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Comparative study of Aircraft wing orientation

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ABSTRACT

Today, Unmanned aerial vehicles are employed in numerous real life applications such as aerial surveillance for agriculture, traffic monitoring and pollution control, meteorological data collection, pipeline survey, early forest fire detection, etc. These vehicles use an electronic control system and electronic sensors to stabilize the aircraft. With their compact size and agile maneuverability, these gliders are in spotlight.Two types of aircraft (UAV) wing structure namely tip dihedral and central dihedral are taken under study. The two wings are modeled and analyzed by using the software packages CATIA V5 and ANSYS respectively.

Glider prototype is designed and fabricated. The parameters such as ability to control and self-stabilize were tested during flight and supported with the ANSYS analysis results. It concludes, Central dihedral wing structure vibrates at the higher frequency than the Tip dihedral, which illustrates that the Tip dihedral wing is more stable.

Keywords - Aircraft wing orientation, Airfoil, ANSYS analysis, CATIA V5 modelling, UAV, Wing structure.

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I. INTRODUCTION

A glider is a special kind of aircraft that has no engine. There are many different types of gliders. Paper airplanes are the simplest gliders to build and fly. Balsa wood or Styrofoam toy gliders are an inexpensive vehicle for students to have fun while learning the basics of aerodynamics. Hang-gliders are piloted aircraft having cloth wings and minimal structure. Some hang-gliders look like piloted kites, while others resemble manoeuvrable parachutes. Sailplanes are piloted gliders that have standard aircraft parts, construction, and flight control systems, but no engine. The Space Shuttle returns to earth as a glider; the rocket engines are used only during liftoff. Even the Wright Brothers gained piloting experience through a series of glider flights from 1900 to 1903.[15]

In flight, a glider has three forces acting on it as compared to the four forces that act on a powered aircraft. Both types of aircraft are subjected to the forces of lift, drag, and weight. The powered aircraft has an engine that generates thrust, while the glider has no thrust.

In order for a glider to fly, it must generate lift to oppose its weight. To generate lift, a glider must move through the air. The motion of a glider through the air also generates drag. In a powered aircraft, the thrust from the engine opposes drag, but a glider has no engine to generate thrust. With the drag unopposed, a glider quickly slows down until it can no longer generate enough lift to oppose the weight, and it then falls to earth.

The paper intends to study two different wing orientations. For which design and fabrication of a glider is taken into consideration and completed flight test with the help of Elcctronic control units. The flight test results were supported by ANSYS analysis results and after comparing the results, conclusion was drawn.
Whole design, fabrication and test phases are explained in following topics.

II. DESIGN METHODOLOGY

2.1 Introduction

The design process began by establishing the key design requirement and specification for the aircraft.

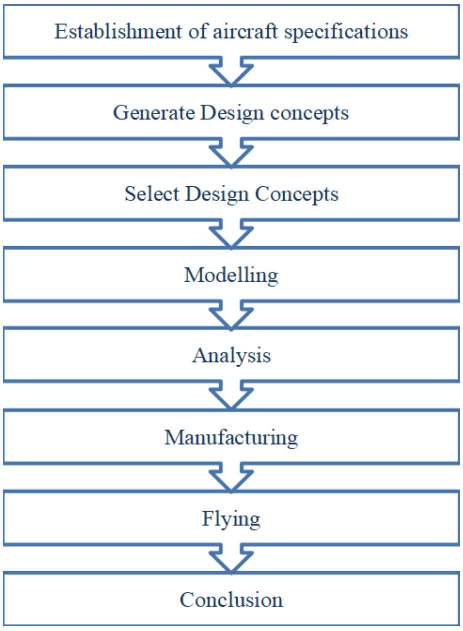

Fig. 1.1. : Flow Chart-Design Process

2.1.1. Establish design specifications

Minimum Thrust-to-Weight Ratio	1.5
Maximum Weight	500 gm
Maximum Dimension	1 m

Table. 1.1. : Design specification

2.1.2. Concept generation

Details collected of previous full scale manned, unmanned and Glider designs was analysed and studied in detail before selecting a suitable design. As different concepts could be selected as possible design solutions, using existing models and design requirements as a guide, the project narrowed down to suitable design and components.
The prototype manufactured is of light weight material i.e. balsa wood. For manufacturing of prototype this wood is most commonly used to get better flight performance and efficiency. Furthermore the aircraft's frame should tolerate the stress applied during the hovering.

III. MECHANICAL DESIGN

2.1. Introduction

Mechanical design includes estimation and calculation of different parameters for the material selection and fabrication process. Motor and propeller selection depends upon the weight which glider carries and on desirable altitude required.MAC, aspect ratio, wing loading etc.

2.1.1. Airfoils

Any section of the wing cut by a plane parallel to the aircraft x-z plane is called an airfoil. It is usually looks like a positive cambered section that the thicker part is in front of the airfoil. An airfoil-shaped body moved through the air will vary the static pressure on the top surface and on the bottom surface of the airfoil. A typical airfoil section is shown in figure, where several geometric parameters are illustrated. If the mean camber line in a straight line, the airfoil is referred to as symmetric airfoil, otherwise it is called cambered airfoil. The camber of airfoil is usually positive.

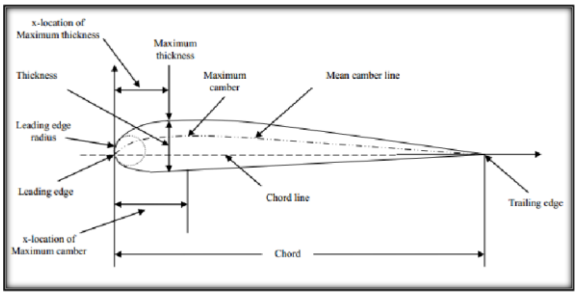

Fig. 1.2. : Airfoil sketch

2.1.2. Types of Airfoils

a) Flat bottom airfoil

b) Semi-symmetrical airfoil

c) Symmetrical airfoil

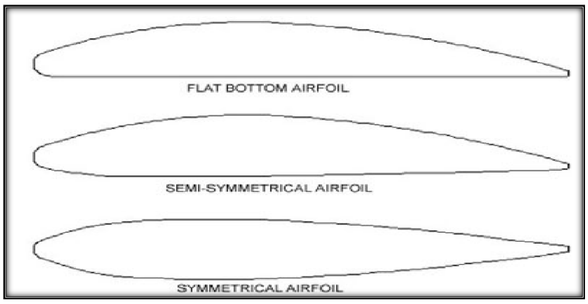

Fig. 1.3. : Types of Airfoil

2.1.3. Semi-Symmetrical Airfoil

CLARK-Y

Clark-Y is the name of a particular aerfoil profile, widely used in general purpose aircraft designs, and much studied in aerodynamics over the years. The profile was designed in 1922 by Virginius E. Clark. The airfoil has a thickness of 11.7 percent and is flat on the lower surface from 30 percent of chord back. The flat bottom simplifies angle measurements on propellers, and makes for easy construction of wings on a flat surface. [3][8]

2.1.4. Wing orientations

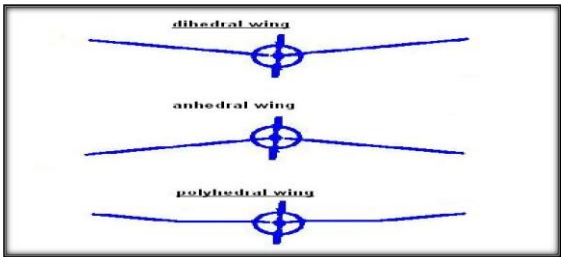

Fig. 1.4. : Orientations

2.1.4.1. Dihedral Wing

Wing Dihedral is the upward angle of an aircraft's wing, from the wing root to the wing tip. The amount of dihedral determines the amount of inherent stability along the roll axis. Although an increase of dihedral will increase inherent stability, it will also decrease lift, increase drag, and decreased the axial roll rate. As roll stability is increased, an aircraft will naturally return to its original position if it is subject to a brief or slight roll displacement. Most large airliner wings are designed with dihedral.

The purpose of dihedral is to improve the aircraft stability during flight. Dihedral angle is added to the wings for later or rolls stability. When the aircraft encounters a slight roll displacement caused by distribute from air stream or a gust of wind. An aircraft wings with some dihedral will naturally return to its original position.[2]

2.2. Weight Estimation

Estimation of Mass of Glider was done in order to decide the configuration of motor which will eventually lead to provide required thrust.

Table. 1.2 : Weight Estimation

Item	Tip Dihedral Mass (gm)	Central Dihedral Mass (gm)
Motor	40	40
Battery	60	60
Electronic Speed Control × 2	100	100
Fuselage	120	120
Payload	40	40
Wing	110	90
Total	470	450

2.3. Glider specification

It is basically a glider having a wing span of 1 meter and made out of balsa wood. It has two control surfaces one is rudder for turning and other is elevator for pitching of the aircraft. Following are the specifications:

2.3.1. Wing specification

Wing Span : 1m
(Centre part 18” and Wing Tips 10” each)
Chord length : 15cm
Polyhedral Angle : 4o
Angle of Attack : 4o
No. of Spars : 3
No. of Ribs : 10 for centre part and 6 for wing tips(Ribs are placed 5cm apart)
Leading Edge dimensions : 18” × 1cm
Trailing Edge dimensions : 18” × 2cm
Material used : Balsa Wood
For Ribs : 1/16”
For Leading Edge : 3 × 1/8”
For Trailing Edge : 1/8”

2.3.2. Fuselage specification

Length : 39”
Firewall Dimensions : 3cm × 3.5cm
Balsa Wood used : 1/8”

2.3.3. Tail specification

Fin : 8cm at the base and 2cm at thetop
Stabilizer : 8cm at the centre and 5cm at the sides

2.4. Motor selection

From above weight estimation it can be logically thought that motor should be selected in such a way that it will provide the thrust which will be maximum than the total weight of body. At the same time based on our requirement for high thrust it is required that motor should have very high RPM in order to turn the props at very high speed which will eventually produce the lift required.

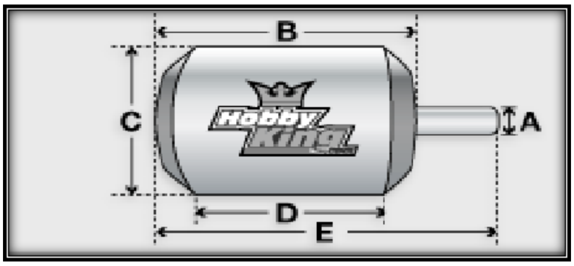

Fig. 1.5. : Motor configuration

Lift=Thrust= Weight

KV (rpm/v): 1400

Weight (g) : 40
Max Current (A):1.5
Max Voltage (V):12
Thrust (gm) : 462
Shaft A (mm) : 3
Length B (mm) : 24
Diameter C (mm): 28
Can Length D (mm): 20
Total Length E (mm): 36

2.5. Propellers

Next comes the propellers which play very important role in order to develop the additional thrust. The propeller on an aircraft converts the turning power of an engine's crankshaft into the thrust force. This thrust is equal to the mass of air forced downward by the propeller. Basically, a propeller blade is a small wing producing a resultant aerodynamic force that may be resolved into a force pointing along the axis of the airplane (thrust), and a force in the plane of the propeller blades (the torque force). The torque force opposes the rotary motion of the motor by acting as a "drag" on it. In equilibrium, the propeller rotates at a constant rate determined by the motor torque that is equal and opposite of the propeller torque.

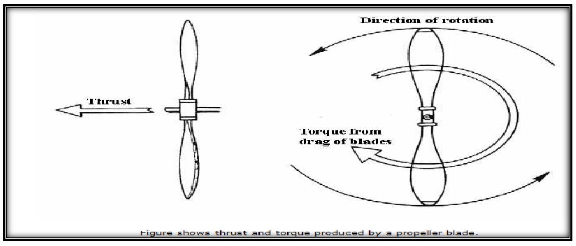

Fig. 1.6. : Propeller thrust

2.5. Calculations

2.5.1. Wing loading

Wing loading is the loaded weight of the aircraft divided by area of the wing. The faster an aircraft flies the more lift is produced by each unit area of wing, so a smaller wing can carry the same weight in level flight, operating at a higher wing loading.

$$\boldsymbol{WL = \frac{Wing\ Planform\ Area}{Weight\ Of\ Aircraft}} \quad \text{………… (1)}$$

Wing Loading of TD Wing is,

$$WL = \frac{1500}{470}$$

$$WL = 3.2 \quad gm/cm^2$$

Wing CD Loading of wing is,

$$\boldsymbol{T = 462\ gm}$$

$$WL = \frac{1350}{450}$$

$$\boldsymbol{WL = 3 \quad gm/cm^2}$$

2.5.2. Aspect ratio

Aspect ratio is the ratio of span of wing to the chord length. Higher the aspect ratio more is the lift obtained. The aspect ratio (AR) is given by,

$$\boldsymbol{AR = \frac{b^2}{S_w}} \quad \text{……….…………………. (2)}$$

AR for TD wing is,

$$AR = \frac{10000}{1500}$$

$$\boldsymbol{AR = 6.66}$$

AR for CD wing is,

$$AR = \frac{8100}{1350}$$

$$\boldsymbol{AR = 6}$$

2.5.3. Mean aerodynamic chord

The Mean Aerodynamic Chord is given by,

$$\boldsymbol{MAC = \frac{2}{S_w} \int_0^{b/2} c^2\ dy} \quad \text{……………… (3)}$$

The MAC for TD wing is,

$$MAC = 70\ cm$$

The MAC for CD wing is,

$$\boldsymbol{MAC = 67.5}$$

Where, y is the co-ordinate along wing span.

2.5.4. Thrust

Thrust is a force which moves an aircraft through the air. It is used to overcome drag of the aircraft.

$$\boldsymbol{T = [(n \times P)^2 \times 2 \times \pi \times R^2 \times \rho]^{0.3333}} \quad \text{………………. (4)}$$

n = Prop Hover Efficiency= 0.85

P = Shaft Power

R = Prop Radius

ρ = Air Density= 1.22 kg/m3

The thrust produced by our glider is,

2.5.5. Coefficient of lift

The lift coefficients a dimensionless coefficient that relates the lift generated by a lifting body, the dynamic pressure of the fluid flow around the body, and a reference area associated with the body. A lifting body is a foil or a complete foil-bearing body such as a fixed-wing aircraft.
Lift coefficient is also used to refer to the dynamic lift characteristics of a two dimensional foil section, whereby the reference area is taken as the foil chord.
Lift coefficient may be used to relate the total lift generated by a foil-equipped craft to the total area of the foil. In this application the lift coefficient is called the aircraft or platform lift coefficient 'CL '

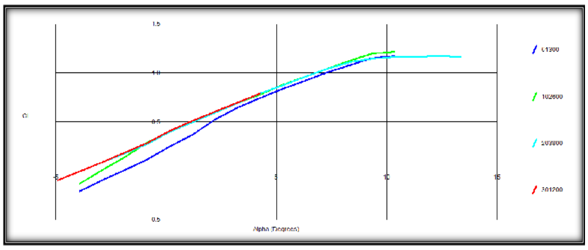

Fig. 1.7. : Angle of Attack vs Coefficient of Lift

Calculated the coefficient of lift with the help of Winfoil3.0 software at different angle of attack and Reynolds number.

CL max = 1.213 ………at Re = 102600

CL max = 1.172 ...…….at Re = 61300

IV. ELECTRONICS USED

3.1. Components

3.1.1. Motors

Fig. 1.8. : Brushless DC Motor

Specifications
DC 1400 KV Brushless motors
Speed: 1400RPM
Input Voltage: 7.4 ~ 11.1 V
Load Current: 1.5 ~ 2 A

3.1.2. ESC

The ESCs, i.e. Electronic Speed controllers are mainly used to control the speed of the motors to control the direction flight. The ESCs receives signals from the transmitter, & makes changes accordingly to the supply current & voltage to motors, causing the speed of motors to change & hence resulting in change in direction of flight.

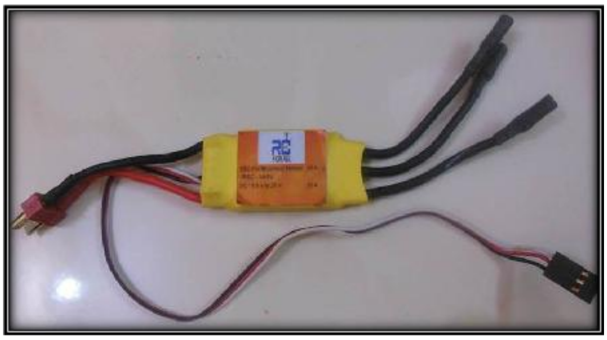

Fig. 1.9. : ESC

Specifications
Weight : 57g
Size : 36x22x10mm
Cells : 2-3S (AutoDetect)
Max.Current : 20A

3.1.3. Battery

Fig. 2.0. : Battery

Specifications
Lithium polymer 7.4V 1000mAh 20C
Pack Weight : 70g
The Battery is placed onboard the glider& it supplies power to all ESCs, Motors & Flight controller board. The battery has 3 cells & is rechargeable

3.1.4. Transmitter – Receiver

Fig. 2.1. : Transmitter

Fly Sky2.4 GHz, 6 Channels
Transmitter Parameters
Channels : 6 Channels
Power source : 1.5V * 8 AA Battery
Frequency ban : 2.4 GHz
Modulation type : FM
Receiver Parameters
Channels : 6 Channels
Power source : 1.5 V × 8 AA Battery
Modulation type : FM
Antenna length : 7 cm

3.2. Electrical layout

Fig. 2.2. : Electrical layout

V. MODELLING

Fuselage and wing structure model in CATIA V5.

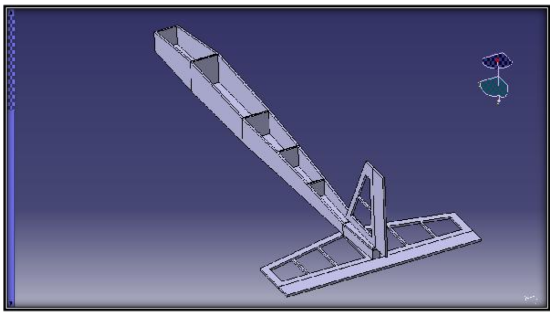

Fig. 2.3. : CATIA Modelling of Fuselage

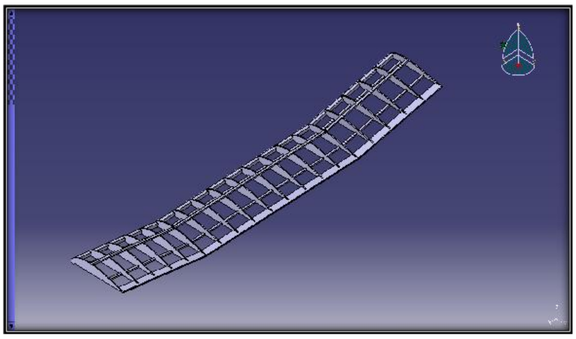

Fig. 2.4. : CATIA Modelling of Wing

VI. FABRICATION

5.1. Fabrication process

Fabrication of any glider prototype is very crucial thing. Many factors like stability, weight, Centre of gravity etc. are to be considered while fabricating.

Firstly, fuselage fabricated by using balsa wood which is in the shape of rectangle of varying cross section and also carries the undercarriage with the landing wheels. The fuselage is separated into different sections in order to mount the electronic equipment. Then we manufactured the two wings which are having different orientations that are tip dihedral (TD) wing and central dihedral (CD) wing. For TDW the angle is given at the tip and it varies from 2 to 10 degrees. The angle considered for study is 10 degrees. Next is the CDW where the angle is given at the centre of the wing and it varies from 2 to 5 degrees. Considered 5 degrees for central dihedral angle. Used 22 ribs and 3 spars in TD wing and 20 ribs and 3 spars in CD wing. Ribs and spars are used to increase the structural stability as well as the strength of the wings. Once done with the assembling of spars and ribs it is covered with the thick tracing paper.

The fuselage body and the wings can be attached and detached easily with the help of rubber bands. The brushless DC motor and propeller are placed at the front part of fuselage. The batteries are placed in the front section portion of the fuselage so that it can be easily attached to the motor. The ESC is mounted on the bottom side of fuselage that is on undercarriage in order to get better signals during the flying. The servomotor controls the motion of horizontal and vertical wing which are mounted at the aft of the fuselage. The horizontal wing controls the up and down motion given to the aircraft while the vertical wing steers the craft to the left and right. These motions are controlled with the help of 2 servomotors one for each tail wings.

Then for landing, wheels are provided two at the front and a single wheel at the back so that while landing it should balance, land smoothly and distribute its weight equally at the front and aft wheels. The overall weight of the whole assembly was observed to be approximately 500 grams.[12]

5.2. Actual process

Fabrication process is illustrated sequentially in the form of images.

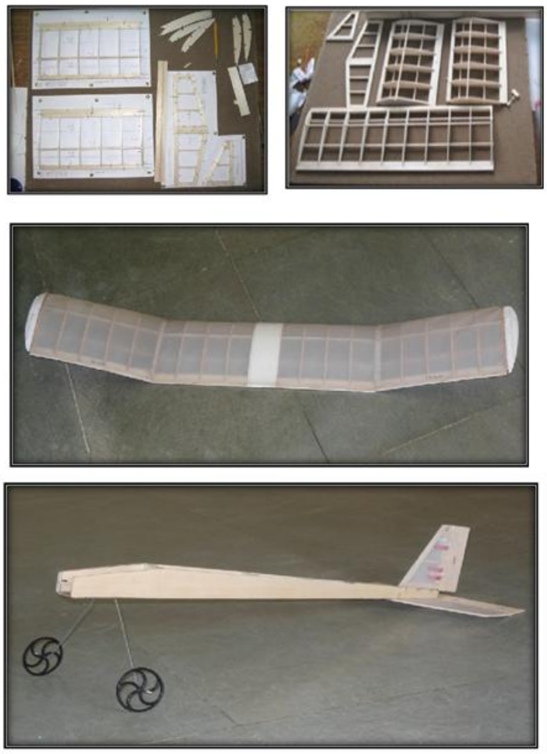

Fig. 2.5. : Actual Process

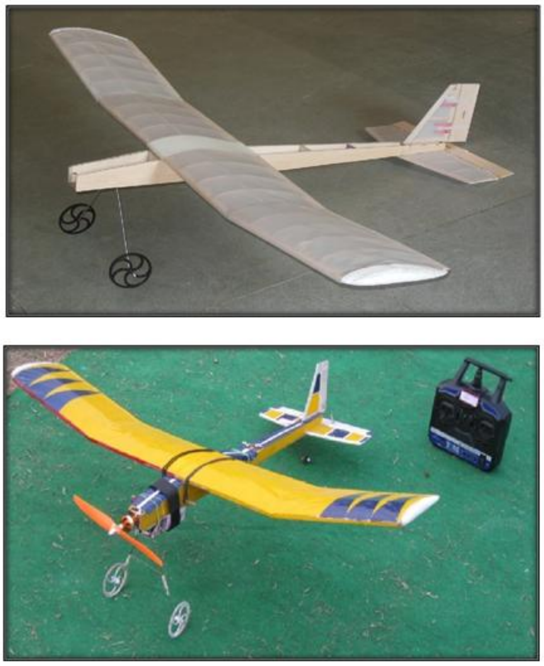

Fig. 2.6. : Final Prototype

VII. FLIGHT TEST

6.1. Testing

Transmitter- Receiver (TR) is used to control and steer the craft. The TR transmits the signal from the ground and it is received by the ESC which is mounted on the craft. Then the craft follows the instruction and acts according to it.

VIII. OBSERVATIONS

7.1. Tip Dihedral wing

After the tuning process now the craft is ready for testing. Let us first consider TD wing and mount it on the fuselage with rubber bands. Then connect the battery to the motor and check the propellers, horizontal wing and vertical wing operations by using transmitter. The craft can be hand launched or it can take off by running on the runway. By giving it a upward motion with the help of transmitter the craft take offs and reaches to a particular height. Now it can be steered in the air and right or left circuits are completed. By observations, listed the following results

- It is easy to control the craft during the flight
- Steering the craft to the left or right disturbs the stability of the craft. But with tip dihedral gained its stability within seconds.
- During the gusty conditions the craft self stabilizes.
- When the power failure occurs the craft can glide easily in the air and it can be landed smoothly.

7.2. Central Dihedral wing

Now consider the central dihedral wing which is having a dihedral angle of 5 degrees at the center of the wing. When the mounting of this wing is done the battery is connected to the motor and all the beginning operations are checked once again to verify the working of the craft. By observations, listed the following results for CD wing.

- By using CD wing speed obtained is more comparatively to the TD wing.
- During the gusty conditions it is difficult to control this craft as it easily loses its stability.
- Due to loss of stability the lift is reduced because obtained lift is used to retain the stability back.
- Steering the craft is difficult as there are chances of craft completing bending towards one side or rolling may also take place.

7.3. Results

Operations	Tip Dihedral Wing	Central Dihedral wing
Control Ability	Easy to Control	Difficult to control
Self-Stabilizing Ability	Gets Self stabilized within seconds	Difficult to get self stabilized
Speed Obtained	Medium speed	High speed gained
Changes in conditions of the atmosphere (Gusty or Turbulence conditions)	Can be easily controlled	Difficult to control as there are chances of rolling.

Table. 1.3. : Results

IX. ANALYSIS

Modal analysis gives the vibrational frequency of model in various modes. The results obtained from analysis are given below.

A) TD Wing

Five modes of vibrations are as follows

Mode 1

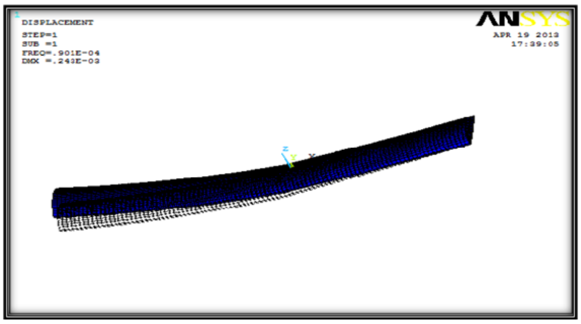

Fig. 2.7. : Mode 1 Analysis of TD Wing

The Frequency of TD wing for Mode 1- 901 Hz

Mode 2

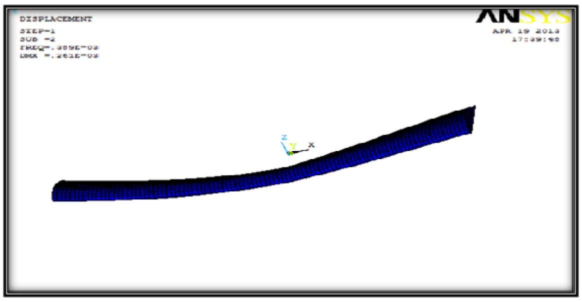

Fig. 2.8. : Mode 2 Analysis of TD Wing

The Frequency of TD wing for Mode 2- 389 Hz

Mode 3

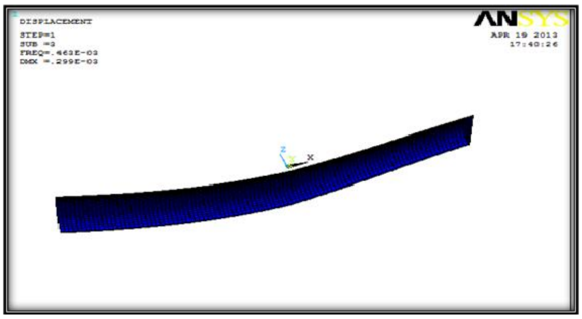

Fig. 2.9. : Mode 3 Analysis of TD Wing

The Frequency of TD wing for Mode 3- 463 Hz

Mode 4

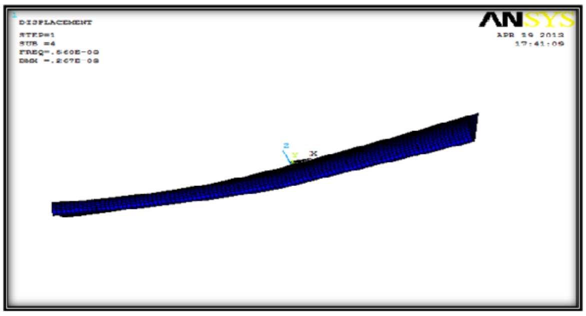

Fig. 3.0. : Mode 4 Analysis of TD Wing

The Frequency of TD wing for Mode 4- 560 Hz

Mode 5

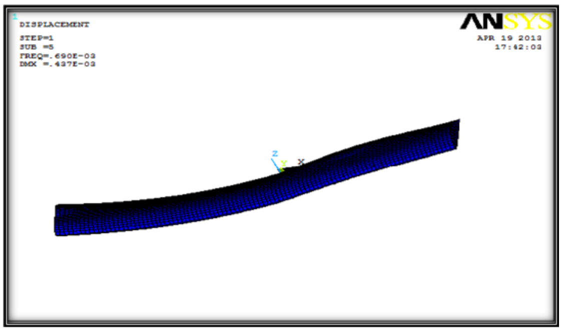

Fig. 3.1. : Mode 5 Analysis of TD Wing

The Frequency of TD wing for Mode 5- 690 Hz

B) CD Wing

Five modes of vibrations are as follows

Mode 1

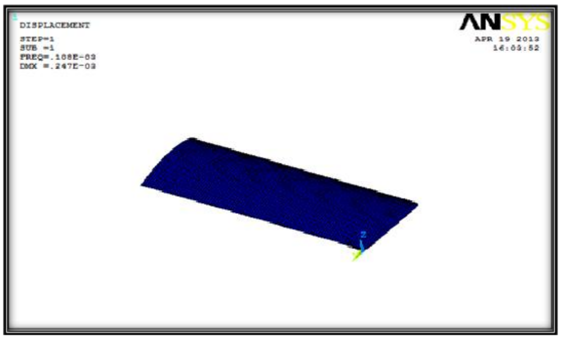

Fig. 3.2. : Mode 1 Analysis of CD Wing

The Frequency of CD wing for Mode 1- 1080 Hz

Mode 2

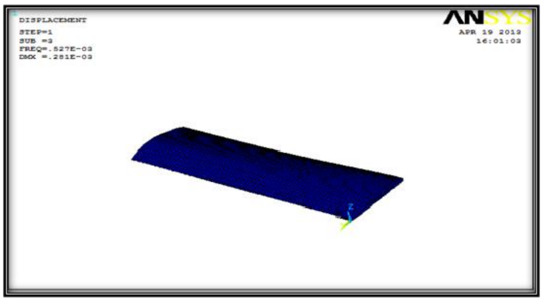

Fig. 3.3. : Mode 2 Analysis of CD Wing

The Frequency of CD wing for Mode 2- 457 Hz

Mode 3

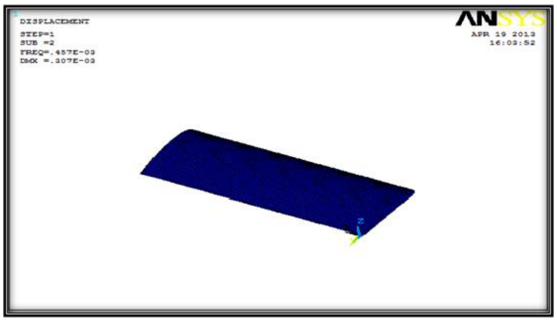

Fig. 3.4. : Mode 3 Analysis of CD Wing

The Frequency of CD wing for Mode 3- 527 Hz

Mode 4

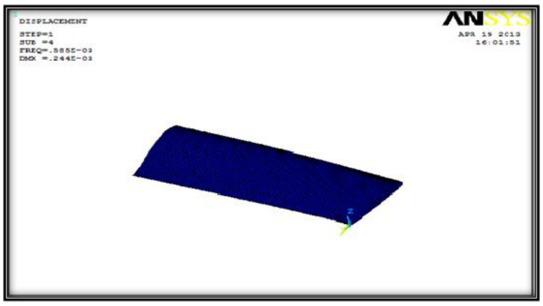

Fig. 3.5. :Mode 4 Analysis of CD Wing

The Frequency of CD wing for Mode 4- 585 Hz

Mode 5

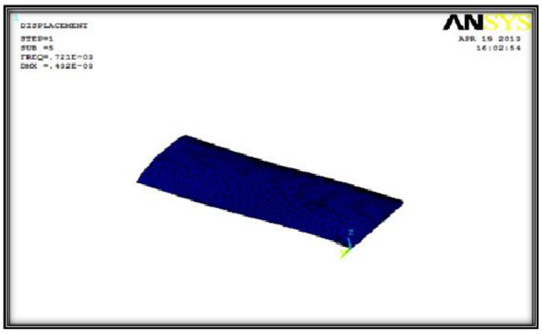

Fig. 3.6. : Mode 5 Analysis of CD Wing

The Frequency of CD wing for Mode 5- 721 Hz

X. COMPARISON OF ANALYSIS AND OBSERVED RESULTS

Modes	Central Dihedral Wing	Tip Dihedral Wing
1	1080 Hz	901 Hz
2	457 Hz	389 Hz
3	527 Hz	463 Hz
4	585 Hz	560 Hz
5	721 Hz	690 Hz

Table. 1.3. : Analysis Results

XI. CONCLUSION

The results obtained from the ANSYS can be seen that the CD wing vibrates at the higher frequency than the TD wing, which illustrates that the TD wing is more stable than the CD WING. But the speed obtained is more with the use of CD wing. Hence for the higher Mach number vehicles such as passenger crafts, military jets, etc. the CD wing should be used to attain high speed, whereas for lower Mach number vehicles such as gliders, private jets, etc. the TD wing is more suitable.

Ability to self stabilize in turbulent situations and ease to control, these are the two important factors which decide the success rate of the design in performing the intended function.

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