Design and Optimization of Sailplane for Static and Dynamic Stability

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Abstract - *The analysis-based optimization of conventional sailplane for the stable design using open source software is presented in this paper. The iterative design process leads to the plane with static and dynamic stability. Stability is major factor considered for the plane to be airborne. Aircraft is designed to stay airborne and need to be controlled. Highly stable aircraft is convinced with the controllability and vice versa.*

***Key Words*: Dutch roll, Dynamic stability, neutral point, sailplane, static margin, static stability.**

1. INTRODUCTION

Sailplane is unpowered aircraft, which uses aerodynamic shape and natural uprising air in the atmosphere to keep in flight. These planes need to be designed with stability to maintain motion in air. In this paper, we tried to design a stable plane. XFLR5 is the open source software used in this research to design and analysis of sailplane and its stability characteristics.

The stability of plane depends on the three main points.

- Centre of Pressure (CP) is the point of the body where the aerodynamic forces acts.
- Centre of Gravity (CG) is the Point at which the moment of the body acts that is purely depend on the distribution of mass only.
- Neutral Point (NP) is the Reference point where the moment of pitch depends on plane external geometry alone.
  - During the situation of CG in front of the NP: Stable flight.
  - During the condition of CG slightly forward of the NP: Stable flight but unstable on slight gust.
  - During CG overlaps with position of NP: Unstable flight.
  - During the CG positioned behind the NP: Stable in reverse position

1.1 Airfoil analysis

The current work consists of XFLR5 software-based analysis of an aircraft model to estimate the stability performance of an aircraft. The following steps have been carried out to understand the Static Stability of an aircraft. The initial step involves conducting a batch analysis for an airfoil type. The following airfoil are used in this aircraft.

- •Clark y
- •MH 45
- •NACA 0007

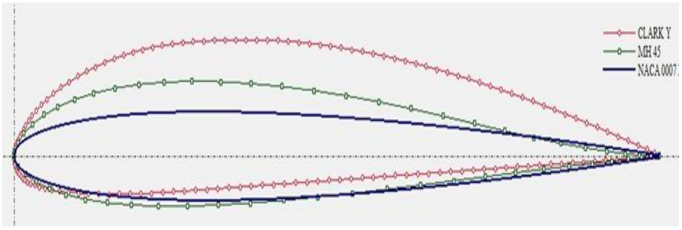


Fig -1: Airfoil

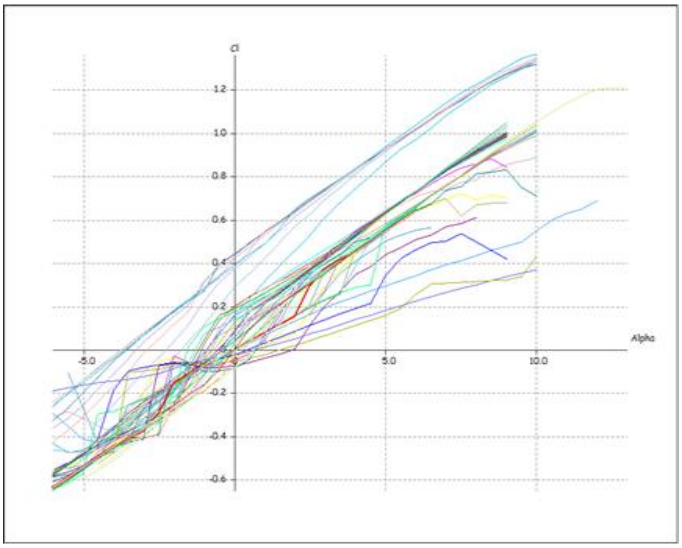


Fig -2: C_L vs Alpha

The above fig.2 describes the coefficient of lift against the angle of attack characteristics of the selected airfoils together.

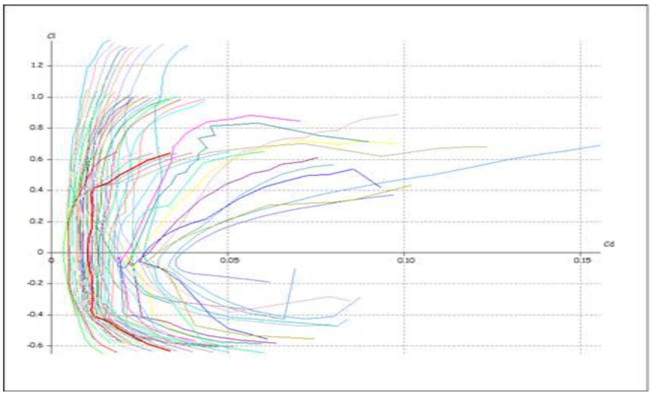


Fig -3: C_L vs C_D

Above Fig.3 describes the coefficient of lift against coefficient of drag behavior

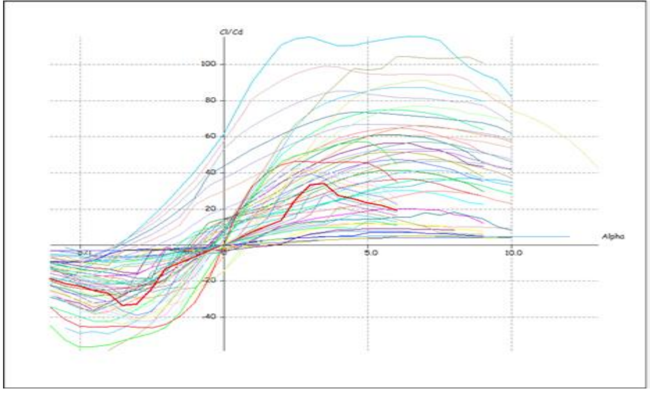


Fig -4: C_L/C_D vs alpha

Fig.4 gives details about the cl/cd against various angle of attack

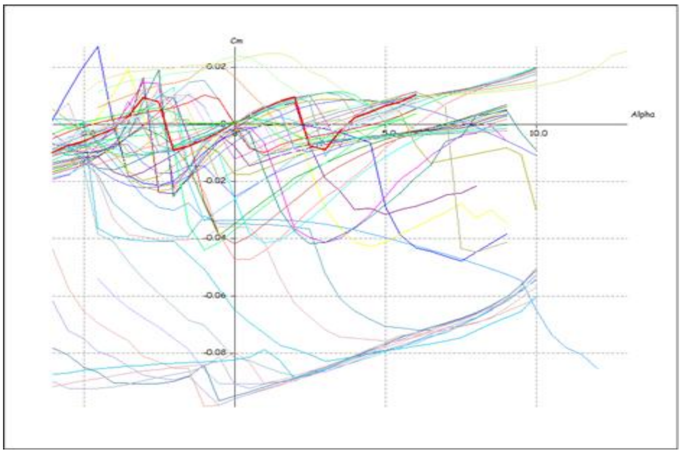
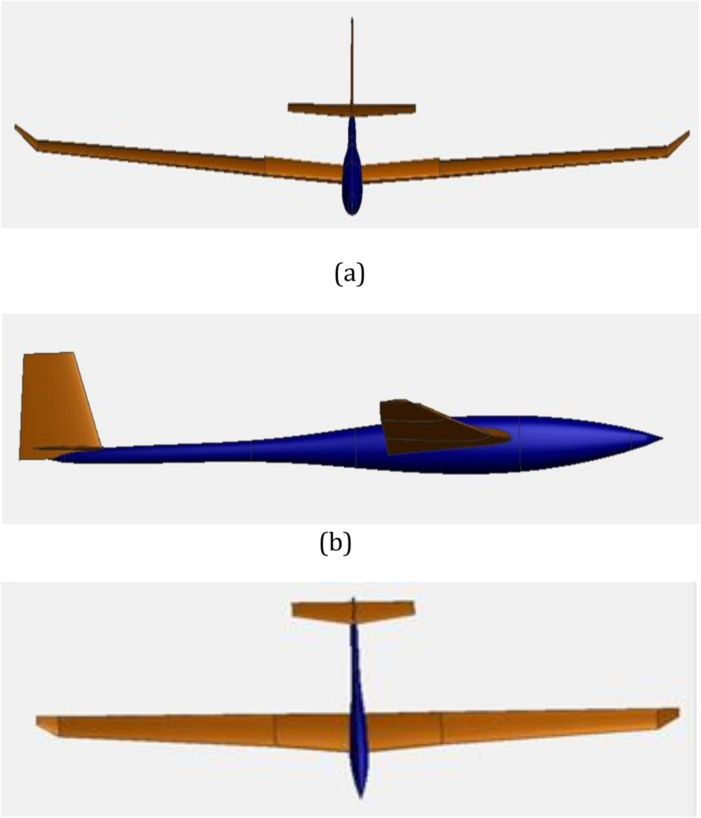


Fig -5: C_M vs Alpha

Above Fig.5, describe about the graph of various position of coefficient of moment for different angle of attack

1.2 Design of the aircraft:



(a)

(b)

(c)

Fig -6: Three basic view (a,b,c) of the sailplane

Table -1: Aircraft data:

Wing span	1700 mm
Wing area	0.216 m^2
Plane mass	3.120 kg
Wing load	14.479 kg/m^2
Tail volume	0.497
Root chord	180 mm
Mean aerodynamic chord (MAC)	133.8 mm
Tip twist	0^0
Aspect ratio	13
Taper ratio	4.5
Root-tip sweep	7^0
Position at CP	30 mm
Position at CG	31 mm

2. STATIC STABILITY ANALYSIS OF THE AIRCRAFT

When the system such as aircraft is tending to non-equilibrium condition, the moment is created to restore the system to regains its equilibrium condition is static stability. The position of center of gravity and the elevator are positioned after an iterative process to produce moment against the aircraft pitching and to bring the aircraft stable condition. Center of gravity is positioned on 30% of mean aerodynamic chord. The wing twist helps the lateral stability.

$$Static\ Margin\ (SM) = \left(\frac{X_{Np} - X_{CoG}}{Mean\ Aerodynamic\ Chord}\right) \quad (1)$$

On rearranging the values to find the X_{NP}, taking the Static Margin value as 0.35

Mean Aerodynamic Chord = 133.827 mm

Center of gravity at 31mm

Neutral point NP = 77.83 mm from the central axis. (Theoretical value)

3. ANALYSIS

3.1 Longitudinal static stability

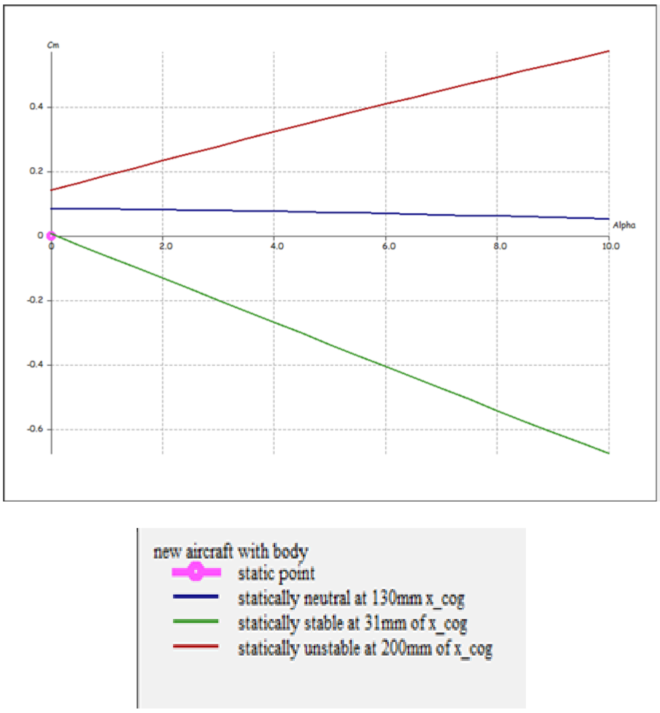


Fig -7: Longitudinal static stability

The above-mentioned graphs show the stability performance of an aircraft with respect to the positions of its Centre of Gravity (CoG). The aircraft's initial stability graph (green line) is found using the plane inertia. The graph denotes that the aircraft center of gravity at 131 mm before the nose tip is statically neutral. Above this point, the aircraft will tends to unstable (red line) and will not retain its original position after the disturbance. When the CoG is moved further front and positioned at 31mm the aircraft stable. As the theoretical value obtained is 77 mm and experimental stable value is 31mm. The aircraft is stable at 31mm of CoG.

3.2 Dynamic stability

The sailplane is disturbed during the motion, it undergoes different oscillatory motion and returns to original position due to the symmetric force created.

Longitudinal stability characteristics u (t), w (t), q (t), θ (t) for the short period and phugoid modes.

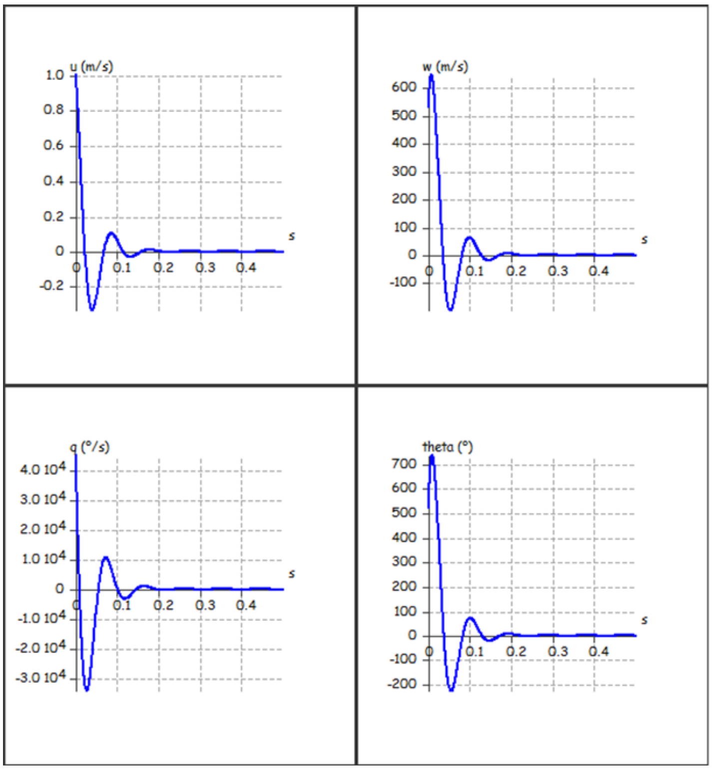


Fig -8: longitudinal Dynamic stability modes

The fig.8 graph shows that aircraft returns to its stable position after 0.2 seconds after disturbing. The pitch rate q and pitch angle θ against time is shown in graph. As the sailplane is disturbed, the two-symmetric short period motion occurs and the symmetric force produced by the opposite side dampens it. Thus, the aircraft is returned to its original position after 2-3 seconds.

The fig.9 graph shows the symmetric longer period oscillatory mode of the designed aircraft. This mode has large amplitude variation due to air speed, pitching angle, and altitude but almost no variation in the angle-of-attack. The phugoid oscillation can be considered as a slow interchange of kinetic energy due to velocity and potential energy due to height, about some energy level at equilibrium [1].

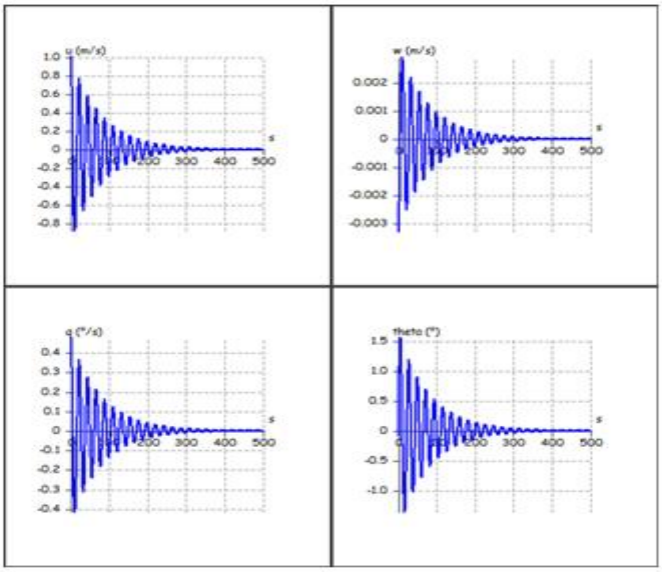


Fig -9: phugoid mode

The typical time period for aircraft dynamic stability regaining due to phugoid is between 400-500 seconds but as it is visible from the above-obtained graphs that the designed aircraft crosses that limit. Pilots can control this instability by using corrective measures.

3.3 Roll Subsidence Mode.

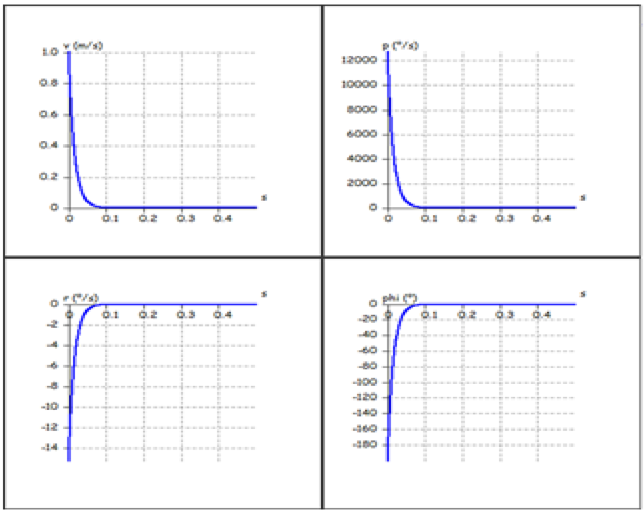


Fig -10: lateral dynamic stability mode 1

This aircraft returns to stable condition after 0.1 second of disturbing.

Lateral stability characteristics such as v(t), roll rate(p) vs time, yaw rate (r) vs time(t), heading angle (Φ) vs time(t) is calculated. This stability involves the study of the stability aspect in case of rolling and yawing motions. It is called Lateral-Directional Stability mode because it is an amalgamation of the two axes. This analysis has one spiral mode, one roll-damping mode, and two Dutch roll mode.

3.4. Dutch Roll Mode

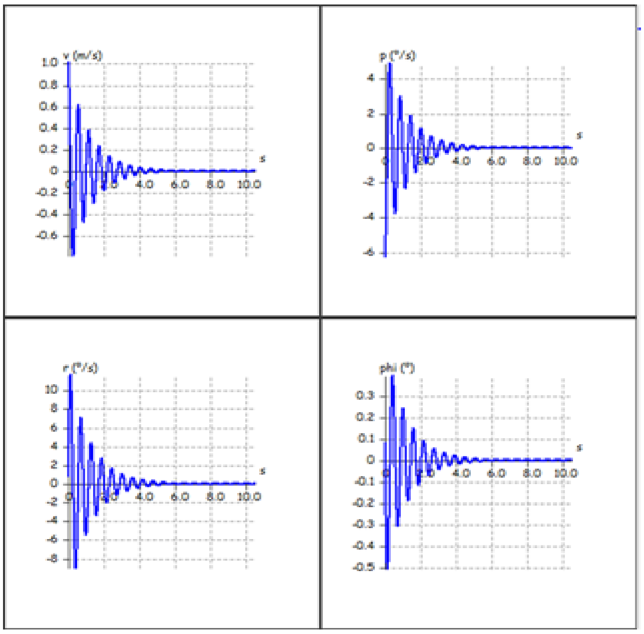


Fig -11: lateral dynamic stability mode 3

The Dutch roll period subsides within a time period of 5-6 seconds, but the variance can occur in terms of light aircrafts when compared to airliners. To increase damping, the directional stability needs to be increased with small dihedral. It can be decreased by small directional stability and large dihedral.

4. CONCLUSIONS

The results obtained after the iterative values of design.

Condition	Recovery time
Symmetric short-term mode	0.2 seconds
Symmetric phugoid mode	400 seconds
Spiral and roll damping mode	0.1 second
Dutch roll mode	6 seconds

The above conducted study shows the stability characteristics that need to be achieved in-order to design aircraft that is lateral, longitudinal and directionally stable. The aircraft needs to be stable to handle any sudden disturbing force in order to maintain its desired flight-path. The designed aircraft shows good static and dynamic stability performance and the pilot has full control to adjust or alter the condition if required.

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