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NUMERICAL STUDY ON STABILITY OF OBLIQUE WING CONFIGURATION

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ABSTRACT: Oblique wing is one of the morphing wing configurations that offer a superior high speed aerodynamic performance. The mechanism in which a straight wing is being rotated by a pivot at the centre resulting swept back wing on one side and swept forward on the other side. It was proven that this configuration was able to reduce drag for a given lift at both supersonic cruise and subsonic; however, there are serious control issues. CFD analysis using SolidWorks software was performed to study and visualize the aerodynamic performance of an oblique wing for a high sweep angle. The results obtained were later used to compare with other swept configurations on its stability and control.

KEYWORDS: *Aerodynamics; Oblique wing; Asymmetric sweep; CFD; Stability*

1. INTRODUCTION

Modern-day high-speed aircraft are made of morphing wings to achieve high aerodynamic efficiency in all phases of flight. A morphing geometry wing is an aeroplane wing that can be adjusted during flight or on the ground. This configuration can provide aerodynamic advantages to an aircraft under low-speed and high speed conditions through the straight wing and swept wing respectively. During subsonic flight, a high aspect ratio wing is desired due to the fact that induced drag is inversely proportional to aspect ratio; however, during supersonic, drag is dominated by wave drag. Variable sweep and Oblique Wing aircraft are classes of aircraft that adopt such morphing wing concepts to achieve high aerodynamic efficiency.

The first oblique wing design was the Blohm and Voss P-202, designed in Germany by Richard Vogt in 1942 Hirschberg et al. [1]. Jones, the father of delta and swept wing proposed oblique wing as an alternative in his research papers during 1950s [2-3]. He proved analytically that at any flight Mach number, the minimum drag for a given lift could be achieved by an oblique swept wing with an elliptical planform. Jones proved that oblique wing configuration can minimize wave drag and induced drag with an elliptical lift distribution. For equivalent span, sweep and volume they distribute lift twice the length of conventional swept wing configuration during supersonic. This reduces wave drag by factor of 4 and volume dependent wave drag by a factor of 16. Jones also proved that the induced drag of an oblique wing at optimal sweep angle is half that of the delta wing with same span.

Kroo [4] later proved through wind tunnel experiment, oblique wings are very effective at reducing wave drag at supersonic flight. whereas years later, oblique wing configuration was rejected due to their control issue and flight complexity [1].

The desired feature of variable geometry wing aircraft is to maximize aerodynamics performances over wide range of Mach Numbers [5]. Comparing to the present Grumman F-14 Tomcat, additional masses are added for secondary system for variable wings of the aircraft, it emphasizes that, single pivot oblique wing is structurally advantageous compared to conventional swept wing and variable swept wing. For symmetric swept wing, the presence of bending moment results in additional mass of materials for the design. A straight through structure of oblique wing however does not experience bending moments, at the same time it is able to avoid torques by fuselage structure and it is easy to manufacture [5]. It was concluded that the majority of the wave drag advantages of the oblique wing are handicapped by the dominant volume wave drag of the fuselage, which lead to the idea of Flying Oblique Wing [5].

Stability and control of an oblique wing is complex and often discussed as its disadvantage. Bruce Larrimer [6] reported that, the NASA AD-1 pilots concluded that at or below sweep of 30°, the handling quality is satisfactory. Between 30° to 45°, the grade of handling quality decrease and worst control is at 45° to 60°. The evaluation is categorized in directional stability (yaw stability), unusual trim requirements, roll-pitch couplings, dynamic by aeroelastics and stall.

Kempel et al. [7] performed F-8 oblique research aircraft and they noted in general, as dynamic pressure and sweep angle increase, pilot ratings degraded. They noticed that in open-loop configuration (control system) there was significant pitch-to-roll coupling and an unacceptable amount of pitch-to-banking force coupling. At high dynamic pressure, a pilot described the pitching responses as “scary”.

At low sweep angles, an oblique wing aircraft can be controlled as conventional swept wing aircraft. Campbell et al. [8] noted that at sweep angles above 60°, ailerons become unsatisfactorily weak, and he theorized that aileron rolling effectiveness wasn’t reduced by skewing wing from 0° to 40° because damping in roll decreased approximately the same amount as aileron rolling moments.

Mushfiqul and Kashyapa [9] as well as Asif Shahriar et al [10] performed a numerical analysis of aerodynamic forces on an oblique wing, Wang et al [11] performed the dynamic characteristics analysis and flight control design for oblique wing aircraft. Recently Josuha [12] studied the effects of a bell shaped lift distribution on an Oblique flying wing and its impact on aerodynamic performance.

It can be noted that oblique wing has many advantages whereas it is found out that sweeping more than 45° causes instability and rolling control issue for the light aircraft. Most of the work carried out is on experimental, with the availability of modern CFD tools, it is easier and more cost effective to perform parametric analysis and to study the aerodynamic characteristics. In this work, the aerodynamic characteristics and hence the stability of an oblique wing is studied using SolidWorks CFD software and compared with the other swept wing configurations.

2. MODELLING AND SIMULATION

SolidWorks software was selected for CFD analysis to study the stability of the oblique wing. In this work, wing-only geometry stability was analysed by checking the six degree of freedom force/moment components (L, D, Z, M_x, M_y, M_z) of the wing at certain incoming air speed. As the objective of the work is to compare the stability of oblique wing with the other available wing configurations, SolidWorks modelling tool was used to model three different wing configurations viz. Swept forward, swept back and oblique wing-only geometry as shown in Fig. 1. NACA 64(2)-415 was chosen as the wing section for all three configurations.

Ideal wall assumption was applied in the CFD analysis since the surface roughness and material are not defined and this assumption can be advantageous to save computational time. Errors are expected in the CFD analysis especially due to the geometry difference (scaling error), ideal wall assumptions, meshing and scheme (second order).

Fig. 1.1. 60° Oblique Wing

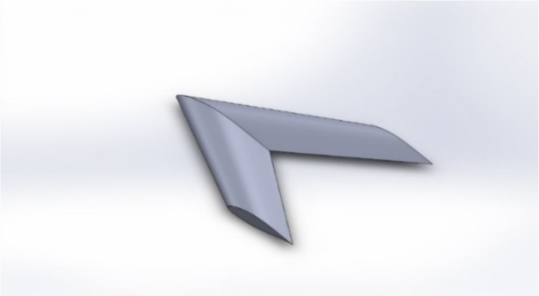


Fig.1.2. 60° Swept Back Wing

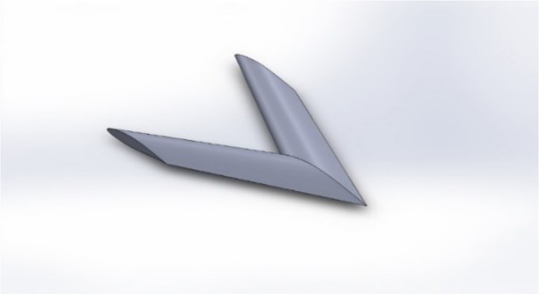


Fig.1.3. 60° Swept Forward Wing

Fig. 1. Geometry of three different swept wing configuration

Flow characteristics for the CFD analysis are listed below in Table 1.

Table 1: Inputs used for CFD analysis.

Parameter	Value
Fluid	Ideal Air
Mach number, M	0.5
Density	1.225 kg/m^3
Pressure	101325 Pa
Temperature	293.2 K
Wall	Ideal wall
Turbulence intensity	0.02%
Turbulence model	k-ω SST model

For meshing, a uniform structured mesh in SolidWorks was used. Although some accuracy penalty is known due to the inclination of incoming flow, it is inferred that it is reliable, and the expected error would be around 20% at most with low order scheme factor included. In SolidWorks, mesh refinement can be done simply by setting up the meshing space and increasing the meshing level of the domain. The figure below illustrates the meshing with that the Dark blue, Aqua and Green coloured region defines the meshing refinement as coarse, medium, and fine mesh region respectively. The medium mesh shown in Fig 2.was selected for analysis so that to balance the accuracy and the computational time.

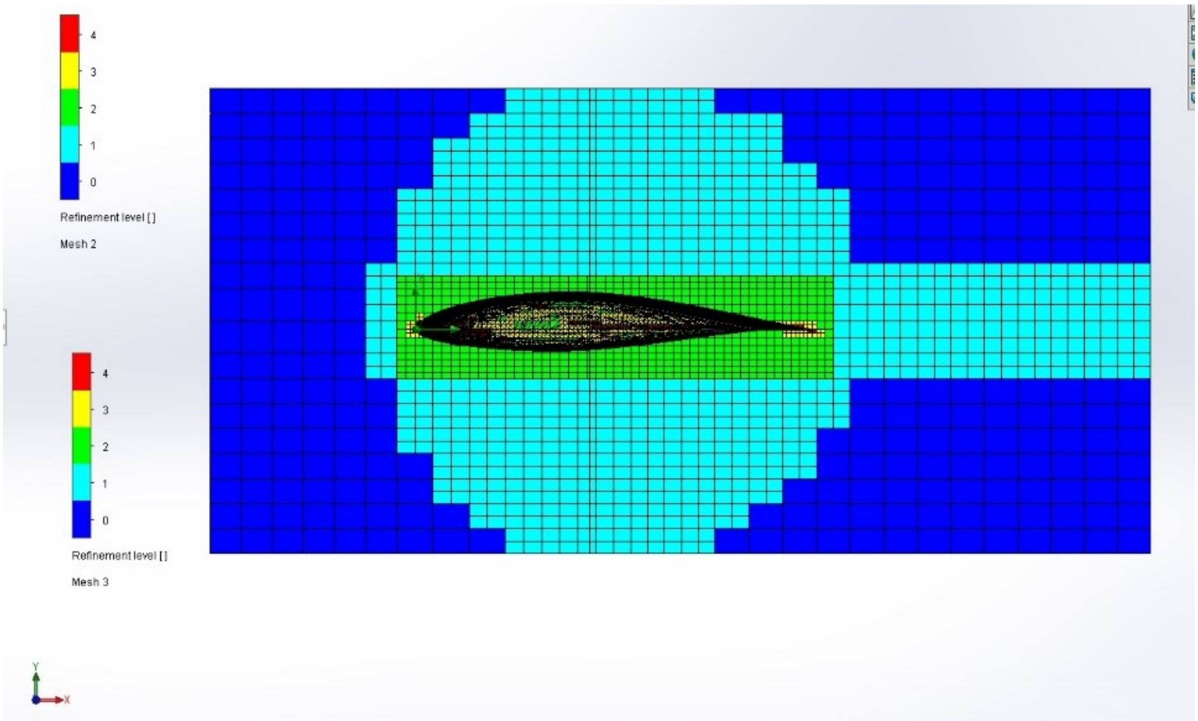


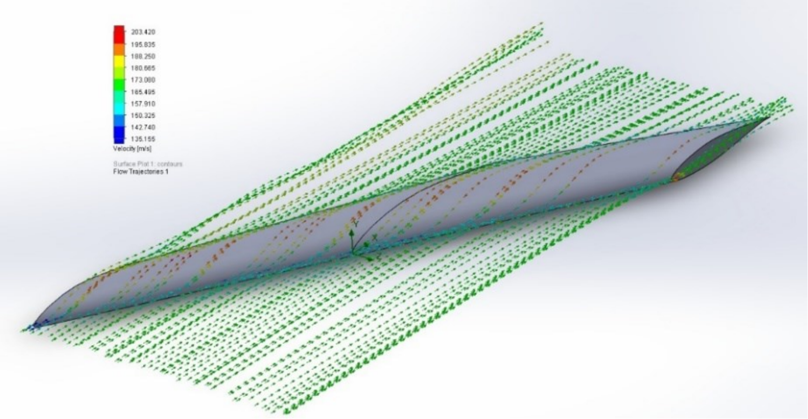
Fig. 2. Structured Medium Mesh

3. RESULTS AND DISCUSSION

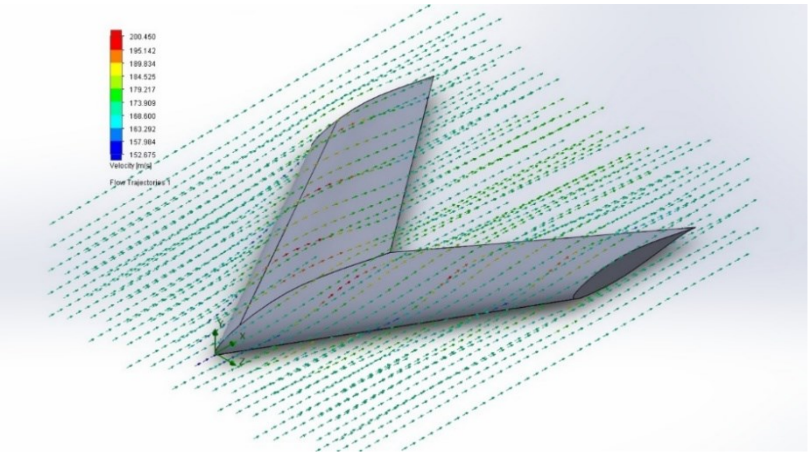
Swept forward, swept back and oblique wing-only geometry stability are to be analyzed for stability by checking six degrees of freedom of force/moment components (L, D, Z, M_x,M_y,M_z) of the wing at a given incoming air speed. In this analysis, three wing configurations of equivalent span and sweep angle (60°) are analyzed with the geometric parameters as defined in Table 1. The objective of the analysis is to monitor, observe and compare forces and moments generated by three different wing configurations. As stated earlier, NACA 64(2)-415 is chosen as the wing section for all configurations.

Table 2: Geometric parameters for different wing configurations

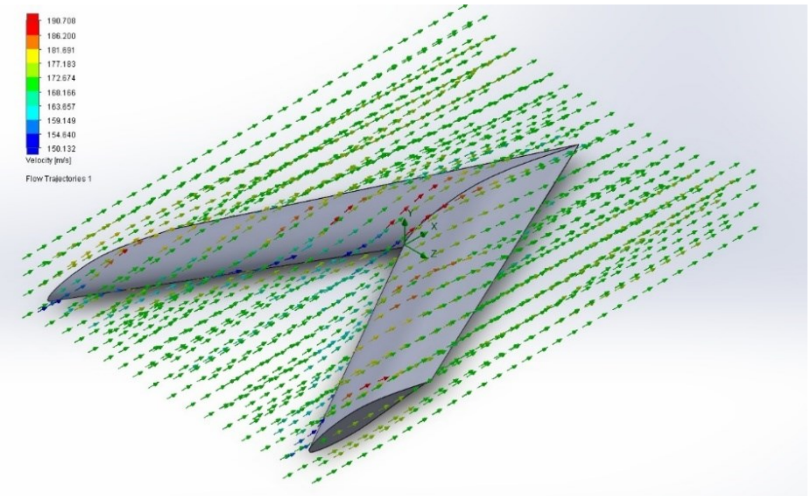
Geometric Parameter	Value
Wing span, b	1.5m
Root chord, C_r	1m
Taper Ratio, λ	0.7
Aspect Ratio, AR	1.7647
Angle of attack, α	0°
Sweep angle, Λ_{LE}	60°



(a) Oblique Wing with 60º angle

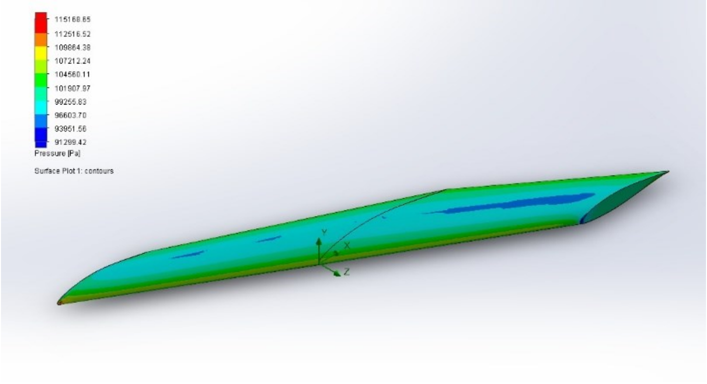


(b) Swept back Wing with 60º Sweep angle

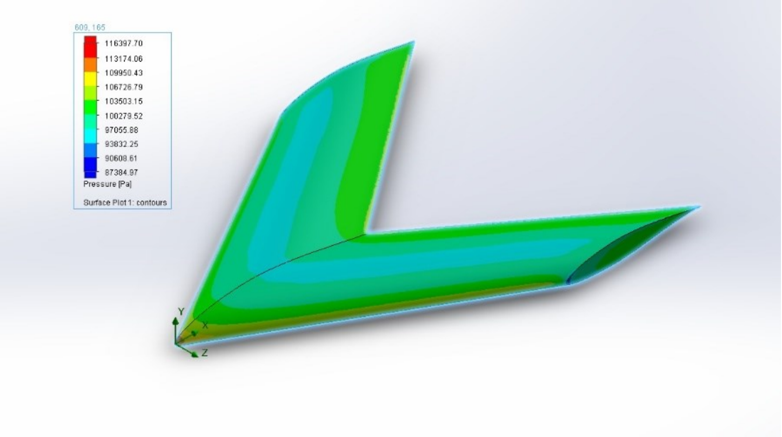


(c) Forward Swept Wing with 60º Sweep angle

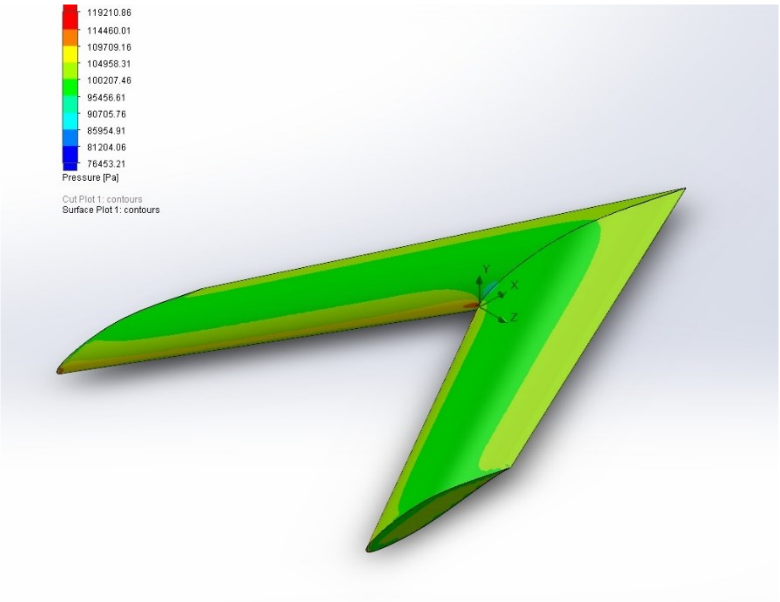
Fig. 3. Velocity Vector plot for three different wing configuration



(a) Oblique Wing with 60° angle



(b) Swept back Wing with 60° Sweep angle



(c) Forward Swept Wing with 60° Sweep angle

Fig. 4. Surface Pressure Contour plot for three different wing configurations

Based on the CFD analysis, Fig. 3 and Fig. 4 shows the velocity contour and the pressure contour plot respectively for all the three wing configurations considered.

CFD results for stability observation is as follows. To simplify the analysis, all six components are equivalent to:-

- *X force = Drag*
- *Y force = Lift*
- *Z force = Sideslip force*
- *Moment about x-axis,* M_x *= Rolling moment*
- *Moment about y-axis,* M_y *= Yawing moment*
- *Moment about z-axis,* M_z*= Pitching moment*

Table 3: Forces and Moments on Different Wing Configurations

Force/Moment	Unit	60° Oblique	60° Swept Back	60° Swept Forward
D	N	83.609	88.041	67.275
L	N	1587.834	1692.756	1005.036
Z	N	-135.722	1.233	-1.526
M_x	N.m	-147.155	2.263	1.56
M_y	N.m	-304.626	-2.282	-1.045
M_z	N.m	1215.06	2164.471	143.634

All six components of forces and moments shown in Table 3 above were all subjected to origin (which is about the root leading edge). The Table 3 shows all six components of forces and moments for all 3 wing configurations considered in this analysis. Firstly, to observe whether the data is qualitatively reliable, the $\frac{L}{D}$ ratio of each of the wing configuration is checked as follows. From the Table 3 we can note that

- Oblique Wing, $\frac{L}{D}$ = 18.9911
- Swept Back, $\frac{L}{D}$ = 19.2269
- Swept Forward, $\frac{L}{D}$ = 14.9392

which is acceptable and within the range of expectation at Mach number = 0.5 for subsonic wing profile and it can be noted that aerodynamic performance of swept forward wing configuration is lower than sweptback wing as reported by Xue et al [13]. Moreover, it can be noted that oblique wing configuration has almost same $\frac{L}{D}$ value as compared to swept back wing which may not be true, it is expected to perform better than sweptback wing, this error may be due to quality of meshing.

It can be seen that for swept forward and swept back configuration sideslip force, Z, moment of x-axis, M_x, and moment of y-axis, M_y have low values of force and moments which can be neglected comparing to oblique wing which has significant value that obviously cannot be neglected. Thus, the oblique wing has a side slip and rotates about both x and y axis at the same time, thus causing serious stability problem making oblique wings highly unstable. The CFD analysis results obtained for high sweep angle of 60° confirms the flight experience reported by the experimental oblique wing aircraft pilots [6], that the flight performance dropped as sweep angle increased and also encountered serious lateral and directional instability. Thus, for high sweep angle at 60°, it can be noted that swept back and forward swept wings are better than oblique wings from the point of view of stability.

All wing configurations pitches as it is expected and known that wing is longitudinally unstable (pitching) which is countered by horizontal tail in complete aircraft. Surprisingly, it can be noted that swept forward wing has the lowest amount of all, followed by oblique wing and swept back respectively.

4. CONCLUSION

The aerodynamic performance and hence stability analysis was carried out for swept forward, swept back and oblique wing-only using SolidWorks software. Aerodynamic efficiency of Oblique wing is compared with other sweptwing configurations. From the present CFD analysis, it can be concluded that the flight performance of oblique wing drops at high sweep angle of 60º coupled with high lateral and directional instability. Thus, for high sweep angle of 60º, it can be noted that the sweptback and forward swept wings are better than oblique wing, as oblique wings are highly unstable. It is one of the prime reasons why oblique wing configuration could not be employed until recently, but the present day modern automatic control system may be able to control such unstable aircraft.

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