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Design and Analysis of UAV for High Payload

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Abstract*: *This project presents design process for a medium range unmanned aircraft. The objective is to design an aircraft which carries high payload with restricted wing span. The project deals with study of various innovative techniques to improve the aerodynamic performance of the aircraft. It emphasizes on usage of box wing technology after considering various aspect of design and fabrication. The design process involved is a conventional design cycle with initial sizing and trade studies followed by analysis for the validation of the design. The study of the downwash and effect of the stagger angle due to two wings on their aerodynamic performance was also carried out. Flow analysis for the required conditions of cruise is performed and had shown that the lift is sufficient and drag is slightly high. For the applied loads the structure designed has stresses within the limits of the structural integrity. The propulsive force required was comparatively high when compared to single wing of same area.

Keywords: Unmanned Aircraft, Box Wing, Aerodynamic Performance, Payload.

I. INTRODUCTION

The UAVs are unmanned aerial vehicles capable of carrying out the required operation without an onboard pilot. The pilot will be located in a remote place from which he can control the aircraft through the communication and flight control systems. These UAVs can be classified into various categories based on size, mode of operation, mode of communication, type of propulsive systems, etc. The use of UAVs to carry more payloads and for higher ranges and endurances is increasing day to day. Hence there is a need to develop an aircraft which operates as per the requirements.

A. Objectives

The primary objective of the design is to develop a UAV which can be carry high payload[5]. The second objective is wing span must be less such that it can land and take-off at with lesser space requirement.

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B. Scope of the work

The UAV developed shall be used in agricultural sector as pesticide spraying and can also be used as an option for Medical purpose when ever required

II. METHODOLOGY

The design process is a cyclic process which involved various phases. Design process employed to develop the UAV is given in the Fig. 1 below

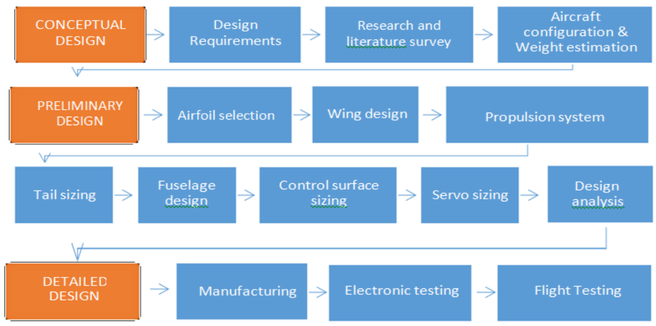

Fig. 1.Design Process

The design process started with the mission profile which gives the information of the operation of the UAV. The mission profile is given below in Fig 2.

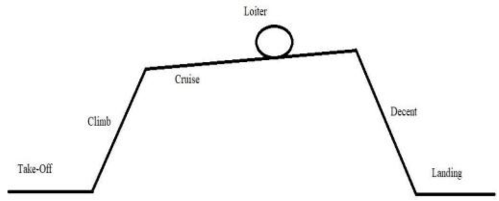

Fig. 2. Mission Profile

III. DESIGN

An approximate weight of the total aircraft is calculated based on the payload it has to carry. The details of the components and the materials used to predict the weight of the aircraft are given below in Table I

Table- I: Initial weight estimation

S.No	Component	Weight (gm)
1	Motor	350
2	Propeller	40
3	Servos	220
4	Servo Extensions	10
5	Empty weight (full structure)	2100
6	Adhesive	100
7	Payload	2800
8	Landing gear	250
9	Hinges	10
10	R/C Receiver with Antenna	10
11	Li Battery 6-cell including ESC	1100
TOTAL		6990
		6.99kg

A. Airfoil Selection

The selection of the Airfoil for an aircraft's wings is a crucial component to ensuring the aircraft's performance is good[4]. Team researched and analyzed the available Airfoil databases selected MH-114 airfoil based on manufacturability and performance requirements such as moderate stalling angle, high maximum lift coefficient and aerodynamic efficiency.

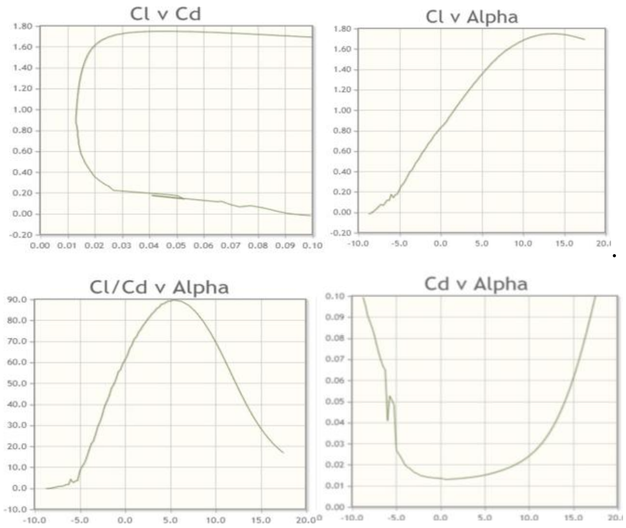

Fig. 3.Airfoil performance curves

B. Wing Loading

It is an important parameter for an aircraft which emphasis on the performance of the aircraft and sets the limitation of the operation and helps in structural design[2]. A plot between Wing loading and the stall speed is plotted as below.

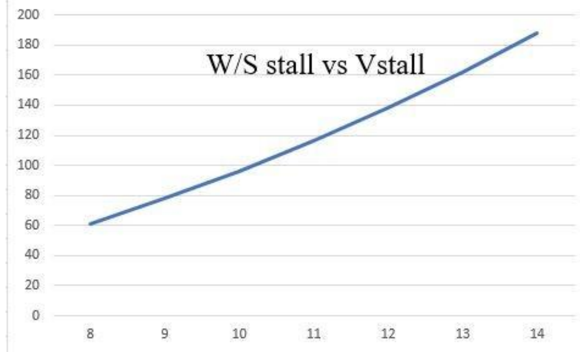

Fig. 4. Graph between wing loading V/s Stall speed

C. Tail Sizing

The following equation[3] was used to determine the surface area of the stabilizer and necessary parameters was taken from historical data. From the trade studies, moment arm length is 0.88m.

$$S_{vt} = \frac{C_{vt} b_w S_w}{L_{vt}} \qquad S_{ht} = \frac{C_{ht} b_w S_w}{L_{ht}}$$

Table-II: Horizontal and Vertical tail dimensions

Horizontal Tail		
Horizontal Surface area (S_{HT})	0.1071	m²
Span (bh)	0.6545	m
Chord (ch)	0.1636	m
Aspect ratio (AR_H)	4.0	
Moment arm length (L_{HT})	0.88	m
Vertical Tail		
Vertical Surface area (S_{VT})	0.059	m²
Span (b_v)	0.3762	m
Chord (c_v)	0.1567	m
Aspect ratio (AR_V)	2.4	
Moment arm length (L_{VT})	0.88	m

D. Control Surface Sizing

Sizing of the control surface was done based on the available moment arm and tail area. The torque requirements were also calculated. The torque required values for each control surface are given in table

Table-III: Torque requirements

Control Surface	Torque Required (N-m)
Aileron	0.5986
Rudder	0.4887
Elevator	0.4059

Servo motors which can give more than the required torque were selected.

E. Thrust generated

The minimum thrust required for the model is taken from the drag forces that the model creates. But considering the losses and atmospheric conditions, the T/W ratio is chosen in between 1 and 1.3. This excess thrust is helpful at the take-off conditions and while taking turns. The drag forces caused by the model in cruise is 19N so the minimum thrust required is 1.4 times the drag forces.

The Fig. 5 shows plot between the required RPM of the motor and the thrust generated by the propeller with varying pitch angles.

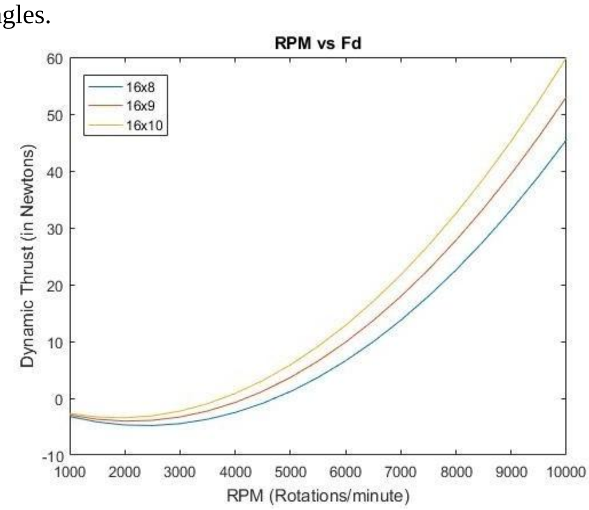

Fig. 5.Power plant matching

F. Power Plant Matching and Power to Weight Ratio (P/W)

The maximum power to weight ratio calculated for the proposed motor is 0.7 where as required is only 0.5. Thus, making it an over powered aircraft. 30-50%.

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The additional thrust is required to maneuver the aircraft and almost all the UAV's operate at 80% instead of using 100%. Being excess powered, the aircraft can easily fly.

The power plant matching gives a detailed note of the propulsive requirement with that of the max speed of the aircraft. The Power plant matching curves for each mission segment are plotted in the graph below.

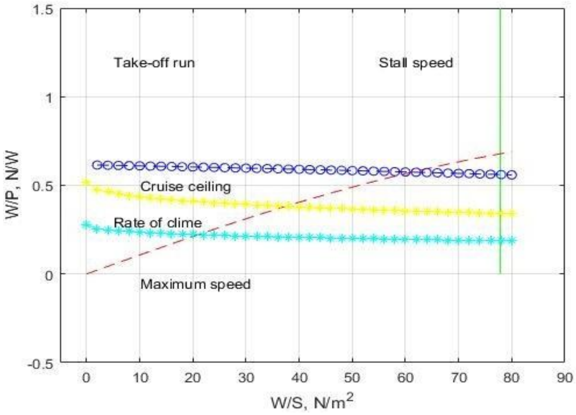

Fig. 6.Power Plant Matching

G. Landing and Take-off performance

The take-off and landing distance are calculated based on the relation suggested by D P Raymer[1]. The Take-off and landing parameters are given in table below.

Table-IV: Landing and Take-off parameters

Parameter	Value
Take-off Speed (V_{TO})	10.8m/s
Touch-Down Speed (V_{TD})	11.07m/s
Friction co-efficient(μ)	0.04
Approach velocity	11.7m/s
Takeoff distance	16.32 m
Landing distance	22.13 m

IV. MODELING AND ANALYSIS

A. Modeling

A 3D model was developed in Autodesk Inventor which has to be simulated for both structural and Fluid Flow analysis. The model created in inventor is given below in Fig. 7

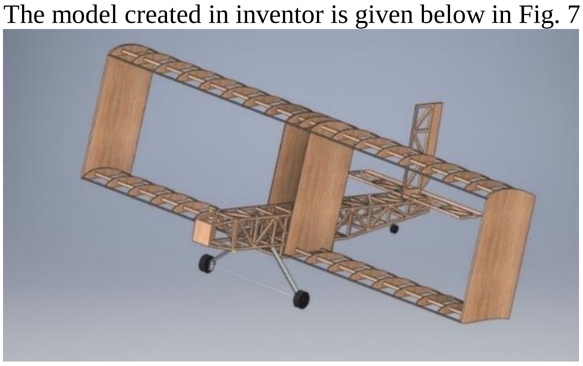

Fig. 7.Model generated in Autodesk

B. Fluid Flow Analysis

Flow analysis was carried out on complete aircraft to check its aerodynamics performance at given conditions. The flow Mesh properties are given below in Table V

Table-V: Mesh parameters

Parameter	Value
Total Nodes	2053732
Total Elements	10251223
Fluid Elements	10162416
Solid Elements	88807

The model meshed is given below in Fig. 8

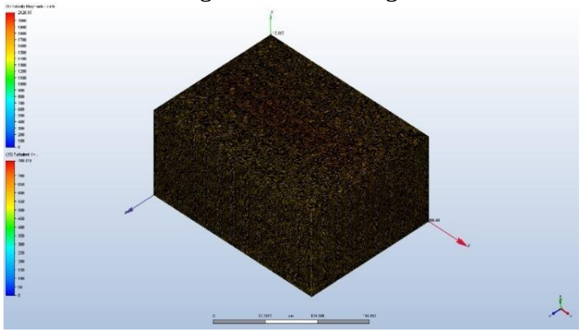

Fig. 8.Meshed model for CFD Analysis

C. Structural Analysis

Structural analysis of individual components of the aircraft is performed. Autodesk-Inventor was used to analyze the structural integrity of all the components prior to the construction. A fine mesh with quad elements of minimum edge length of 2.54cm is considered for accurate results. Static load tests were carried out on wing with ribs, spars and trussed structures by applying a distributed load along the lower portion of the wing, with the innermost rib fixed in place to simulate the effect of fuselage integration. Material selected is balsa wood and aluminum for spar which has isotropic elasticity by nature and its properties are given in table below.

Table-V: Material properties

Material / Properties	Balsa	Aluminum
Young's modulus (Psi)	0.44e6	1.015e7
Poisson's ratio	0.38	0.33
Density(gm/cm3)	0.13	2.7
Shear Modulus (Psi)	0.33e6	3.771e6

V. RESULTS AND DISCUSSION

The results obtained from each of the analysis were interpreted to check for the validity of the initial sizing values.

A. Flow Analysis

The results obtained from flow analysis indicate that the drag is slightly above that of the drag calculated from initial sizing. The results of drag are plotted in the Table below

Table-VI: Drag contribution of each structure

S. No	Model	Drag Force (N)
1	Wing	7.36
2	Fuselage	2.54
3	Empennage	0.91

4	Power plant	5.41
5	Landing gear	8.42
	TOTAL	**24.64**

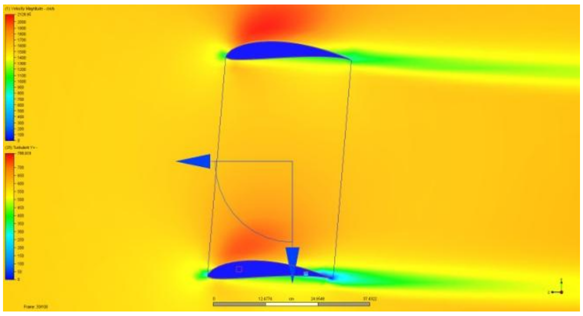

Fig. 9.Contours Of Static Pressure

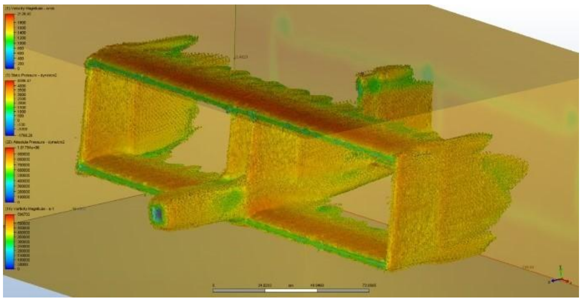

Fig. 10. Contours of Vorticity and Turbulance

B. Structural Analysis

The most crucial loading conditions were assumed corresponding to total distributed pressure of about 0.080psi. The results indicated that the wing is fully capable of carrying anticipated flight loads. Also, the maximum stress was distributed over the length of the aluminum Spar, which has much higher yield strength than the balsa wood components. The contours of wing stress distribution and deflection are shown below in Fig. 11 and Fig.12 respectively.

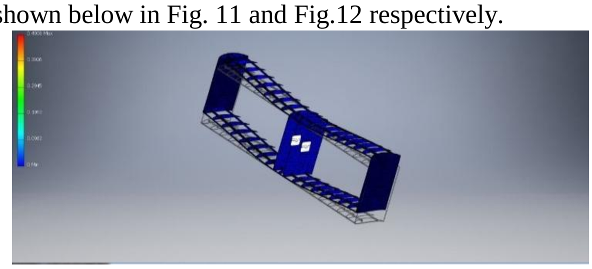

Fig. 11. Contours of wing stress distribution

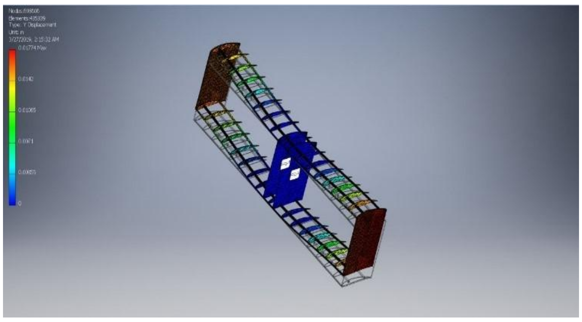

Fig. 12. Contours of wing deflection

VI. CONCLUSION

After considering all the aspects and analyzing the results obtained, it can be stated that the model is well capable of lifting a payload not less than 2.5 kgs. The model can be operated for a time period of 20 min with a 6000 Mah battery. The final model produced will be as gicen below

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