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UNMANNED AERIAL VEHICLE FOR WILDLIFE CONSERVATION AND MULTIDISCIPLINARY RESEARCHES

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ABSTRACT

The advancement of UAV technology has become a global phenomenon. Currently, UAV technology is being researched in a range of ways in numerous nations throughout the world. Thousands of approaches for the Vertical Take Off and Landing abilities (VTOL) are currently being investigated using UAV technology. And also, UAV technology is currently used in numerous applications, including data and information collecting, military uses, agricultural practices and transportation etc.

However, VTOL technology is still in its infancy in Sri Lanka. Not that but the gap between the technological background of Sri Lanka and the technological concepts of the modern world also obstructs the development of these concepts in Sri Lanka this is attributed to the high cost of the equipment's as well as lack of technical literacy.

This project is conducted to develop a drone using VTOL technology for Forest and Wildlife conservation and multidisciplinary researches. The structure of the VTOL is design by using SolidWorks software.it can be used to create 3D models of aircraft and to support to analysis of models. The selection of the parameters, mathematical analysis, data collection and controlling system, flight control unit, the use of power supply methods and electric system are most critical parts of the project. The design of the vehicle is analyzed to endure maximum thrust range is 4 Kilograms. And also, structure is made by using Aluminum and Iron which are acquired locally. MPU 9250 9-axis motion monitoring device is used as the Internal Measurement Unit. For motor control 220 kV brushless motors and Servo motors are employed.

As a final outcome, the vehicle could be presented as a good UAV application, with abilities of wildlife conservation and multidisciplinary research applications. Once completed, the VTOL is expected to be effective in the agricultural, wild life monitoring, military and Data collection fields, specially, in Sri Lanka

Keywords: UAV, VTOL technology, Wildlife conservation, SolidWorks, MPU 9250.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), colloquially known as drones, are defined as flying robots capable of autonomous or remote operation. In technical literature, they are formally referred to as Unmanned Aerial Systems (UAS) [1] or Remotely Piloted Aircraft (RPA), as categorized by the International Civil Aviation Organization (ICAO). These systems are either controlled remotely by a pilot at a ground control station or operate independently through pre-programmed flight plans [2].

The historical trajectory of UAVs begins as early as 1849, when Austria utilized unmanned balloons carrying explosives against Venice. However, modern UAV technology matured as a critical defense system in the late 20th century, notably when the Israeli Defense Forces developed small-scale UAV platforms; subsequently, many nations adopted and advanced this manufacturing capability [3]. Beyond military utility, UAVs are now integral to weather monitoring, firefighting, search and rescue, and traffic management. Recently, their

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application has expanded into biodiversity conservation, specifically for mapping and tracking wildlife species and monitoring illegal human activities in forested areas, such as poaching, illegal logging, and arson.

UAV development has become a global priority, with approximately 70 countries currently advancing indigenous technology. By 2010, global UAV expenditure exceeded US$ 3 billion, reflecting a growth rate of over 12% [4]. These systems are uniquely suited for data collection in hostile or desolate regions where human support is unavailable, offering portability and reliability for recurrent use [5].

A significant engineering challenge involves the development of Vertical Take-off and Landing (VTOL) capabilities. While Nikola Tesla conceptualized VTOL flight in 1928, modern advanced VTOL aircraft often utilize single-engine designs with thrust vectoring [6]. Thrust vectoring allows the aircraft to redirect engine thrust at varying angles, enabling a single power plant to manage both vertical and horizontal flight—a design famously exemplified by the Harrier Jump Jet. In the 21st century, VTOL potentiality has become more accessible through multi-rotor designs, such as quadcopters, which are frequently used in both large-scale and specialized UAV applications [7].

1.1 Problem Statement

In Sri Lanka, the preservation of wildlife is hindered by economic constraints, political fluctuations, and a rising demand for illegal wildlife products [8]. Despite conservation efforts, iconic species are in decline. While the Sri Lankan elephant faces numerous threats, poaching remains a primary cause of mortality for species such as deer and peacocks. Furthermore, deforestation has reached critical levels; Sri Lanka's forest cover declined from 75% at the turn of the century to less than 25% by the late 1980s [9]. By 1983, wet-zone forests covered barely 10% of their original area [10].

This environmental crisis is a global phenomenon; for instance, African elephant populations declined by 30% between 2007 and 2014 [11]. Human population growth, land-use changes, and forest fragmentation continue to exacerbate human-wildlife conflict (HWC) [12]. In Sri Lanka, HWC has intensified in the Northern Province following the civil war [13]. National forest cover estimates dropped from 29.6% in 2009 to just 16.5% in 2019 [14]. Although the Northern Province retains a significant portion of the country's remaining forest [15], these habitats require urgent protection.

1.2 Research Objectives and Aims

This project aims to strengthen Sri Lanka's conservation capacity by developing an interdisciplinary VTOL drone platform. By integrating remote sensing and industrial applications, this research seeks to reduce technology gaps and lower the costs associated with wildlife monitoring [16]. The specific objectives are:

1. To identify the specific technical requirements for UAV operations within the Sri Lankan context.
2. To design a VTOL UAV incorporating appropriate aerodynamic criteria.
3. To develop a structural sketch and conduct flight simulations using SolidWorks 2016.
4. To fabricate a low-cost VTOL UAV prototype that meets all development requirements.
5. To design the electrical and electronic control systems.
6. To develop the necessary computer code for autonomous flight.
7. To test, modify, and evaluate the UAV prototype following fabrication.

II. METHODOLOGY

A. Overview of Research Design

The methodology for this project is structured into two distinct phases: (1) Technical Analysis and Specification, and (2) Fabrication, Laboratory Assembly, and Field Testing. This systematic approach ensures that the resulting VTOL UAV is optimized for its primary objective: wildlife conservation and habitat monitoring in Sri Lanka.

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B. Specifying Requirements

The technical requirements for the proposed VTOL system were established through a comprehensive literature survey and an assessment of the local environmental constraints. The UAV is designed as a hybrid platform, combining a traditional fixed-wing airframe with four fixed vertical rotors for multi-rotor stability.

Mission Profile

The UAV must perform a hybrid flight cycle consisting of:

1. **Vertical Launch:** For deployment in dense forest clearings.
2. **Transition:** Converting vertical thrust to horizontal lift.
3. **Cruise:** Efficient fixed-wing flight for long-distance monitoring.
4. **Landing:** Precision vertical descent back to the home point.

C. Structural Design and Weight Estimation

A critical step in the methodology was the accurate estimation of the All-Up Weight (AUW), which dictates the required propulsion power and aerodynamic lift.

Table 1: Prototype Weight Estimation

Item	Mass (g)	Quantity	Total (g)
Brushless Motors	65	4	260
ESCs	40	4	160
Battery (LiPo)	360	1	360
Servo Motors	110	2	220
Aluminum Frame Elements	336	1	336
Polystyrene Body Panels	354	-	354
Circuitry/Wiring/Adhesives	510	-	510
Total Estimated Mass			**2200**

The maximum weight tolerance for the design was set at 3.5 kg to ensure a safe thrust-to-weight ratio.

D. Aerodynamic and Mathematical Modeling

The aerodynamic design focused on a **Straight Wing** configuration. This choice was made due to its high stability and lift-to-drag ratio at the low cruising speeds required for tracking wildlife in canopy environments.

➢ **Force Equations**

The behavior of the wings is governed by the standard Lift (FL) and Drag (FD) equations:

$$F_D = c_D \tfrac{1}{2} \rho v^2 A$$

$$F_L = c_L \tfrac{1}{2} \rho v^2 A$$

➢ **Mathematical Modeling of Dynamics**

The UAV is modeled as a 10-degree-of-freedom (DOF) non-linear system. Movement is controlled via four fundamental inputs: throttle, roll, pitch, and yaw. These movements are achieved by varying the angular velocities of the four vertical propellers to create specific torques and thrust vectors.

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➢ **Control Systems and Electronics**

PID Control Strategy

To manage the inherent instability of the VTOL during transition, six PID (Proportional-Integral-Derivative) controllers are implemented. The Inner Loop manages altitude and attitude (roll/pitch/yaw), while the Outer Loop manages the spatial (X and Y) coordinates.

Component Selection

- Motors: 2200 KV brushless DC motors were selected for their high RPM and cost-efficiency.
- Power: High-discharge Lithium Polymer (LiPo) batteries with a high "C-rating" provide the necessary current for vertical lift.
- ESCs: Calibrated Electronic Speed Controllers regulate the voltage pulses to the motors based on flight controller feedback.

E. Fabrication and Assembly

The prototype was fabricated using high-density polystyrene (foam) boards, selected for their low cost and ease of shaping during the "Proof of Concept" phase.

Fabrication Steps:

- 3D Modeling: Schematics were generated in SolidWorks to ensure structural symmetry.
- Layered Slicing: The fuselage was divided into horizontal and vertical layers, cut from 3/4-inch foam boards.
- Bonding and Sanding: Layers were bonded with industrial adhesives and sanded to achieve an aerodynamic finish.
- Hardware Integration: The fuselage was modified with a removable "hood" to allow access to the internal electronics bay while maintaining structural integrity during flight.

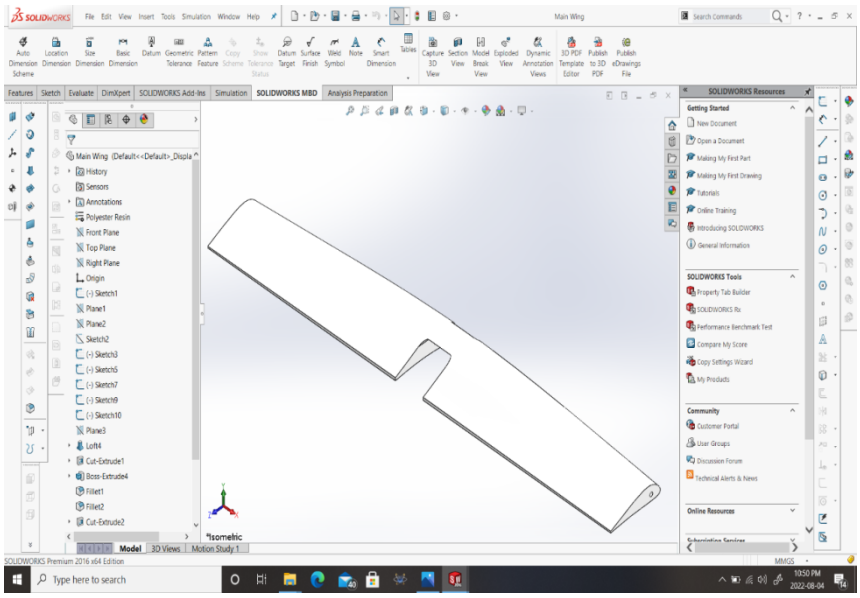


Figure 1: 3D Modeling Process

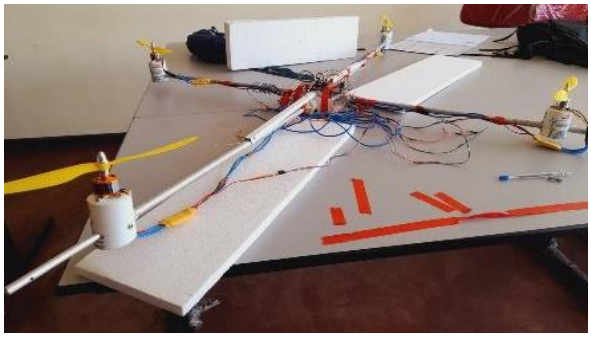


Figure 2: Assembly Process

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III. RESULTS AND DISCUSSION

Magnetometer Calibration Results

The primary function of a magnetometer in a UAV application is to measure the Earth's magnetic field to determine heading. However, measurements are often corrupted by various errors, including sensor zero deviation, scale-factor error, cross-axis sensitivity, and external magnetic interference. These external interferences are classified into "Hard Iron" and "Soft Iron" errors.

"Hard Iron" errors are caused by materials on the UAV that generate a static magnetic field, while "Soft Iron" errors result from materials that distort the pre-existing magnetic field. To ensure flight stability and heading accuracy, a calibration process using the Levenberg-Marquardt (L-M) algorithm was implemented.

The Levenberg-Marquardt (L-M) Algorithm

The L-M algorithm was utilized to calculate correction parameters by combining the benefits of the Newton method and the steepest descent method. It is highly effective for solving non-linear least-squares problems. In this study, the algorithm was applied to fit magnetometer measurement data into both spheres and ellipsoids to isolate and compensate for Hard and Soft iron distortions.

Sphere and Ellipsoid Fitting

The calibration follows a two-stage hypothesis:

1. **Sphere Fitting:** Initial data is fitted to a sphere to assess Hard Iron error. The L-M algorithm estimates the optimal sphere radius.

2. **Ellipsoid Fitting:** Magnetometer data is then monitored for deviations from a perfect sphere. By performing ellipsoid fitting using the initial sphere radius as a convergence criterion, the Soft Iron error is accurately estimated.

Calibration Process

The calibration involves rotating the UAV within the Earth's magnetic field. A sphere fitting method computes the Hard Iron correction until acceptance conditions are met. Once the sample buffer is replenished, an ellipsoid fitting method uses these initial values to correct for Soft Iron errors, resulting in a compensated heading output.

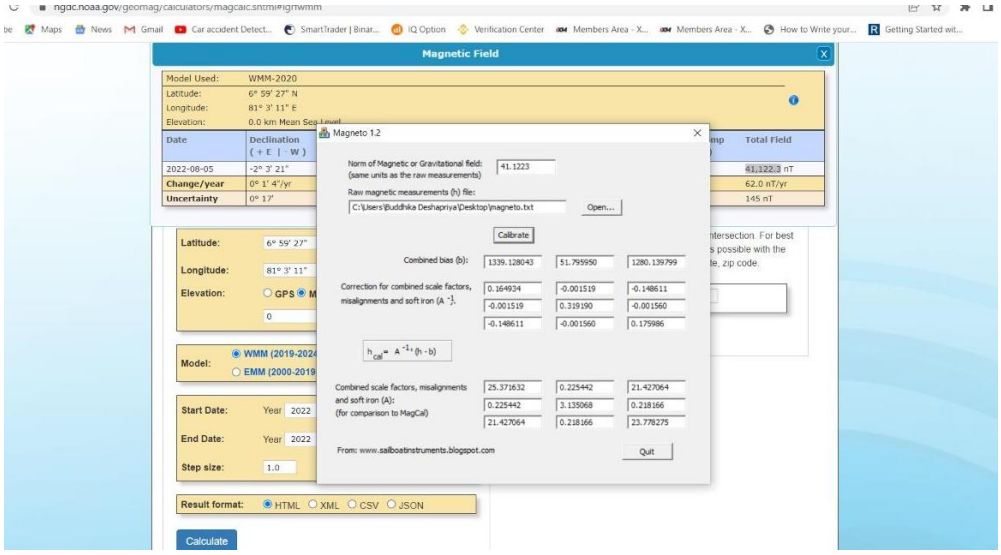


Figure 3: Magnetometer calibration results

Computational Fluid Dynamics (CFD) Analysis

In-flight lift and drag forces are the results of fluid flow interacting with the aircraft airframe. CFD simulations were performed to analyze these interactions under various boundary conditions, reducing the need for multiple physical prototypes and lowering development costs.

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The analysis is grounded in the **Continuity Equation**, which dictates that for a steady-state fluid, mass flow must be conserved across different cross-sections of a stream tube. Furthermore, **Bernoulli's Equation** describes the behavior of the fluid along a streamline, where changes in cross-sectional area result in inverse changes between flow velocity and pressure.

CFD analysis was also used to determine thrust generation. The following data represents maximum thrust generation based on specific RPM ratios using 10-inch propellers.

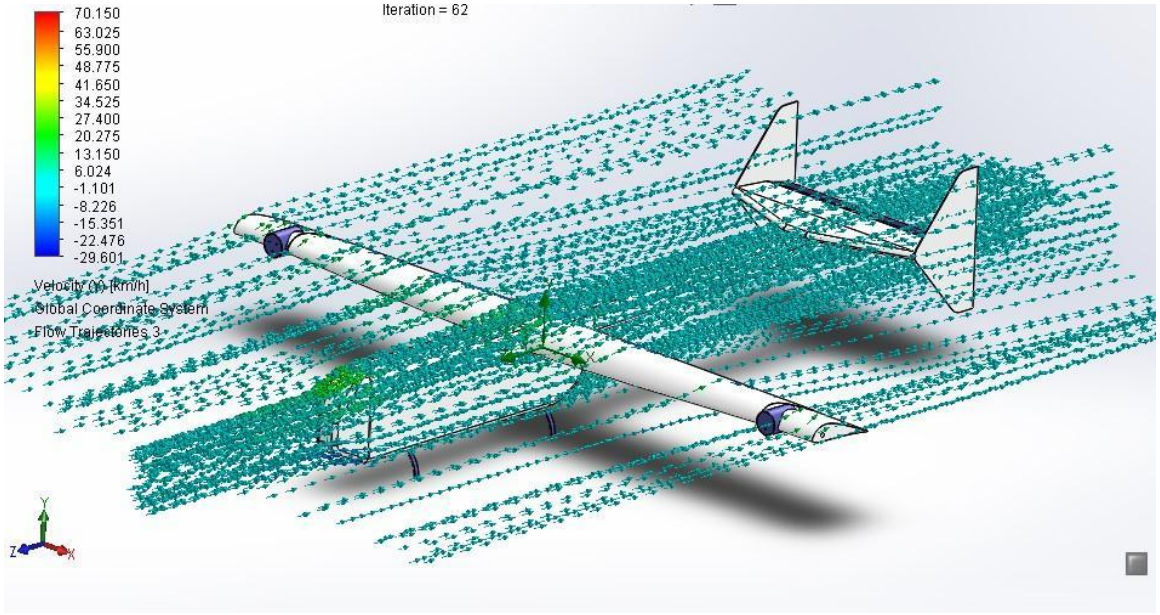


Figure 4: CFD Results

Stress-Strain Analysis

To ensure the structural integrity of the UAV frame, particularly the sections holding the internal components (POD), an engineering stress and strain investigation was conducted.

- **Engineering Stress (σ):** Defined as the applied load (P) divided by the original cross-sectional area
- **Engineering Strain (ϵ):** Defined as the change in length (Δl) relative to the initial length (l0).
- **Poisson's Ratio (ν):** During tensile stress, elastic elongation occurs in the direction of the load, causing a simultaneous lateral constriction. The ratio of lateral strain to axial strain (Poisson's Ratio) was used to select materials that prevent structural failure under flight loads.

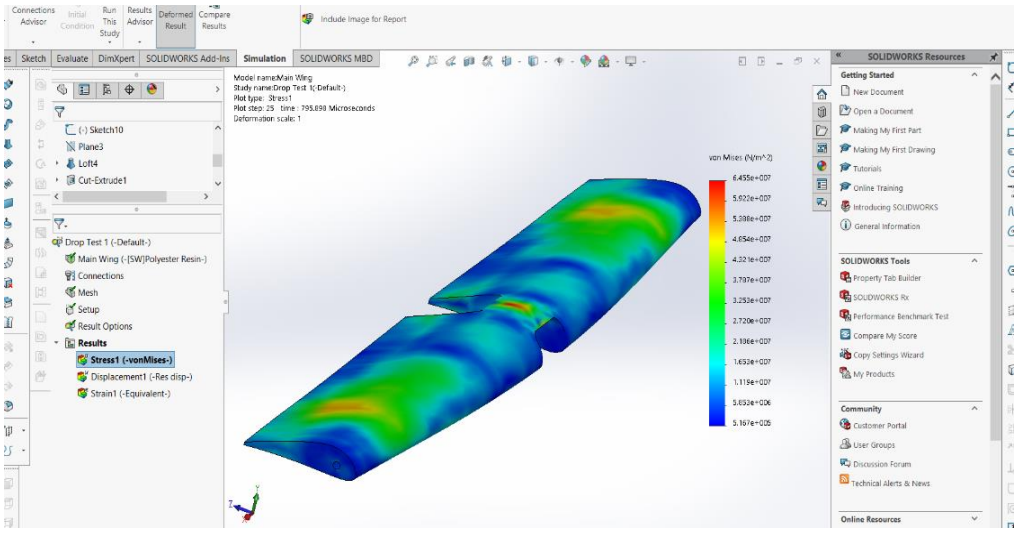


Figure 5: Stress-Strain Analysis Results

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IV. CONCLUSION

This research successfully demonstrated the feasibility of developing a customized Unmanned Aerial Vehicle (UAV) utilizing **Vertical Take-Off and Landing (VTOL)** technology to address the specific needs of wildlife conservation and multidisciplinary research in Sri Lanka.

Design and Performance Summary

The project culminated in the selection of a mid-wing aircraft design characterized by a high wingspan-to-fuselage ratio, optimized for aerodynamic efficiency over traditional helicopter designs. This configuration was chosen to balance payload capacity with programming stability and cost-effectiveness. Key findings from the development phase include:

- **Structural Integrity:** Mathematical simulations confirmed that the design is capable of carrying the necessary sensors and equipment required for field tasks.
- **Aerodynamic Validation:** Initial testing using a commercial surrogate model confirmed strong aerodynamic performance, though it highlighted a payload limitation of 2200g, necessitating further structural optimization.
- **Fabrication Insights:** While financial constraints influenced the development timeline of the student-built prototype, the design phase proved that local facilities are sufficient for constructing high-capability VTOL systems.

Future Impact and Applications

The successful integration of VTOL capabilities allows this UAV to operate in dense forest environments where traditional runways are unavailable. Once fully deployed, this system is expected to serve as a versatile platform for:

- **Wildlife Conservation:** Real-time monitoring of endangered species and anti-poaching surveillance.
- **Agriculture and Research:** Precision data collection and crop monitoring.
- **National Security:** Supporting military and search-and-rescue operations.

In conclusion, this project provides a viable, low-cost solution to bridge the technological gap in Sri Lanka's conservation efforts. The resulting vehicle stands as a multi-purpose application capable of meeting international UAV standards while serving local ecological and industrial needs.

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