CFD-based numerical analysis of the aerodynamic effects of a Taper wing at different taper ratio

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Abstract - *Wing design is the crucial challenges for a designer during the aircraft design process. Therefore, in order to get an effective wing geometry that complies with the design requirements, a designer must optimise a large number of wing geometrical characteristics. One of these characteristics is the taper ratio, which is the ratio of a wing's root chord to tip chord lengths. In this study, the taper ratio of an aircraft wing was explored numerically in terms of induced drag and lift coefficients by computational fluid dynamics programme. At the start of the analyses, the program's mesh reliability was evaluated. Later, the updated versions of the wings with taper ratios ranging from 0.4 to 0.8 (with a 0.2 increment) were evaluated in order to observe the impacts of taper ratio on* C_L, C_D, *L/D of aircraft wing. In the context of the results of the analysis, the computed aerodynamic characteristics and lift distributions of wings with various taper ratios were compared. Additionally, the sizes of the tip vortices on each wing were measured and compared.*

Key Words: CFD, taper wing, taper ratio, Lift to drag ratio

1. INTRODUCTION

In recent years, research on how to reduce drag on wing surfaces while using aerodynamic engineering technologies has gained international attention. Therefore, various taper ratios are frequently tried in an effort to reduce the drag in order to increase the airfoil's working efficiency. Taper ratio It is defined as the ratio of root chord length to tip chord length The lift and drag force can be given as,

Lift Force, $FL = C_L \times 0.5 \rho A\, v^2$

Drag Force, $FD = C_D \times 0.5 \rho A\, v^2$

lift coefficient (C_L)

Drag coefficient (C_D)

Surface Area (A)

Free stream velocity (V)

Density of Air (**ρ**)

Ahluwalia and others, this study concentrated on the wing aerodynamic characteristics in low subsonic flow, both with and without winglets. The NACA 653-218 profile was used for four variations elliptical, semi-circular, and straight winglets. Utilizing the Spallart-Allmarus model are used as turbulence model. The CFD simulation was done at 8° angle of attack and a V = 40 m/s, yielding an approximate Reynolds number (Re) of 327931. The NACA six-digit number 653218 was used to create the similar profile for the wing and winglet in Solid Works. In every instance, the semi-wing span and chord were set at 330 mm and 121 mm, respectively. The study finds that elliptical winglets, followed by semi-circular and straight winglets, provide the best balance of maximum lift and minimum drag [1].

Bergmann et al, Numerical or experimental evaluations can be used to determine how the taper ratio affects the parameters of the wing's aerodynamics. It may be advantageous to employ computational fluid dynamics software while in conceptual design phase of an aeroplane rather than time-consuming wind tunnel setups. There are numerous tools available to carry out these assessments, including Solidworks Flow Simulation, XFLR5, and Ansys Fluent [2].

Zhang et al, the goal of this experimental analysis at Beijing University of Aeronautics and Astronautics' low-speed wind tunnel was to examine the impacts of delta wings' taper ratio on their aerodynamic performance. The study analyses delta wing models with a Re= 3.45×10^5 and geometrically variable taper ratios. A root chord length of 200 mm were employed in this study's investigation. According to the analysis' findings, wings with taper ratios less than 0.3. Additionally, it was discovered that the delta-wing the stall angle, maximum taper ratio, and the range between 0.3 and 0.68 Lift rises as the taper ratio decreases, peaking at 0.725 taper ratio. Also discovered were consistent potential C_L = 2.3 and C_D =0.3 in the wings with taper ratios less than 0.5. When taper ratio exceeds 0.5, Kp was seen to drop rapidly with greater taper ratio. Additionally, this adjustment was divided into two possibilities for aspect ratios, ranging from 0.56 to 4.77 and 0.5 to 2.38, respectively. According to analysis findings, all cropped delta wings were found to have less drag than non-cropped ones at low angles of attack at the taper ratio range of 0 to 0.3. It was discovered that the maximum CL increases and the stall angle of the wing delays at taper ratios between 0.3 and 0.79 [3].

Hariyadi SP. et al., Numerical research conducted on the tips of the NACA 23018 airfoil wings, blended winglets were examined. A V= 40 m/s or Re = 1×10^6 is used together with angles of attack of 0, 5, 10, and 15. When analysing a parameter, the coefficient pressure (Cp), velocity profile, lift, drag, and ratio C_L/C_D are all taken into account. The obtained contours are the pressure contour, velocity, and vorticity. In light of all of this, the C_L/C_D ratio is enhancing the aerodynamic performance of wings with blended winglets and plain wings [4].

Manikantissar, in this study, the notional delta-wing aircraft model was examined in terms of its subsonic speed, AOA, C_D, C_L, stall angle, and turbulences. The outcome would determine whether it may be used by UAV drones, commercial aircraft, and fighter jets. Computational fluid dynamics and the programme ANSYS CFX are both utilised to analyse the issue. the computational flow past the delta-wing cross section with aspect ratio show physically possible flow filed demonstrated by surface pressure distribution the F_D and F_L is generated by aircraft is computed with taper ratio 0.125 and 0.4 and analysed if taper ratio 0.125 stall angle is 18° and when taper ratio 0.4 then stall angle at 15° [5].

Wang et al, in this work using numerical simulation to compare the smooth surface and the textured surface in this work Discovered that the textured airfoil can significantly reduce the C_D and improve the C_L [6].

Kumar, the idea of morphing winglets is presented and investigated using a CFD-aided analysis. In cruise flying, three different configurations are studied computationally. winglet cant under different attack angles and situations the morphing parameter is angle. The arrangements are compared for aerodynamic effectiveness to establish the optimum configuration for each pre-defined flight of the BWB mission segments. Then, the top configuration is contrasted with the starting point. arrangement to gauge aerodynamic efficiency advantages to the morphing winglet concept. Findings reveal that the drag winglet reduces coefficient at a high AOA arrangement that improves the L/D ratio as well [7].

2. Modeling

2.1 Design

Modelling of a wing is done on solidworks different wing model is shown in Fig.1. to Fig.5. The wingspan and root chord is L= 330mm and C=120mm respectively and tip chord is change according to taper ratios the wing with different taper ratio is shown in fig. and important wing terminology and dimensions of wing is shown in Fig. 7. Fluid domain dimensions is 660mm×360mm×600mm is shown in figure 3.

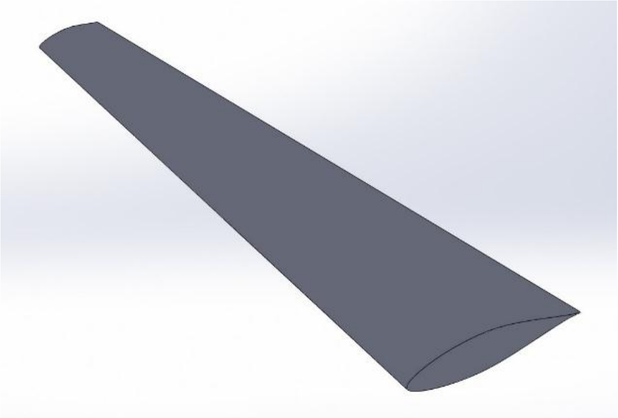


Fig -1: Wing with different taper ratio 0.4

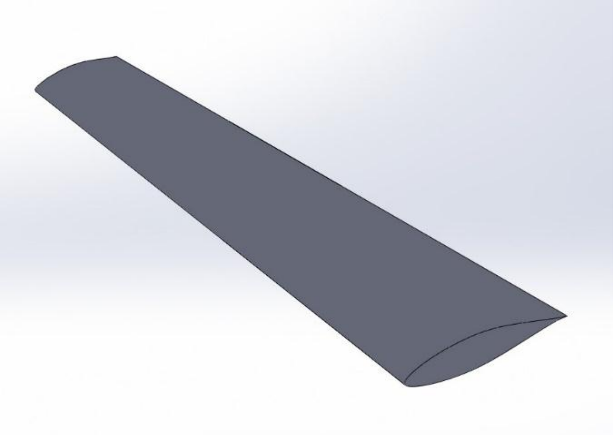


Fig -2: Wing with taper ratio 0.5

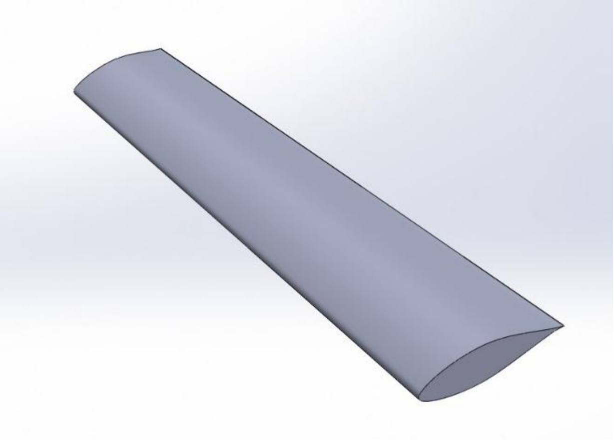


Fig -3: Wing with taper ratio 0.6

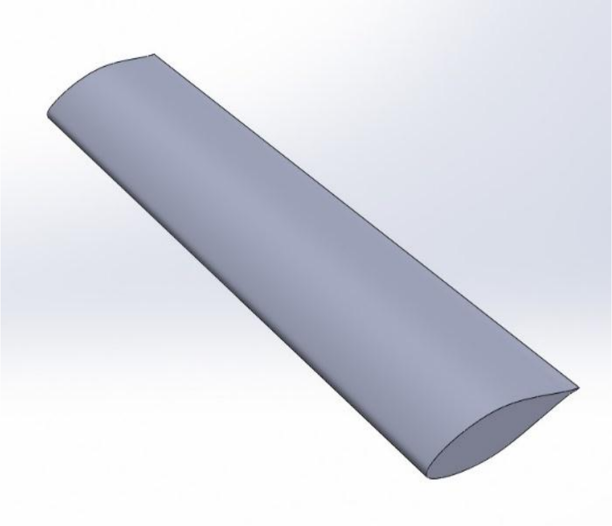


Fig -4: Wing with taper ratio 0.7

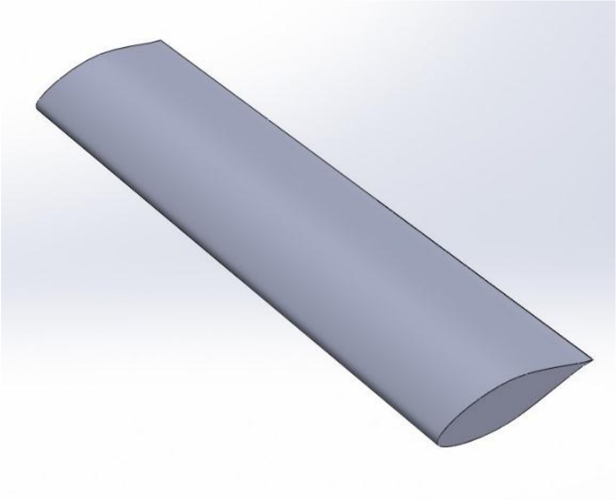


Fig -5: Wing with taper ratio 0.8

Fig -6: Top view of Wing

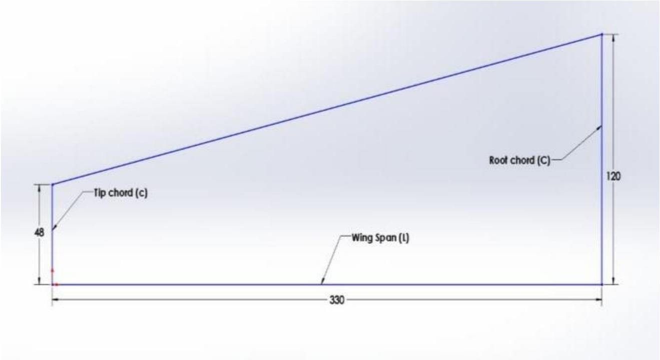


Fig -7: Top view of wing with dimensions in mm

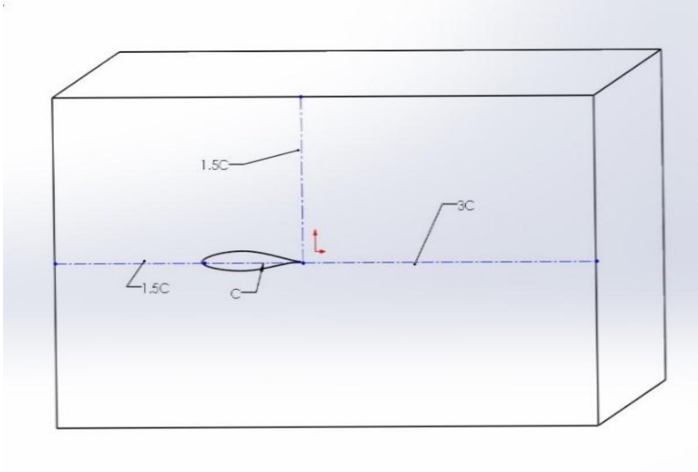


Fig -8: Computational domain

2.2 Meshed Model

Mesh creation is the next stage after the model has been prepared for analysis of various wing configurations is shown in Fig. 8. Edge sizing, face sizing, and the tetrahedron path conforming approach, which approximate 100000 nodes and 3000000 elements for each computational analysis after the performing the grid independency test, it should be used in the analysis to produce a more refined mesh. While using more cells often results in a more accurate numerical solution, doing so also requires more computer memory and longer computation times. five different mesh types were produced in order to investigate the results' independence from cell number. Variation drag coefficient with no of element shown in chart -1. respectively. Displays the results of these five meshes for the C_L and C_D with the number of cells at an 8° AOA in a taper wing. The time for 500000 was almost 1 hour, while the time for 3000000 was roughly 3 to 4 hours.

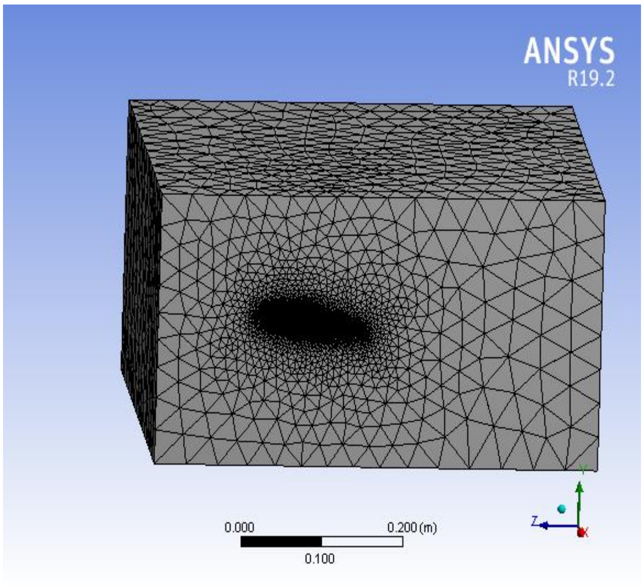


Fig -8: Meshing

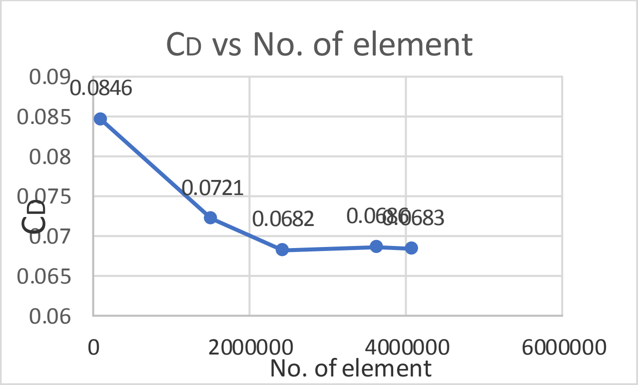


Chart -1: Variation of CD vs no of element

2.3 Methodology

At a freestream velocity of 40 m/s, the computations were completed, yielding a Reynolds number of approximately 327931.As depicted in Fig.-9, the flow region is made up of 4 limits that form a rectangular shape is shown in Fig-9 and Table-2. Boundary circumstances are in order to complete the calculations, the Spallart-Allmarus model was used. Following properties are used for computational study

Density -1.2225 kg/m^3

Viscosity-1.7894e-05 kg/m-s

Pressure-101325 Pa

Velocity-40 m/s

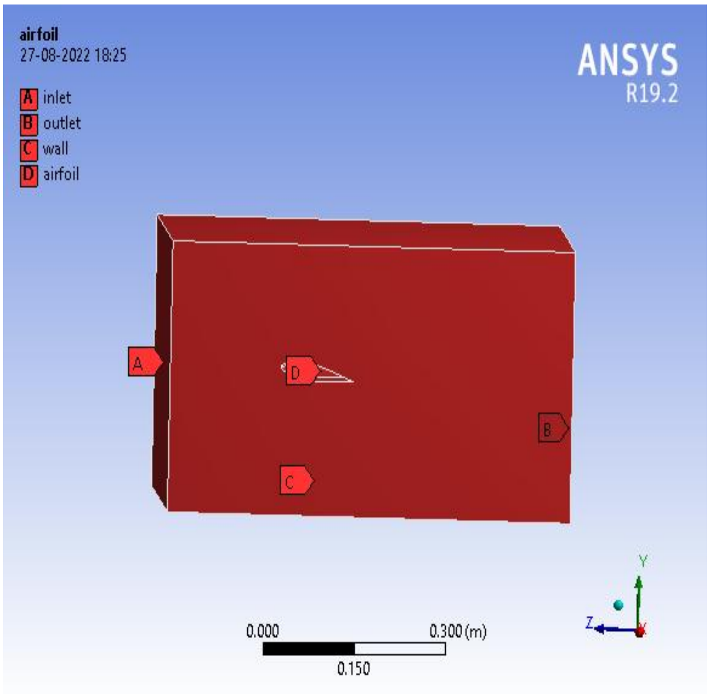


Fig -9: Boundary conditions

3.Comparsion with previous data

By comparing the current results to those from other studies, the CL, CD, and L/D ratio are all validated. Table 1. When compared to data given by Ahluwalia et al. [1], the CD and CL measured in the current study fits their findings rather well, is a study of a NACA 653-218 aerofoil with a straight wing and a straight wing with winglets at an 8° AOA and 40 m/s free stream velocity.

Table -1: Comparison of over a wing's lift, drag, and lift to drag ratios with previously reported findings

Author	Wing type	Mach No.	CL	CD
Ahluwalia et al. (2017)	Rectangular	0.1	0.5121	0.0653
Present	Taper	0.1	0.7077	0.0691

4. Results

A number of analyses have been done on various wing models in order to determine the efficiency of the wing by comparing CL, CD, L/D. Wing models with taper ratio 0.4, 0.5, 0.6, 0.7 and 0.8 at an angle of attack of 8° are evaluated using a flow velocity of 0.1 Mach. The CL and CD were calculated using the analysis's results for the lift and drag forces operating on the wing profile. The CL CD L/D is obtained by computational analysis is shown in Table-2 and plotted in Charts – 1,2 & 3.

Table -2: C_L, C_D and L/D at different taper ratio

Taper ratio	C_L	C_D	L/D
0.4	0.7077	0.0691	10.232
0.5	0.6929	0.0702	9.870
0.6	0.6804	0.0713	9.537
0.7	0.6751	0.0721	9.222
0.8	0.6502	0.0732	8.882

Chart -2: Variation of C_L vs taper ratio

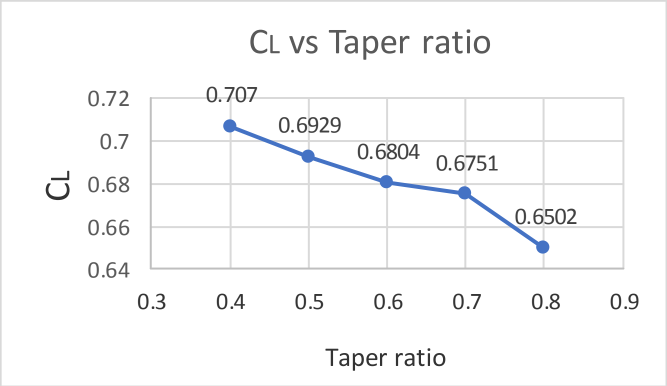


Chart -3: Variation of C_D vs taper ratio

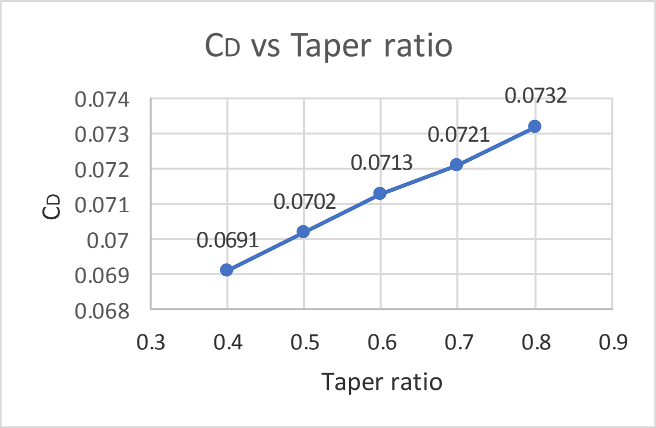
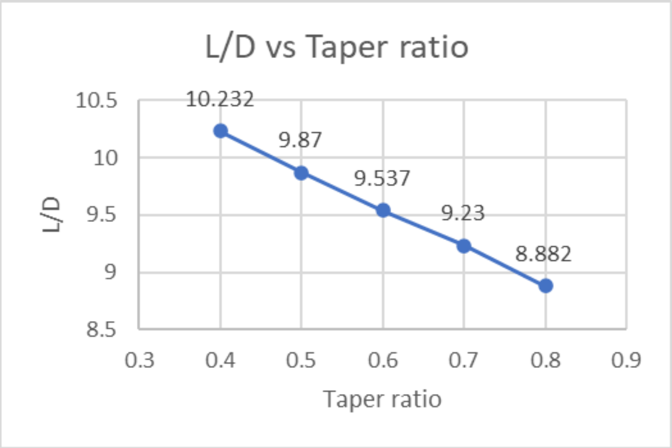


Chart -4: Variation of L/D vs taper ratio



5. Pressure Contour

Contours of the upper static pressure for the Wing in Fig.10 to Fig.-14. it is were forecasted for Wing at various taper ratios at 8° AOA. The Top surface is having a lower static pressure then bottom surface. As the taper ratio falls, the pressure losses that result from it also fall, making the pressure more uniform and reducing drag. The high intensity blue area on the top surface having a minimum static pressure and bottom surface red region is maximum static pressure this pressure gradient is responsible for lift generation.

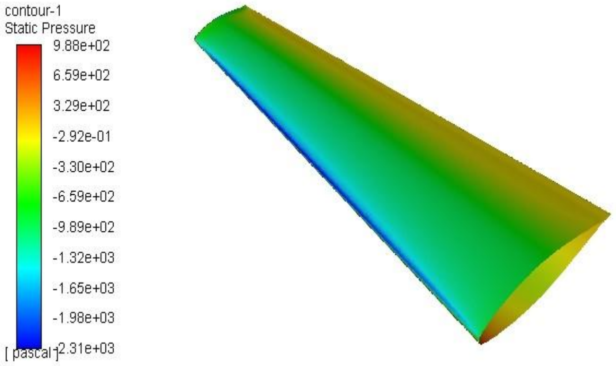


Fig -10: Pressure contour of wing with taper ratio 0.4

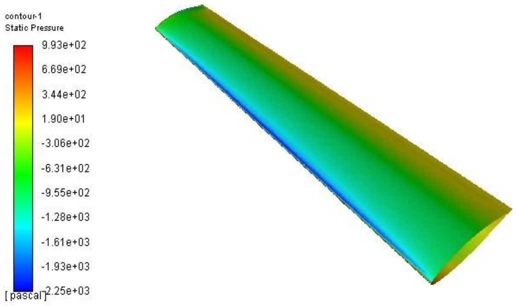


Fig -11: Pressure contour of wing with taper ratio 0.5

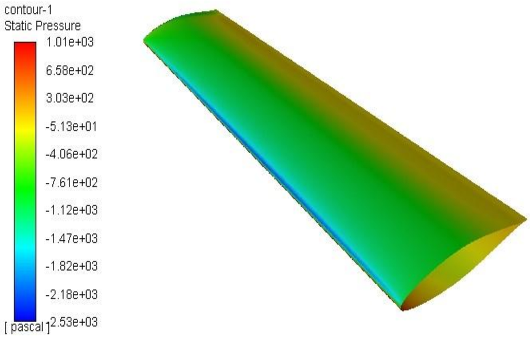


Fig -12: Pressure contour of wing with taper ratio 0.6

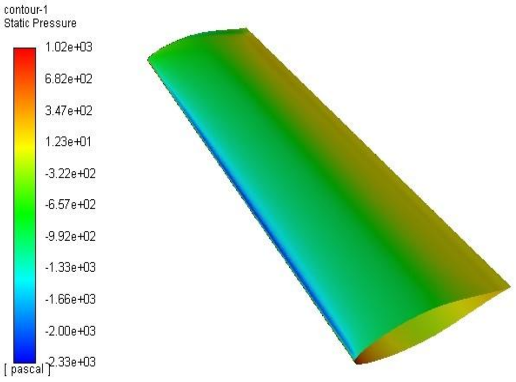


Fig -13: Pressure contour of wing with taper ratio 0.7

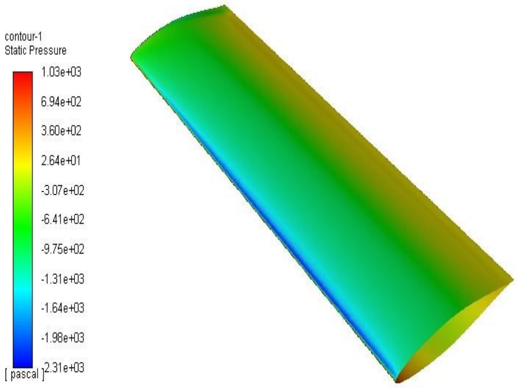


Fig -14: Pressure contour of wing with taper ratio 0.8

6. Path-line

The vortex generation of the path-line in the tapered wing was caused by the pressure gradient between the top and bottom surfaces of the wing. When the taper ratio was lowered, the pressure difference increased, which in turn caused the vortex and wing drag to increase. As expected, the wing only exhibits a single sizable vortex at the wingtip. It is simple to deduce the rotation sense from the path-line. This demonstrates that fluid effectively has a strong inclination to move from lower to upper surfaces. Path-line vortex is shown in Fig.15 and Fig.16.

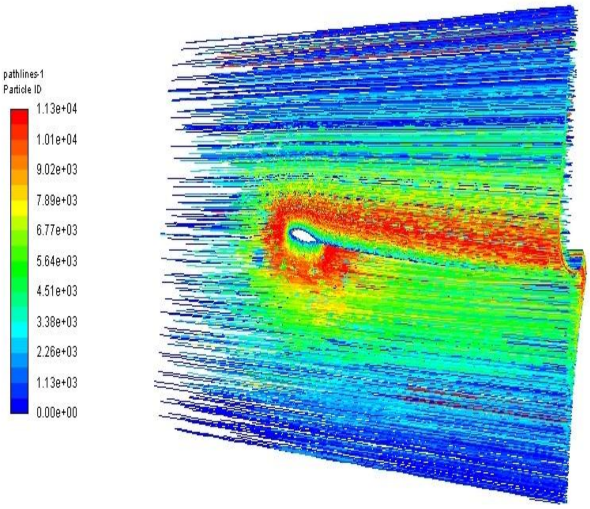


Fig -15: Path- lines behind the wing

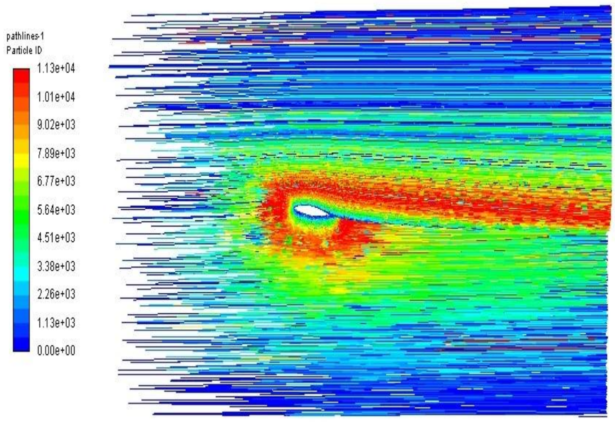


Fig -16: Path- lines on the wing

7. CONCLUSIONS

In this work, several taper ratios were numerically analysed with the intention of examining the impacts of taper ratio on aerodynamic characteristics of wing. A rectangular wing model was modified into five different versions with different taper ratios at the same aspect ratio and root chord in order to compare their aerodynamic properties. Following the evaluation of the program's mesh accuracy, the induced drag and lift coefficients along with the span-wise lift distribution were examined for all the models with taper ratios between 0.4 and 0.8 (with an increment of 0.2). This work showed that as the L/D ratio increased and drag decreased along with the decreasing taper ratio, if drag will be reduced it is favour to less fuel consumption.

REFERENCES

[1] Shivam Kapil Ahluwalia, Vaibhav Negi, Nayan Anand, Varun Goyal, Raj Kumar Singh. “CFD Analysis on Different Shapes of winglet at Low Subsonic Flow”.2017.

[2] Bergmann, A., Huebner, A., and Loeser, T. (2008). “Experimental and numerical research on the aerodynamics of unsteady moving aircraft”. Progress in Aerospace Sciences, 2008. 44(2): p. 121-13. Doi:10.1016/j.paerosci.2007.10.0

[3] Zhang, P. F., Wang, J. J., Liu, Y., Wu, Z. (2009). “Effect of taper ratio on aerodynamic performance of cropped nonslender delta wings”. Journal of Aircraft, 46(1), 320-325.

[4] Setyo Hariyadi S.P, “An analysis on Aerodynamics Performance Simulation of NACA 23018 Airfoil Wings on Cant Angles”, Journal of Energy, Mechanical, Material, and Manufacturing Engineering 2017.

[5] Manikantissar, Dr.Ankur geete. CFD Analysis of conceptual Aircraft body

[6] Xiao Yu Wang, Sooyoung Lee, Pilkee Kim and Jongwon Seok. “Aerodynamic effect of 3d pattern on airfoil” ICETI-2014 J1031_SCI No. 15-CSME-31, E.I.C. Accession 3806

[7] Swarna Mayuri Kumar. “Aerodynamic Design and Analysis of a Blended Wing Body UAV Configuration”. International Journal of Engineering Research & Technology 2022

[8] John D. Anderson, Jr., “Fundamentals of computational Fluid Dynamics”, McGraw Hill International Editions.