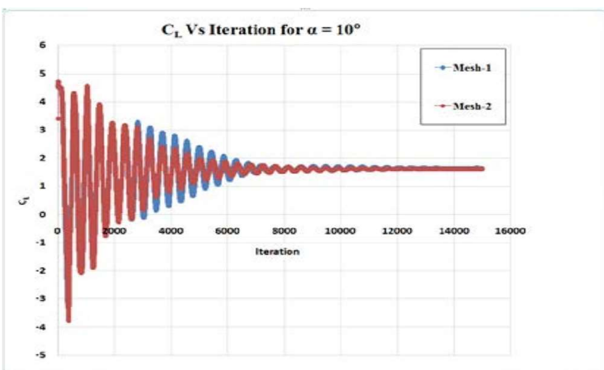



**FIGURE7:** $C_L$ Vs ITERATION COMPARISON AT α = 10°.

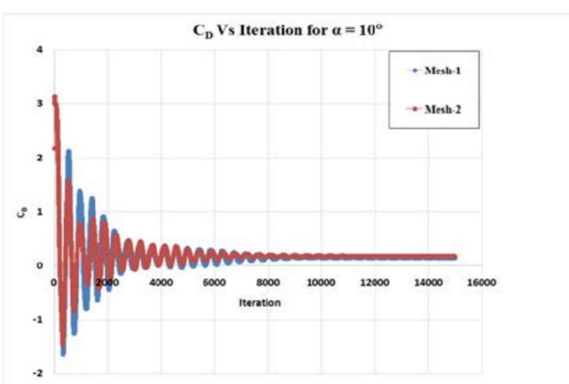



**FIGURE 8:** $C_D$ vs. ITERATION COMPARISON AT α = $10^0$

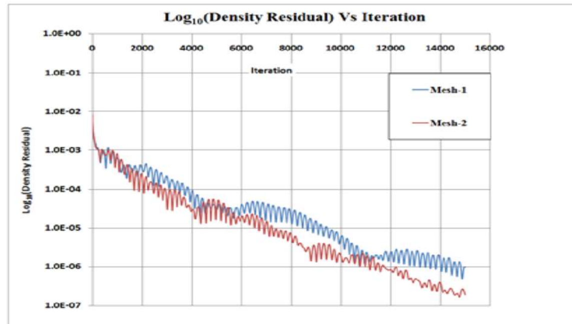



**FIGURE 9:** NSITY RESIDUAL VS ITERATIONS AT α = $10^0$

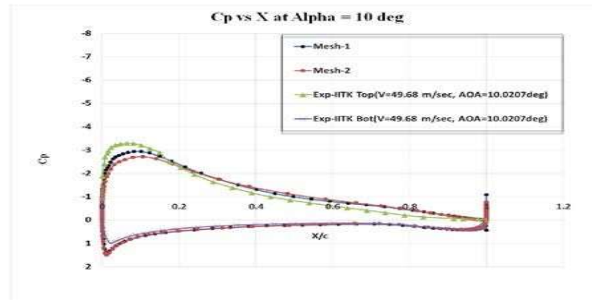
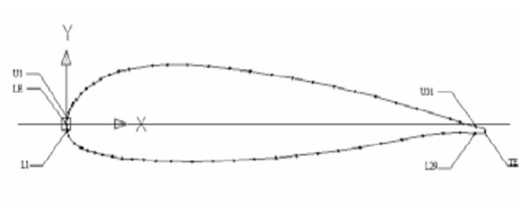



**FIGURE 10:** Cp PLOT COMPARISON BETWEEN THE MESH AT α = 10°.

**FIGURE 11:** ADE AIRFOIL MODEL ON THE SYNCHRONOUSLY DRIVEN TWIN-TURNTABLES (FLOOR AND ROOF) AT NWTF, IITK.




LE – Leading Edge Port,
LE – Leading Edge Port
TE – Trailing Edge Port
U1-U31 – Upper Surface Ports
L1-L29 – Lower Surface Ports

**FIGURE 12:** PRESSURE PORT LOCATIONS ON ADE AIRFOIL MODEL

## CONCLUSION

In-house parallel 3D RANS code has been used to study the effect of Trailing edge refinement on force and residual convergence and accuracy of capturing base flow behavior for low subsonic flow over ADE 19% thickness cambered high lift airfoil. From the study it is found that, mesh refinement at trailing edge of airfoil improves the force and residual convergence and also captures flow near the trailing.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