Design And Implementation Of Optimized
Multi-Target Aerial Delivery System
For Flood Relief Packages

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

Muhammad Dayan Shahid

Muhammad Haider Ahtsham

Mirnaz Ali

Abdul Rehman Mohsin

June 2024

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Muhammad Dayan Shahid	334499
Mirnaz Ali	349414
Abdul Rehman Mohsin	340690
Muhammad Haider Ahtsham	334082

Titled: "Design And Implementation Of Optimized Multi-Target Aerial Delivery System For Flood Relief Packages" be accepted in partial fulfillment of the requirements for the award of BE Mechanical Engineering degree with grade ___

Supervisor: Dr. Zaib Ali, Associate Professor Department of Mechanical Engineering	Dated: 7/6/24
Committee Member: Dr. Emaduddin, Professor Department of Mechanical Engineering	Dated: 11/7/24
Committee Member: Dr. Shahbaz Khan, Assistant Professor Department of Mechanical Engineering	Dated: 7/6/24.

(Head of Department)

24-7-2024

(Date)

COUNTERSIGNED

Dated: 24-7-24

(Dean / Principal)

TABLE OF CONTENTS

ABSTRACT

This report presents a detailed exploration of the design and implementation of an optimized multi-target aerial delivery system tailored for flood relief packages. It comprehensively addresses various aspects, including aerodynamic analysis, structural integrity assessment, manufacturing processes, business case evaluation, qualification test plan, cost breakdown, and references. Through rigorous aerodynamic analysis using Computational Fluid Dynamics (CFD) simulations, critical parameters such as thrust generation and drag calculation are determined, ensuring stable flight performance in adverse weather conditions. Structural analysis, conducted via Finite Element Analysis (FEA), confirms the integrity and safety of the drone under diverse flight scenarios, with a particular focus on payload mechanisms and delivery precision. Manufacturing processes involve a strategic combination of commercial off-the-shelf (COTS) components, 3D printing for intricate parts, and precision machining for structural elements, ensuring efficiency and reliability. The business case highlights the mission-oriented approach of the project, emphasizing its potential to revolutionize flood relief efforts. A comprehensive qualification test plan outlines success criteria and objectives for lift capability, gear dropping mechanism, maneuverability, thrust generation, endurance, and structural integrity, ensuring the system's readiness for real-world deployment. The cost breakdown provides valuable insights into component pricing, facilitating budget planning and resource allocation. References from relevant studies and publications offer further validation and support for the design and development process. Overall, this report presents a holistic view of the multidisciplinary efforts involved in creating an advanced aerial delivery system poised to address the pressing needs of flood relief operations.

ACKNOWLEDGMENTS

First and foremost, we express our heartfelt gratitude to Allah SWT for His blessings and guidance throughout the journey of designing and implementing the Optimized Multi-Target Aerial Delivery System for Flood Relief Packages.

We extend our sincerest thanks to **Dr. Zaib Ali**, our esteemed supervisor, for his unwavering support, invaluable guidance, and mentorship. His expertise and encouragement have been instrumental in shaping our project's success.

We are immensely grateful to our dedicated team members at Vitesse, including Adil Ali Tariq, Ahmed Bilal, Mahashan Ahmad, Mirnaz Ali, Muhammad Abdullah, Muhammad Dayan Shahid, Muhammad Ehtisham Hassan, Muhammad Haider Ahtsham, and Muhammad Samiullah, whose collective efforts and collaboration played a pivotal role in every aspect of this project's development. Their dedication, expertise, and teamwork were indispensable in overcoming challenges and achieving our goals.

We also acknowledge the invaluable support and guidance provided by the supervisors of the UAS challenge. Their feedback, suggestions, and insights were invaluable in refining our design and ensuring its suitability for real-world applications.

Additionally, we extend our thanks to our batchmates for their advice, encouragement, and guidance throughout the project. Their insights and support were greatly appreciated and contributed to the overall success of our endeavor.

ORIGINALITY REPORT

The report has been passed through several platforms to identify any instances of plagiarism. Notably, Grammarly detected only 5% similarity with content from 18 distinct sources, well within acceptable tolerance limits.

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

1. CFD - Computational Fluid Dynamics
2. N - Newton
3. kg - Kilogram
4. TWR - Thrust-to-Weight Ratio
5. UAV - Unmanned Aerial Vehicle
6. ANSYS - ANalysis SYStem
7. APDL - ANSYS Parametric Design Language
8. ESCs - Electronic Speed Controllers
9. ABS - Acrylonitrile Butadiene Styrene
10. GPS - Global Positioning System
11. FOS - Factor of Safety
12. GPa - GigaPascal
13. COTS - Commercial Off-The-Shelf
14. MRC - Manufacturing Research Center
15. SMME - School of Mechanical and Manufacturing Engineering
16. SUPARCO - Space and Upper Atmosphere Research Commission
17. Rs. - Pakistani Rupees
18. LiPo - Lithium Polymer
19. VTOL- Vertical take-off and landing

NOMENCLATURE

1. *Lift (Symbol: L)*
2. *Drag (Symbol: D)*
3. *Thrust (Symbol: T)*
4. *Weight (Symbol: W)*
5. *Torsion (Symbol: τ)*
6. *Max Deformation (Symbol: δ_max)*
7. *Equivalent Stress (Symbol: σ_equiv)*
8. *Factor of Safety (Symbol: FOS)*
9. *Payload (Symbol: P)*
10. *CAD (Computer-Aided Design)*
11. *FEA (Finite Element Analysis)*

CHAPTER 1: INTRODUCTION

This introductory chapter sets the stage for the project by presenting its motivation, defining the problem statement, and outlining the project's objectives.

1.1 Motivation

The impetus for this project arises from the critical need to develop an optimized multi-target aerial delivery system tailored specifically for flood relief packages. The devastating impact of floods on communities necessitates swift and efficient relief efforts to mitigate human suffering and property damage. Traditional relief methods often face logistical challenges, including delays in accessing affected areas and limitations in reaching stranded populations. By harnessing the capabilities of unmanned aerial systems (UAS), we aim to revolutionize flood relief operations, enabling rapid and targeted delivery of essential supplies to those in need. This project is driven by a commitment to leveraging innovative technologies to enhance disaster response capabilities and save lives in flood-prone regions.

1.2 Problem Statement

The primary challenge addressed by this project revolves around the inefficiencies and limitations inherent in current flood relief delivery mechanisms. Conventional methods, such as ground-based transportation and manual airdrops, are hindered by logistical constraints, including restricted access to flooded areas, unpredictable weather conditions, and limited payload capacities. These challenges often result in delays in delivering critical supplies, leading to exacerbated humanitarian crises and increased vulnerability among affected populations. Moreover, the lack of precision targeting in relief operations can result in resource wastage and inequitable distribution of aid. Thus, there exists a compelling need to develop an innovative aerial delivery system capable of overcoming these challenges and optimizing the efficiency and effectiveness of flood relief efforts.

1.3 Objectives

The overarching objectives of this project are as follows:

1. Design and develop a robust and versatile multi-target aerial delivery system capable of autonomously transporting multiple flood relief packages to those in need.
2. Develop a machine learning model trained to detect survivors struck in flood that cannot be reached via ground vehicles.
3. Design and develop an advanced payload mechanism capable of multiple drops in a single run with precise targeting, delivery accuracy, and quick refill time.
4. Conduct comprehensive testing and validation of the developed system under simulated flood conditions to assess its performance, reliability, and operational readiness.

By addressing these objectives, this project aims to advance the state-of-the-art in flood relief logistics and contribute to the development of innovative solutions for enhancing disaster resilience and humanitarian assistance efforts.

CHAPTER 2: LITERATURE REVIEW

The literature review provides insights into various aspects relevant to the project. The study conducted can be divided into 2 parts, the research done, and the available designs.

2.1 Research

The research conducted by the German Rescue Robotics Center (DRZ) [11] underscores the importance of developing modular robotic systems equipped with robust communication architecture and autonomous assistance functions. These findings are particularly relevant as they highlight the potential for integrating similar autonomous capabilities into disaster relief drones. By leveraging modular designs and robust communication protocols, our project can enhance the adaptability and resilience of multi-target payload mechanisms, ensuring seamless coordination and operation in dynamic disaster environments.

The research on flood detection, presented in Munawar et al., Sustainability, 2021 [12], using deep learning models presents a compelling opportunity to augment the capabilities of disaster relief drones. By leveraging CNNs for flood detection from UAV-captured imagery, our project can incorporate advanced sensing and detection algorithms to identify flood-affected areas swiftly and accurately. This integration can significantly enhance situational awareness and enable targeted delivery of relief supplies to areas most in need, thereby maximizing the impact of our aerial delivery system.

Additionally, DroneServ's [13] deployment of drones for disaster management in Pakistan highlights the transformative potential of UAV technology in streamlining disaster response efforts. By integrating insights from DroneServ's operations, our project can glean valuable lessons on optimizing flight routes, coordinating multiple drones, and delivering critical supplies to disaster-affected areas efficiently. Leveraging lessons learned from real-world deployments, we can refine our multi-target payload mechanism to enhance reliability, speed, and scalability in disaster relief missions.

Dr. Rizwan Ahmed's research, in H. Ijaz et al., IEEE Transactions on Geoscience, 2023 [14], on edge computing frameworks for disaster classification offers a novel approach to enhancing detection speed and accuracy. By leveraging edge computing capabilities, our project can expedite the processing of sensor data onboard the drones, enabling real-time analysis and decision-making during disaster relief missions. This integration can significantly reduce response times and improve the overall effectiveness of our aerial delivery system in delivering timely assistance to disaster-affected communities.

In parallel to that, the feasibility study on delivery systems using UAVs [1] addresses crucial challenges in drone-based logistics, offering insights into optimizing vehicle routing, drone assignment, and recharging station deployment. By leveraging mathematical modeling and optimization algorithms, our project can refine the operational efficiency of our aerial delivery system, ensuring timely and cost-effective delivery of relief supplies in disaster-affected areas. Additionally, the study's emphasis on fleet dimensioning can inform strategic decision-making in deploying drones for disaster relief missions, maximizing the system's scalability and impact.

Moreover, the study on payload drop mechanisms [3] for fire-fighting UAVs offers valuable insights into designing robust and versatile payload delivery systems. By leveraging similar mechanisms, our project can develop a payload delivery system capable of releasing multiple relief packages with precision and reliability. The incorporation of advanced servo motor control and release mechanisms can enable our aerial delivery system to operate effectively in challenging environments, such as rugged terrain and adverse weather conditions, thereby enhancing its utility in disaster relief operations.

2.2 Design:

The comprehensive investigation into drone-based package delivery elucidates key considerations and challenges in designing embedded payload solutions for UAVs. By integrating insights from this study, our project can refine the design and implementation of the multi-target payload mechanism, ensuring compatibility with various cargo types and optimizing delivery efficiency. Additionally, the emphasis on user-oriented design can inform the development of intuitive interfaces and safety features, enhancing the usability and reliability of our aerial delivery system in demanding disaster scenarios.

The wing structures utilize rear spars actuated by servomotors to efficiently adjust camber angles, optimizing performance throughout flight phases. Compliant ribs, made from ABS via 3D printing, offer flexibility while resisting buckling. Pre-tensioned latex sheets, secured with epoxy, maintain aerodynamic integrity by minimizing drag-inducing gaps. Double corrugated structures provide strength without sacrificing aerodynamics. However, the morphed wing's inability to selectively adjust sections due to rigid ribs and stringers compromises independent control functions like flaps and ailerons, highlighting the practicality of traditional control surfaces for maneuverability.

The Fairey Rotodyne VTOL reduces power needs during takeoff and landing by using a large helicopter propeller atop a fixed-wing airframe, eliminating the need for tilting mechanisms. However, noise and stability issues arise with these propellers, possibly requiring extra counter-rotating ones. Additionally, mimicking intricate helicopter mechanisms poses engineering challenges, while the propellers' redundancy during cruise adds unnecessary weight without significant thrust contribution, limiting effectiveness. Despite its power-saving advantages, the Rotodyne's design priorities and drawbacks make it less suitable for guiding our drone's aerodynamic parameters.

Cyclo-rotors [8], utilizing the Magnus effect, offer efficient thrust perpendicular to airflow, particularly effective in small-scale aircraft testing. With blades mounted between frames allowing continuous pitch adjustments, they enable thrust vectoring for VTOL capability. Uniform aerodynamic flow along the blade span simplifies blade design, reducing manufacturing complexity. However, complexities in pitching mechanisms, limited experimental data, and material durability concerns prompted the team to abandon this innovative plan. Despite its potential, the focus on rotor design left overall craft optimization and structural durability unaddressed.

The second option, VTOL [4] enables aircraft to ascend and descend vertically, bypassing the need for runways and offering enhanced flexibility. However, this capability comes with drawbacks including increased complexity, weight, and operational costs. Additionally, VTOL operations may generate higher noise levels and consume more energy compared to traditional aircraft, limiting their suitability for certain environments and missions

Finally, fixed-wing [7] aircraft maintain flight through the forward motion generated by engines and lift produced by wings. This design offers advantages such as efficient fuel consumption, longer range, and higher speeds compared to VTOL aircraft. However, fixed-wing aircraft require runways for takeoff and landing, limiting their access to confined or remote areas. Additionally, they may not be well-suited for missions requiring vertical maneuverability or hover capability.

2.3 The Necessity of our project

The necessity of the project in the context of previous works becomes apparent when examining the challenges highlighted in our literature review. Flood crises demand solutions that can efficiently cover vast areas, preserve resources over extended periods, and deliver aid to multiple targets in a timely manner. However, existing approaches often fall short in addressing these complex logistical hurdles.

Our review of the literature reveals that while drones have been increasingly utilized in disaster response efforts, including flood management, current payload mechanisms lack the efficiency and scalability needed to meet the demands of such scenarios. Traditional single-target delivery systems are inefficient, requiring multiple flights to distribute aid to various locations, leading to increased response times, energy consumption, and resource depletion.

Introducing a multi-target payload mechanism represents a significant innovation in disaster relief operations. By allowing drones to drop multiple packages in a single flight sequence, without the need for repeated trips, this approach offers several advantages. It streamlines the delivery process, reduces response times, conserves energy, and enhances overall operational efficiency.

However, our literature review also highlights a notable gap in the exploration of multi-target payload mechanisms specifically tailored for flood relief. While research has investigated various aspects of drone technology and payload delivery, few studies have addressed the unique challenges posed by flood crises comprehensively.

Therefore, this gap was bridged by developing and implementing an optimized multi-target aerial delivery system for flood relief packages. By drawing on insights from our literature review and leveraging advanced payload technologies, we aim to design a system capable of efficiently distributing aid across flood-affected regions. Through innovative design and rigorous testing, we aspire to enhance the effectiveness and sustainability of disaster response efforts, ultimately ensuring that aid reaches those in need in a timely and efficient manner.

CHAPTER 3: METHODOLOGY

3.1. Summary of Design

A. Drone description and target specifications:

The drone to be designed is a quadcopter built for versatile applications, focusing on efficient search and rescue operations. Key components include a Pixhawk flight controller, Raspberry Pi companion board, and a sophisticated flight control system. The novel features encompass a modular payload system and enhanced payload capacity. The thrust-to-weight ratio is targeted at 1.5:1, with the ability to carry a payload exceeding 5 kg for an estimated flight time of 12 minutes.

The target design specifications are as follows:

- Flight time: 12-15 minutes
- Maximum speed: 8-10 m/s
- Weight: 6-7 kg
- Payload Capacity: 4-5 kg
- Rain proof (for light showers)

B. Payload Summary:

The payload mechanism consists of an enclosed container with three separated compartments, each with a door attached with a spring to force it closed. Three servo motors with extended horns attached are used to hold the doors in place. When the controller sends the signal, the servomotor rotates and the door is free to open. The package forces the door open on its own weight and drops. The mechanism is designed to be lightweight and spontaneous with three independent mechanisms. It will hold the packages in place to maintain the stability of the drone.

The package may consist of edibles, drinks, first aid kits, medicine and whatever else may be essential for survival, making it weigh up to 1.5 Kg. Thus, the total payload capacity of the mechanism is 4.5 kg.

3.2. Project Phases:

The plan is divided into six parts that are to be implemented step by step as shown:

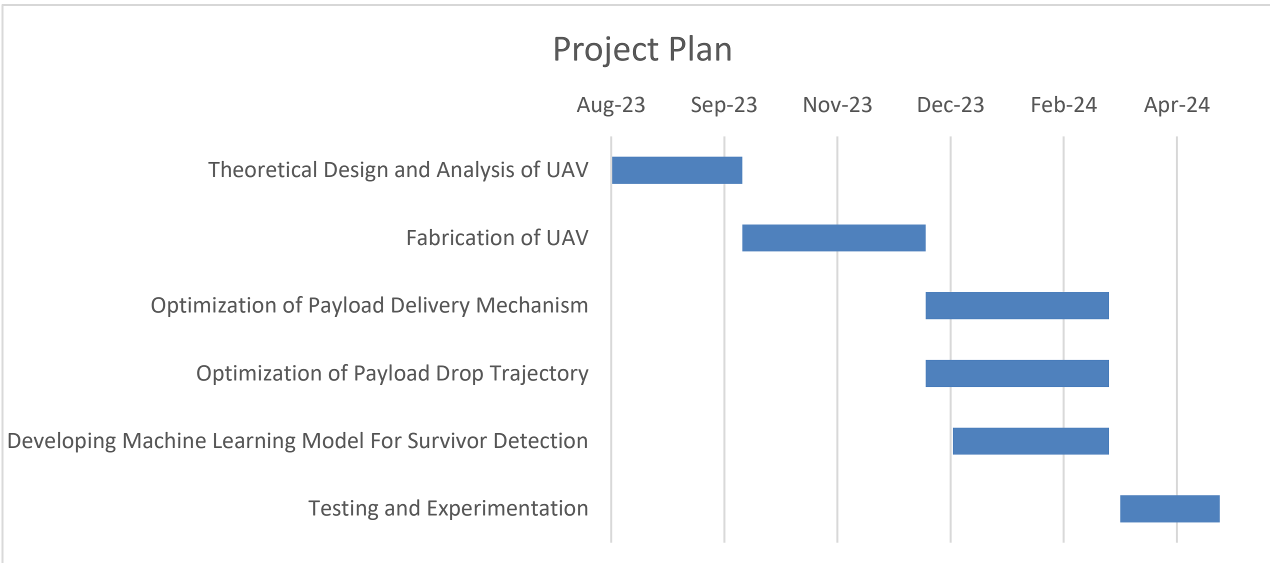

Figure 1: Project Timelines

3.3. Design Description

A. Air Frame

The airframe of a quadcopter drone provides structural support and housing for essential flight components, determining aerodynamics and performance. Its main components include the main frame, typically made of carbon fiber, supporting arms arranged in an "X" configuration, and motor mounts made of PETg. The arms extend from the main frame, providing attachment points for motors and propellers, crucial for lift and controlled movement. The propulsion system involves four propellers and motors strategically positioned on the airframe's arms, enabling flight, hovering, and directional control.

B. Propulsion

Quadcopter propulsion involves the coordinated rotation of motors and propellers, generating thrust for flight. The flight controller adjusts motor speeds independently, controlling orientation and movement. Varying motor speeds causes pitching, rolling, and yawing motions. Hovering is achieved through constant motor speed adjustments based on sensor data. Altitude control is managed by adjusting collective thrust. Overall, quadcopters achieve stable flight and controlled movement through precise motor control by the flight controller, enabling various aerial maneuvers.

C. DC Brushless Motors

We chose Gartt ML5210 340kv motors for vertical propulsion. It was because they operate on batteries which are more environmentally friendly. These DC motors will be connected to their respective Electronic Speed Controllers (ESC) which will control the current flowing through each motor depending on the propulsion force required for the task to be performed.

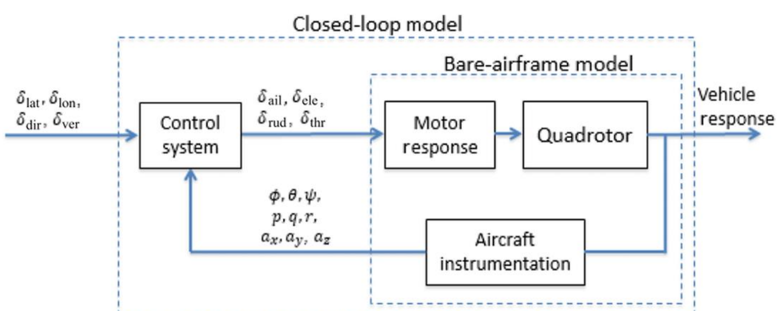

Figure 2: Propulsion Architecture

D. Autonomous Flight Control

The flight control system manages the autonomous flight of the air vehicle and consists of two key components: the flight controller and the flight computer. The flight controller is responsible for inner loop commands, ensuring stability during flight by adjusting servo angles and motor speeds. The PIX HAWK 2.4.8 flight controller, integrated with a GPS module and Wi-Fi telemetry, interprets commands and facilitates real-time monitoring. Electronic Speed Controllers regulate motor speeds. The flight computer, exemplified by the Raspberry Pi 3 B, directs autonomous flight from Point A to Point B, prioritizing navigation over stability.

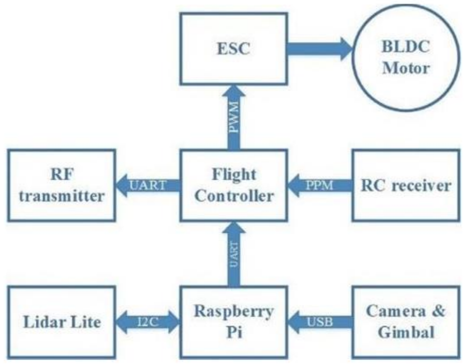

Figure 3: Flight Control

E. Navigation and Mission Control

To enable continuous monitoring of the drone's coordinates on a computer device, a Navigation system is imperative. This is facilitated by the GPS module integrated into both the PIX HAWK Flight Controller and the Flight Computer (Raspberry Pi 3 B). The Raspberry Pi 3B communicates with the PIX HAWK, guiding the drone to the desired location for spraying purposes, leveraging Wi-Fi telemetry and the Mission Planner software.

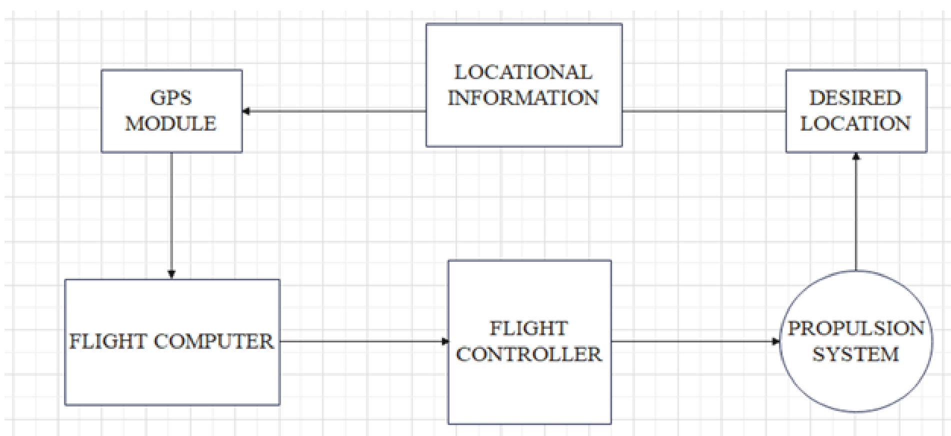

Figure 4: Mission Control Flowchart

Cutting-edge technologies and engineering enhance drone performance and reliability in diverse operational scenarios.

3.4. Mathematical Modeling

Aerodynamic Calculations:

The aerodynamic calculations are as follows:

A. Thrust Calculations: We choose precisely the propellers and throttle to be able to provide enough thrust to be able to carry out the flight. We are using 17x55 propellers and operating the motors at 82% throttle. From the datasheet of the Gartt ML5210 340kv motors, we can calculate the thrust as follows:

$$3.61\ kg \times 9.81\ ms^{-2} = 36.4\ N \tag{1}$$

$$\text{Total thrust} = 36.4\ N \times 4 = \mathbf{145.6N} \tag{2}$$

B. Weight Calculations:

Mass Distribution by Components		
Sr. No.	**Component**	**Mass (Approx.) in grams**
1	Motors (x4)	920
2	Airframe	2300
3	Battery	2450
4	Pixhawk	50
5	Servo	70
6	Raspberry Pi	50
7	Other Components (ESCs, Wiring)	160
8	Payload	5000
Total		**11000**

Table 1: Weight Breakdown

$\text{T}otal\ mass\ without\ payload$ = 6000g

Mass of $Payload$ = 5000g

$\text{T}otal\ weight\ incl.\ payload$ = $Wtotal$ = $11kg\ x$ 9.81 $ms^{-2}\ =\ 107.8\ N$ (3)

C. Thrust-to-Weight Ratio Calculations:

$Thrust - to - Weight\ Ratio = \frac{145.6N}{107.8N} = \mathbf{1.35}$ (4)

which is around optimum thrust-to-weight ratio of 1.5, a common guideline in aviation and aerospace engineering.

D. Max. Climbing Rate of the UAV:

$$a = \frac{F}{m} = \frac{145.6}{11} = 13.23ms^{-2} \quad (5)$$

E. Motor RPM:

$$Motor\ KV\ = 340\ kV$$

$$Battery\ rated\ voltage = 22.2\ V$$

$$Motor\ RPM = 340 \times 22.2 = 7548 \quad (6)$$

F. Flight Time Calculations:

Battery capacity = 22 Ah × 22.2 W = 488.4 Wh

Total Power consumption: 2530 W

Estimated Flight Time = 488.4/2530 × 60 *=11.5 min* (7)

3.5. CFD Analysis

A. **Abstract**

This section aims to conduct a Computational Fluid Dynamics (CFD) analysis of our UAV to understand its aerodynamic characteristics. Using SolidWorks, we modeled the drone and conducted flow simulations to optimize its design for real-world performance.

B. **Methodology**

Fluid flow add-in of SolidWorks was utilized for meshing and computation, streamlining the simulation process.

C. **Analysis Environment**

Advanced CFD solvers and high-performance computing systems were employed for accuracy. SolidWorks was chosen for its robust capabilities in simulating quadcopters.

1. **Size of Computational Domain**

   The domain encapsulates the airspace around the drone, balancing computational resources with accuracy.

+X	1.6m
-X	-1.3m
+Y	2m
-Y	-0.9m
+Z	1.5m
-Z	-1.1m
+X	1.6m

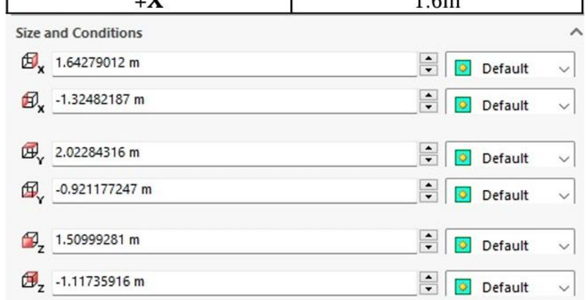

Figure 5: CFD Domain Size

2. **Mesh Analysis**

Total cells	12,577
Fluid Cells	12,577
Iterations	58

Table 2: Mesh Characteristics

3. **Material**

   Material properties for the drone and surrounding air are considered, with air modeled as an ideal gas.

4. **Initial Conditions**

   Initial conditions and simulation parameters are defined for an accurate representation of real-world scenarios.

5. **Results**

   Thrust analysis reveals the drone's capability to generate sufficient thrust for stability and maneuverability. Through our CFD simulations, we have determined that each individual propeller, operating under specific conditions, generates an average force of **55.969 N** in the Y direction. The total thrust is therefore **223.876** which gives a thrust to weight ratio of 2.28 ideally.

3.6. Structural Analysis:

A. Study 1

1) **Overview:**

Using ANSYS Static Structural, we simulated the UAV's scenario during vertical flight by fixing the lower plate and applying a 5kg equivalent force to each motor mount. This conservative approach ensures safety even in extreme conditions.

2) **Modifications in Geometry:**

Propellers were excluded from the analysis due to their manufacturer-specified resilience. The payload container was replaced by boundary conditions.

3) **Boundary Conditions:**

Motor Mounts: Upward force of 50 N each

Lower Plate: Fixed Support

4) **Results:**

Max Deformation: 3.5 mm (at motor mount)

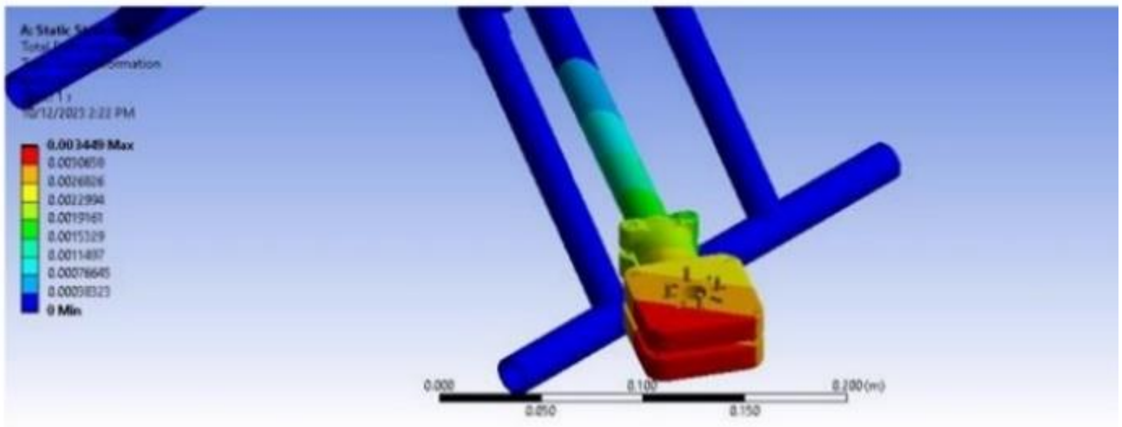

Figure 6: Total Deformation

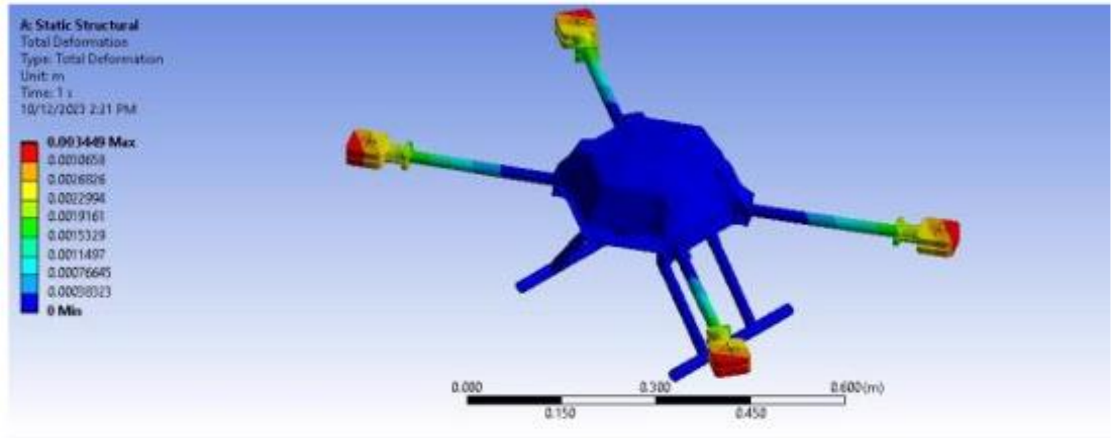

Figure 7: Maximum Deformation at Motor Mounts

Max. Equivalent Stress: 76 MPa (at Carbon Fiber Rod and PETg Bracket Junction)

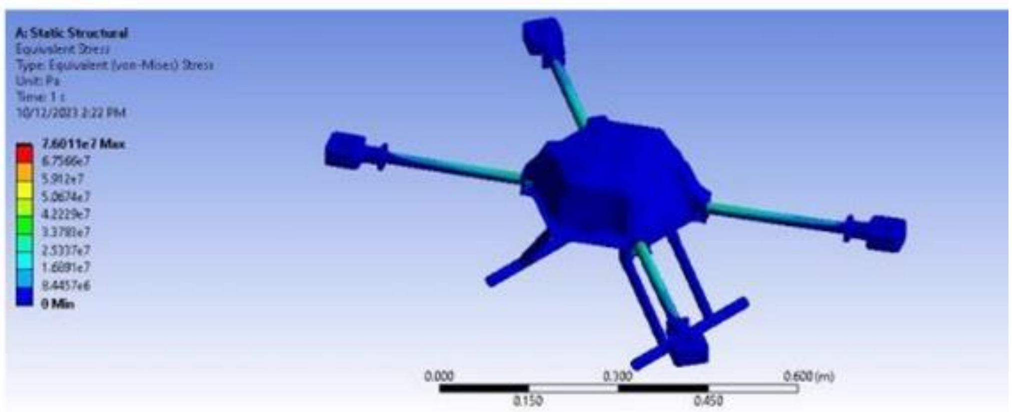

Figure 8: Total Equivalent Stress

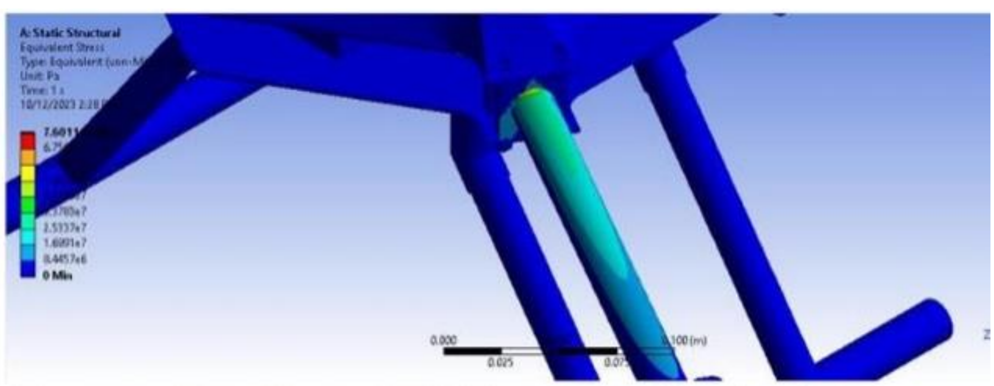

Figure 9: Maximum Stress at Carbon Fiber rod and Bracket Junction

5) **Factor of Safety (FOS):**

Industrial-grade carbon fiber rods which have tensile strengths in the range of 3 GPa to 7 GPa. So, assuming the worst-case scenario, FOS is calculated as:

$$FOS = 3/0.076 = 39.47 \tag{8}$$

which is sufficient to ensure safety whilst accommodating inaccuracies.

B. Study 2:

1) Overview:

The motor mounts were fixed, and a 200 N (20kg) load was applied to the lower plate to simulate the drone's entire load on the mounts.

2) Modifications in Geometry:

Similar simplifications as Study 1 were applied.

3) Boundary Conditions:

Motor Mounts: Fixed Support

Lower Plate: Downward force of 200 N

4**) Results:**

Max. Deformation: 0.8mm (at Canopy made of ABS Plastic)

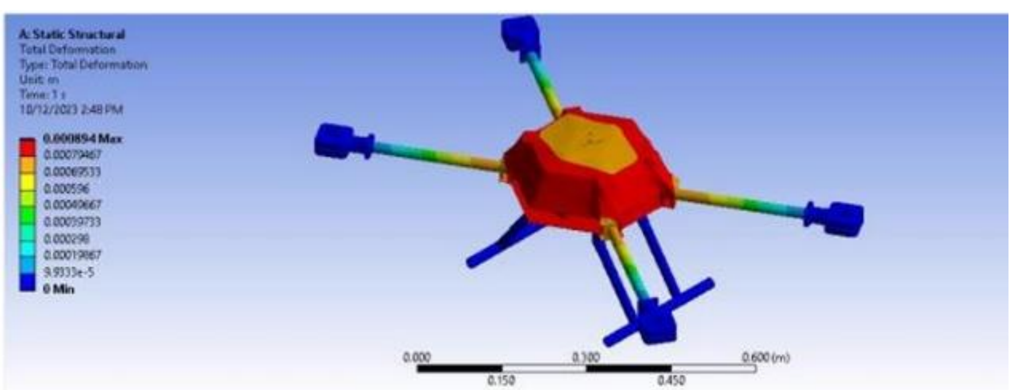

Figure 10: Total Deformation

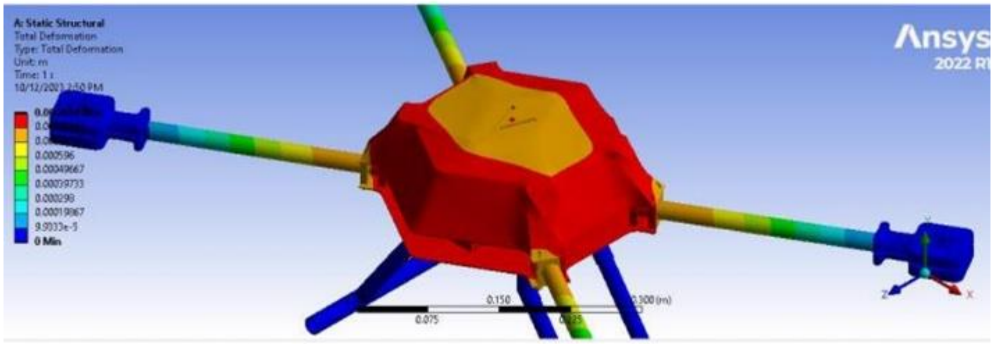

Figure 11: Maximum Deformation at Joining Brackets

Max. Equivalent Stress: 45 MPa (at CF Rod and PETg Bracket Junction)

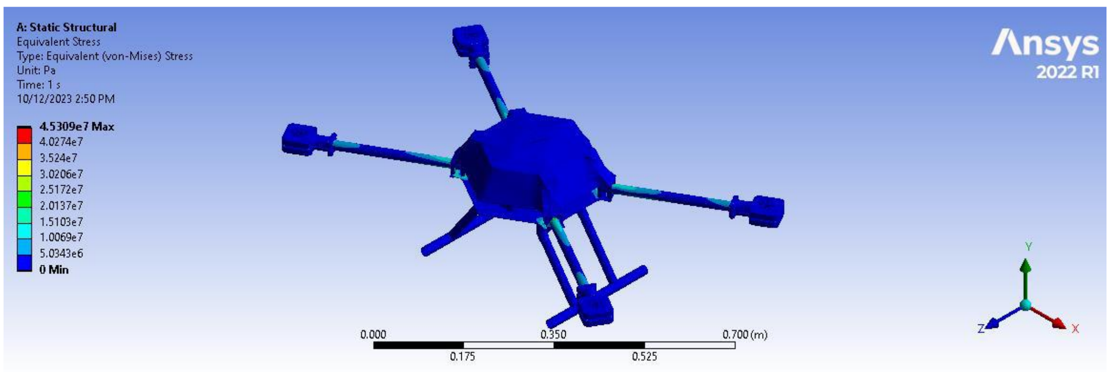

Figure 12: Total Equivalent Stress

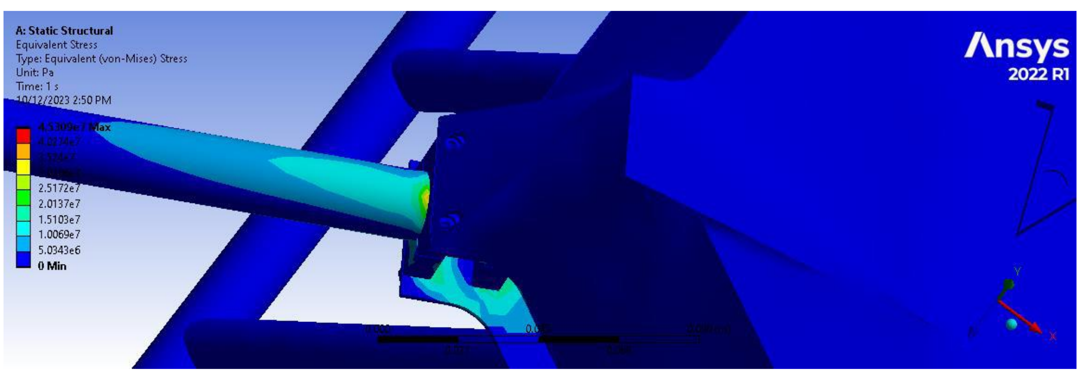

Figure 13: Max. Equivalent Stress

5) Factor of Safety (FOS):

Calculated as before:

FOS = 66.67

C. Deductions From The Structural Study:

The studies ensure structural integrity in all flight scenarios. A conservative modeling approach and simplification of geometry were used.

3.7. Design Drawing and Description:

SCALED MODEL ENGINEERING DRAWING:

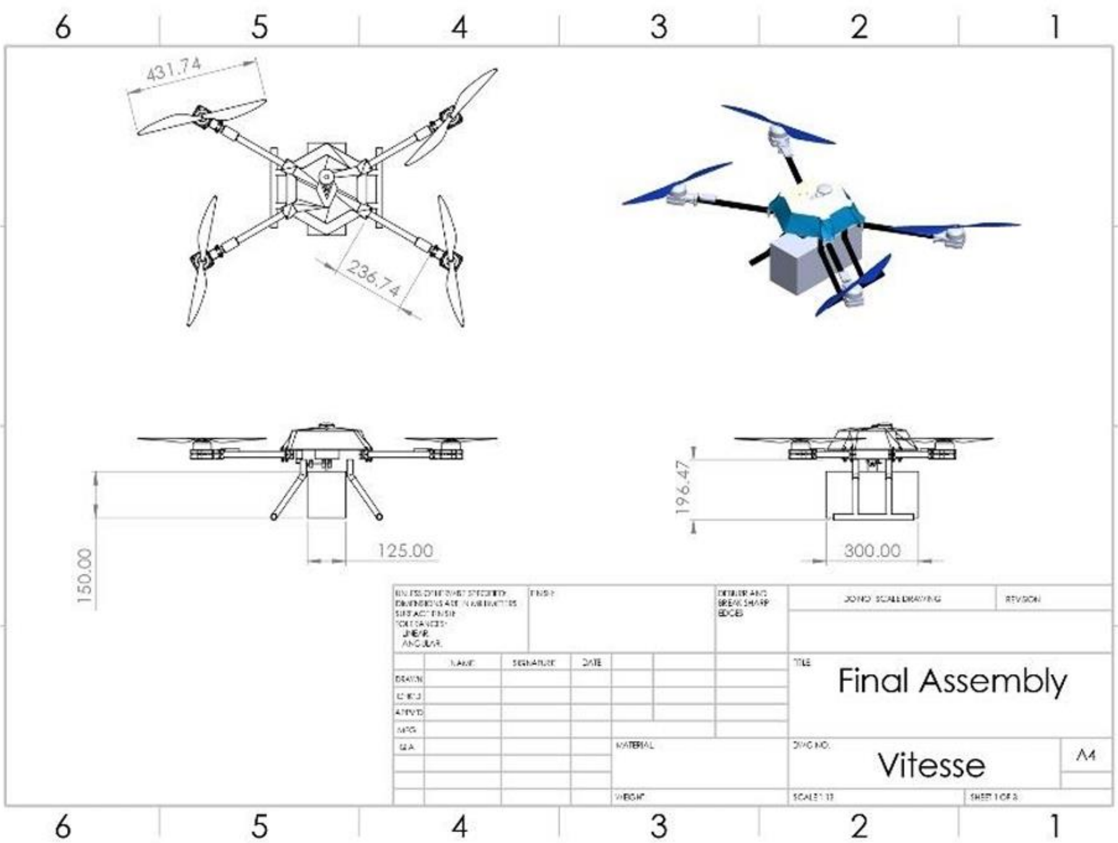

Figure 14: Engineering Drawing of Complete Drone Assembly (Third Angle Projection Technique)

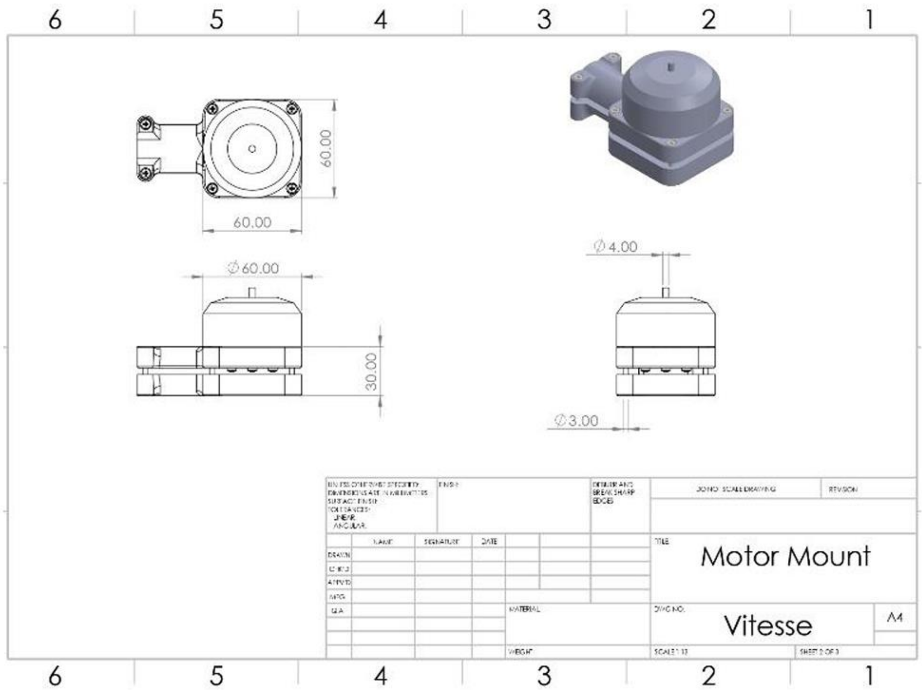

Figure 15: Engineering Drawing of Motor Mounts (Third Angle Projection Technique)

3D CAD MODEL:

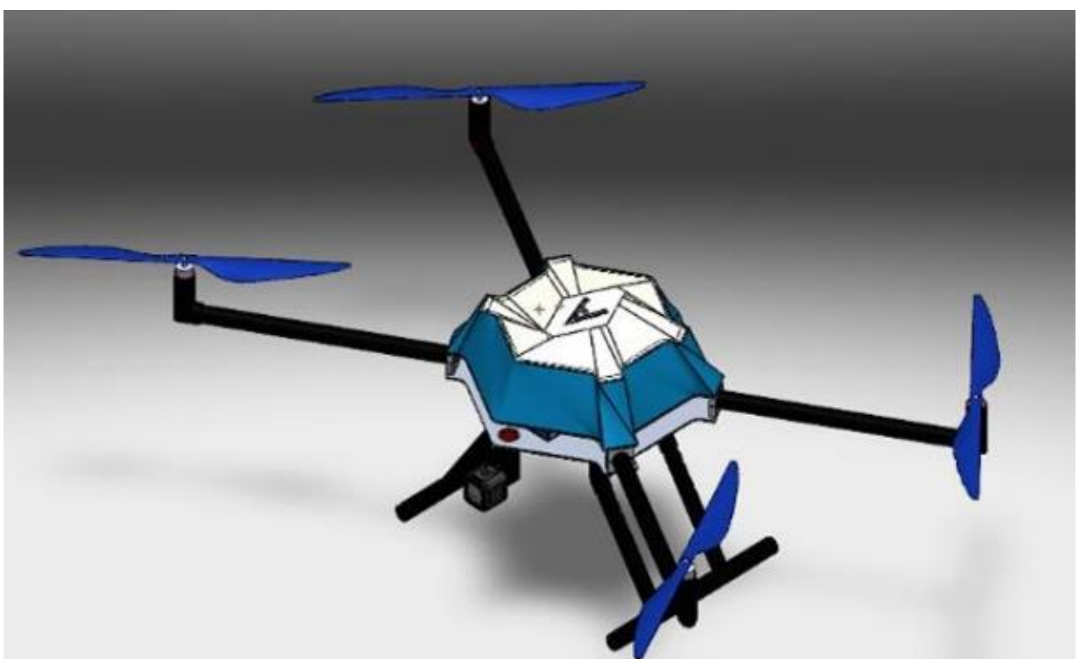

Figure 16: Isometric View of Drone Assembly

3.8. Multi-target payload delivery mechanism

A. Description.

The payload mechanism is enclosed and consists of three compartments. Doors are hinged at the bottom and held in place by springs. For each door, there is a servomotor with a horn attached that blocks the door from opening. The servomotors are connected with the pins of the Pixhawk. When a servomotor receives a signal, the horn rotates out of the way and the door is free to open. The weight of the package forces the door open and the package drops. The spring then helps shut the door.

B. Drawing and CAD design.

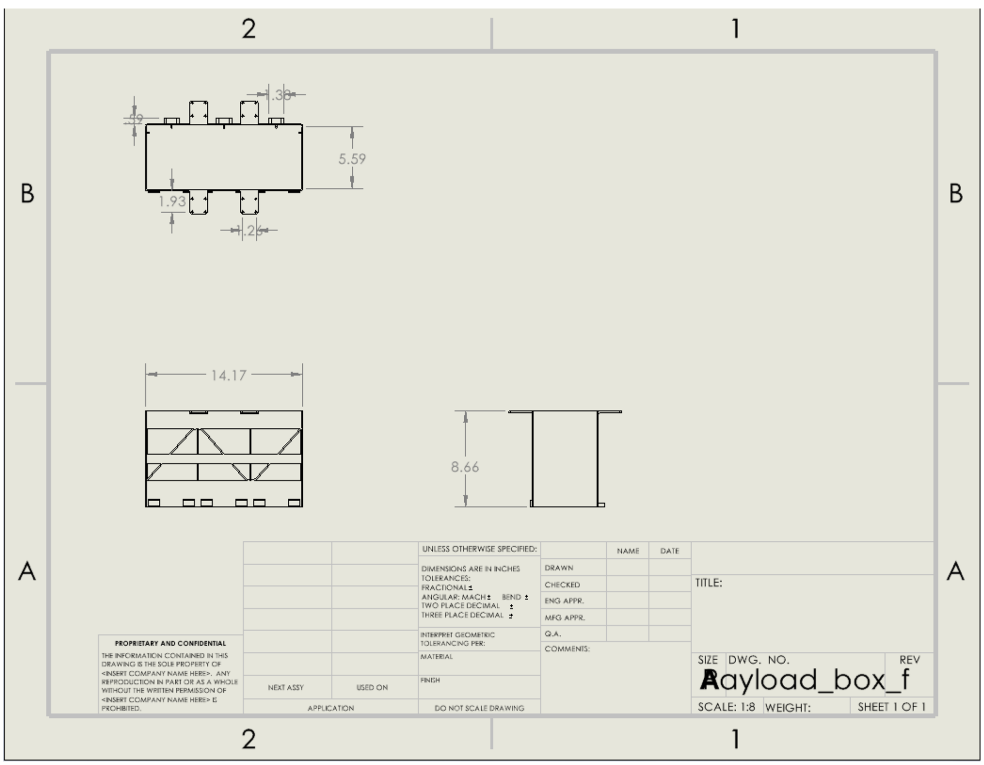

Figure 17: Payload mechanism drawing

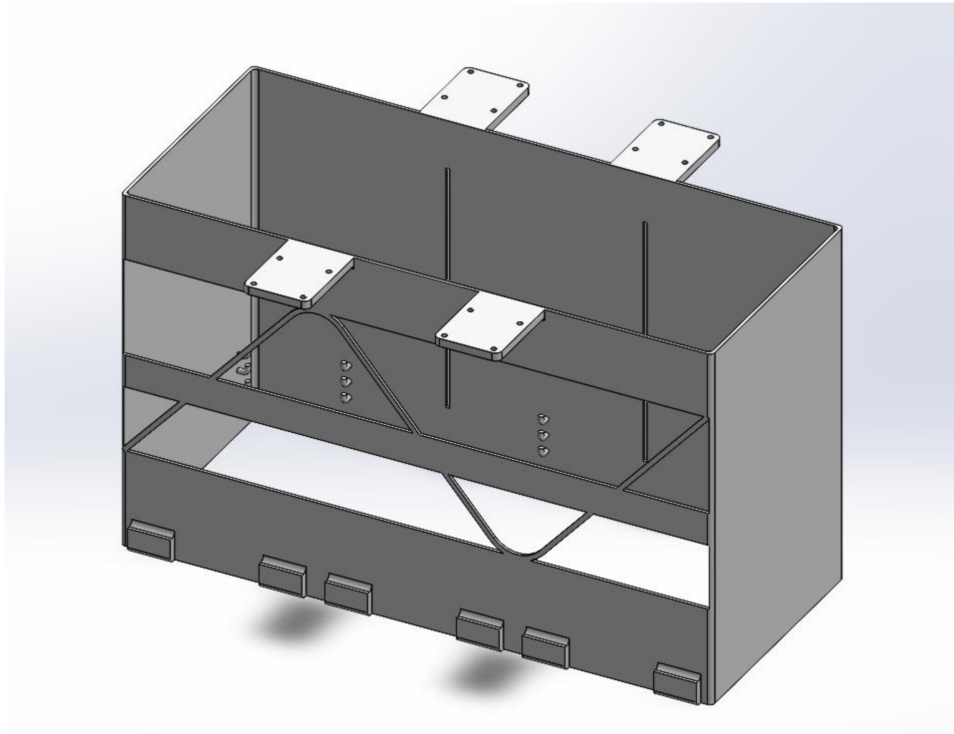

Figure 18: Isometric view of the payload mechanism

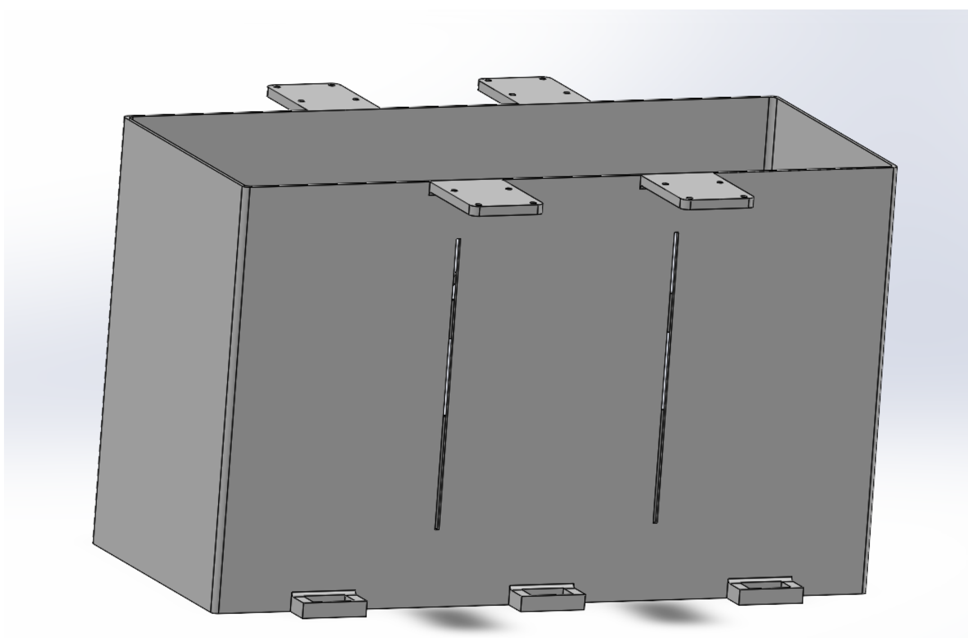

Figure 19: Front view of the payload mechanism

C. Structural Analysis

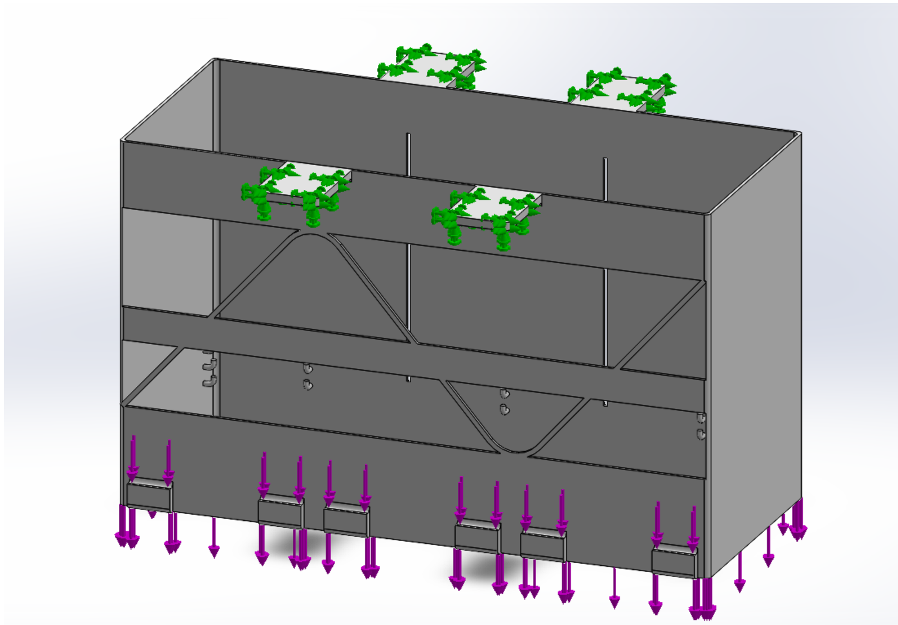

Figure 20: Boundary conditions

The figure shows the boundary conditions used for this analysis. The material used in this simulation is PETg, which also the actual material. The mechanism was fixed on the top from the supports. Loads ranging from 20 N to -80 N were applied at the bottom. These loads are overexaggerated. The results are shown below:

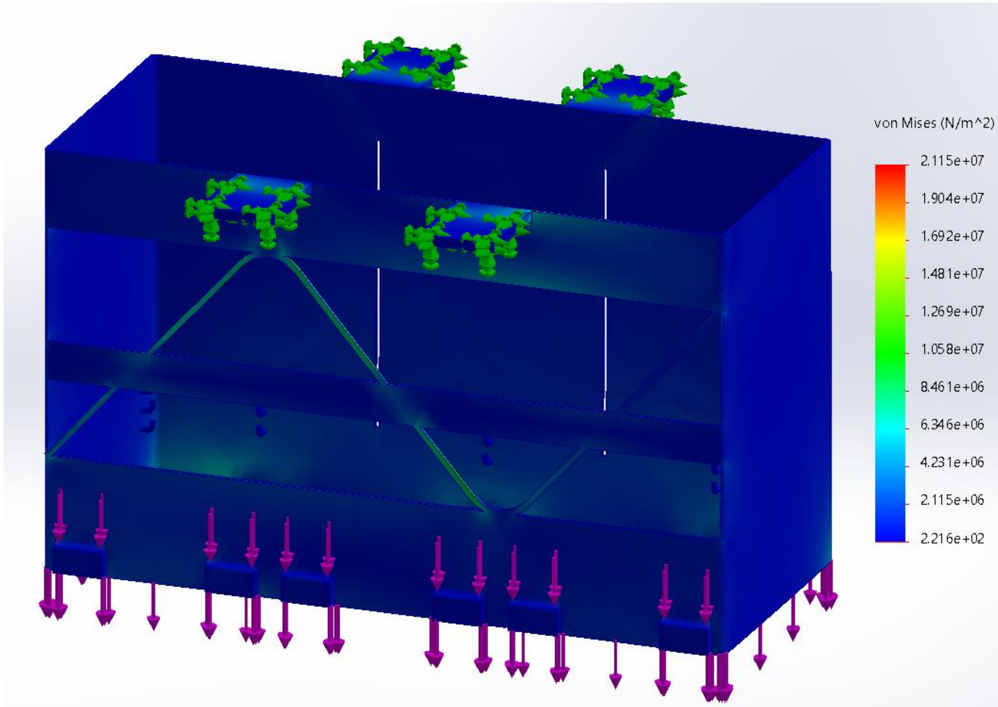

Figure 21: Payload mechanism stress analysis

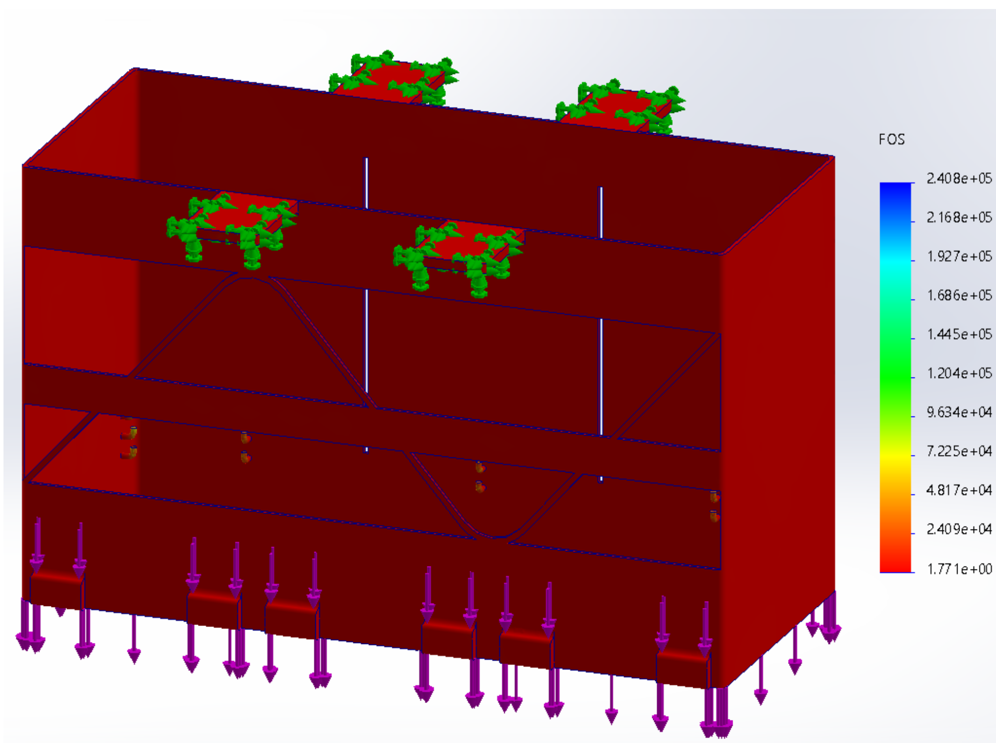

Figure 22: Factor of safety graph

The factor of safety obtained is **1.7**.

D. Manufacturing and Assembly.

The payload mechanism was 3D printed with the material PETg. The doors were hinged at the bottom and springs were attached to the hooks on the doors. The payload mechanism was then fixed to the drone frame with nuts and bolts. Three servomotors were fitted into the placeholders at the front and they were connected to the to the pixhawk pins.

3.9. Manufacturing and Support

A. Manufacturing Processes:

Our drone's manufacturing involves using a mix of commercial off-the-shelf (COTS) items, 3D printing, and machining. COTS components like batteries, motors, and electronics are sourced from reliable suppliers. Parts like motor mounts and canopy are 3D printed using ABS material for precision and flexibility. Machined parts, such as aluminum blocks and carbon fiber sheets, ensure structural integrity and aerodynamics.

B. Construction Techniques:

Other than COTS items, development of parts involves 3D printing. Components are assembled using screws and mechanical assembly for robustness. Epoxy is used to bond carbon fibers for stability.

C. Safety and Environmental Concerns:

Manufacturing is conducted under expert supervision in controlled environments to ensure safety compliance. We use eco-friendly carbon fiber materials and follow waste minimization practices.

D. Final Assembly and Handling:

All components are seamlessly integrated during final assembly. Handling and storage fixtures are designed for easy transportation, maintenance, and protection of delicate parts.

4.0. Machine Learning Model

The choice of the machine learning model is pivotal in ensuring accurate and efficient detection of key elements such as flood victims, infrastructure damage, and potential hazards. After careful consideration of various factors including computational resources and model performance, the YOLOv8n (where n denotes the Nano version) was selected as the backbone for object detection tasks.

Selection Criteria:

- **Resource Constraints:** Given the limitations in computational resources, particularly on Raspberry Pi, the choice of YOLOv8n Nano was driven by the need for a lightweight yet effective model that could operate efficiently on constrained hardware.
- **Model Performance:** Several iterations were conducted to evaluate different versions of the YOLO[15] family, including YOLOv5, YOLOv7, and YOLOv8. Through a series of trial and error experiments, it was observed that YOLOv8 demonstrated slightly superior performance in terms of both speed and accuracy compared to its counterparts. While the differences were marginal, the overall efficiency of YOLOv8n was deemed more suitable for real-time deployment scenarios, where rapid response is critical.
- **Refinement and Stability:** YOLO (You Only Look Once) has been a pioneering model in object detection for nearly a decade, undergoing continuous refinement and optimization. Leveraging the collective advancements and extensive

community contributions over the years, YOLOv8n benefits from a robust architecture that has been fine-tuned to handle diverse environmental conditions and object classes, including those encountered in flood relief operations.

Justification for Using Pre-Trained Models:

Given the complexity and variability of flood environments, the decision to utilize pre-trained models such as YOLOv8n was based on the understanding that object detection is inherently challenging and often requires extensive data and computational resources for effective training. By leveraging pre-trained weights and architectures, we harness the accumulated knowledge and expertise embedded within these models, significantly reducing the need for manual annotation and training iterations.

4.1 Hardware Pieces

This section details the hardware pieces used for this project.

A. Raspberry Pi:

Raspberry Pi 3 model B+ was used with an operating system of 32-bit raspberry pi lite OS was used as it had far less RAM consumption and greater efficiency for our project.

Figure 23: Raspberry Pi 3 Model B+

B. Camera:

The project employed a Camera Module Rev v1.3, a model commonly paired with older distributions like Bullseye. This module incorporates a camera itself, a 15-pin CSI connector, and a yellow P5V04A SUNNY cable.

The specific camera utilized was the Omnivision OV5647 Monocular camera. This camera is widely known as the Arducam 5MP due to its extensive documentation and compatibility with Raspberry Pi, facilitated by the 15-pin CSI connector. Notably, it is the most cost-effective option within the Arducam product line.

The camera offers four resolution options: 1080p30, 720p60, and 640x480p60/90 video recording.

C. AWM 20624 80C:

This is a flat flexible cable that uses a specific UL-listed insulation material (details not publicly available). The cable is rated for continuous use at temperatures up to 80°C.

4.2 AI and software

A. Operating System

Raspberry Pi OS Lite (bookworm 4.8.0) is a lightweight version of the Raspberry Pi OS operating system designed for users who don't need a graphical desktop environment. This makes it a good choice for tasks that require less processing power, such as running servers or robots. The latest version was released on March 15, 2024 and includes several improvements:

Improved audio handling: Audio streams will no longer be interrupted when you connect or disconnect other audio devices.

Easier Orca installation: The keyboard shortcut to install Orca, a screen reader for visually impaired users, no longer requires a password and will wait for your clock to synchronize before proceeding, preventing silent failures. Orca itself has also been updated to version 45 with various bug fixes.

Driver update: The obsolete fbturbo video driver has been removed to streamline the system.

B. Packages:

1) Libcamera-dev[18]: Libcamera-dev is a development library that provides access to the libcamera API. Libcamera itself is an open-source software library for image signal processors and embedded cameras on Linux systems. It's described as a successor to the older Video4Linux2 (V4L2) API, and is designed to provide a more modern and flexible way to interact with camera hardware.

2) Picamera2[19]: Picamera is a pure Python interface to the Raspberry Pi camera module. It allows users to take pictures, record videos, and manipulate camera settings from Python scripts.

C. Drivers:

1) V412[17]: V412 refers to the Video for Linux Two (V4L2) API, a set of instructions and definitions that programs can use to interact with video capture and playback devices on Linux operating systems. It provides a standardized way for applications to access features like webcams, digital video recorders (DVRs), and TV tuners.

There are actually two main parts to the V4L2 documentation:

- Part I: Common Elements - This section focuses on the core functionalities that most V4L2 applications will utilize. It covers essential aspects like:
    - Device Management: How to discover, open, and close connections to V4L2 devices.

    - Capability Inquiry: Extracting information about a device's capabilities, such as supported video formats, resolutions, and input/output options.
    - Video Streams: Specifying sources and destinations for video capture and playback.
    - Image Formats: Understanding and configuring the various image formats supported by V4L2 devices, including common formats like RGB and their color depths.
    - Data Transfer: Techniques for streaming video data between applications and V4L2 devices.
    - API Interfaces: Explanations of how applications interact with V4L2 using system calls and optional libraries.
- Additional Topics: Part I also delves into more specific functionalities:
    - Cropping and scaling video streams to fit specific requirements.
    - Capturing individual video frames for processing or analysis.
    - Utilizing extended controls for advanced device configuration, allowing fine-tuning of video capture and playback.

In essence, V412, particularly Part I, serves as a foundation for developers building applications that leverage video hardware on Linux systems. By following the V4L2 API guidelines, programmers can create software that interacts with various video devices in a standardized and efficient manner.

D. Pymavlink and mavlink:

This section details the software libraries and functions used to establish communication between a Raspberry Pi (Rpi) and a Pixhawk flight controller for the purpose of controlling a drone.

Software Libraries

- **MAVLink (Micro Air Vehicle Link):** This is a communication protocol specifically designed for unmanned aerial vehicles (UAVs). It defines a standardized message set and data format for exchanging information between autopilot systems, ground control stations (GCS), and other onboard applications.
- **pymavlink:** This is a Python library that provides an interface to the MAVLink protocol. It allows Python scripts to send and receive MAVLink messages to/from the Pixhawk flight controller.

Version Used: The report specifies pymavlink version 2.4.20 was chosen due to its compatibility with the specific task requirements.

Communication Details

- **Connection:** The Rpi connects to the Pixhawk via UDP (User Datagram Protocol) on port 14555. UDP is a connectionless protocol suitable for real-time data exchange.
- **pymavlink Functions:**

- **recv_match[20][21]:** This function is used to request specific MAVLink messages from the Pixhawk. In this case, the script utilizes recv_match to request the following message types:
  - **Mission ACK:** This message confirms the successful completion of a mission task by the Pixhawk.
  - **Command ACK:** This message acknowledges that a command has been received and understood by the Pixhawk.
  - **ATTITUDE:** This message provides real-time data on the drone's attitude, including its roll, pitch, and yaw angles.
  - **LOCAL_POSITION_NED:** This message transmits the drone's current position relative to a North-East-Down (NED) reference frame.
- **mav_send[22]:** This function allows the script to send commands to the Pixhawk. The report specifies using MAVLink_set_position_target_local_ned_message to send commands related to guided mode maneuvers. This message likely transmits the desired distance information to the Pixhawk, which then translates it into a series of waypoints to guide the drone towards the target location.

Overall, pymavlink facilitates communication between the Rpi and Pixhawk by providing a Python interface to the MAVLink protocol. The chosen functions enable the script to request critical data from the Pixhawk (drone's position, attitude, mission status) and send control commands for guided mode navigation.

E. Survivor distance computation:

$$\text{Distance to object(mm)} = \frac{\text{f(mm)} \times \text{real width(mm)} \times \text{image width(pixels)}}{\text{object width (pixels)} \times \text{sensor width(mm)}}$$

The above formula can be used to compute the distance from the camera lens to the survivor. The real width will be the average width of a human shoulder, which was taken as 45 cm, f is the focal length of the camera used and the image width is the width of the annotation rectangle over the survivor. Then, the camera orientation angle can be used to calculate the horizontal distance from the drone to the survivor detected. This distance is then forwarded to the Pixhawk so that the drone can fly towards that spot and deliver the package.

CHAPTER 4: RESULTS AND DISCUSSIONS

The project has been completed successfully. Several test flights have been done. Elaborate tests including tests of endurance and power capacity have been carried out. The result for each deliverable will now be explicated along with certain limitations and prospects of further improvement.

4.1. UAV and autonomous flight

Figure 24: The completed drone

A fully functioning autonomous drone capable of various flight modes has been built. The drone can be instructed to follow a well specified path, to make brief stops at waypoints and to speed up or slow down throughout its flight and return to its take off position once the mission is done or if either the signal is lost or the battery level is low.

The drone can reach a maximum speed of 10 m/s and it has a range of about 8 kilometers. The battery life is 15 minutes. The drone is also exceptionally stable by virtue of the

Pixhawk. It quickly stabilizes itself if a heavy package is released and can traverse through highspeed winds. The canopy completely encloses the internals of the drone and the motors are water proof. This means the drone can easily fly in light rain, though this has not been tested thoroughly.

In terms of limitations and improvements to be had, though the battery significantly increases the life of the drone, it also adds quite a lot to the weight. Extensive rain proof testing must also be done to thoroughly validate the claim that the drone is rain-proof, which is a very relevant and useful feature, especially in the context of floods.

4.2. Payload Mechanism

The payload mechanism has been tested extensively in terms of working and endurance. It can successively deliver three packages at three distinct locations. Each compartment can safely hold up to 1.5 kg of weight. The payload capacity is therefore 4.5 kg. The mechanism is light weight. It keeps the contents stable and fixed in the compartments, enhancing the stability of the drone.

One limitation to note is that the payload mechanism marginally worsens the aerodynamics of the drone, but the overall benefits outweigh the costs. Further, the drone needs to lower itself to release the package. This limitation can be overcome by attaching small parachutes to the packages.

4.3. Autonomous Delivery Operation

The camera and the raspberry pi module have been integrated with the Pixhawk so that the drone can detect survivors, approach them and drop packages nearby from a reasonable height. All of this can be done autonomously. The machine learning model is trained on extensive data and can detect lone survivors or crowds trapped in flooded areas or otherwise.

Figure 25: Survivor detection testing

A limitation noted is that the camera loses its focus at high flight speeds, making the survivor detection relatively ineffective in that case. This can be resolved by integrating a clearer FPV camera. Night vision can also be added for navigation in the night. The machine learning model can also be improved by training it on a larger dataset. Another improvement that can be made is to make it so that the drone releases the packages based on the size of the crowd or the number of people present together. If five or more are stranded close to each other, the drone can drop all three packages before proceeding.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion:

The development of a fully operational Unmanned Aerial Vehicle (UAV) has progressed significantly. Through dedicated effort, the project has successfully addressed fundamental tasks essential for UAV functionality. These initial tasks, though seemingly basic, lay the groundwork for the entire project and were arguably the most challenging phase to implement. The project will continue with increased focus on expanding functionalities and exploring innovative applications of UAV technology. The development process has encountered challenges, but each obstacle has provided valuable learning opportunities that have driven refinement and improvement. The project has achieved its initial goals and delivered positive results. However, it has also identified limitations that present opportunities for future research and development.

5.2. Recommendation:

The successful completion of the project, including test flights and functionality demonstrations, lays a solid foundation for further development. Here are key recommendations to consider:

1. Enhance Flight Performance:

- **Extend Flight Time:** Explore methods to increase flight time beyond 15 minutes. This could involve investigating higher capacity batteries, alternative power sources (e.g., solar panels), or optimizing flight patterns for energy efficiency.

- **Improve Range and Speed:** Research options to extend the operational range beyond 8 kilometers and potentially increase the maximum speed of 10 m/s while maintaining stability. This could involve aerodynamic design tweaks, more powerful motors, or lighter construction materials.

2. Refine Payload Mechanism:

- **Mitigate Aerodynamic Impact:** Refine the payload mechanism design to minimize its impact on aerodynamics. This could involve exploring alternative deployment configurations or using lighter construction materials.

3. Enhance Survivor Detection and Delivery:

- **Upgrade Camera System:** Integrate a higher-resolution FPV camera with improved focus at high speeds to ensure effective survivor detection during various flight conditions.

- **Night Vision Capability:** Explore adding a night vision camera module for autonomous navigation and survivor detection in low-light environments.

- **Advanced Machine Learning Model:** Train the model on a significantly larger and more diverse dataset to improve its accuracy in detecting survivors in various scenarios.

- **Adaptive Payload Delivery:** Implement logic within the machine learning model to adjust payload delivery based on survivor numbers. The drone could potentially drop all three packages if it detects a large group to maximize efficiency.

4. Future Considerations:

- **Evaluate Cost-Effectiveness and Scalability:** Conduct a cost analysis to determine the feasibility of mass production and widespread adoption by humanitarian organizations and government agencies. Explore strategies to reduce costs and ensure scalability for large-scale disaster response operations.

5. Continued Testing and Refinement:

- Conduct extensive testing in diverse weather conditions, including heavy rain, to thoroughly validate the drone's weatherproofing capabilities.
- Develop a comprehensive testing program that incorporates simulations alongside physical testing to optimize performance and minimize risks.

By implementing these recommendations, the project can further refine the capabilities of the disaster relief drone. This includes extending its operational range, improving flight time, and enhancing survivor detection and delivery while maintaining cost-effectiveness for widespread adoption in real-world disaster response scenarios.

REFERENCES

[1] Alberto Sigala (2020). Applications of Unmanned Aerial Systems (UAS): A Delphi Study Projecting Future UAS Missions and Relevant Challenges [Online]. Available: https://www.mdpi.com/2504 446X/4/1/8/html

[2] Batra, N., Kimball, D. F., Sheehan, T., & Co, B. V. (1986). Early Evaluation of the V-22 Osprey Through Piloted Simulation. Retrieved 4 15, 2022, from https://vtol.org/store/product/early-evaluation-of-the v22-osprey-through-piloted-simulation-1464.cfm

[3] Driggers, M. (2018). Spraying and Surveying Applications of Drones to the Precision Agriculture Industry: Writing Prototype Software to Automatically Fly a Drone for Survey or Spray Purposes. Retrieved 4 15, 2022, from https://scholarexchange.furman.edu/scjas/2018/all/47

[4] Escareno, J., Salazar, S., & Rondon, E. (2013). Two Rotor VTOL Mini UAV: Design, Modeling and Control. Retrieved 4 15, 2022, from http://onlinelibrary.wiley.com/doi/10.1002/97811185 99938.ch3/summary

[5] 99938.ch3/summary Katz, K., Helicopters, B., & Poulin, R. (1991). Flight Testing the Avionics System of the V22 Osprey. Retrieved 4

[6] 15, 2022, from https://vtol.org/store/product/flight-testing-the avionics-system-of-the-v22-osprey-982.cfm Khateb, A. H., Rahim, N. A., & Selvaraj, J. (2013). Cascaded DC-DC Converters as a Battery Charger and Maximum Power Point Tracker for PV Systems. Retrieved 4

[7] 15, 2022, from https://ieeexplore.ieee.org/document/6529642 Kohno, S., & Uchiyama, K. (2014). Design of robust controller of fixed-wing UAV for transition flight. Retrieved 4

[8] 15, 2022, from http://ieeexplore.ieee.org/xpl/articledetails.jsp?reload =true&arnumber=6842364 Sage P., Design, Development, and Flight Test of a Small-Scale Cyclo-gyro UAV Utilizing a Novel Cam Based Passive Blade Pitching Mechanism: https://journals.sagepub.com/doi/pdf/10.1260/1756 8293.5.2.1

[9] Anne, B. (2011). Environmental-Friendly Biodegradable Polymers and Composites. Retrieved 4 15, 2022, https://intechopen.com/books/integrated-waste management-volume-i/environmental-friendly biodegradable-polymers-and-composites

[10] Pakistan: Flood Damages and Economic Losses Over USD 30 billion and Reconstruction Needs Over USD 16 billion - New Assessment (worldbank.org)

[11] I. Kruijff-Korbayová et al., "German Rescue Robotics Center (DRZ): A Holistic Approach for Robotic Systems Assisting in Emergency Response," 2021 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), New York City, NY, USA, 2021, pp. 138-145, doi: 10.1109/SSRR53300.2021.9597869

[12] Munawar, H.S.; Ullah, F.; Qayyum, S.; Khan, S.I.; Mojtahedi, M. UAVs in Disaster Management: Application of Integrated Aerial Imagery and Convolutional Neural Network for Flood Detection. *Sustainability* 2021, *13*, 7547. https://doi.org/10.3390/su13147547

[13] Drones for Disaster Management in Pakistan By haadshaikh from: https://drones-serv.com/2023/01/24/drones-for-disaster-management-in-pakistan/

[14] H. Ijaz, R. Ahmad, R. Ahmed, W. Ahmed, Y. Kai and W. Jun, "A UAV-Assisted Edge Framework for Real-Time Disaster Management," in IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-13, 2023, Art no. 1001013, doi: 10.1109/TGRS.2023.3306151.

[15] J. Redmon, S. Divvala, R. Girshick and A. Farhadi, "You Only Look Once: Unified, Real-Time Object Detection," 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, 2016, pp. 779-788, doi: 10.1109/CVPR.2016.91. keywords: {Computer architecture;Microprocessors;Object detection;Training;Real-time systems;Neural networks;Pipelines},

[16] https://downloads.raspberrypi.com/raspios_lite_armhf/release_notes.txt

[17] Part I - Video for Linux API — The Linux Kernel documentation, 6.1. Introduction — The Linux Kernel documentation, 5.1. Introduction — The Linux Kernel documentation, Part I - Video for Linux API — The Linux Kernel documentation ,philips/libv4l: libv4l (github.com)

[18] Documentation — libcamera

[19] picamera — Picamera 1.13 Documentation

[20] https://mavlink.io/en/mavgen_python/howto_requestmessages.html

[21] https://mavlink.io/en/messages/common.html#MISSION_ACK

[22] https://ardupilot.org/dev/docs/copter-commands-in-guided-mode.html#copter-commands-in-guided-mode-set-position-target-local-ned