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Design and analysis of fixed wing UAV

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Abstract

Unmanned aerial vehicle (UAV) is an aircraft that is guided autonomously or by remote control or both and that carries sensors, target designators, offensive ordnance or electronic transmitters designed to interfere with or destroy enemy targets. These descended from target drones and remotely piloted vehicles (RPVs) employed by the military forces of many countries in the decades immediately after World War II. This project focuses on the design, analysis and prototyping of an Unmanned Aerial Vehicle (UAV) with the aim for developing an efficient and reliable aerial platform for required applications. The project employs a systematic approach, encompassing conceptualization, design, analysis and physical prototyping to ensure successful development of the UAV. The design phase involves defining the mission requirements and objectives. A comprehensive study is conducted to identify potential design improvements and innovative features. Structural analysis techniques, including FEA, are used to evaluate structural integrity and strength of critical components whereas aerodynamic analysis is employed to minimize UAV's drag and maximize its lift. The prototyping phase involves translating the design into a physical UAV model. Rapid prototyping techniques are utilized to fabricate the UAV. By combining design, analysis and prototyping this project aims to develop an optimized and reliable UAV.

1. Introduction

A UAV is an aircraft that is operated remotely without a pilot on board. These can be controlled by a human operator on the ground using a remote control or can be programmed to fly autonomously using pre-defined routes and commands. They are used for surveillance, search and rescue operations, mapping, etc. An unmanned aerial vehicle is able to use aerodynamic forces to provide vehicle lift and can be expendable or recoverable. UAV is a term commonly applied to military use cases. Missiles with warheads are not considered UAVs because the vehicle itself is munitions. Also, the relation of UAVs to remote- controlled model aircraft is unclear where in UAVs may or may not include remote- controlled models. A similar term that's been around is remotely piloted aerial vehicles. The earliest recorded use of an unmanned aerial vehicle for war fighting occurred in July 1849 with a balloon carrier in the first offensive use of air power in naval aviation. Austrian forces besieging Venice attempted to launch some balloons at the besieged city. Significant development of drones started in the 1900s and originally focused on providing practice targets for training military personnel. The earliest attempt at a powered UAV was A. M. Low's Aerial Target in 1916. The development of smart technologies and improved electrical-power systems led to a parallel increase in the use of drones for consumer and general aviation activities. As of 2021, quadcopter drones exemplify the widespread popularity of hobby radio- controlled aircraft and toys. However, the use of UAVs in commercial and general aviation is limited by a lack of autonomy and new regulatory environments requiring line-of- sight contact with the pilot. Miniaturization is also supporting the development of small UAVs which can be used as individual systems or in a fleet offering the possibility to survey large areas in a relatively small amount of time. Also considered to be the future of combat, modern warfare as well as logistics, the role and influence of UAVs in the current world is increasing. The original purpose of UAVs was to carry out missions that were inaccessible or dangerous to humans. However, with more technology and innovation their adaptability and functionality have increased leaps and bounds. From carrying out drone strikes to delivering pizzas, drones currently are doing it all. Civilian UAVs vastly outnumber military UAVs in the current world which is a testimony to their dominance. However, with more technology and innovation their adaptability and functionality have increased leaps and bounds. From carrying out drone strikes to delivering pizzas, drones currently are doing it all. Civilian UAVs vastly outnumber military UAVs in the current world which is a testimony to their dominance. There are many moral, legal and ethical issues regarding the usage of drones. In terms of legality, in many countries, UAV is not permitted to fly openly and needs a licensed pilot. However, with the advent of time and special permissions, some countries are allowing to do so. The morality and ethicality of using drones have come under the scanner in recent years after their extensive usage in conducting airstrikes. Statistically the world has seen numerous civilian casualties from drone strikes which depicts that drones dehumanize war.

2. Literature review

2.1 **Design, Manufacturing, and Flight Testing of an Experimental Flying Wing UAV:** This paper presents the design, manufacturing, and flight testing of an electric-powered experimental flying wing unmanned aerial vehicle (UAV). The design process starts with defining the performance requirements including the stall speed, maximal speed, cruise altitude, absolute ceiling, and turn radius and speed. The wing loading and associated power loading are obtained based on the defined performance requirements. The wing area, UAV mass, and power requirements are determined from the endurance and payload requirements. The power requirement determines the motor size. Aerodynamics and stability designs are obtained based on the selected airfoil and obtained wing area. After completing the design, the UAV is manufactured using composite materials. The UAV is equipped with an Axi 4130/20 kv305 brushless motor and a Pixhawk flight control board. Its total weight is 8.6 kg. Flight tests were conducted to evaluate the UAV's performance and dynamic characteristics and to demonstrate the success of the design.

2.2 **Aerodynamic analysis over Unmanned Aerial Vehicle (UAV) using CFD:** In this study, the computational investigations of the streamlined qualities of RANGER, TUAV were completed utilizing CFD. The fundamental goal of this examination was to assess the most proper outline that will enhance the streamlined execution of RANGER, TUAV. The essential points of this anticipate has been to research the potential burdens on various parts of a structure of an air ship. A survey of the writing in this field uncovered that not very many such studies have been distributed to date. For this a normal and testing configuration was considered and preparatory stream examination was done for the determination of the heaps following up on the distinctive parts. Concluding from results Material distribution is more where stress is high and material is made void where stress is considerably low and all design aspects can be met with minimal material.

2.3 **Design and analysis of fixed-wing UAV**: The paper involves the generation of a robust

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conceptual design procedure for developing a UAV. The conceptual design involves determining the dimensions of the aircraft without compromising on all aspects of aerodynamics, structures, performance, and stability of the UAV. The design procedure is generated using general commercial aircraft and extrapolated to mini UAV. The work shows a single iteration of the design process. This can be run through several iterations to arrive at optimum value. The above design process is semi-automated. Macros are used in Ms Excel and CATIA. Replay scripts are used in ICEM CFD. Script files are used in Fluent and Mechanical APDL UAV designed is put through performance analysis, Stability analysis, and CFD analysis to validate the design.

2.4 **Design and production of small tailless UAV**: The paper involves development of a tailless small UAV for military application and short range reconnaissance. SUAV is much more portable than its large counterparts and requires only one operator. A smaller reconnaissance plane can access ground targets at a closer range without being detected. Most SUAVs use electric motors for advantages as it is less affected by environmental circumstances, lower weight, less vibration and having lower cost. The paper desires to design a UAV by improving its aerodynamic features, surveillance capability and controlling systems. Then the paper concludes the design of a flying wing need not imply a difficult, time-consuming process and, ultimately, an unstable and uncontrollable aircraft. We describe in this paper how by using project requirements a design area which includes those requirements can be determined. Once the airfoil and aircraft geometry are established, stability and lift and drag analysis are performed to odelle aircraft tendency to be stable one. By utilizing these suggested methods a flying wing aircraft can be created from a few relatively simple requirements. The modifications in production molds concerns assembly and disassembly techniques for SAKR 2 has to be fulfilled in order to acquire manback UAS.

3. **Wing and control surface sizing:**

The wing may be considered as the most important component of an aircraft, since a fixed wing aircraft is not able to fly without it. The primary function of the wing is to generate sufficient lift force. However, the wing has two other functions as well which are drag and nose down pitching moment. While a wing designer is looking to maximize the lift, the other two must be minimized. In fact, wing is assumed as a lifting surface that lift is produced due to the pressure difference between lower and upper surfaces.

4. **Procedure employed:**

- Defining mission requirements and setting upmission profile.
- Weight estimation of the wing including the battery weight, structural weight, payload weight, propulsion system weight.
- Wing and control surface sizing with the helpof estimated weight.
- Winglet sizing.
- Selection of airfoil.
- Control surface sizing.
- Positioning of centre of gravity.

5. **Mission requirements:**

Max. take-off weight	< 3.5 kg
Payload weight	< 1 kg
Endurance	< 45 min
Cruise speed	20 m/s
Wing span	< 1.5 m
Altitude	150 m
Propulsion	Electric motor

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Mission profile:

The mission profile of our UAV has 6 steps which are as follows: takeoff and climb; cruise; loiter; cruise back and lastly descent and landing.

Figure 1. Mission profile

The assumptions of the structural parameters such as wing loading, aspect ratio and taper ratio were done as explained below: W/S = 6, this was selected as we need a greater wing surface area compared to the weight of the wing for a greater lift of the UAV; A.R = 3, since we need a compromise between low induced drag and vulnerability of the wing to damage due to low lateral thickness, this value was selected from historical data; λ = 0.6, this was selected to have a greater lift distribution and ease of manufacturing.

Calculations:

After assuming the above values, the following parameters were calculated as follows:

- **Surface area :**

S = W W/S= 3.410 = 0.5683 $m2$

- **Wing span:**

$b = \sqrt{S * A.R} = \sqrt{0.5683 * 3} = 1.3057\ m$

- **Root chord:**

$C_R = 2 * S/(1+\lambda) * b = 2 * 0.5683/(1 + 0.6) * 1.3057 = 0.5441\ m$

- **Tip chord:**

$CT = \lambda * CR = 0.6 * 0.5441 = 0.3265\ m$

- **Sweep:**

$\Lambda c/2 = 170$

Airfoil selection:

To maintain a positive pitching moment to resist the changes in the pitch altitude we need to use a reflex airfoil. This helps to have more stability of UAV during climb and descent. If we use a normal airfoil the resulting pitching moment may make the UAV go down into a circular motion. The effective Reynolds number was calculated to be 592908.0617. From www.airfoiltools.com and study of several similar UAVs the following airfoils were selected: E174, E186, E197, MH45, MH60, S5010, S5020 and SD7080. The above airfoils are all reflex airfoils taking into consideration their self-stabilizing properties.

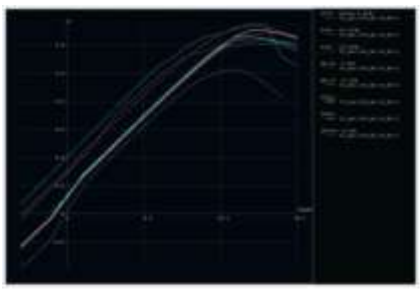

Figure 3. CL vs α

On the basis of comparison and trade-offs, the airfoil S5010 which provides excellent stall characteristics and sufficient lift as required from the design criterion is selected. The selected airfoil shows zero pitching moment coefficient at the calculated Reynolds number which best suits our interests for stable flight.

Positioning of centre of gravity:

In most conventional designs, the centre of gravity is positioned ahead of the neutral point for longitudinal stability. This ensures that the aircraft naturally tends to return to its trimmed or equilibrium attitude after experiencing disturbances. The placement of the CG also greatly depends on static margin. Aerodynamic centre was measured to be 0.111m and since it is recommended to have CG to be at 15% of MAC, the final value of CG was determined to be at SM of 10% where CG = 0.2485 m.

Figure 4. 3D model of wing

4. Analysis:

Structural analysis: for structural analysis Fusion 360 was chosen. There the load constraint given was pressure along the surface. The acting pressure at that altitude was calculated to be 0.997 MPa.

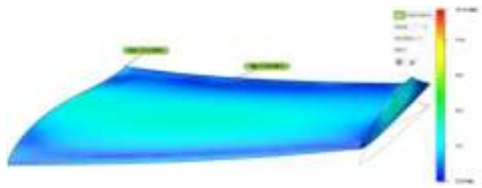

Figure 5. Stress contour of the wing

The simulation resulted in factor of safety of 3.996 which is good and ensures that the wing will not deform at the desired altitude. This provides a significant margin of safety and ensures that the wing has ample capacity to handle unforeseen or exceptional conditions, variations in load, material weaknesses or other factors that may cause fracture. The result also conveys that the design was more of a conservative approach prioritizing safety and reliability.

Aerodynamic analysis: This was done using Ansys CFX. The input variables used were: inlet velocity 20m/s, far-field static pressure 1atm and output static pressure 1atm. The turbulence model used was k-epsilon and automatic mesh was generated with quality set as high.

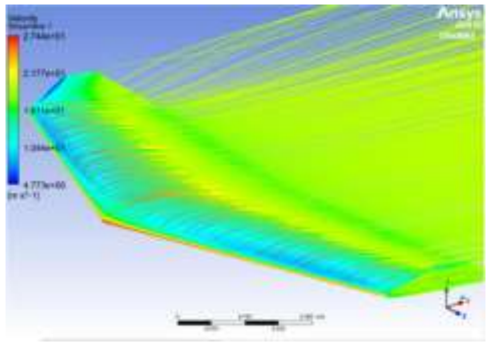

Figure 6. Velocity contour of the wing

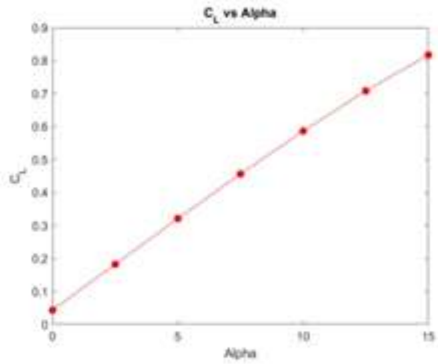

Figure 7. CL vs α

6. Prototyping of UAV:

3D printing was employed to prototype the wing and the printer that was used was Ultimaker S5 Pro. The software used to slice was Ultimaker Cura.

Figure 8. Sliced components

7. Results:

Property	Allowable	Actual	comments
Stress	75MPa	15.52MPa	Less than allowable so conservative design
displacement	30 mm	21 mm	Actual deflection is inrange of allowable
F.O.S	>3	3.996	Exceeds the required. Therefore design is conservative

Table 2. Comments on output parameters of structural analysis

Property	Desgined	Actual	Comments
Velocity	20 m/s	22 m/s	Allowable variation
C_L	0.24	0.445	Greater lift coeff means less power for climb
C_D	0.0432	0.1301	As a result of introduction of winglets for stability

Table 3. Comments on output parameters of aerodynamic analysis

Conclusion:

The design procedure followed is not too complex and is a simpler way to develop a flying wing UAV under the required mission requirements set accordingly. The work shows a single iteration of the design process but several iterations can be made through flight testing and wind tunnel tests. The UAV designed is put through structural analysis, stability analysis and aerodynamic analysis. Fusion 360 was used for design and structural analysis, this proved to be a simpler way because several iterations were made through the design workflow within the software. Even before the modeling stage XFLR5 was used for preliminary analysis of the structured wing and its cross section, the software needed very less inputs and was easier to use without any prior knowledge. Therefore it is possible to say using these softwares is very useful for a quick start to complete aircraft modeling. It can be said that the manufacturing of the wing can be done with the help of Additive Manufacturing technology rather than the traditional method so as to save time and achieve complex airfoil shapes with ease.

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