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Design & Development of a Surveillance UAV

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ABSTRACT

This work details the design and development of a lightweight Unmanned Aerial Vehicle (UAV) for aerial intelligence, surveillance and reconnaissance missions. The objective is to design a dependable, operational and cost-effective platform that can gather information from an aerial viewpoint for enhanced situational awareness. The UAV is built with a high lift-to-drag (L/D) ratio, high aspect ratio, and low wing loading to provide improved aerodynamic performance and extended flying endurance. The airframe has been fabricated using Foamboard for high strength to weight ratio and a very low density, making the airframe very light. A brushless DC motor and propeller combination makes up the propulsion system. The UAV features a V – tail for further weight and drag reduction. The UAV can house a varied array of sensors/cameras that can be customized according to the operators' needs for the mission profile. The UAV can be programmed to fly autonomously or hand flown in third person mode or in First Person mode using the onboard video system. To sum up, this research effectively illustrates a realistic and cost-effective method for designing and building UAVs. The designed surveillance UAV achieves dependable ISR operation with remarkable flight stability, aerodynamic efficiency, lightweight materials, and easily accessible avionics equipment.

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INTRODUCTION

UAVs are now an essential component of modern aerospace industry due to their highly adaptable, affordable and effective attributes. Applications like defence operations where live updates of the situational awareness is crucial for mission safety and success make the most use of these systems. Due to development in composite materials and electronic systems it is now feasible to design and build systems like these. In addition to their practical applications, these UAVs are great educational tools for researchers and engineering students (McCormick, 1995).

The aim of this research, "Design and Development of a Surveillance UAV" is to develop a lightweight, medium-range aerial platform that is intended especially for reconnaissance and surveillance (El Adawy et al., 2023). The UAV offers wide-area visual coverage while in flight utilizing the onboard sensors/cameras. The major aims are to integrate the necessary avionics components for stable and controllable flight operations, choosing appropriate materials for a lightweight construction, and creating an aerodynamically efficient airframe (Desai et al., 2024).

The UAV features a high L/D ratio with a high Aspect Ratio and a low wing loading to assure high efficiency and stable flight characteristics. Longer endurance, smoother maneuverability, and lower power consumption during flight are all made possible by these characteristics. A high strength to weight ratio is maintained to guarantee the airframe can accommodate all the avionics and surveillance equipment. The airframe shape is optimized throughout the design phase to decrease drag and maintain stable flying characteristics (Austin, 2010b; Cook, 2013; Watkins et al., 2006).

Foam board which is a composite made up of Extruded polystyrene foam sandwiched between two layers of paper making it extremely light weight and buoyant with a density of 0.10g/cm^3, while also being very cost effective and readily available Foamboard presents itself as an ideal material for the fabrication of such UAVs. Pultruded Carbon Fiber rods and Pine wood spars are used as the load bearing members for the wing to resist deformation and provide the necessary structural strength. While also reducing weight, the use of these materials makes the UAV highly cost effective and easy to repair and service (Hargreaves et al., 2018). The production methodology ensures that the aircraft can be easily mass produced and repaired very quickly and at a very small cost (Beard & McLain, 2012).

The propulsion system comprises of a BLDC motor paired with a Bi Blade propeller, which is controlled using an Electronic Speed Controller (ESC). Servo motors are used to actuate the control surfaces; the UAV is controlled remotely using an ELRS control link involving a transmitter and a receiver. This combination of lightweight materials, avionics, and aerodynamic design shows a detailed approach to creating a medium-range surveillance UAV that is practical, economical, and effective in real use case scenarios (Austin, 2010a).

DESIGN

The goal of this UAV is to achieve a lightweight design while achieving efficient aerodynamic performance and structural strength. The UAV can fly steadily for long periods of time with increased gliding efficiency and high lift generation due to its high aspect ratio design. A low wing loading is maintained to minimize the stall speed and improve maneuverability. By achieving a high lift–to-drag (L/D) ratio the UAV's flying time is increased dramatically while also consuming much less power for the same making the UAV highly energy efficient. A high strength to weight ratio is also maintained in the construction of the UAV to guarantee structural strength (Anderson & Cadou, 2024).

Wing Design

The wing has a straight leading edge with a tapered trailing edge giving the wing a pentagonal shape, providing high aerodynamic efficiency and very less drag while also being easy to manufacture. The wing has a semi span of 1 meter for a total wingspan of 2 meters. It features a root chord of 0.25 m and tip chord of 0.12 m providing a taper ratio of 0.48 maximizing the elliptical lift distribution of lift across the span.

The wing features a total planform area of 370 m2 providing sufficient lifting surface for the payload and endurance requirements. An aspect ratio of 10 provides a high lift-to-drag ratio and efficient gliding characteristics. With an overall weight of 1200g the UAV has a wing loading of 3kg/m2 providing slower stall speeds and smoother handling characteristics making the UAV ideal for surveillance missions where slow and steady flying is critical.

Ailerons are used as the control surfaces to induce roll in the UAV; these measure about 0.6m in span and 0.04m in width providing an area of 0.024 m2. The ailerons are positioned towards the extreme ends of the wing to not hinder the lift distribution of the wing and provide maximum rolling moment.

The airfoil chosen is a flat bottom S7055 airfoil (Figure 1) which works best in low Reynolds number applications. The flat bottom nature of the airfoil makes it very easy to fabricate while providing advantageous properties for slow and steady flight.

Charecteristics of S7055 Airfoil

- **Type:** Flat-bottom, low Reynolds number airfoil
- **Maximum Camber:** Approximately 2.1% located at 38% of chord
- **Maximum Thickness:** 10.5% of chord
- **Design Reynolds Number:** 200,000 – 500,000
- **Ideal Angle of Attack Range:** 0° to 8° for optimal L/D performance
- **Cl (Lift Coefficient) max:** ~1.4
- **Cd (Drag Coefficient) min:** ~0.009
- **Cl/Cd Ratio:** High (indicative of good aerodynamic efficiency)
- **Stall Characteristics:** Gentle and predictable stall behaviour
- **Pressure Distribution:** Smooth upper-surface pressure gradient ensuring steady lift generation

S7055 was selected as the best option due to its ease of manufacturing and consistent low speed characteristics paired with high lift characteristics. The wing design combines low wing loading, structural simplicity, and aerodynamic efficiency enabling the UAV to carry out steady, energy-efficient surveillance missions.

Fuselage Design

The fuselage balances the lightweight design, structural strength and the aerodynamic smoothness of the UAV. The overall design of the fuselage reduces drag while providing ample space for the payload, avionics, and propulsion system. To ensure adequate longitudinal stability and aerodynamic balance throughout the flight, the overall length of the fuselage is designed to be 60% of the wingspan, or 1.18 m, which contributes to effective and stable performance by facilitating a seamless airflow over the wing and the tail.

The fuselage of the UAV is divided into 3 sections – the nose, the central, and the empennage sections, that are divided in a 3:4:3 ratio. The nose has a length of 35 cm with a base of 3 cm and walls of 4 cm, housing the motor along with the ESC, battery and the receiver. This design ensures that the motor-mount is sturdy enough to tolerate the vibrations induced by the propulsion system.

The middle section has a length of 48 cm with a squared cross-section of 5x5 cm. This serves as the primary structural compartment for attaching the wing along with housing the payload. The payload (camera and the VTX system) has been positioned

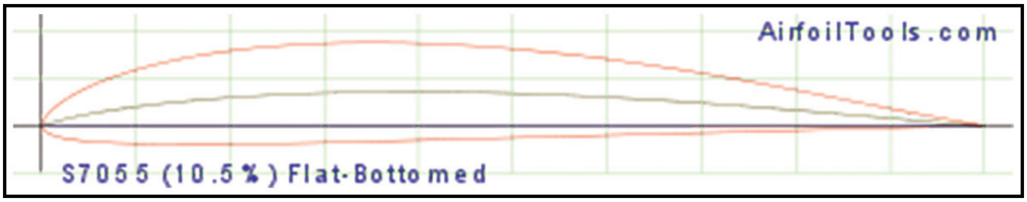

Figure 1 S7055 Airfoil

in order to keep the center of gravity low for flight stability. The wing is firmly fixed in this area to provide appropriate load transfer between the fuselage and the wing during the flight maneuvers.

To guarantee structural integrity, fibre-reinforced tapes are put at crucial joints (motor mount, wing attachment zone, and tail joint), and the entire fuselage is taped externally. This reinforcement reduces deformation and improves torsional stiffness under aerodynamic loads.

The fuselage design features a good combination between lightweight construction, structural effectiveness, and aerodynamic performance. The strengthened structure, tapered geometry, and proportional dimensions of the UAV ensure longitudinal stability, reduced drag, and enough internal volume to house the required payload and avionics components.

Tail Design

The V-tail configuration was selected for the UAV mainly because it blends aerodynamic efficiency, lightweight design, and stable control. By merging the functionalities of both the vertical and horizontal stabilizers into a pair of angled surfaces, the design reduces induced drag while retaining stable flight characteristics. With a total surface area of 1110 cm² (30% of the wing area), the UAV has adequate stability and control authority for its mission profile.

To provide a combined pitch and yaw control with lesser mechanical complexity, each tail surface has a control surface that acts as an elevator and rudder. The deflection space measures 30 cm in height and 5 cm in width. To provide adequate airflow and aerodynamic lift at the tail, each tail's primary body is made up of a rectangular section (30 cm × 7 cm) along with a right-angled triangular section (13 cm base × 30 cm height). An angle of 120° between the two tails provides a reasonable balance between aerodynamic efficiency and control response.

This layout improves the UAV's aerodynamic efficiency and endurance because of its lighter, simpler, and more aerodynamically clean tail, making it perfect for long-duration surveillance missions.

AERODYNAMIC ANALYSIS

The maximum Lift-to-Drag ratio of the UAV was calculated through OpenVSP, and resulted in a value of 28 L/D (Figure 2) max value approximately.

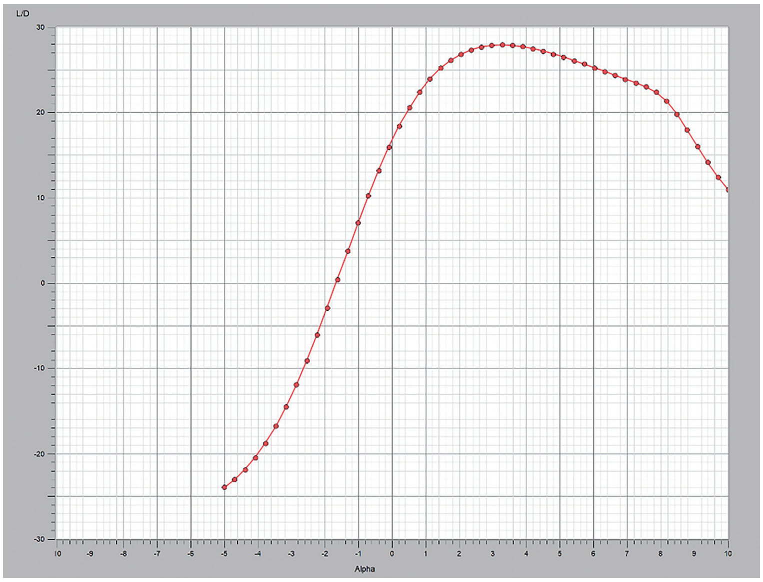

Figure 2 L/D vs Alpha Graph

The Cm vs Alpha Graph is demonstrated below (Figure 3).

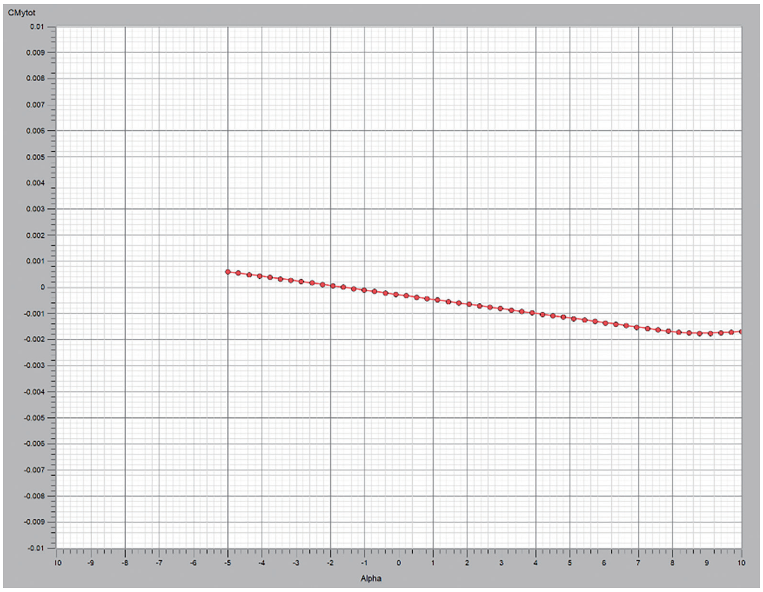

Figure 3 CMy vs Alpha Graph

Finally, the Cl vs Alpha graph (Figure 4) demonstrated the maximum lift coefficient.

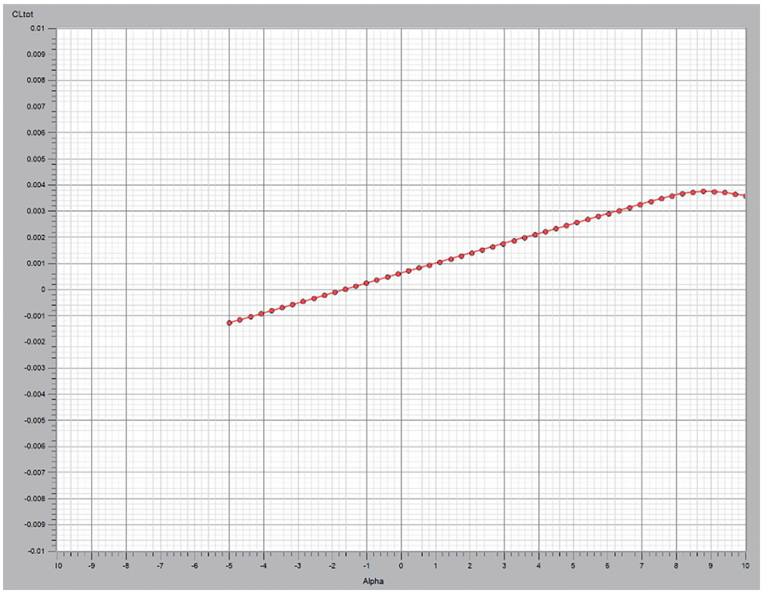

Figure 4 CL vs Alpha Graph

FABRICATION

A composite material called Foam Board with a density of 0.10 g/cm^3 and a thickness of 0.5cm is used to manufacture the UAV as it offers an optimal balance between strength, ease of manufacturing and affordability. The material can be easily cut shaped and put together while retaining its structural integrity. Composite fiber tapes are used to reinforce all crucial corners and joints subjected to repeated stress in flight. 45° cuts are made to achieve a streamlines shape to minimize form drag. Ethylene-Vinyl Acetate based adhesive is used as the primary bonding agent to join all the key components. This combination guarantees a strong but lightweight structure that is perfect for the endurance and performance needs of the UAV (Figure 5 & 6).

AVIONICS

At the heart of the avionics system of the UAV (Figure 7) is the Flight controller which acts as the brain of the UAV relaying all the commands and instructions to the other electronics. The propulsion system includes a Brushless DC motor paired with a Bi-blade propeller, connected to the FC via an Electronic Speed Controller (ESC). Servo motors are used as actuators for the control surfaces (ailerons & ruddervators). A DJI O4 Digital VTX system which can record high quality footage while also providing live video feeds up to a distance of 15km is equipped on the UAV for surveillance purposes, allowing for efficient area monitoring and observation.

Figure 5 Front View of the UAV

Figure 6 Isometric View of the UAV

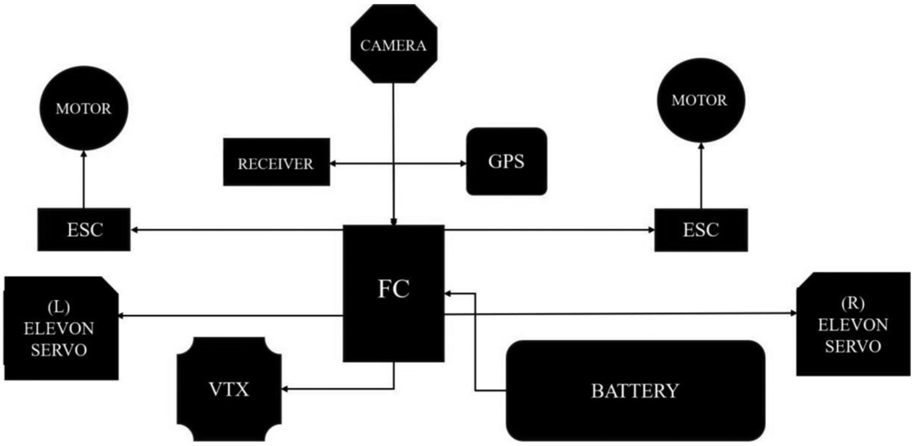

Figure 7 Avionics Flow Chart

Flight Controller

The FC used is a Matek Systems F765 WSE Flight controller which provides the UAV fully autonomous capabilities and stabilization modes like Fly By Wire A & B for manual flying. The FC is flashed with Ardupilot software and Mission Planner software is used as the Ground Control System. All the Avionics are connected to each other via the FC which takes in commands from the operator via the control link and executes them. The FC uses its inbuilt compass, Inertial Measurement Unit along with the Compass to carry out autonomous flight on predetermined waypoints as programmed by the operator. Any modern flight controller can be used in such application by switching out the peripherals to the ones compatible with the said FC.

Propulsion System

An A2212 Brushless DC motor with a 2200 KV rating and a 6-inch and 4.5-inch pitch is the selected configuration of propulsion system paired with a BlHeli 40A ESC to regulate power delivery, providing dependable speed control and protection against voltage variations. A 2200mAh 11.1V 3S 35C Li-Po battery, is used as the power source for all electronics offering sufficient flight time for testing. The UAV can carry much larger battery packs, increasing the flight time drastically for the required mission needs. The motor/propeller/ ESC combination can also be upgraded to utilize lower KV motors and bigger propellers for a much more efficient propulsions system increasing the endurance and flight time of the UAV.

Actuators

9 grams SG90 servos from TowerPro are used as actuators to deflect the control surfaces in order to maneuver the UAV. The control surfaces have been fabricated with a hinge mechanism that help deflect them 45 degrees up or down which are connected to the arms of the servos using a control rod. A total of 4 servos have been employed in the UAV one on either side of the wing to control the ailerons and two on the tail to control the ruddervators.

Control Link

The UAV utilizes a 2.4Ghz radio control link for exchanging telemetry information and control of the UAV via an ELRS receiver and a compatible transmitter. Although any control link can be used in the said application given its compatibility with the FC and the range requirements of the operator. With the current configuration an Happy Model ELRS receiver and a Radiomaster Ranger Micro 1 Watt ELRS module the UAV is believed to have a theoretical range of over 15 kilometers.

Surveillance Method

The UAV has been designed to be able to easily accommodate any kind of surveillance system that falls under the weight limit of UAV (Wing Loading < 20oz/ft^2). In this case we have chosen a DJI O4 Air Unit Pro as the video system for surveillance, providing us with a transmission range of 15Km and a video quality of 1080p at 100 Fps with a Field of view of 155° paired with DJI Goggle 3 this provides the operator with live video feed from the UAV providing live

situational awareness of the battlefield with a birds eye view. The DJI O4 Air Unit Pro has a size of 33.5×33.5×1mm (L×W×H) for the Transmission Module, 25.55×20×23.30 mm (L×W×H) for the Camera Module and a very light weight of 32grams. Making it a very ideal choice for the application because of its compact form factor enabling the UAV to carry many more sensors and equipments,

RESULTS & DISCUSSIONS

The UAV was fabricated successfully meeting all design parameters and structural requirements. Subsequent flight trials validated the aerodynamic characteristics of the UAV which coincided with the calculated theoretical values. The UAV demonstrated stable flying characteristics with predictable in-flight behaviour. The propulsion system was found to be adequate enough to sustain the UAV's flight with a thrust-to-weight ratio of 1.2 and a take-off weight of 1200 g. The wing proved to generate enough lift by enabling the UAV to cruise at 60% throttle.

The V-tail layout was especially effective in terms of stability and control. Without requiring additional pilot corrections, it efficiently counteracted undesired or unstable aerodynamic moments, ensuring balanced yaw and pitch stability. The control link and video transmission system operated as expected and provided effective communication between the UAV and the operator, and the VTX provided live and clear in-flight footage to the operator.

The FC functioned as expected, assisting the operator with in-flight stabilization, helping reduce the workload. The FC also enabled the UAV to fly autonomously and carried out missions based on the pre-programmed waypoints. The onboard GPS enabled the operator to actively track the UAV throughout the mission.

The UAV achieved a flight endurance of around 15 minutes with a 2200 mAh 3S Li-Po battery, proving the highly efficient design of the UAV, which has a good lift-to-drag ratio.

In conclusion, the objective of creating a medium-range surveillance UAV, that is lightweight, stable, and having predictable flying performance and superior aerial imaging was accomplished.

FUTURE SCOPE

- Higher capacity and energy-density batteries can significantly increase flight endurance and mission range.
- The propulsion system can be optimized using lower KV motors and larger propellers for improved efficiency and range.
- Advanced ISR payloads including HD cameras, thermal sensors, and LiDAR can be integrated.
- Improved communication systems can be used for longer range control.
- Improved VTX systems with high wattage and high-resolution cameras can be used for increased range.
- Composite materials such as carbon fiber reinforced polymer (CFRP) and other composite materials can be used to improve the strength-to-weight ratio and decrease the overall weight.
- The UAV can be employed in multiple expanded mission roles including surveillance, search-and-rescue, logistics, sensor deployment and tactical warfare.

Conflict Of Interest

The authors declare that there is no conflict of interest.

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