Design and Development of Reconnaissance Un- Manned Aerial Vehicle

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ABSTRACT

Un-manned aerial systems are advancing around the world and expanding into various sectors far beyond what was imaginable 10 years ago. With the advancement of lightweight mate- rials and efficient manufacturing methods like AM, the possibilities are endless. Drones are no longer used only for reconnaissance and modern warfare missions, but have become an essential tool for photographers, farmers, surveyors and logistics. This paper will explore the integration of materials, manufacturing and fittings for a reconnaissance drone capable of carrying a camera for a rescue operation to be carried out in a flooded area.

Keywords: UAV, CFD, FLUENT, CAD, Modeling.

1. INTRODUCTION:

UAV stands for Unmanned Autonomous Vehicle, indicating a self-governing and intelligent technology capable of making independent decisions [1,2]. The introduction of artificial intelligence in the 1980s and 1990s led to the exploration of automated systems, allowing machines to mimic human behavior by sensing their surroundings and responding accordingly [11]. As a result, efforts have been dedicated to developing autonomous and intelligent UAVs capable of making in-flight decisions. During the cruise phase of an aircraft, four main forces come into play: Weight, Lift, Drag, and Thrust. Weight is the force exerted by gravity, pulling the plane towards the ground [3]. To counteract this force and enable flight, an upward force called lift is generated as the plane moves through the air. Lift is primarily produced by the wings, which have a specialized shape known as an airfoil. The airfoil design creates a pressure differ ence between the top and bottom surfaces of the wing, resulting in an upward force that balances the weight force [4,5]. Drag, another force acting on the plane, is caused by its movement through the air. When objects move through fluids, such as air or water, the fluid exerts a resistance force opposing the motion [4]. This resistance is referred to as drag and must be overcome to maintain a constant forward speed during flight Thrust, on the other hand, is the force generated by the plane's engines. It propels the aircraft forward, counteracting the drag force produced by the air [4]. Different types of engines, such as propellers or jet engines, are used to produce thrust. Propellers rotate and create lift forces, similar to wings, while jet engines accelerate a stream of air with higher speed but lower mass [6].

The momentum imparted to the air is balanced by the momentum added to the plane, resulting in the forward thrust required for flight. A key focus for aero designers is maximizing the aerodynamic efficiency of aerial vehicles. Each component of an aircraft or UAV contributes to the overall drag force, and optimizing the geometry can lead to reduced drag and operational cost savings [5]. Early studies by Max Munk in 1923 examined the impact of the fuselage on pitch stability, while Multhopp later considered the interaction between slender fuselage configurations and wing flow [5]. The airfoil, often referred to as the heart of an airplane, plays a crucial role in lift generation. Research has shown that a 1% increase in the lift-to-drag ratio can enable the same energy to accommodate an additional payload of approximately 2800 lbs [6]. Achieving reliable fuselage aerodynamics, particularly at junctions, is critical for enhancing overall efficiency and reducing drag [7]. A standard aircraft fuselage comprises the nose, cabin, and tail cone, with parameters like nose cone diameter, cabin diameter, and tail cone angle being adjustable for optimization. However, meeting both structural and aerodynamic requirements often proves challenging. Profile improvements sometimes encounter efficiency limitations, which can be addressed through techniques like flow suction, blowing, or the use of passive flow control devices such as vortex generators [5-6].

Numerous drag estimation methods have been developed to improve accuracy, with numerical flow solvers and mesh generation tools being essential for assessing realistic configurations [8]. Recent advancements in low-speed computational simulations have narrowed the gap to experimental results, with differences now below 10% [8].

2. DESIGN REQUIREMENT

Following are the design requirement: -

1. Payload capacity: The UAV should be able to carry a payload, such as a camera or other equipment, while still being able to fly safely and efficiently.

2. Range: The UAV should have a range that is sufficient to cover the required area, while still maintaining a reliable connection with the remote-control system.

3. Stability and maneuverability: The UAV should be designed to be stable and maneuverable to handle different flight conditions and perform specific maneuvers.

4. Durability and reliability: The UAV should be designed to withstand various environmental conditions, such as wind and rain, and be reliable enough to complete the mission without frequent breakdowns.

5. Compliance: The UAV should comply with all applicable regulations and laws governing its operation, including FAA regulations for airspace use and data privacy laws for video recording).

3. MATHEMATICAL CALCULATIONS

3.1 Design Load Coefficient

Load Coefficient (CL) design helps us to choose the airfoil which will at least fulfill our requirement to lift the weight. For our safety margin, the preliminary weight is mul- tiplied with 1.5 times and it incorporates all the losses due to the 3D effect or any ideal conditions taken during the design [9]. CL design will be taken at the cruise speed.

Design Lift = Weight = C_L design × ½ × ρ × V × V × S

$$C_L \text{ design} = W/ \rho \times S$$

Where 'W' is the weight = 5kg =11.02 lbs. x safety factor (1.25) = 13.775 lbs.

q is the dynamic pressure
S is the wing lifting surface area = 5sq.ft
Velocity cruise = V = 15ft/s
C_L design =13.781/2 × 0.0765 × 15^2 × 5

C_L design = 0.3202

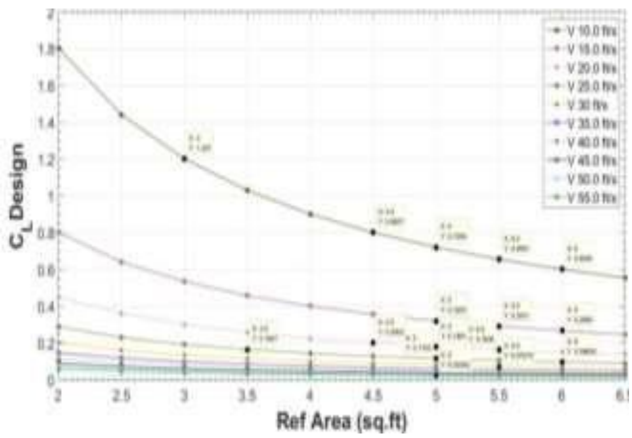

Figure 1: Design Lift Coefficient variation with the reference area at different Velocities.

3.2 Wing Geometry

Root chord: For $\lambda = 1.0$
$b = \sqrt{AR * S}$
$b = 5.612\ ft$
Root chord:

$Croot = 2S/\ b\ (1 + \lambda)$
$Croot = 0.802\ ft$

Mean Aerodynamic chord

$$\bar{c} = \frac{2}{3} C_{root} \frac{(1 + \lambda + \lambda^2)}{(1 + \lambda)}$$

Putting the values, we get

$$\bar{c} = 0.802 \ \text{ft}$$

Location of Mean Aerodynamic Chord from centerline

$$\bar{Y} = \left(\frac{b}{6}\right)\left[\frac{(1 + 2\lambda)}{(1 + \lambda)}\right]$$

$$\bar{Y} = 1.403 \ \text{ft}$$

3.3 Horizontal Tail

The tail of an aircraft counters the moments produced by the wing. Tail sizing is estimated using a historical approach for initial design purposes.

Forces due to tail lift are proportional to the tail area. The tail effectiveness is proportional to the tail area times moment arm and is called the tail volume co-efficient

$$\text{CHT} = \frac{L_{ht} * S_{HT}}{C_W S_W}$$

L_{ht} can be taken as 2.5-3 times of the wing chord thus, confirming the distance compatibility.

Taking $L_{ht} = 2.2456$ ft

$$L_{ht} = 2.2456 \ \text{ft}$$

$$S_{HT} = \frac{0.5 * 0.802 * 4.5}{2.2456}$$

$S_{HT} = 0.804$ ft²

The values for constants for Home built composite are taken as

$$Length = aWo^c$$
$$Length = 3.50 * 11.02^{0.23}$$
$$Length = 6.08 \ ft$$

Horizontal tail span

$$b = \sqrt{AR * S_{HT}}$$
$$b = \sqrt{5 * 0.804}$$
$$b = 2.004 \ \text{ft}$$

Root chord

$$C_{ROOT} = 2 * \frac{S}{[b(1+\lambda)]}$$
$$C_{ROOT} = 2 * \frac{0.804}{[2.236(1+0.4)]}$$

$$C_{root} = 0.572 \ \text{ft}$$

Tip chord

$$C_{tip} = \lambda C_{root}$$
$$C_{tip} = 0.4 * 0.572$$
$$C_{tip} = 0.2291 \ \text{ft}$$

Mean Aerodynamic chord

$$\text{MAC} = \frac{2}{3} * C_{Root} * \frac{1 + \lambda + \lambda^2}{1 + \lambda}$$
$$\text{MAC} = \frac{2}{3} * 0.572 * \frac{1 + 0.4 + 0.4}{1 + 0.4}$$
$$\text{MAC} = 0.4254 \ \text{ft}$$

Tip chord

$$C_{tip} = \lambda C_{root}$$
$$C_{tip} = 0.313 \text{ ft}$$

Mean Aerodynamic chord

$$\text{MAC} = \frac{2}{3} * C_{\text{Root}} * \frac{1 + \lambda + \lambda^2}{1 + \lambda}$$

Putting values, we get,

$$\text{MAC} = 0.5819 \text{ ft}$$

Location of maximum MAC

$$Y = \frac{b}{6}\left(\frac{1 + 2\lambda}{1 + \lambda}\right)$$

Plugging in the values we get,

$$Y = 0.1409 \text{ ft}$$

3.4 Rudders

Rudders again taking the common practices, span is 90% of vertical tail span and

chord is 30 % of vertical tail chord MAC
span = 0.9 ∗ 0.65799
span = 0.5922 ft
chord = 0.3 ∗ 0.5819
chord = 0.1745ft

4. CFD ANALYSIS

Following are the operating parameters for CFD Analysis

Table 1: Operating Parameters for CFD Analysis

Inlet (Velocity m/s)		Outlet	Outflow
Upper, Lower, Left Far Field	Symmetry	Operating Pressure / Temperature	101325Pa / 300K
Fluid	Air (ideal)	Density	1.225kg/m3
Reference Length	0.2m	Kinematic Viscosity	1.7894E-5kg/m.s

4.1 Geometry Formation

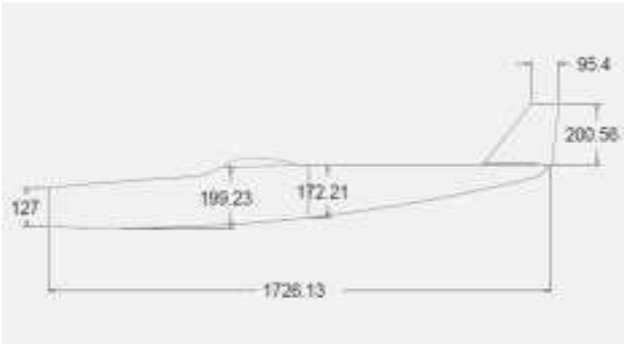

Figure 2: Isometric Side view.

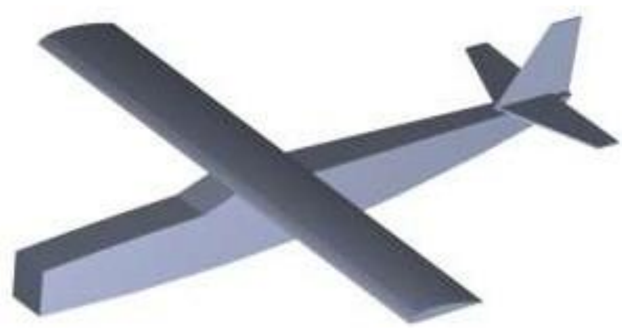

Figure 3: 3D Model of complete design

5. MESHING AND BOUNDARY CONDITIONS

Definition of the good mesh is a mesh which gives good accurate results and con- verges in the least possible time. It is important to locate the critical parts and area and refine only at some particular section of geometry, else mesh size will be reduced un necessarily. Topology of the mesh is also an important factor to define the accuracy. For ex- ample, hexahedral geometry should be preferred over triangular or quadrilateral geometry for better accuracy. Mesh quality can be improved by using smoothening of mesh.

The boundary conditions of the domain are specified as the as default outflow. The temperature (T), density (rho) and kinematic viscosity (μ) are taken from the standard atmosphere (ISA) and are 300K (ambient T), 1.225kg/m3 and 1.7894×10-5 respectively.

6. RESULTS AND ANALYSIS

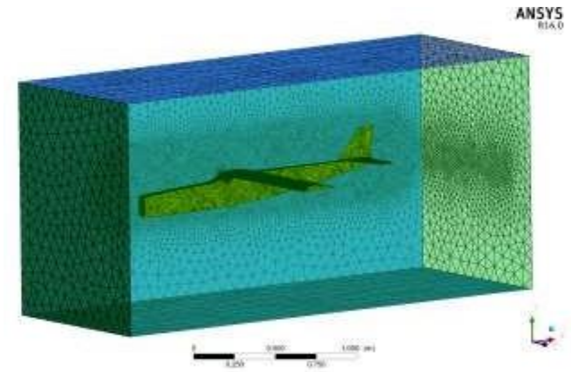

Figure 4: Meshing of design on ANSYS 16.0

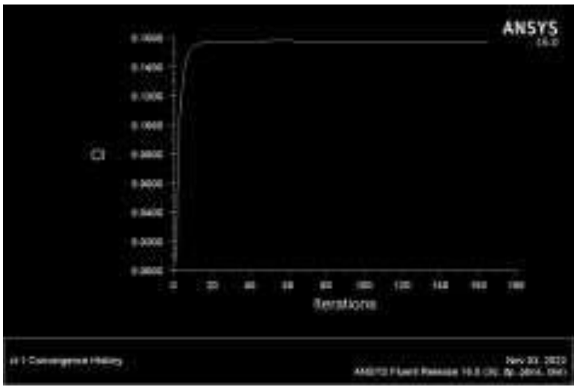

Figure 5: Lift Coefficient

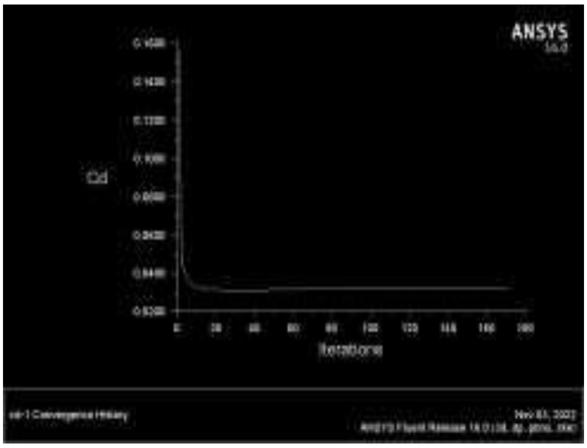

Figure 6. Drag Coefficient

The results for the attained lift coefficient of 0.16 and drag coefficient of 0.4 in this case indicate the aerodynamic performance of the object you analyzed.
o Lift Coefficient (Cl = 0.16): The lift coefficient represents the ratio of the lift force generated by the object to the dynamic pressure of the fluid and the reference area of the object. In your case, a lift coefficient of 0.16 indicates that the object is producing a relatively low amount of lift. This means that the object may not generate significant upward forces and may have a relatively lower ability to generate lift compared to other designs or under different conditions. It's important to note that the lift coefficient can vary based on factors such as the shape of the object, angle of attack, and flow conditions.

o Drag Coefficient (Cd = 0.4): The drag coefficient represents the ratio of the drag force experienced by the object to the dynamic pressure of the fluid and the reference area of the object. A drag coefficient of 0.4 indicates that the object is experiencing a moderate amount of drag. This suggests that there is a significant resistance to the object's motion through the fluid. The drag coefficient can be influenced by factors such as the object's shape, surface roughness, and flow conditions. Reducing the drag coefficient is often desirable in many applications to minimize energy losses and improve efficiency.

Here's an over- view of what these values suggest:

Total Drag will be equal to the drag contribution of all individual components of an aircraft. The breakdown can be given as follows:

Airplane drag = Component drag of "(wing + fuselage + empennage + nacelle + flaps + landing gears + canopy + store + trim + interference + miscellaneous)"

Total Airplane drag is given as;

$$Cd_{ow} = (R_{wf})(R_{ls})(Cf_w)\left(1 + L'\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right) Swet_{wing}/S$$

Where, R_{wf} is wing to fuselage interference factor, R_{ls} is lifting surface correction factor, C_{fw} is turbulent flat plate friction coefficient and L’ is the Airfoil thickness location parameter.

6.1 Zero Lift Drag of Wing

$$Cd_{LW} = \frac{Clw^2}{\pi Ae} \quad 2\pi.\, Cl_w \varepsilon_t v + 4\pi^2(\varepsilon_t)^2 w$$

Total Wing drag

Total drag of the wing can be calculated as

$$Cd_W = Cd_{oW} + Cd_{LW}$$

Putting the values calculated above,

$$Cd_W = 0.0117 + 0.0037 = 0.0309$$

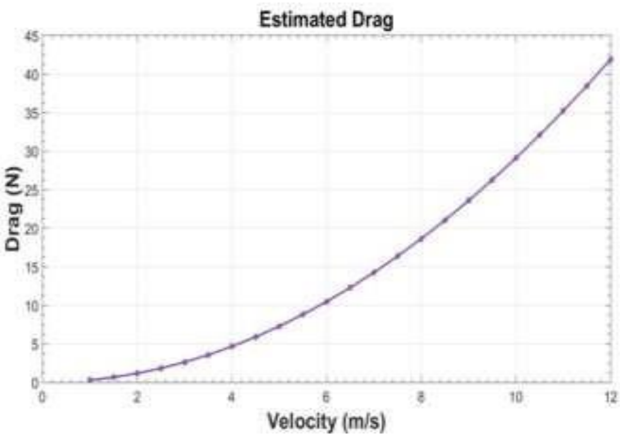

Figure 7: This graph shows the relation

6.2 Comparison

Comparison of Performance Parameters are observed below through the table,

Table 2: Performance Parameters Un- Manned Aerial Vehicle

Parameters	Required	Calculated	Deviation
MTOW (lbs)	350	386	10.2%
Range (nm)	370	349	5.6%
Endurance (hrs)	10	9.07	6.87%
TO Distance(ft)	500	423.5	12%
Landing distance (ft)	500	337.05	32.5%

7. CONCLUSION

As modern UAVs have grown significant research and development interest, much more research papers and scientific articles are being published. The rapidly increasing R&D of UAVs is a consequence of these advancements. Moreover, the demand for in- creased mobility, more autonomy and higher range of UAVs resulted in the design of novel systems for battery swapping, multi-stations and precision landing. The application of these is being used in surveillance, security, tracking, agriculture, for fire detection and prevention, disaster monitoring, wireless communication, remote sensing, monitoring, and highway traffic control etc. In this regard, efforts have been made to develop a proto- type model. Parameters calculated from Mathematical model are used as input for finalization of geometry design. The model has been validated through CFD analysis. UAV model has been manufactured, developed and resulted in successful aerial test flight. Way forward in this area research includes the innovation and further testing /evaluation.

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