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Comparative Aerodynamic Analysis of Different Wing Configurations

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Abstract: Wing is a structure made up of aerofoils which generates lift so that the aircraft can fly. In this paper we will see some analyses of different wing configurations mainly rectangular wing, tapered wing and swept back wing. An analytical software has been used to perform analyses. This paper focuses on the comparative study of aerodynamic characteristics like stall angle, lift to drag ratio, downwash, lift distribution along the wing span of different wing configurations.
Keywords: Rectangular wing, Tapered wing, Swept back wing, Prandtl lifting-line theory, Aerodynamic characteristics

I. INTRODUCTION

Wings are found in different shapes and configurations depending on the requirements. Wing shape and configuration plays a major role in producing lift need for the aircraft to fly [5]. Proper combination of aerofoil and wing shape and configuration results in good aerodynamic performance of the aircraft [1]. Some wings like rectangular, tapered and swept back wings are frequently used for aircrafts basically in non-combat aircrafts. Discussing about rectangular wing, it is that the form of wing planform in which the root chord and the tip chord length are identical. The rectangular or constant chord wing is generally found on low-subsonic aircrafts [3]. In rectangular wing, pressure due to ground effect results in strong wing-tip. Also factor causing an increase in drag is the induced drag due to lift itself which results as one of the drawbacks [4]. Advantage of using rectangular wing is that it has better stall angle than other types. Also it easy to manufacture. Rectangular wings can be seen in low speed small aircrafts like Piper pa-38. Now talking about tapered wing, it basically a modified rectangular wing with tip chord smaller than the root chord. This type of wing can be seen in aircrafts like P-51 Mustang. A swept wing is a type of wing whose leading edge is swept backward at certain angle. Swept wings are widely used in commercial aircraft at transonic speed because of comparatively less drag than straight wings at transonic speed condition [2]. To attain higher critical Mach speed, Trainer aircraft prefers swept wings. Swept wings preferred because of its low drag at transonic speed. This kind of wing configuration can be seen in most of the modern commercial aircrafts like Boeing 787 Dreamliner.

A. Symbols and Acronyms

Cl-coefficient of lift
Cd-coefficient of drag
ar-aspect ratio
Re-Reynolds number
α- alpha
S-Projected Surface area
v- Velocity

II. METHODOLOGY

Appropriate aerofoil was selected for the analysis and same aerofoil was used in all wing configurations namely rectangle wing, tapered wing and swept back wing. The tail and boom length dimensions was kept constant in all the analyses and same tail configuration was used (conventional tail). Lift depends on various factors, basically velocity, density of air, coefficient of lift, area of the wing and also shape of the wing. For analysis of aerodynamic characteristics of different wing shape, the parameters like velocity, density of air, area of wing has been kept constant. Analyses were performed in an analytical software and various aerodynamic parameters were compared. All the analyses were performed in the same range of parameters.

Lift(L)=$1/2*\rho*v^2*Cl*S$; velocity is kept constant for all the analyses at 10 m/s and analyses were performed to observe the influence of shape and configuration of the wing in lift generation.

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III.ANALYSIS

For performing the analysis same aerofoil S1223.rtl have been used for all the configurations. Depending on the surrounding environment, the Re was taken less than 500,000. The analysis was performed on a small scale aircraft. The velocity taken for analyses was 10m/s.

1) *Downwash:* It is basically the air flow deflected downward by the wing which helps in producing lift. The Cl for rectangular wing is 0.813, for tapered wing is 0.952 and for swept back wing is 0.902 at 0º angle of attack. The aspect ratio for rectangle wing is 4.762, tapered wing is 8.254 and swept back wing is 8.250. Downwash can be calculated using a basic formula;

Downwash(degrees)=(36.5*Cl)/(ar)

The downwash value for rectangle wing is 6.231º, for tapered wing is 4.209º, and for swept back wing is 3.990º.

2) *Lift Distribution:* The lift distribution along the wing can be visualize by the life distribution line or Prandtl lifting-line. For ideal lift distribution the lift-line should trace an elliptical path which can be seen in an elliptical wing.

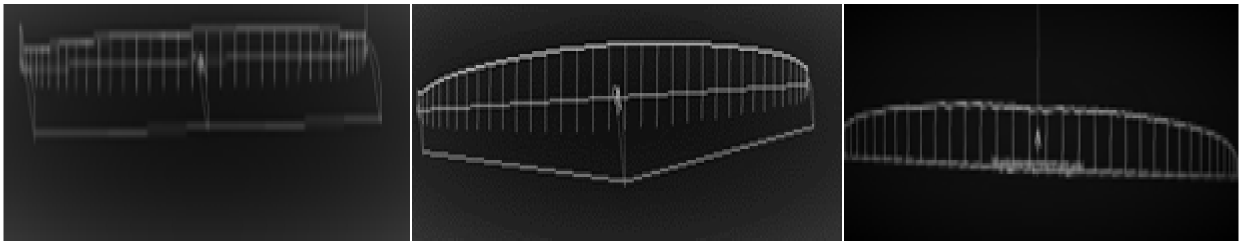

Fig.1 Lift-distribution Line in Rectangular, Tapered and Swept Back Wings

3) *Cl/Cd vs Alpha plot:* The Cl/Cd vs α graph shows the relation of lift-drag ratio with angle of attack. The Y-axis represents Cl/Cd ratio and X-axis represents alpha(α) or angle of attack. The Cl/Cd ratio also depicts the efficiency of the aerofoil. Aircraft is said to be more efficient if the lift-drag ratio is maximum. At a particular angle of attack, the lift-drag ratio is maximum. Usually at a steady flight the Cl/Cd ratio is maximum. The glide ratio and gliding range of an aircraft also depends on the Cl/Cd ratio as because the glide ratio depends on the aerodynamic forces acting on the aircraft. The weight of the aircraft does not affect the glide ratio and gliding range. Proper aerofoil selection and wing geometry helps to obtain appropriate lift-drag ratio.

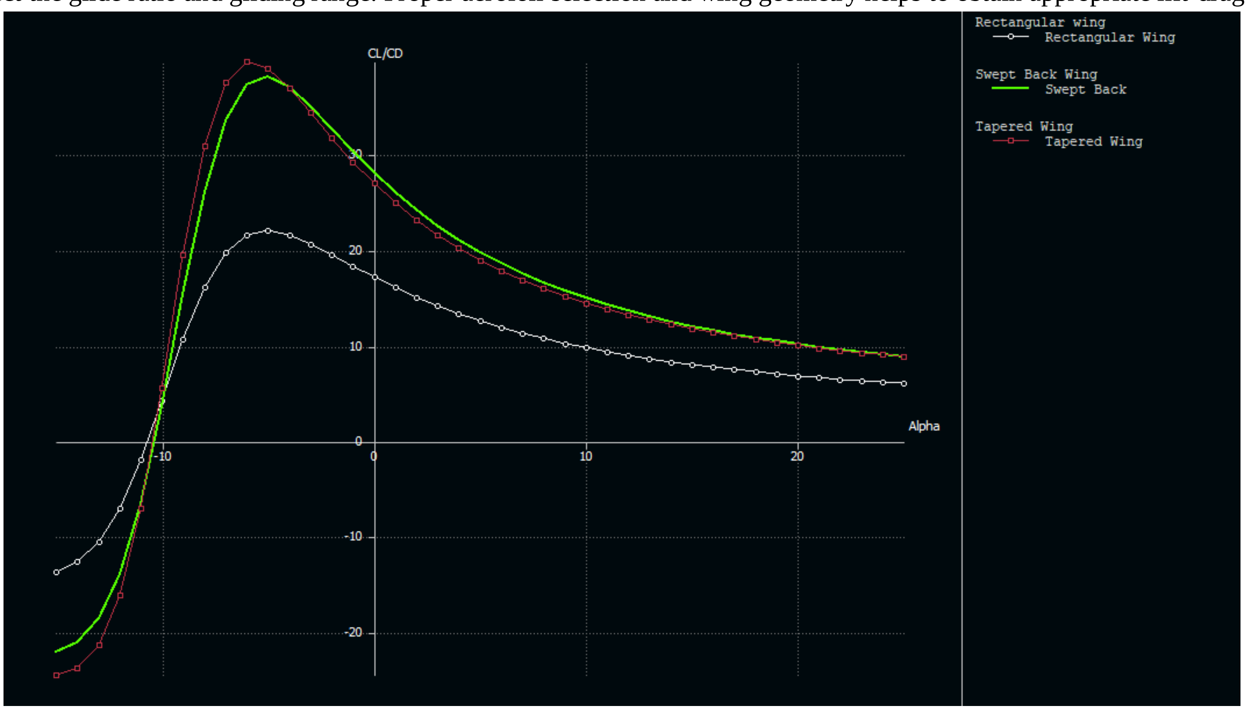

Fig.2 Cl/Cd vs Alpha

4) *Cl vs Cd plot:* This graph shows the variation of Cl with respect to Cd during the change in angle of attack. This is also known as drag polar. Initially Cl and Cd both increases because due to increase in angle of attack and follows a parabolic curve. Cd increases due to lift induced drag. This graph shows how Cl varies for the same amount of drag in three wings, rectangular, tapered and swept back wings.

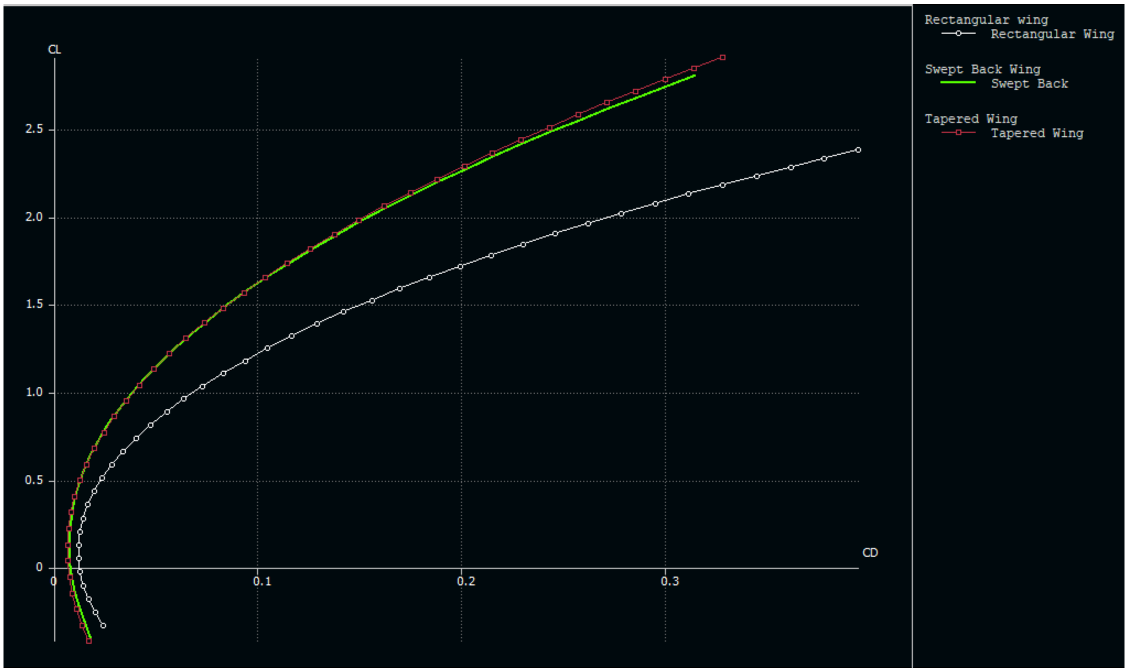

Fig.3 Cl vs Cd

5) *Cl-alpha plot:* First of all, the main significance of the graph is to determine the stall angle. Stall angle is basically the critical angle of attack at which lift coefficient is maximum. After this angle, the drag drastically increases and Cl decreases significantly by which plane becomes highly unstable. The instability is due to flow separation on the wing surface by which there is no lift generation. Due to increase in drag, speed also drastically gets reduced. In this graph X-axis is denoted by alpha and Y-axis is denoted by Cl. We can clearly see there is a point on curve where Cl is maximum. That correspondence alpha is basically the stall angle. Proper aerofoil selection and wing shape, according to the requirements, yields appropriate stall angle.

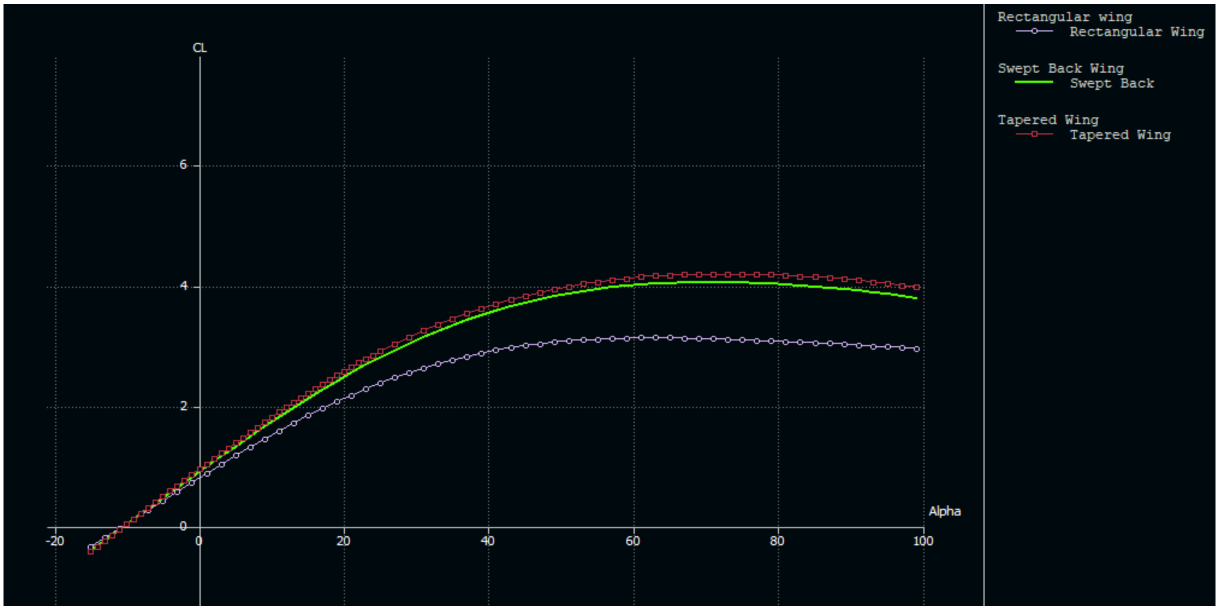

Fig.4 Cl vs Alpha

IV. RESULT AND DISCUSSION

From the above analyses we can make some conclusion about rectangular, tapered and swept back wings. First of all, talking about Prandtl Lift-line distribution of the three wings in Fig.1, in rectangular wing the lift distribution at the tip of the wing is high and thus cause induce drag and in tapered and swept back wing the lift distribution is almost same but in tapered wing the lift at the centre point of the wing is quite high and keeps decreasing gradually. In swept back wing the lift remains high at the centre point of the wing and also in either side of the centre maintains constant height till some extent and then gradually decrease. In Fig.2 we can see the Cl/Cd is high for the swept back wing at 0º angle of attack i.e., at steady flight compared to other wings which means swept back wing has good glide ratio. The Cl vs Cd graph showed that for tapered and swept back wings the curve is almost same. The Cl generated by tapered and swept wings is more than rectangular wing for the same amount of drag. The stall angle for rectangular, tapered and swept back wings was found as 63º,73º and 71º in the above analyse.

The swept back shape of the wing helps to move through the air very easily than other wing shapes also the tip chord of swept and tapered wings being small in length, the wingtip vortex is also less as compared to rectangular wing, hence less drag. We observed that swept wing has more benefits then tapered and rectangular wings and also in high speed flight swept wing has more advantages than other wing shapes. Hence in modern aircrafts swept back wings are used more than other types of wings.

V. CONCLUSION

From the above analyses we have observed different aerodynamic characteristics of different wings and also seen their advantages. Due to change in aircraft shape, size and operations different wings are being used as per the requirement. We get to see why most fast cruising aircraft use swept back wing and some small aircrafts use rectangular and tapered wings. In the above paper we get to know why they are preferred and why the use of tapered and swept back wings are preferred more now-a- days. As they have more benefits then other types of wings.

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