DIHEDRAL AND ANHEDRAL CONVERTIBLE WING MECHANISM FOR UAV

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Abstract: One of the most essential requirements of UAVs is to have stability. It is required to counter the disturbance caused due to gust loads, crosswinds and uneven stick moment. To encounter this, the aircraft needs to be stable and capable to maneuvers at different flight conditions. The current generation UAVs are designed with fixed-wing configuration with either dihedral or anhedral or straight wing configuration. With this approach, one can only harness the abilities of the configuration with which it is designed. For instance, an aircraft with dihedral configuration might have good roll stability but will not be maneuverable as an aircraft with anhedral configuration and vice versa. There is a requirement of having a UAV whose dihedral angle can be changed an aircraft, which can avail the pros of both dihedral, and anhedral configuration allowing the pilot an advantage over control of roll stability and roll maneuverability based on the flight condition.

Index Terms – Servo-Powered Mechanism, Dihedral, Anhedral, DACA, UAV.

I. INTRODUCTION

Modern day aircrafts are built with great intuition to meet the mission requirements. Aerodynamic, Structures, Propulsion are some of the key areas which affects the aircraft configuration, design and performance. Similarly, Stability and control is also equally important to impart stable flight and successful completion of the mission.

This project is related to adjusting the dihedral angle to get the desired dihedral effect. The change in the dihedral angle changes the behavior of the aircraft which can be used in the UAVs and improve its overall performance. Thus making the aircraft useful for all terrain and altitudes. The importance of a stable flight is ever demanding and at the end it all depends on how well the aircraft can behave to the external disturbances. To suffice the desired mission, the aircraft should be able to tackle the disturbances and that is when DACA (Dihedral-Anhedral Convertible Aircraft) comes into picture.

A conventional UAV will not have any liberty in the stability aspect; the aircraft will be designed according to a set of predetermined fixed values making it less versatile and limits its usage. Whereas, DACA has the liberty to change its stability characteristics according to the flight conditions. When the aircraft is made to change its dihedral angle, it in turn change the overall dihedral effect. This gives the benefit of operating the aircraft in harsh terrain and in all weather conditions. This project is an attempt to understand the effect of radical change in the geometry of the aircraft with the dihedral angle. It includes design and development of an UAV, which can change its dihedral angle making it to have varying stability.

II. LITERATURE SURVEY

The invention of Donald M. Leitch [1] relates to an aircraft with variable dihedral wings and is more concerned with the problem of modifying the wing to allow a dihedral transition and having a mechanism for achieving such a dihedral angle variation.

William P. Rodden [2] says that the dihedral effect of a flexible wing is regarded as a crucial aero elastic issue due to the role of dihedral in deciding lateral directional dynamic stability and the significant dihedral changes resulting from symmetrical bending of the wing during longitudinal maneuvers that exceed limit load factor. Finally, to exploit recent developments in lifting surface theory, the question of estimating wing dihedral effect is reformulated in terms of structural and aerodynamic coefficients of impact. The experimental results and other examples cited suggest that the dihedral effect aero elastic shift at the limit load factor can be equal to the value calculated on rigid models.

W. F. Phillips [3] solves the dihedral effect of a wing analytical solution. For a typical airplane, the dihedral angle of the wing strongly affects the change in rolling moment due to sideslip. Wing dihedral affects an aircraft's roll stability derivative, as it causes the lift to adjust differently to sideslip on the right and left semi-spans.

The Air Force Research Laboratory Munitions Directorate [4] has developed a prototype of an articulated wing micro air vehicle (MAV) with the goal of studying passive wing deformation in response to wind gusts. The prototype is a first step toward a final design intended to provide insight into the flight and control of MAVs in ragged environments. The paper outlines the construction of two MAVs, one of which is a reference fixed wing configuration and one of which is a prototype articulated wing. The baseline configuration should serve as the reference point where the articulated wing prototype flight characteristics can be contrasted. Coinciding with the prototype is a digital simulation that models the MAV's flight characteristics and acts as a stepping-stone for more complex simulations involving multi-joint MAV wings.

Stability of an Aircraft [5] shows that dihedral angled wings in an aircraft suggest some viability and will offer substantial improvement in the aircraft's efficiency and stability throughout the flight. When a positive dihedral angle is chosen, the absolute stability of the aircraft will be increased. This is because the value of the static lateral stability coefficient is negative because very high angles of attack result in a loss of stability. The complexity of constructing a dihedral twisted high-wing structure increases. The characteristics are reversed by choosing anhedral. Moreover, it gives neutral stability by choosing null dihedral wing.

New Jersey's Governor's School of Engineering and Technology [6] researchers examined potential improvements in properties such as aircraft stability, performance, and maneuverability when the restricted structures are relaxed, and wing configuration can alter in-flight. The spotlight in this project is on a device designed to change the dihedral angle of the wing. They designed a model plane that was radio controlled to demonstrate the mechanisms described. All the systems were working as expected making this project a good design proof. However, the test flight resulted in a crash but this project demonstrated the effective proof of efficient operation of wing dihedral angle adjustment mechanisms.

III. Scope of present work

This project will lead to development of next generation UAVs, which has high performance, and be able to reach faster speeds. UAV can be made autonomous which makes the aircraft to never fail and thereby the life of the UAVs can be increased and decrease the fatal crashes. The DAS can be incorporated to analyze critical observation of landscapes, mapping and surveillance. We also can implement machine learning and artificial intelligence to make a long-range military exercises.

IV. Proposed Methodology

Servo Powered Mechanism (Version 1):

The mechanism for changing the dihedral angle was extensively researched and the team selected the **servo-powered mechanism** shown in Fig.1. The servo-Powered mechanism uses a servo to change the dihedral angle of the wing. Two spars are provided that hold the wing utilizing a ball joint at the root, which is enclosed in the fuselage. The spars run till the mid-way of the wing and are free to rotate only in the longitudinal axis of the aircraft. A 3D printed holder holds the two spars together that make the ball joint rigid and does not allow any other rotation other than in the longitudinal axis of the aircraft.

The servo is fixed to the fuselage. A connecting rod with a ball joint at its end is used to connect the servo arm and the 3D printed holder. The neutral position of the servo is fixed as the straight wing congiguration as shown in Fig.1 (a). As the pilot gives the input, the servo rotates the servo arm, which in turn makes the connecting rod to move up and down. This up and down motion makes the dihedral angle by rotating the two spars. The upward motion will make the dihedral wing as shown in Fig.1 (b) and the downward motion makes the anhedral wing as shown in Fig.1 (c).

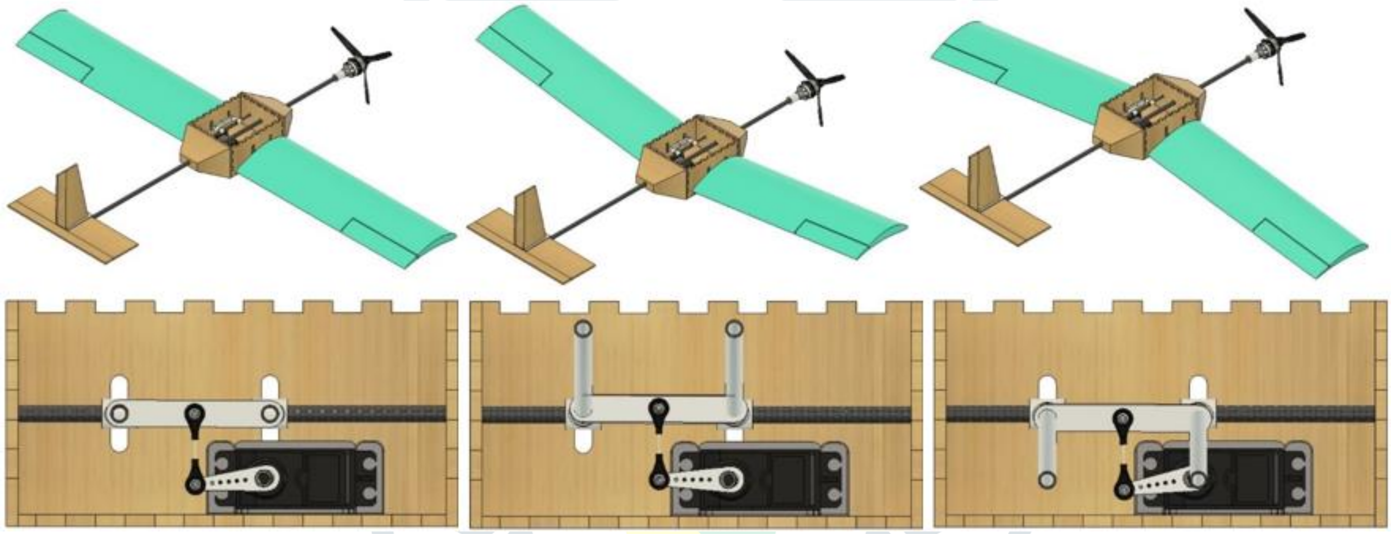

Figure 1: Servo Powered Mechanism (a) Straight Wing, (b) Dihedral Wing and (c) Anhedral Wing

The servo arm is rotated by a servo to a certain angle. The servo receives the signal from the transmitter by a separate channel. A connecting rod joins the servo arm and the holder. The joints are free to move because of the ball joint bearing. As the servo arm rotates, it provides linear or upward and downward motion to the holder as illustrated in Fig.1. The 3D printed holder holds the two spars of the wing together. Hence, the horizontal movement of the holder causes the wing to change its effective dihedral angle as the wing spars are connected to the fuselage rod by a bearing. The bearing essentially provides the freedom of rotation to the spars in a single plane.

The key element in this mechanism is the connecting rod, which makes the curvature of the servo move in a single plane with the help of a ball joint at its ends. This process is applied to both the wing simultaneously by using a Y-connector, which sends the signal to both the servo at once. The parts such as servo, servo-arm, and connecting rod are available in the market with standard dimensions. The 3D printed holder was designed specifically for this project. A simple representation of the mechanism is shown in Fig.1.

UPGRADATION 1: *Servo Powered Gear-Mechanism (Version 2)*

This mechanism includes a servo with a spar gear module, which is attached to the 3D printed holder. As the servo rotates in clockwise, it in turn rotates the holder anticlockwise direction. The 3D printed holder holds the two spars that runs till mid-way of the wing. The neutral position of the servo is fixed as the straight wing congiguration as shown in Fig.2 (a).As the holder rotates, it changes the dihedral angle of the wing. If the holder rotates in anticlockwise direction, the wing will be in anhedral configuration as shown in Fig.2 (c) and if the holder rotates in clockwise direction, then the wing will be in dihedral configuration as shown in Fig.2 (b).

This mechanism works smooth and has advantages over the mechanism with connecting rod. The only problem with this mechanism is that the spar gears are required to be small, precise and must have high strength. Due to these limitations, only metal spars can be used for strength and precision. The size of the spar gear is also tidies to fabricate and the commercially available gears might not be useful as per the requirement for different aircraft sizes.

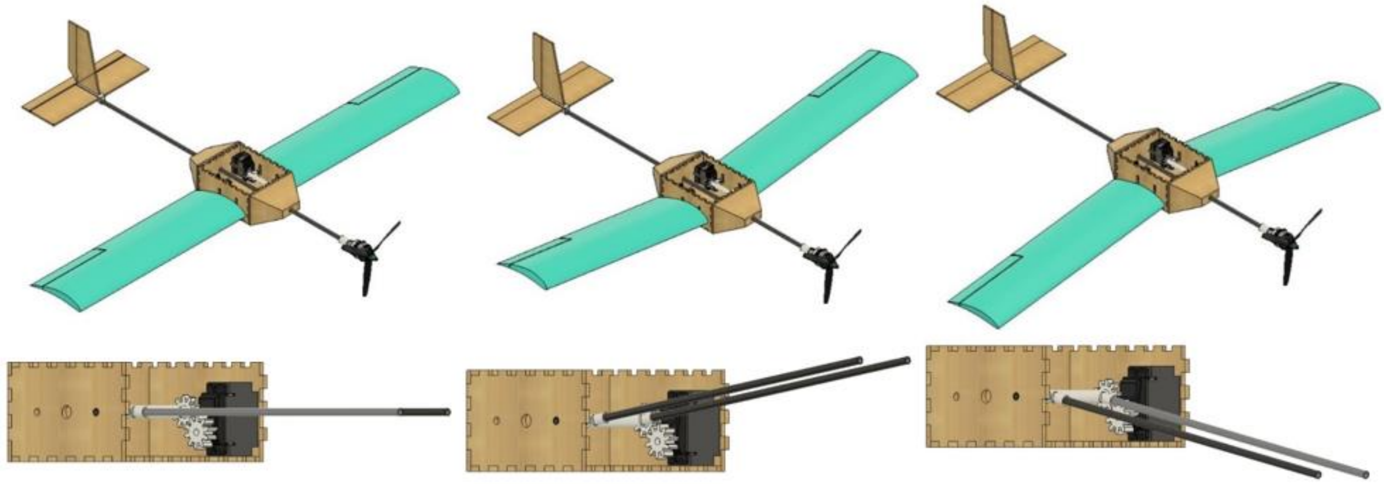

Figure 2: Servo Powered Gear-Mechanism (a) Straight Wing, (b) Dihedral Wing and (c) Anhedral Wing

After testing the mechanism, we found that the connecting rod or the spar gear might act as a point of failure. To avoid this, we decided to rectify this by eliminating the secondary moving part i.e. the connecting rod and spar gear. As a result, we directly attached the servo to the 3D printed fixture. By which we eliminated the point of failure and made the Servo powered mechanism more redundant.

UPGRADATION 2: *Servo Powered Direct Mechanism (Version 3)*

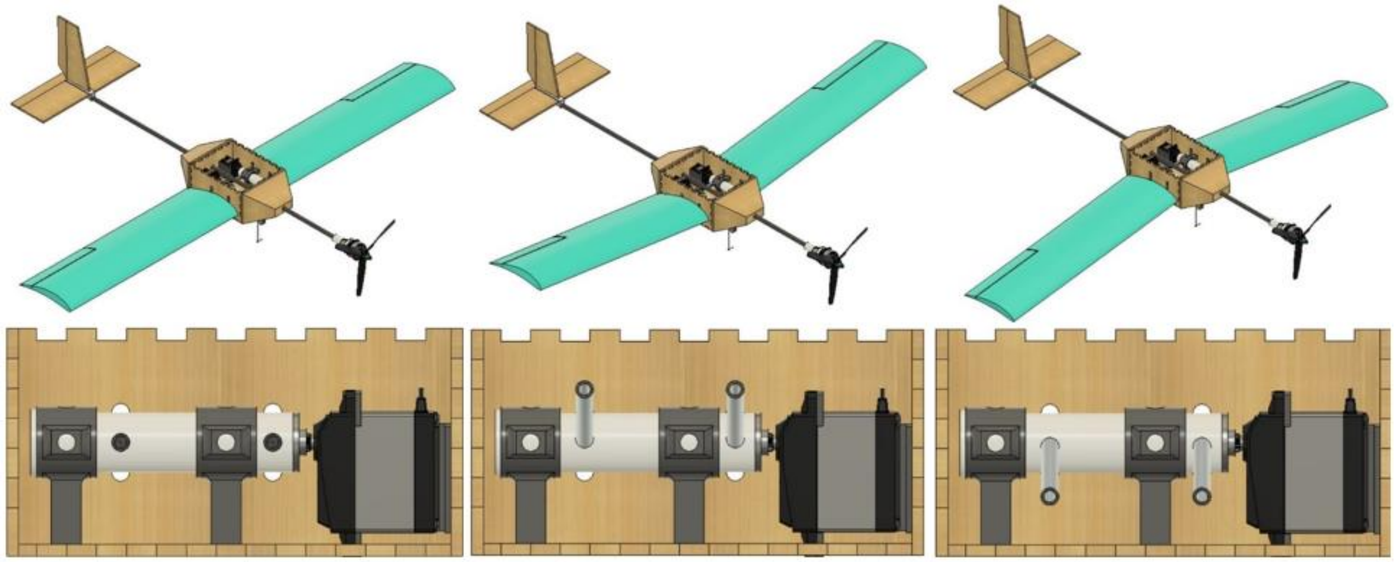

Figure 3: Servo Powered Direct Mechanism (a) Straight Wing, (b) Dihedral Wing and (c) Anhedral Wing

This mechanism works similarly to its predecessors but the only difference is that there is no secondary moving part. This helps mainly to make the mechanism redundant but also to minimize the extra weight. The servo is placed in such a way that its rotation will change the dihedral angle of the wing. The root of the wing is allowed to rotate through the longitudinal axis of the aircraft by keeping the servo fixed. As the pilot gives the input to the servo, it rotates and changes the dihedral angle of the wing. The neutral position of the servo is fixed as the straight wing congiguration as shown in Fig.3 (a). As the holder rotates, it changes the dihedral angle of the wing. If the holder rotates in clockwise direction, then the wing will be in dihedral configuration as shown in Fig.3 (b) and if the holder rotates in anticlockwise direction, the wing will be in anhedral configuration as shown in Fig.3 (c). Thus making a simple setup and serves the objective.

Static Mechanism (Version 4)

The proposed servo powered mechanism is built to incorporate in any UAV to change its dihedral angle in-flight, which requires testing, and critical analysis. Therefore, to make this change in dihedral angle we also designed a static mechanism wherein the wing configurations can be changed without a servo. We designed 3D printed block, which has three parts i.e. top, bottom and middle part. The top and bottom part is fixed to the fuselage and holds the middle part. Again, the middle part is made up of two sections top and bottom. The three wing configurations can be changed by changing these middle parts. The straight wing middle part just has a hole where the ball joint is placed as shown in Fig.4 (a). The middle parts for the dihedral and anhedral has the hole according to the dihedral angle as shown in Fig.4 (b) and (c). The middle parts can be changed according to the requirements.

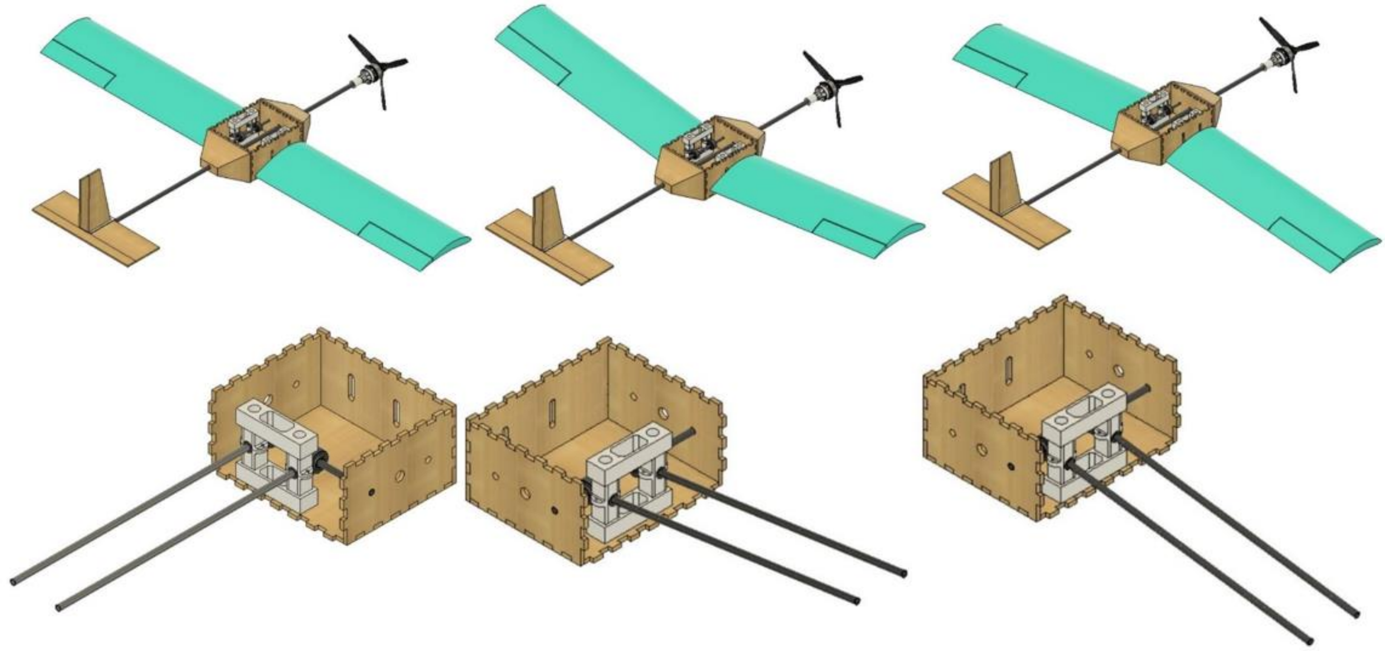

Figure 4: Static Mechanism (a) Straight Wing, (b) Dihedral Wing and (c) Anhedral Wing

a b c

V. Results and Discussions

ANALYSIS OF DIFFERENT WING CONFIGURATION

1. *Geometry:*

A 3D wing of accurate dimensions is modelled in CATIA v5. For the analysis of wing ANSYS WORKBENCH FLUENT is chosen. 3D geometry is imported into design modeler. A suitable domain is created and Boolean operation is used to separate wing from domain. Domain geometry are shown in Fig.5.

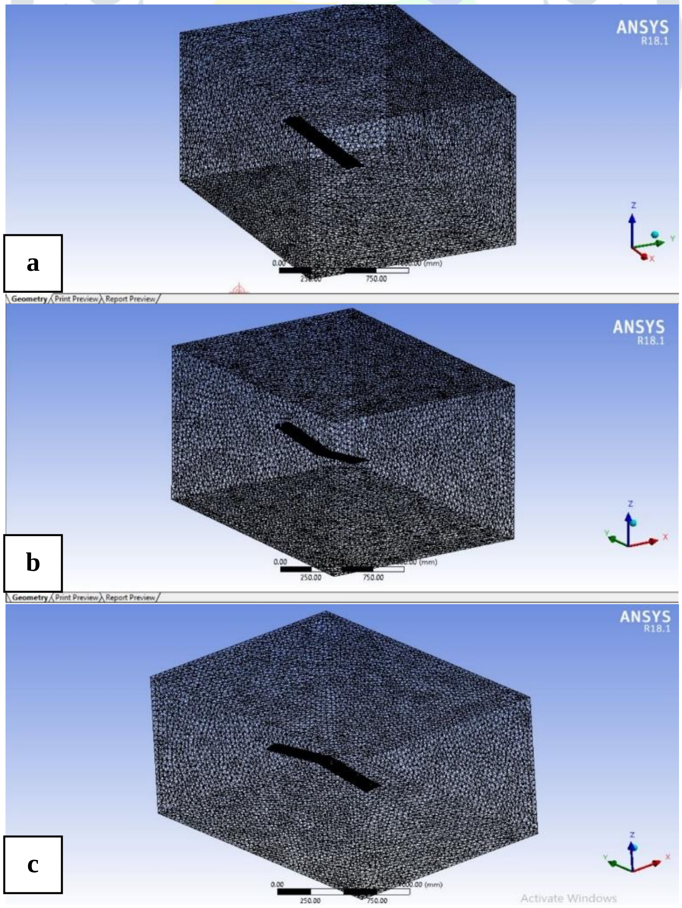

Figure 5: Geometry of wing and domain in Ansys Design Modeler (a) Straight Wing, (b) Dihedral Wing and (c) Anhedral Wing

2. *Meshing:*

The geometry is appropriately meshed for better results by controlling mesh sizing on wing. The meshed geometry is shown in figure 6. Also inlet, outlet, walls and airfoil are named accordingly.

Type of mesh elements = Tetrahedron.

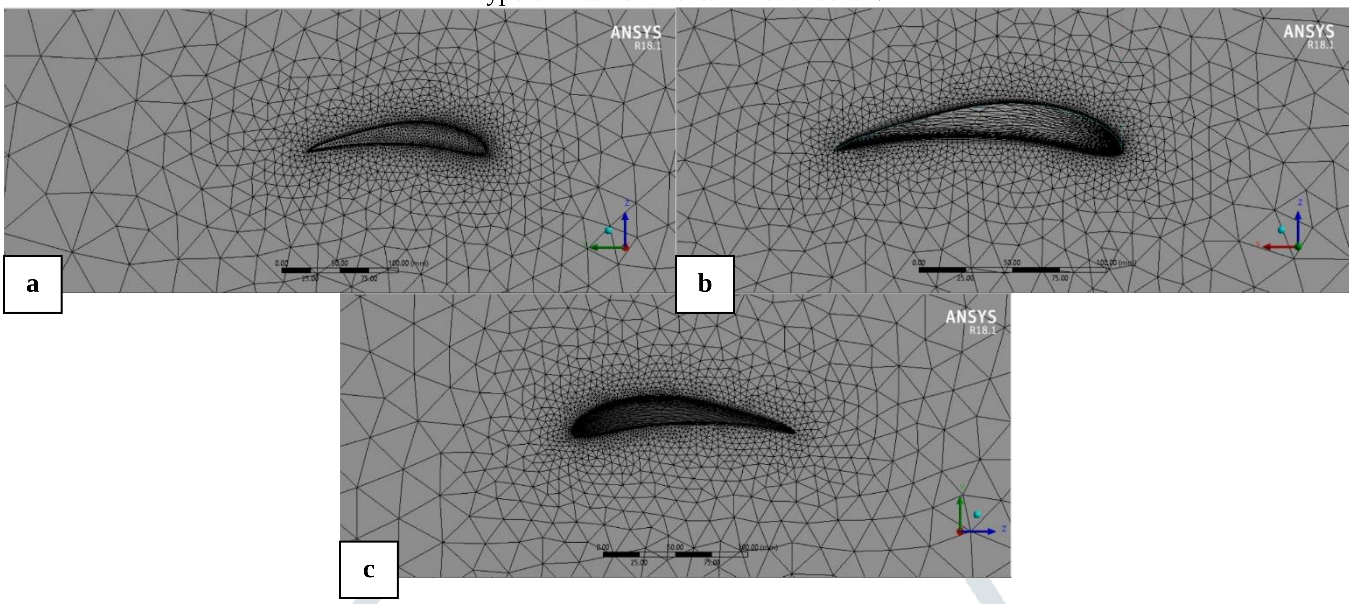

Figure 6: Meshed geometry of (a) Straight (b) Dihedral wing (c) Anhedral wing.

3. *Analysis :*

ANSYS Fluent solver with double precision is used to analyse flow over wing.

- Model: Spalart Allmaras equation model.
- Inlet velocity: 13m/s.
- Outlet pressure: 0 Pa.
- Wall: Stationary and no slip condition.

Residual reports of lift coefficients and drag coefficients are obtained.

4. *Results:*

Pressure contours, lift and drag coefficients and also lift and drag force are obtained and displayed in Fig.7 and table 1 .

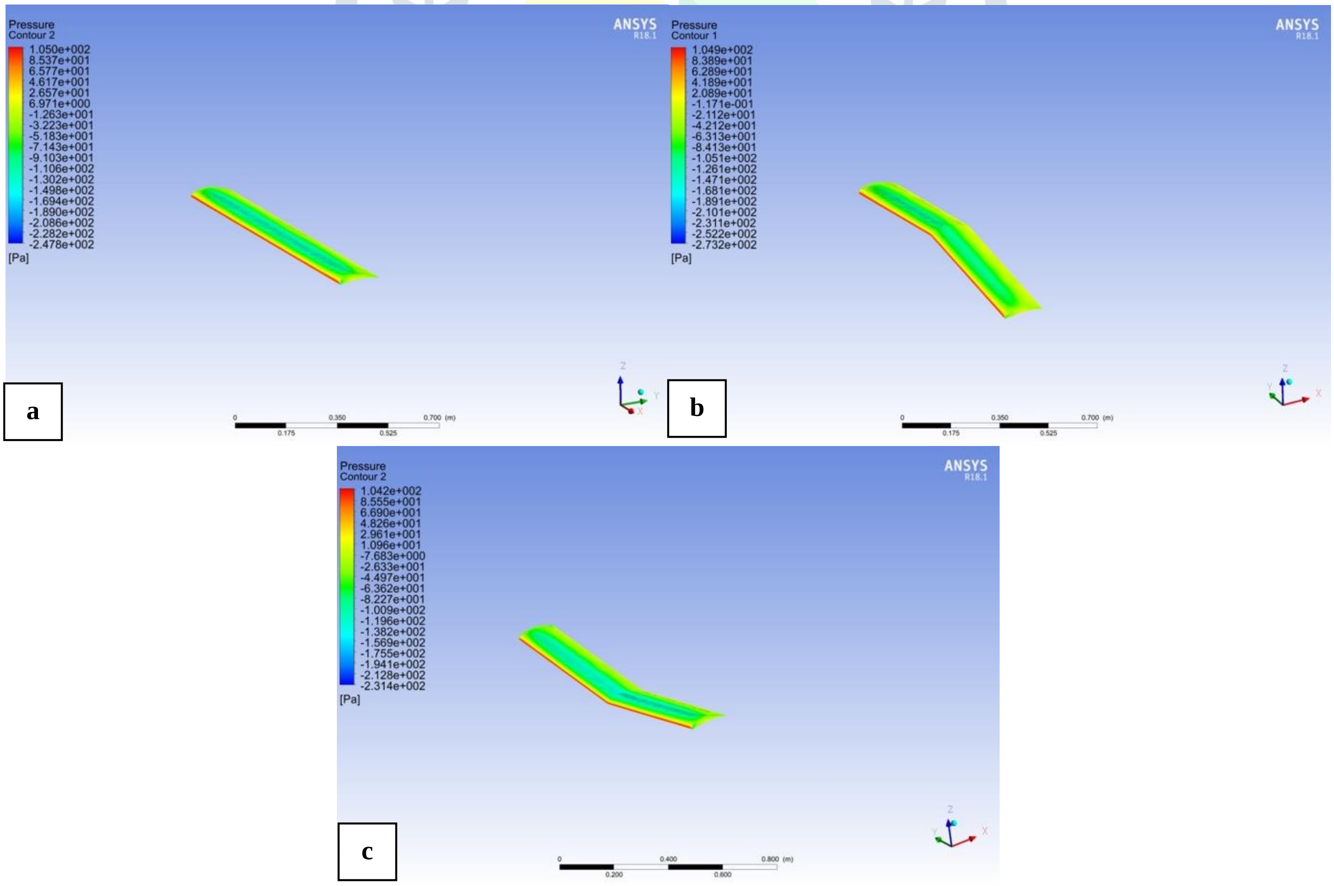

Figure 7: Pressure contour of (a) Straight wing, (b) Anhedral wing and (c) Dihedral wing

Table 1: Recorded analysis results

Parameter	Straight wing	Anhedral (8 deg)	Dihedral (8 deg)
Domain volume	5.0335m^3	5.4157m^3	5.4m^3
Surface area	18.627 m^2	19.43 m^2	19.388m^2
No of elements	1504004	1501099	1525190
No of nodes	357196	359133	365358
lift coefficient Cl	0.1176	0.1049	0.1032
Drag coefficient Cd	0.0116	0.0116	0.0116
Cl/Cd	10.13	9.04	9.38
Lift force	12.178978 N	10.859993 N	10.683976 N
Drag force	1.208589 N	1.201463 N	1.209817 N

The Cl /Cd values of 2 dimensional E423 airfoil was found to be nearly 11 at 0 deg AOA. The above results in the table 1 indicate that the wing has sufficient lift force in all the three wing configurations.

VI. Conclusion

Dihedral and anhedral convertible wing gives liberty to adjust the effective dihedral effect on the aircraft by changing the wing configuration. The variable stability of the aircraft give roll stability and roll maneuverabilty which improve performance of the aircraft in all weather conditions. Different wing configurations were analysed on ANSYS and the results obtained justifies that the lift is sufficient for the aircraft. The Servo Powered Direct mechanism adopted in our project is simulated and the effective deflection of wing is found to be 8 degrees for 10 degrees of servo input. The results from analysis is similar to two dimensional values of E423 airfoil data at zero angle of attack.

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