Primary Morphing Mechanism for Enhanced Flight Performance

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Abstract - *The inefficiency of the conventional airplane wing poses hinderances during the time of variable flight operations, as they are designed taking into consideration only a single mission capability, which often can't achieve a favorable wing configuration for various other objectives. The main intent is to design a morphing wing, that improves the aerodynamic properties of the plane under various flight conditions without incorporating complex and bulky actuator systems, which are used in conventional variable geometry wings. The wing proposes its capability of morphing camber to change its coefficient of lift and coefficient of drag.*

Key Words: Morphing, camber, airfoil, empennage, fuselage

1. INTRODUCTION

The morphing wing is designed to be 'adaptive', which means exhibiting its 'shape-shift' trait seamlessly and autonomously during flight without slots or steps on wing surfaces, to minimize the possible impacts on the aerodynamic drag, using a control system with an indirect intervention by the pilot. The intent of this system is to enable the aircraft fly efficiently in a broader range of scenarios and ultimately increase its flight duration and stability.

2. LITERATURE REVIEW

The primitive concept of conventional fixed wing airplanes is to induce lift and an amalgamation of elevator, ailerons and rudder. A thesis by Khoo Hock Hee, et. Al. showcased the possible iterations and an elaborative approach which needs to be instituted for airfoil profile adjustment. Another literature by Daniel P. Raymer, et. Al. was referred for the basic aerodynamic computation. A plethora of ideas delivering extensive propositions from were found that highlighted the morphing's working mechanism and its eloquent deliverable characteristics. A need of an immaculate design was needed which had to be in accordance with the peculiar aerodynamics traits. It is important to necessitate a continuous and smooth air flow and its delay at the specific flight operations to enhance its lift and stall characteristics.

3. METHODOLOGY

An elaborative engineering process was inducted which was unremitting to tone the desired prodigious results. A margin to make necessary amendments and improvise them persistently was kept, giving us a leverage to finely tune-up the results. The design considerations weren't confined to design a morphing wing; instead design it in accordance with the possible failures it might encounter such as failure in wing sweep angle change, control surface morphing and curving of the material around the morphed region.

4. DESIGN APPROACH

4.1 Wing Planform and Airfoil

The selection of wing planform was done on the basis of a holistic research to achieve the best possible wing configuration. As the intend was to introduce the morphing mechanism, a rectangular wing planform was selected.

In order to meet the requirement of semi-symmetrical airfoil with almost flat base, the research for an airfoil with low Reynolds number and high lift producing traits was carried out.

Parameters	goe629-il	boe106-il	boe103-il	rg15a213-il
C_L Max	1.4	1.51	1.43	1.41
Stall Angle	17	15	15	15
C_L/C_D	70	72	73	69
C_D Min	0.015	0.013	0.008	0.016
Camber (%)	2.80	3.30	3.60	2.50
Thickness (%)	13.60	13.10	12.70	13

Table-1: Airfoil Comparison

The empty weight of the plane was assumed to be 2000gm.

$$Wing\ Area = \frac{Weight}{Wing\ loading} = \frac{2000}{0.404} = 4950\ cm^2$$

Wing loading is the underlying idea as it gives the dissemination of load over the wing. As per the kind of specific airplane which is classified as glider, wing loading of around 9 to 16 oz. /sq. ft. is recommended.

$$Wing\ Loading = \frac{Weight}{Wing\ area} = \frac{2000}{4950} = 0.4040\ gm\ /cm^2$$

0.4040 gm/cm^2 = 13.2393 oz./sq. ft, which is in the range of 9 to 16 oz. /sq. ft.

For good gliding characteristics, an aspect ratio of 7.9 was selected.

$$L = \frac{1}{2} \times \rho \times v^2 \times C_L \times S_W$$

which gives us C_L as 0.873

Now,

$$Aspect\ ratio = \frac{(wing\ span)^2}{wing\ area}$$

which gives us wing span of 198 cm.

Also,

$$Aspect\ ratio = \frac{span}{chord}$$

giving the chord length as 25 cm.

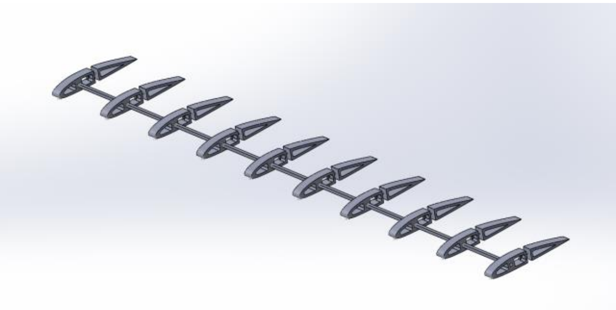

Fig-1: Wing – CAD

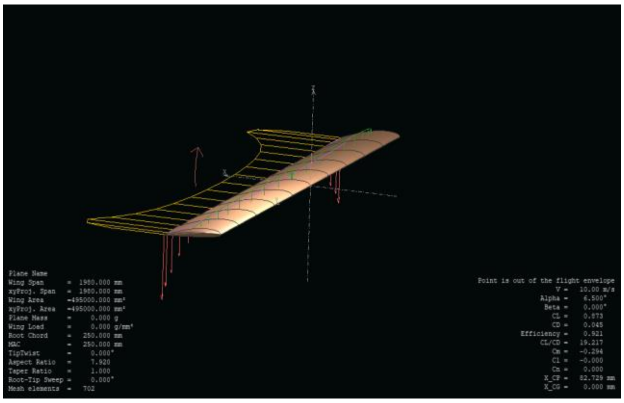

Fig-2: Wing Performance

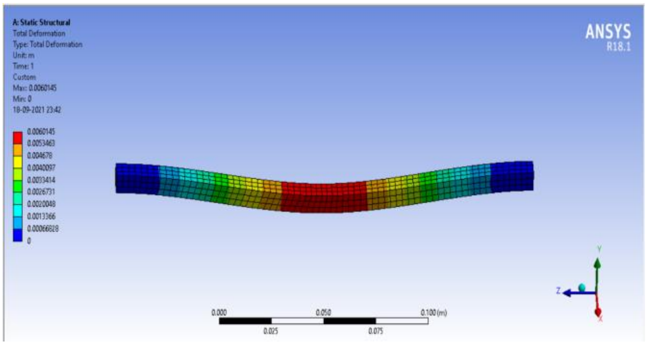

Fig-3: Spar - Total Deformation

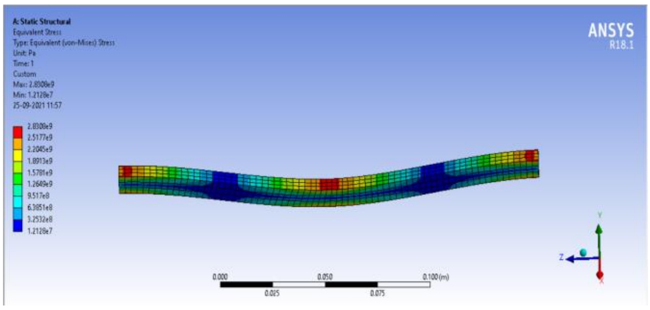

Fig-4: Spar – Equivalent (Von-Mises) Stress

4.2 Fuselage

To diminish drag, the fuselage was planned fit of airfoil. NACA0015 was utilized to frame the fuselage. Tail boom was utilized to associate horizontal and vertical stabilizer with the fuselage. The fuselage was designed 44c m in length, having a width of 18 cm. To take into account the sturdy and lightweight aspect, acrylic sheets were used to frame it.

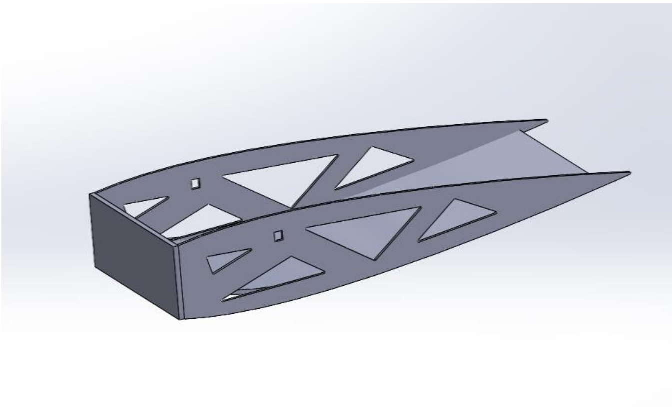

Fig-5: Fuselage - CAD

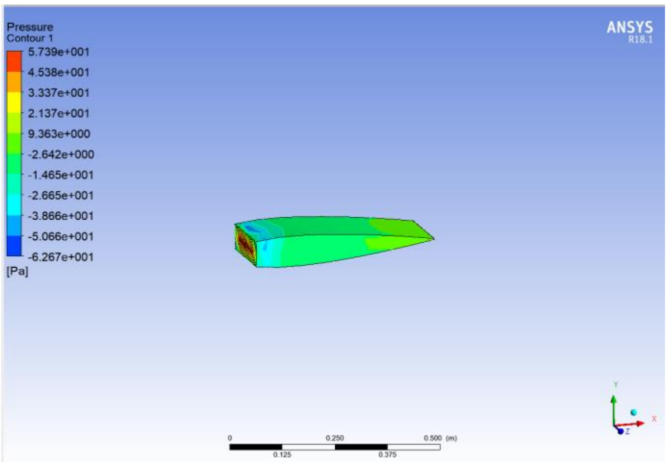

Fig-6: Pressure Contour

Forces - Direction Vector (0 1 0)

Zone	Forces (n) Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wall-surrounding_flow_channel	0.01144951	-0.00055676437	0.010892746	0.018693078	-0.00090900305	0.017784075
Net	0.01144951	-0.00055676437	0.010892746	0.018693078	-0.00090900305	0.017784075

Fig-7: Drag Table

Forces - Direction Vector (1 0 0)

Zone	Forces (n) Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wall-surrounding_flow_channel	0.39917141	4.3955393	4.7947107	0.65170843	7.1763907	7.8280991
Net	0.39917141	4.3955393	4.7947107	0.65170843	7.1763907	7.8280991

Fig-8: Lift Table

4.2 Empennage

The main functionality of the empennage lies in the fact to provide stability to the aircraft during level flights. Along these lines, the empennage was calibrated which gave sufficient soundness and control to the airplane. A conventional structure of a tail-boom format was adopted.

The area of the stabilizers was computed using the following formulas,

For horizontal stabilizer:

$$V_H = \frac{S_H \times L_H}{S_W \times MAC}$$

For vertical stabilizer:

$$V_V = \frac{S_V \times L_V}{S_W \times W_S}$$

The neutral point was calibrated using the following formula,

$$\frac{X_{np}}{c} \cong \frac{1}{4} + \frac{{}^{2}/_{AR}}{1 + {}^{2}/_{AR_h}}\left(1 - \frac{4}{AR+2}\right) V_h$$

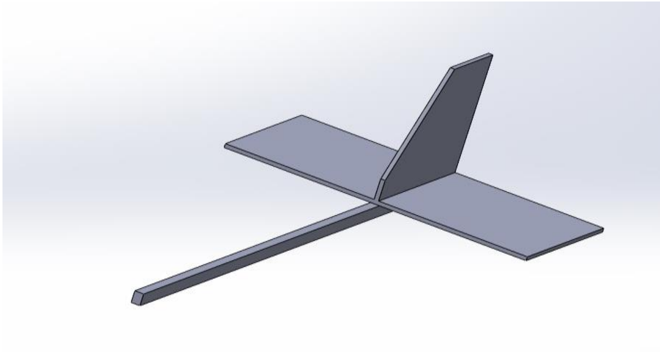

Fig-9: Empennage - CAD

5. Variable Camber Orientations

To alter the aerodynamic properties such as coefficient of lift, coefficient of drag, efficiency, the following main configurations were instituted:

1. Normal Camber Orientation
2. Semi-Negative Camber Orientation
3. Negative Camber Orientation
4. Semi-Positive Camber Orientation
5. Positive Camber Orientation

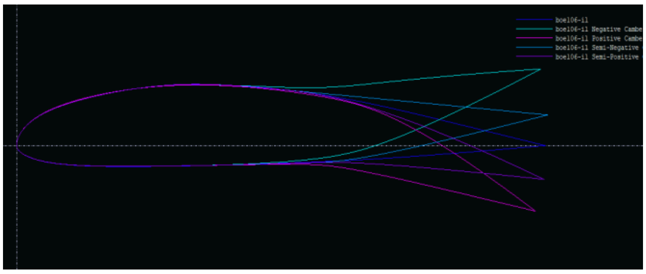

Fig-10: Vivid Camber Orientations

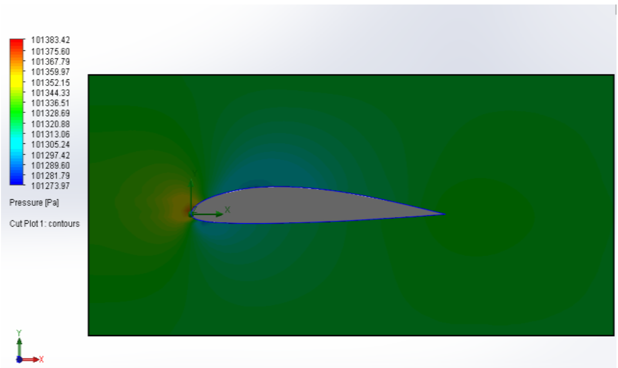

Fig-11: Normal Camber Orientation (Pressure Contour)

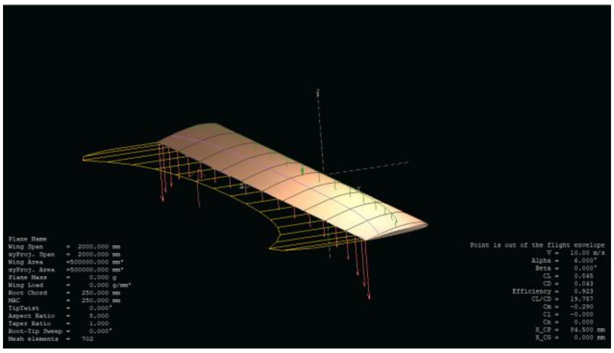

Fig-12: Normal Camber Orientation (Profile performance)

As the progression moves from normal configuration to Positive Camber orientation, a drastic change in the C_L and C_D can be noted. When wing is configured to its semi positive configuration, a constant high lift is obtained. This configuration can be used while flying with a higher payload.

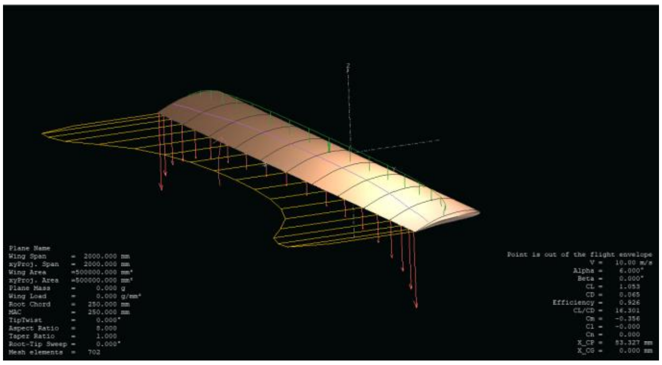

Fig-13: Semi-Positive Camber Orientation (Performance Profile)

Every iteration of the wing's position had a different impact on flight profile. As the more positive camber was introduced, more lift was generated with a slight induction of drag. Such a condition is suitable when the wing's orientation adheres to a higher limit of the angle of attack of the airfoils. When wing is configured to its positive camber configuration, maximum lift is produced by the wing, but this is not an ideal flying configuration as efficiency of wing is reduced. This flying condition can be implemented only in certain flying conditions like take off and used with ailerons while rolling.

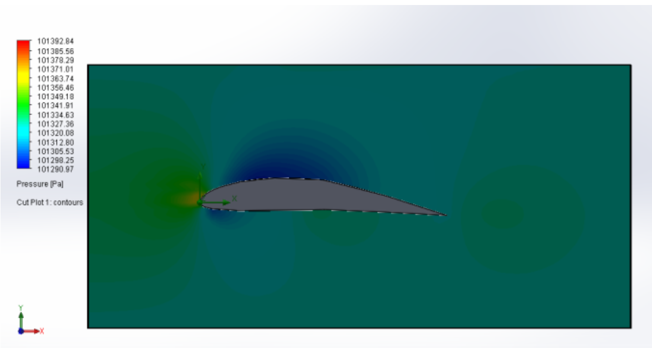

Fig-14: Positive Camber Orientation (Pressure Contour)

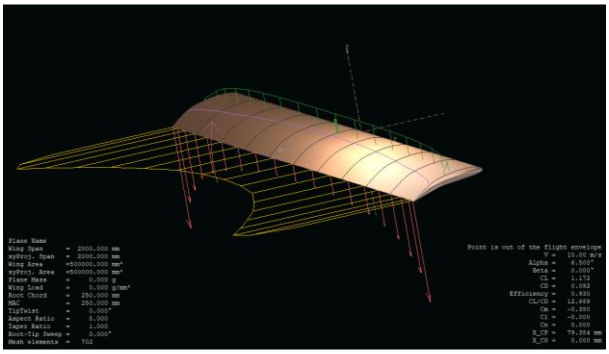

Fig-15: Positive Camber Orientation (Profile Performance)

In conjunction to it, negative camber yielded the results suitable for instances like turbulent cross-wind during take-off or landing. A highly responsive orientation would be correct to name this particular configuration. When wing is configured to its semi negative configuration, a constant low lift is obtained. This is not an ideal condition to fly the plane.

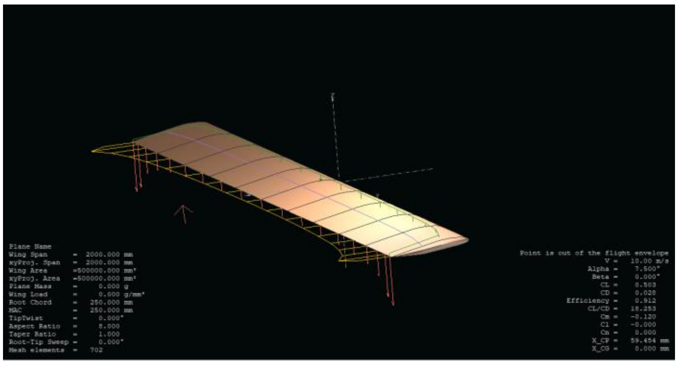

Fig-16: Semi-negative Camber Orientation (Performance Profile)

When wing is configured to its negative configuration, a negative lift is obtained on the wing surface. This is not a flying condition. This is used to stop the plane while landing. Negative lift helps plane overcome ground effect by producing negative lift. This is also the position used with ailerons while rolling.

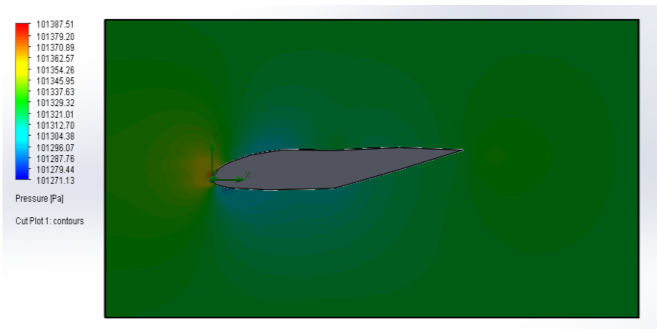

Fig-17: Negative Camber Orientation (Pressure Contour)

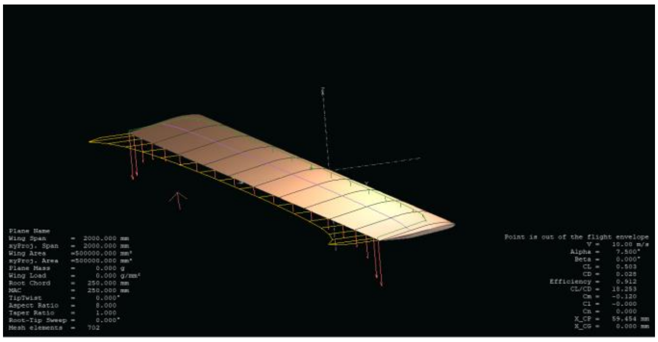

Fig-18: Negative Camber Orientation (Performance Profile)

XFLR5 was used to study the behaviour of various wing configurations and obtain relevant data. From the data obtained it is seen clearly that efficiency of each configuration is different and can be used for different flying conditions. C_L/C_D vs Alpha graph shows that positive camber configuration is not efficient for longer use. Hence it can only be used in specific flying conditions. While graph of C_L vs Alpha shows that Positive camber configuration produces maximum lift but cannot be declared highly optimum. Similarly graphs of C_L vs C_D, C_M vs Alpha are also obtained.

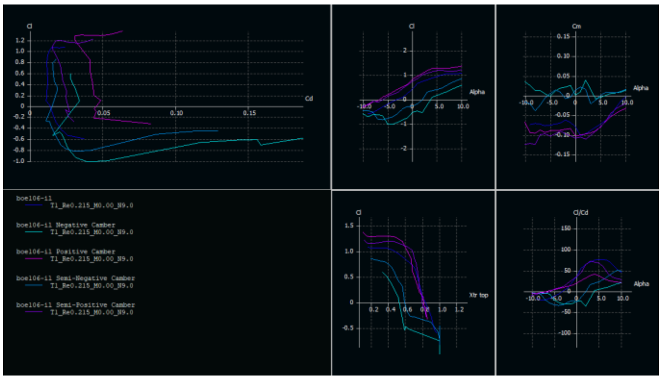

Fig-19: Comparative Graphical Analysis

5. Morphing Mechanism

An airfoil was parted from focus in two sections, leading edge and trailing edge. A servo motor was put in leading edge airfoil which incites the following edge of airfoil by means of an associating pole, and both the edges are joined by a pivot hinge. Entire wing was equipped with airfoil having such similar configuration for transforming its camber without a moment's delay or can transform at individual airfoil positions to improve performing wing efficiency for that particular application.

Signal is received by a 2.4GHz receiver which is a six-channel receiver. Rudder, elevator and ailerons are connected to the flight stabilizer while throttle data pin is connected is directly connected to Arduino. The elevator output channel of the flight stabilizer is directly connected to servo actuating rudder. The aileron output channel of the flight stabilizer is connected to the Arduino Mega. The rudder and elevator channels are connected to their respective actuators and hence the servo motors from the wing are connected to the Arduino. The channel 5 from the receiver is directly connected to the Arduino, such that the wing configurations can be selected manually.

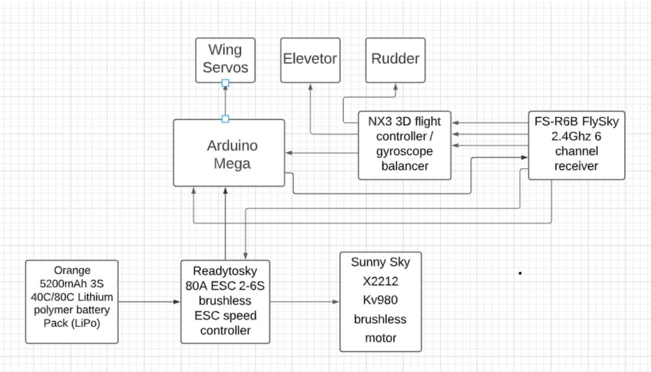

Fig-20: Control Circuitry

6. Avionics

6.1 BLDC Motor

By calculating the required thrust, selection of BLDC was done. It was done on the basis of power output produced by motor.

$$Power = force \times velocity$$

For a 3-cell battery and voltage of 11.1V,

$$RPM = kV_{rating} \times Voltage$$

kV rating of 980 was selected which produced the RPM of 10,878 at 11.1V.

$$Power = Thrut \times Velocity$$

$$Power = Voltage \times Current$$

Therefore, the maximum current drawn from the motor was 29 A.

6.2 Servo Sizing

Servo motors are utilized to control the control surfaces of the plane. The chosen servo motor ought to give adequate force. Servo engine of 9gm was chosen for flight which was promptly accessible in showcase and can likewise support during flight.

Therefore, the maximum current drawn from the servo was 2.5 A.

6.3 ESC Selection

Total current drawn from the circuit is about 62 A. Considering safety factor and overloading of ESC, higher rating ESC ESC of 80 A was selected as selected.

6.4 Battery Selection

The battery was chosen based on schedule of flight and release rate needed by the engine and other aeronautical applications. By keeping edge of security. Flight time of 5 minutes was assumed.

$$\text{mAh} = \frac{\text{time of flight} \times \text{current} \times 1000}{60}$$

mAh rating of battery was calculated to be around 5000 mAh, but for safety purpose battery of 5200 mAh was selected.

7. Conclusion

The characterization of the conventional wing into a morphing instituted static, dynamic and control stability by improvising its aerodynamic traits and proved to be compressive and sustainable. The subsequent results obtained from the iterative research procedure bolstered up the affirmation, thereby instituting morphing as flawless variable geometry.

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