Fire Fighting Drone

Project Report

Team AgniDrone

Team Members

Aryan
Mayank Dhabhai
Shihora Vansh Bhaveshkumar
Tanmay Kumar Garg
Maru Jainil
Khandvi Parth Piyushbhai

Department of Mechanical Engineering
Indian Institute of Technology, Gandhinagar

Jan' 25 - April 25

Contents

1 Introduction

This report outlines the design and technical specifications of a custom hexacopter frame and the integration of Pixhawk 2.4.8 flight controller with other drone components for the firefighting drone project. The design focused on maximizing stability, payload capacity, and ease of control. Initially, our goal was to build a heavy-lift drone from scratch; however, since none of us had prior hands-on experience with drones, we opted to start with a commercially available DJI F450 frame. We selected all other components based on compatibility with this frame. To understand the fundamentals of drone technology including flight dynamics, essential components, and sensor functionality we relied heavily on online resources and this assembly drone. That drone also served as a learning platform for flight training and experimentation. By modifying various parameters, we studied their effects on the drone's stability and control. For this report we are going to explain about the final drone prototype we have build from all the experience we gained from our previous build.

DJI F450 Frame

Figure 1: Initial Quadcopter Drone Frame

2 Hexacopter Frame Design

2.1 Design Overview

The frame was inspired by an H-type quadcopter structure, modified into a hexacopter configuration. Key features include:

- **Materials:** PVC pipes (26mm Outer diameter, 3mm Thickness), T-slots, Custom designed 3D-printed Red Tough PLA motor mounts.
- **Configuration:** Plus (+) type for enhanced low-speed stability.
- **Assembly:** Screw-less design using snap-fit joints,Adhesives and T-slot connectors.

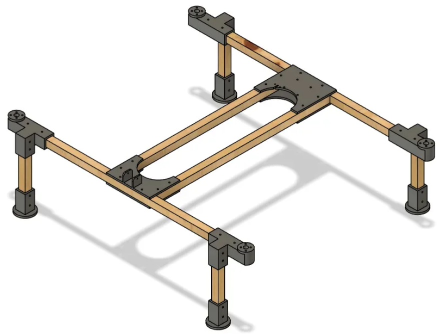

Figure 2: Inspiration for our Hexacopter

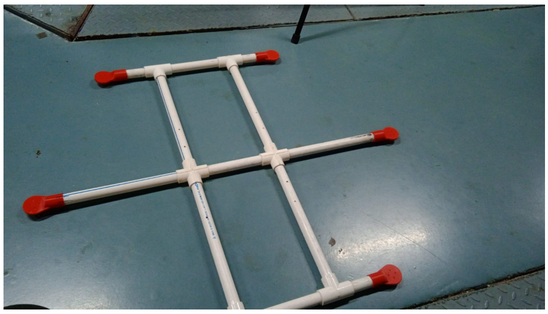

Figure 3: Our Final Frame Design

2.2 Specifications

- **Weight:** 1.2 kg (frame only).
- **Load Capacity at 80 % Throttle**: 10.8 kg (including the Weight of the drone itself)

The Dimensions of the Frame can be found in the below diagram. **All dimensions are in mm**

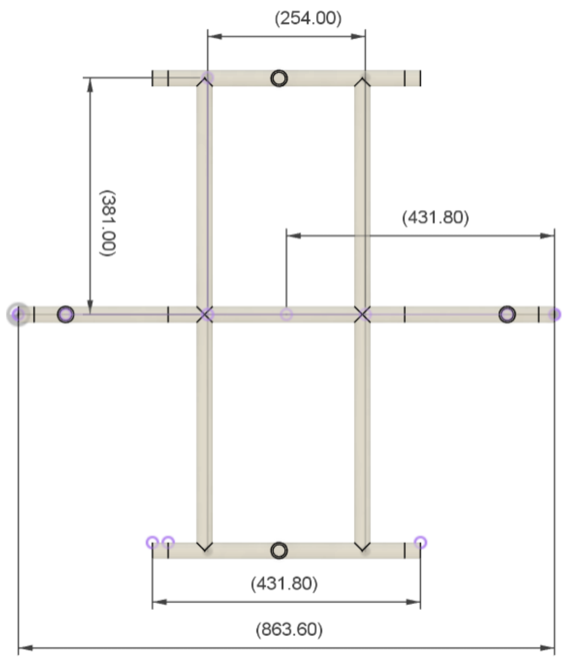

Figure 4: Hexacopter Frame Dimensions

2.3 Design Advantages

- **Plus Configuration:** Superior stability and control at low speeds, critical for firefighting applications.
- **Aerodynamic Trade-off:** Our custom design features a larger frontal area compared to standard commercially available frames. However, typical frames tend to

concentrate most of the load at the center, increasing the risk of structural failure. In our design, while the increased frontal area results in higher drag, this is effectively compensated by the drone's intended low-speed maneuvers, ensuring both stability and structural integrity.

- **Modularity:** Rapid assembly/disassembly for maintenance, Since there is no need of any screw to assemble this drone, so it makes it easier to disassemble and reassemble.
- **3D Printed Motor Mount:** Easy to install on these PVC Pipes and four M3 Screws are needed for mounting a single Motor on it.

3 The reason for choosing the particular Frame in the Project

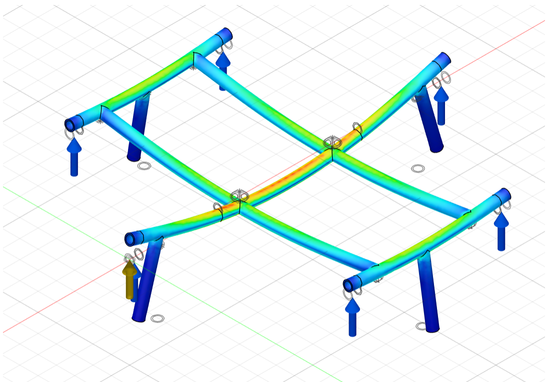

Figure 5: Frame Designed for the Project

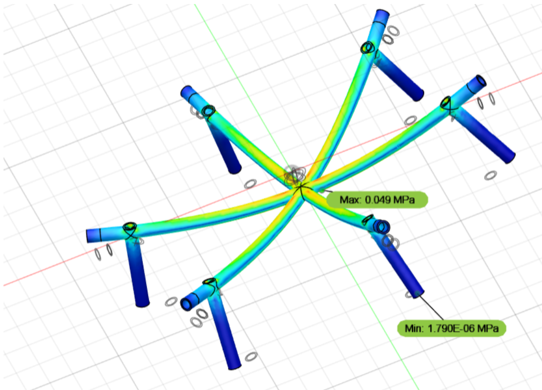

Figure 6: Common Hexacopter Frame used for Agricultural Heavy lift Drones.

- We Performed stress analysis by making a 3D model in the Autodesk Fusion software, we provided the properties of PVC pipe in Fusion, we applied the Thrust forces in the motor such that it perfectly balances the Weight of the Drone.
- Then We performed stress analysis and found the result for both the frame design.
- We observed that the Weight of Frame was nearly same (**1185 gm** for Our frame design and **1033 gm** for Common Frame design used) so the weight difference was much important.
- The lenght of the frame's each arm length was kept minimum such that each propeller doesn't influence the fluid dynamics of other.
- We observed that the stresses in the Common Hexacopter Frame design were concentrated at the centre of the drone, also all the components like Pixhawk setup, battery,etc would add to the load at the centre which might lead to structural failure during flight.
- However the stresses in the Frame Design we used are not concentrated at a particular point rather along each rod and mainly at the central rod, also due to the

Support plate we have made the additional central load of battery and other components would be distributed thus ensure structural integrity.

- Though the Frame we have designed looks asymmetric but we have ensured that the each Motors arm length from the centre is same (thus it does make a regular hexagon upon joining all motor holding points, but the stress distribution is different compared to common frame design.

4 Pixhawk 2.4.8 Flight Controller

Figure 7: Radiolink Pixhawk 2.4.8 Flight Controller

4.1 Key Features

- **Sensors:** 6-axis IMU (accelerometer + gyroscope), barometer (altitude), magnetometer (heading).
- **Autonomy:** Mission scripting, waypoint navigation, auto-tune PID control.
- **Failsafes:** Return-to-Launch (RTL), auto-landing on low battery/signal loss.
- **Connectivity:** 8 motor outputs, GPS, telemetry, RC receiver.
- **Licensing:** Open Source, and cost effective option.

4.2 Technical Specifications

- **Processor:** STM32F427 Cortex-M4 (168 MHz, 256 KB RAM).

- **Firmware:** PX4 Autopilot (ArduPilot compatible).
- **Voltage Range:** 4.8–5.4V (regulated via power module).
- **Telemetry:** 915 MHz/433 MHz options (3DR Radio).

4.3 System Integration

The Pixhawk interfaces with:

- **ESCs & Motors:** PWM signals to regulate hexacopter thrust.
- **GPS Module:** UBlox Neo-M8N for positioning.
- **Ground Control Software:** Mission Planner (PC) and QGroundControl (mobile).

5 Circuit Diagram

Simple Circuit diagram showing all the main components connected to Flight Controller

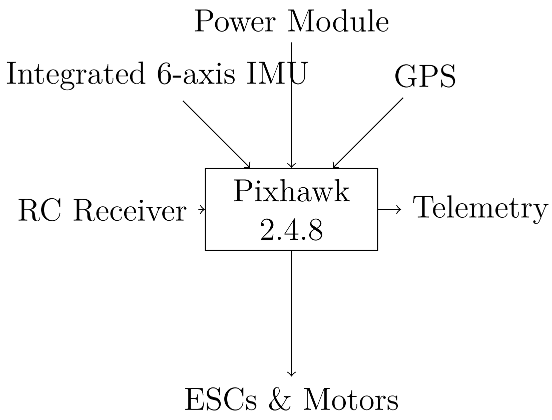

Figure 8: Flight controller system integration diagram.

6 Power Distribution Overview

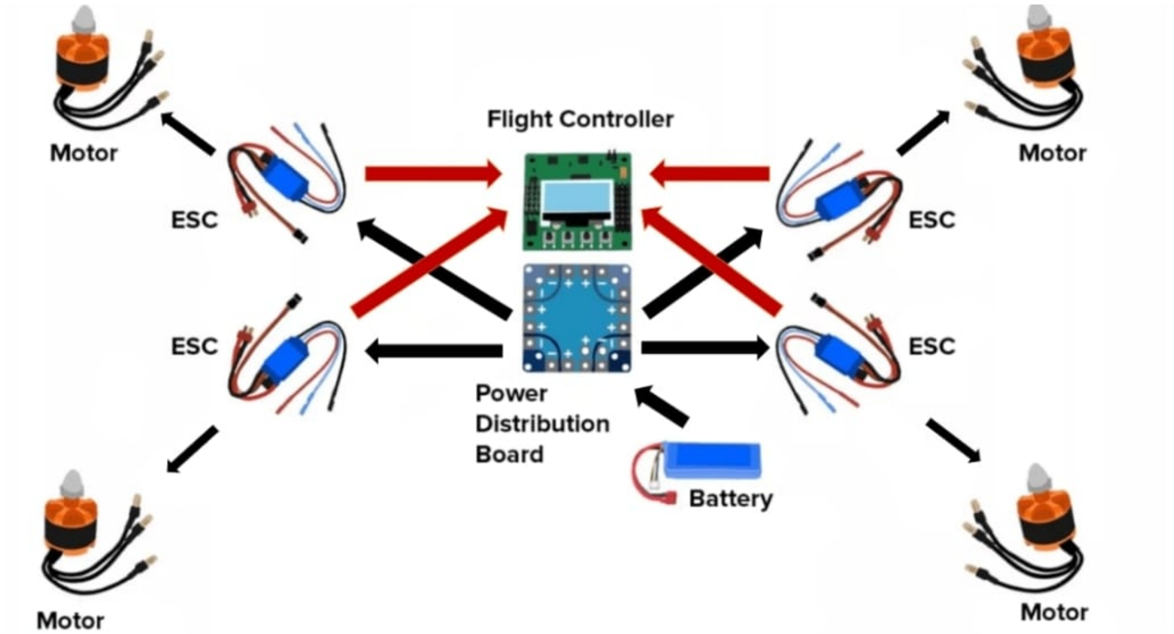

Figure 9: Power connection chart for Quadcopter

Note: - The above power connection chart is for quadcopter, it can be extended to hexacopter by using the Power Module and Flight Controller that supports hexacopter configuration

6.1 Battery to ESCs – via Power Distribution Board (PDB)

Battery: LiPo battery (typically 3S to 6S, 11.1V to 22.2V or higher for 12S setups) as the primary power source.

Connection:

- Battery's positive (V+) and negative (GND) terminals are connected to the input terminals (VSS and GND) of the Power Distribution Board (PDB).
- The connection is done via XT60 and XT90 connector and soldered terminals.

Distribution to ESCs:

- PDB has multiple output pad pairs (VSS and GND), one set for each ESC.
- These output pads provide full battery voltage in parallel to all 4 ESCs (in a quadcopter).
- The connection is carried as follows:
  - ESC power wires (red = +Ve , Black = GND) are soldered to respective VSS and GND pads.
  - All ESCs receive the same input voltage directly from the battery.

In Parallel, all ESCs get the same voltage, and total current is divided among them and is controlled by the flight controller.

Ensures motors run synchronously with equal potential across all ESCs

6.2 Powering Pixhawk Flight Controller and Receiver – via PM02 V3 Power Module

- Powered through PM02 V3
- Powers the Receiver through its RC IN port (5V passthrough).

Main Roles:

- Supplies regulated 5.2V to Pixhawk Flight Controller via POWER 1 port.
- Monitors real-time Battery Voltage and Current.
- Sends telemetry data to Pixhawk for power status alerts,power consumption and battery percentage which can be monitored on a Mobile Device .

Connection:

- PM02 input is connected directly to the battery (V+ and GND same as PDB).
- 5.2 V - 6-pin output cable connects to Pixhawk's POWER 1 port.
- **Note** - PM02 does not power ESCs directly, It's only for the flight controller and telemetry.

6.3 Powering the Receiver

- Pixhawk powers the RC Rx Receiver via the 5V rail on the RC IN port.
- Connection uses a 3-wire cable (GND, VCC, Signal).
- LEDs for orientation/signaling are powered via AUX output pins of Pixhawk.

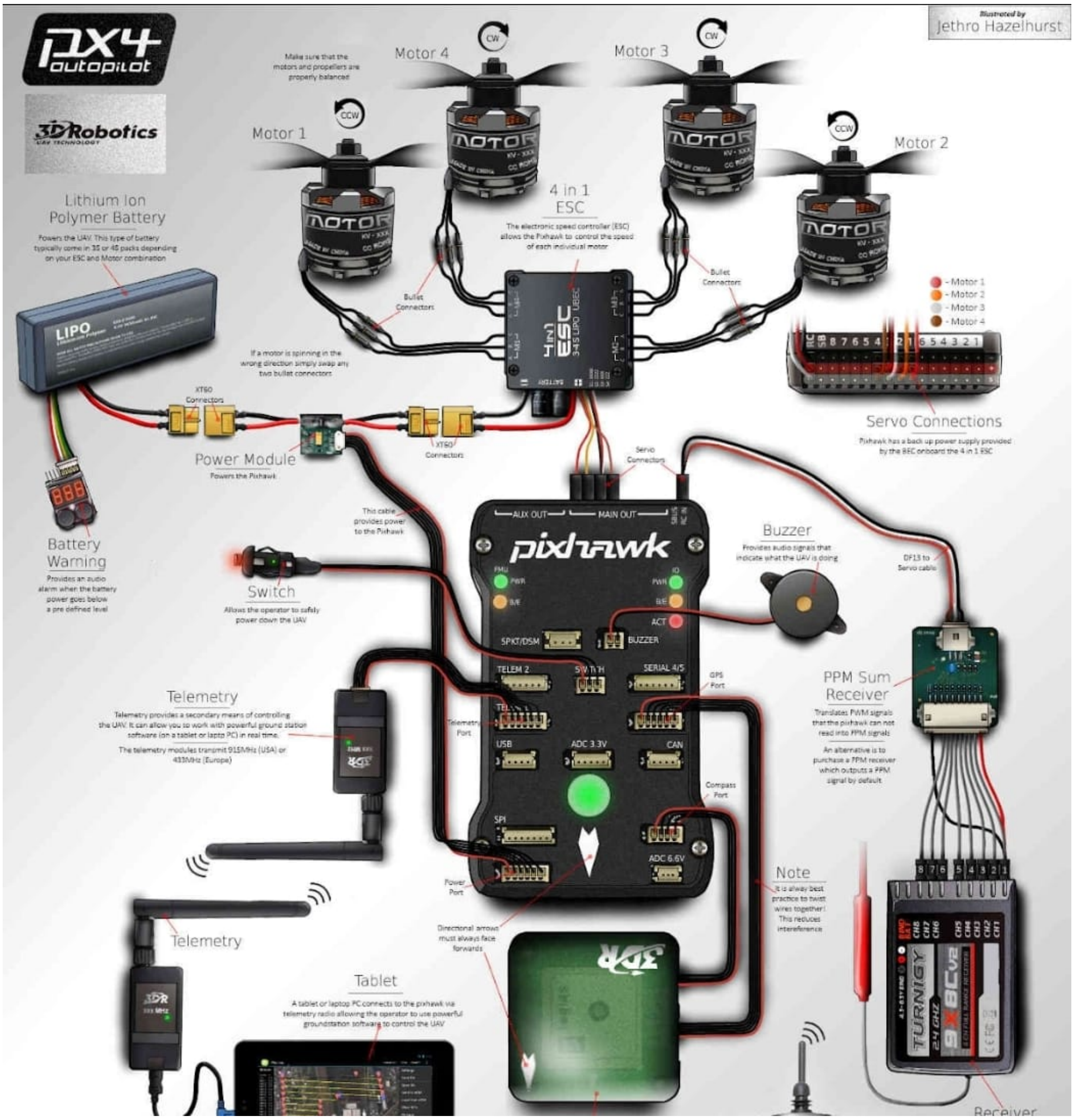

Figure 10: Power Distribution and Connnection chart of Pixhawk

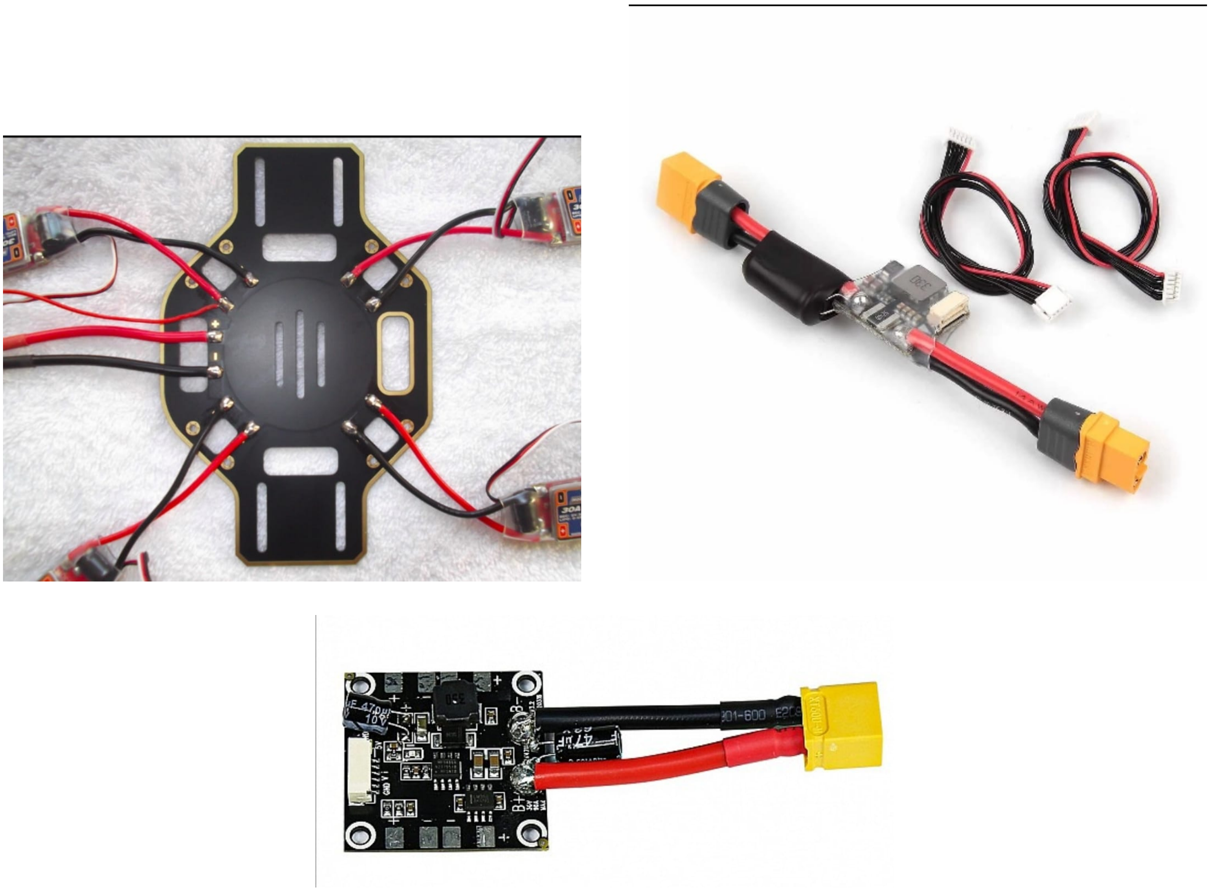

Figure 11: Power distribution plate Board (PM02 V3 12S)

7 Mechanical Design Summary

7.1 Motor Holders

Purpose:

- Six motor holders/mountings were designed to securly fasten brushless motors to the drone's frame.
- The hexagonal symmetry ensures balanced thrust distribution and minimizes rotational instability.

Design Software:

- Autodesk Inventor: Used for initial parametric modeling, ensuring precise alignment of screw holes and motor mounts. .
- Finalized for lightweight topology optimization and stress analysis under simulated flight loads

Material & Print Settings:

- Filament: Tough Red PLA (Polylactic Acid) was selected for its balance of rigidity, impact resistance, and ease of printing.
- Nozzle: AA 0.4 mm nozzle ensured fine detail resolution while maintaining structural integrity.

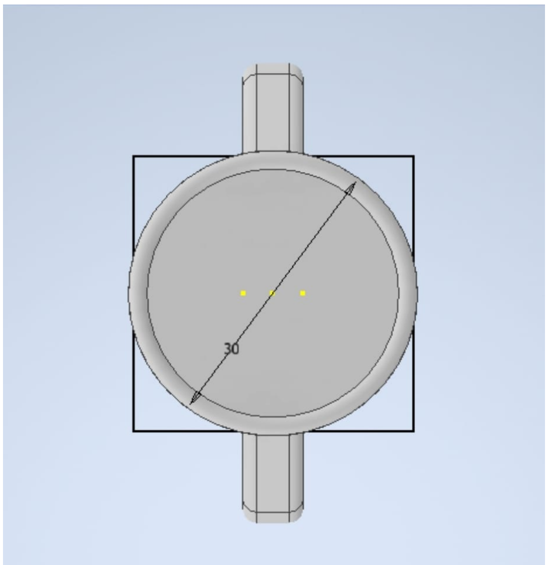

Figure 12: Side View of Final Motor Holder

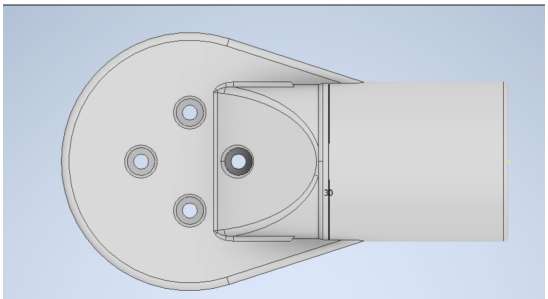

Figure 13: Top View of Final Motor Holder

- Infill 20% Density: Reduced weight without compromising critical load-bearing regions.
- Triangular Pattern: Chosen for its exceptional strength-to-density ratio, resisting torsional and shear forces during aggressive maneuvers.
- Mass: 34 grams per holder, optimized through iterative thinning of non-critical sections while reinforcing stress-prone areas.

Design Iterations:

- **V1:** Grid infill (25%), failed under vibration tests due to insufficient torsional rigidity.
- **V2:** Gyroid infill (20%), improved damping but added print time and failed under asymmetric load.
- **Final:** Triangular infill (20%) gave best strength-to-weight and vibration resistance and 3D printing efficiency.

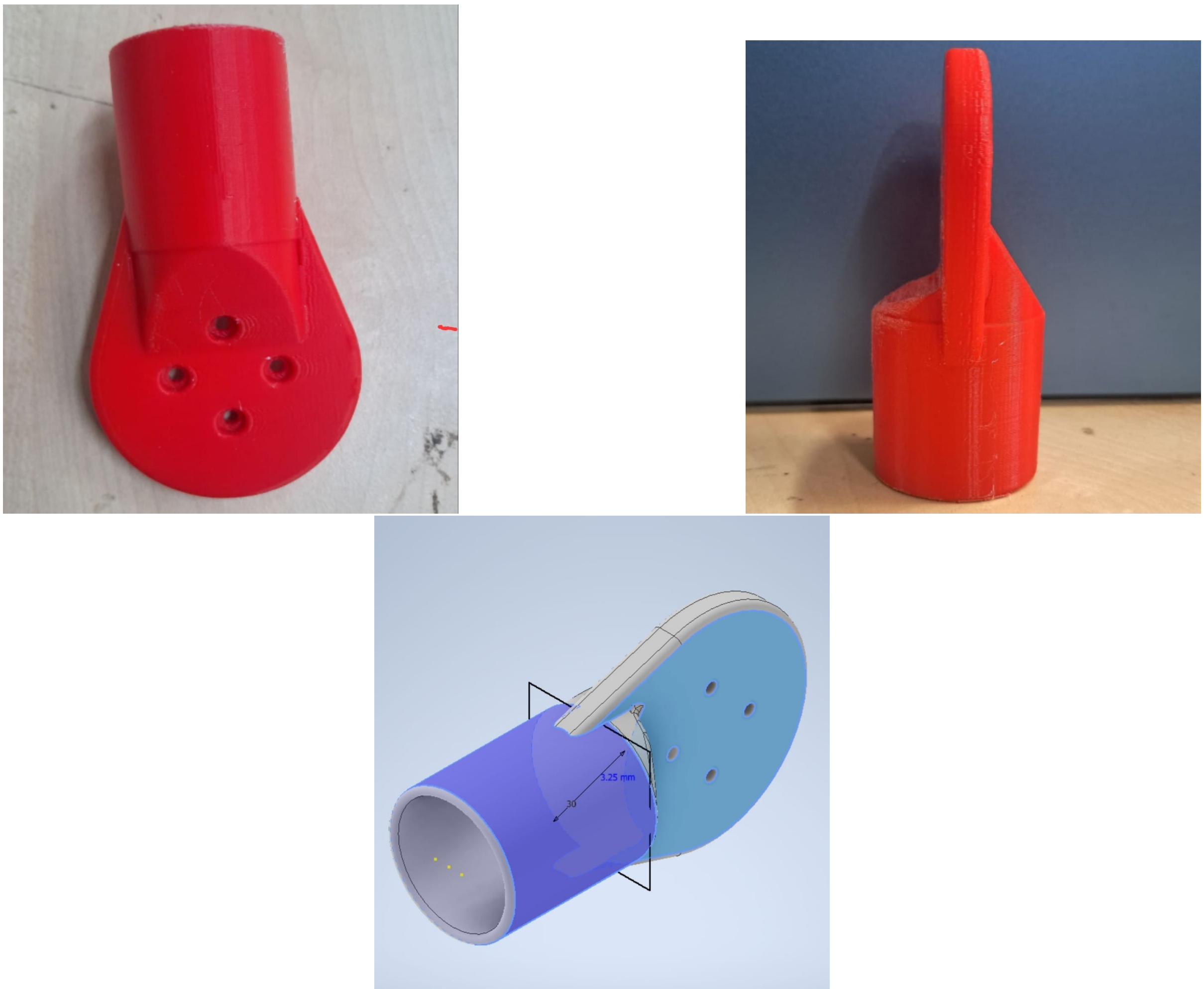

Figure 14: CAD model and Final 3-D printed Motor Holder

7.2 Support Plate for Electronics

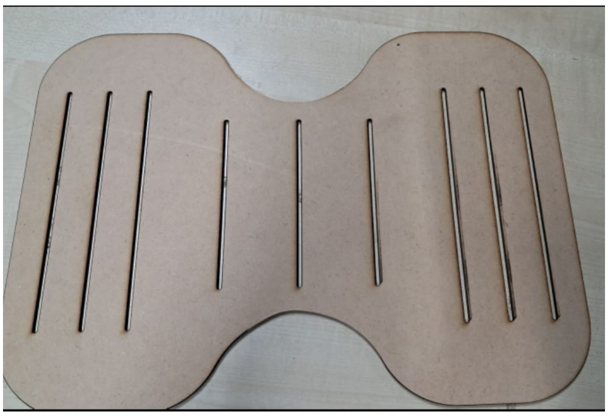

Figure 15: Central MDF support plate

Function:

- Houses and aligns critical electronics: flight controller, receiver, LiPo battery, and power distribution board.

- Acts as a structural backbone, centralizing components to maintain the drone's center of gravity (CoG).

Key Features:

- **Parallel Ventilation Channels:**
  - Airflow Optimization: Parallel vents reduce turbulent airflow beneath the plate and let the air pass through them, preventing destabilizing vortices during hover and forward flight.
  - Thermal Management: Channels dissipate heat from electronics, reducing the risk of overheating during prolonged use.
- **Component Cenering:**
  - Integrated mounting slots and grooves ensure precise alignment of the flight controller and receiver, minimizing calibration errors.
  - Battery straps are anchored to the plate's center.

Material: MDF (Medium-Density Fiberboard)

7.3 Iterative Design and Optimization

The final components resulted from multiple failed prototypes, driven by the goal of maximizing the strength-to-weight ratio **Challenges and Solutions:**

- **Motor Holder Fractures:**
  - Initial designs with uniform wall thickness fractured at motor screw points during thrust tests.
  - Solution: Added localized ribbing around screw holes and motor mounts.
- **Resonance in Electronics Plate:**
  - A flat, unvented plate amplified motor vibrations, causing flight controller errors.
  - Solution: Parallel vents reduced mass and disrupted resonant frequencies.

Key Optimizations:

- Triangular Infill: Validated via Finite Element Analysis (FEA) in Fusion 360, showing 1̃5% higher shear resistance compared to grid patterns.
- Material Selection: Tough PLA outperformed standard PLA in drop tests, surviving impacts from 2m heights without cracking.
- Weight Savings: Iterative thinning reduced total drone mass by 22% compared to early prototypes, enhancing flight time and agility.

8 Motor: Tarot 4114/320KV Brushless Motor

Figure 16: Central MDF support plate

8.1 Purpose

The Tarot 4114/320KV Brushless Motor is selected for its ability to provide strong lift and stable performance in a hexacopter designed to carry heavy payloads such as a water-carrying pipes.

8.2 Component Dimensions

- Large diameter chosen to generate high torque for lifting payloads of 2 kg–3 kg.
- Stator size: 41 mm (diameter) × 14 mm (height).
- The thicker stator allows more copper windings for higher current capacity.
- Bigger stator size contributes to stronger and more efficient lifting.

8.3 Motor Properties

- Better heat dissipation due to large stator size; enhances performance, efficiency, and durability.
- 320KV rating: produces lower speed and higher torque; ideal for large propellers and stable flight.
- Lower KV motors are more suited for heavy lift and precise control applications.

8.4 Thrust Performance

- Motor weight: 148 g; lightweight yet capable of heavy-lift operation.
- Thrust per motor with 15-inch propeller at 80% power: 1.8 kg.
- Motor RPM: 5511 RPM.
- Total thrust from six motors: $6 \times 1.8\,\text{kg} = 10.8\,\text{kg}$.

- Total drone weight with pipe (without water): approximately 4.5 kg.
- Sufficient thrust margin available to lift water through the pipe.

8.5 Material Properties

- Shaft made of alloy steel for strength and durability.
- Special low-friction bearings used to ensure smooth rotation and minimize energy loss.

9 Propeller

Figure 17: Central MDF support plate

9.1 Selection Criteria

- 15-inch diameter selected based on thrust requirement and to prevent collision between adjacent propellers.
- Compatible with Tarot 4114/320KV motor and designed for efficient heavy-lift performance.

9.2 Configuration

- Both CW (clockwise) and CCW (counter-clockwise) propellers are used for balance and torque cancellation.

9.3 Material Properties

- Made of carbon fibre: strong, lightweight, and highly durable.
- Carbon fibre reduces flexing at high RPM and maintains aerodynamic shape.
- Large, lightweight propellers provide better lift, reduce power consumption, and improve flight time.

10 Battery Specifications (Tattu 10000mAh 6S 25C 22.2V LiPo)

- **Capacity**: 10000mAh (10Ah)
- **Voltage**: 22.2V (6S configuration)
- **Discharge Rates**:
  - Continuous: 25C (250A)
  - Burst: 50C (500A)
- **Weight**: 1420 grams
- **Flight Time**: 15-20 minutes (depending on drone configuration)
- **Compatibility**:
  - Works with 6S-optimized ESCs and motors
  - Matches systems requiring ≈320 RPM/Volt
- **Performance**:
  - Produces 2.0–2.2 kg thrust per motor
  - Enables stable flight and heavy lifting
- **Safety Features**:
  - Requires balanced charging
  - Needs over-discharge prevention
- **Applications**: Professional drones requiring power-density balance

11 ESC Specifications (Hobbywing XRotor 40A 2–6S)

- **Current Handling**:
  - Continuous: 40A
  - Peak: 60A
- **Voltage Compatibility**: 2S–6S LiPo (7.4V–22.2V)
- **Control Features**:
  - 621 Hz throttle signal frequency
  - PWM signal integration
  - Brushless motor control
- **Protection Mechanisms**:
  - Overheat protection

- Overcurrent protection
  - Low-voltage cutoff
- **Performance Characteristics**:
  - Smooth throttle transitions
  - High-resolution motor control
  - Rapid response for precise maneuvers
- **Applications**: Medium-to-large drones requiring reliable speed control

12 Transmitter (Skydroid T10)

The Skydroid T10 is a 10-channel 2.4 GHz handheld transmitter. Its main functional blocks are:

- **Control Inputs**: Analog sticks, switches, potentiometers read by an onboard microcontroller.
- **Data Encoder**: Packages the digitized channel values into a framed packet including start/stop markers and CRC.
- **FHSS Modulator**: Implements Frequency-Hopping Spread Spectrum over 2.400–2.483 GHz, hopping pseudo-randomly across sub-channels.
- **RF Power Amplifier & Band-Pass Filter**: Boosts the modulated signal and suppresses out-of-band noise.
- **Antenna**: Radiates the cleaned RF signal into the air.

Figure 18: Transmitter

Working Principle

1. User moves a control; the microcontroller samples the voltages.
2. Samples are digitized and placed into a data packet by the encoder.
3. FHSS modulator up-converts the packet onto a 2.4 GHz carrier, hopping channels in a sequence known to the receiver.
4. The RF amplifier drives the antenna for reliable range.

13 Receiver (R10 Mini / R10)

The R10 series receiver recovers the original channel data and outputs it to servos or a flight controller via PWM/SBUS/PPM. Its main blocks:

- **Antenna & RF Front-End**: Captures the 2.4 GHz FHSS signal.
- **Band-Pass Filter**: Rejects unwanted frequencies.
- **Low-Noise Amplifier (LNA)**: Raises weak signals.
- **Demodulator & Frequency-Hopper**: Synchronizes to the same hopping sequence, down-converts RF to baseband.
- **Data Decoder**: Extracts channel frames, checks CRC, outputs PWM/SBUS/PPM.

Figure 19: Receiver

Binding Process

1. Hold the receiver's bind button until its LED flashes.
2. Power on the T10; it auto-syncs hopping patterns.
3. Receiver LED becomes solid(*Shows continuous green light in PIXHAWK flight controller*) to indicate successful binding.

14 Ublox NEO-M8N GPS Module with Integrated Compass

The **Ublox NEO-M8N** is a high-precision Global Navigation Satellite System (GNSS) receiver module that supports multiple satellite constellations, including GPS, GLONASS, Galileo, and BeiDou. This multi-constellation capability enhances positioning accuracy, reduces satellite acquisition time, and improves reliability, particularly in environments with partial obstructions.

14.1 GNSS Functionality

The NEO-M8N operates by receiving signals from multiple GNSS satellites. Each satellite transmits a unique signal containing timing information and its orbital position. The receiver calculates its own position by determining the time delay between signal transmission and reception from at least four satellites, using the principle of trilateration. Key features include:

Figure 20: Ublox NEO-M8N GPS Module with Compass

- **Concurrent reception of multiple constellations**, enabling faster and more accurate fixes.
- **Built-in EEPROM**, allowing retention of configuration data.
- **Low power consumption**, essential for drone applications.

14.2 Integrated Compass Module

The module integrates a **3-axis digital magnetometer** (such as the HMC5883L), functioning as a compass. It measures Earth's magnetic field in three dimensions, enabling the drone to determine its heading or yaw angle. The compass operates on the **magnetoresistive effect**, where changes in magnetic fields alter the resistance of materials, producing a voltage proportional to the field's strength and direction. This heading information is vital for navigation, waypoint tracking, and orientation correction, especially during autonomous flight.

14.3 Application in Drones

In drone applications, the NEO-M8N module serves dual purposes:

- **Positioning**: Provides precise latitude, longitude, altitude, and velocity data, essential for autonomous navigation, return-to-home (RTH), and geofencing.
- **Orientation**: The compass supplies real-time heading information, which is fused with gyroscope and accelerometer data in the flight controller (e.g., Pixhawk) through sensor fusion algorithms like the Extended Kalman Filter (EKF).

15 Sub-Components

- Wires and connectors
- Vibration dampers
- Safety button

- Antenna
- Mounting hardware
- Battery charger
- LiPo checker
- GPS mount
- SD card
- Buzzer

16 Fire Fighting Mechanism

16.1 Short range and Large Fire Applications (We have used this Approach in our Drone Prototype)

In places like High Rise Buildings where the Fire Fighters not be able to reach in time. The drone can be deployed with a Mechanisms where the Fire Extinguishing water pipe which are available in almost every building directly to the mechanism we have built.

We have bended a PVC pipe which changes the direction of water which reaches the drone vertically upward from the ground using a flexible pipe and then it is bent by an angle of 40 Degrees from the vertical.

The reason we have fixed the angle from the vertical to be 40 Degrees instead of 90 Degrees which is common in Fire Figthing Drone is because when we keep the pipe at an angle less than 90 Degrees from the vertical, the Thrust Force also has a component in the vertical direction, which would help the Drone in lifting the water weight thus helping in the weight carrying capacity and thus also increasing the maximum height upto which the drone can be taken while carrying water inside the flexible pipe.

The Mechanisms can further be enhanced by using a Servo motor, which can vary the Vertical Angle of the Pipe and for changing the horizontal angle of spraying water , the Drone itself is capable of rotating about it central axis parallel to the Motors rotating axis (The Z-Axis). We can change the Yaw of the Drone to control the Angle with horizontal.

16.2 Long Range and Small Fire Applications

For Long range fire applications like Forest Fires of small magnitude (A small fire initiation point). Regions in the dense forest where reaching the fire initiation point is difficult. A Mechanisms can be built on the drone itself for extinguishing the fire.

16.2.1 Fire Extinguishing Ball

one of the approach could be to use a Fire Extinguishing ball , whose weight is around 2 kg. A cage like mechanism could be build attached to the drone, whose gate would be controlled by a servo motor, once the Fire initiation point in directly below the Drone, the Gates could be opened and a stack of Fire Extinguishing Balls can be dropped. The

Fire extinguishing balls have a mechanisms, which blasts upon increment in temperature due to fire, thus spreading the chemical in range of few meters, which is capable of extinguishing fires in small areas.

16.2.2 Water Tank

A tank containing water could itself attached on the drone whose exit point can be controlled by the Servo motor and water can be dropped at the Fire Point. This appoach is widely used in agriculture drone, where pesticides are sprinkled using a tank attached to the drone and programming it to follow a certain path.

However this approach is limited by the weight carrying capacity of the drone, as well as effective area which can be extinguished is also smaller compared to that of Fire Extinguishing Ball.

16.2.3 Fire Extinguisher

The Fire Extinguisher can be attached to the Drone, if the Weight of extinguisher is less than the weight carrying capacity of Drone. Also the Thrust force generated due to Fire Extinguisher should be lesser than the allowable limit of the Maximum Forward Thrust Force that can be produced by the drone.

The direction of the Nozzle of the fire Extinguisher can be controlled by a servo motor. However for Manual controlling of Drone it might be difficult to controlled the drone's and nozzle's direction, however Semi-Automatic (Position Hold Mode) or Fully-automatic (Pre-Programmed position controll method) it would be a effective option.

17 Theoretical Maximum Height Upto which the Drone can reach while carrying water.

Known Parameters

We have chosen the maximum thrust available for carrying payload to be **80 % of the maximum thrust** provided by motor, because some amount of thrust is needed for stabilizing the drone along each rotatory axis, thus not all Motor's Thrust can be used for carrying payload.

- Thrust per motor at 80 % Throttle: 1.8 kgf
- Number of motors: 6
- Total thrust: $1.8 \times 6 = 10.8\,\text{kgf} = 10.8 \times 9.81 = 105.948\,\text{N}$
- Maximum lift mass: $\frac{105.948}{9.81} = 10.8\,\text{kg}$
- Drone weight: 4.5 kg
- Pipe outer diameter: $D_o = 18\,\text{mm} = 0.018\,\text{m}$
- Pipe inner diameter: $D_i = 15\,\text{mm} = 0.015\,\text{m}$
- Density of Common Garden Pipe : $\rho_{\text{PVC}} = 1400\,\text{kg/m}^3$

- Water density: $\rho_{\text{water}} = 1000\,\text{kg/m}^3$

Cross-sectional Areas

$$A_{\text{outer}} = \pi \left(\frac{D_o}{2}\right)^2 = \pi(0.009)^2 = 2.544 \times 10^{-4}\,\text{m}^2$$
$$A_{\text{inner}} = \pi \left(\frac{D_i}{2}\right)^2 = \pi(0.0075)^2 = 1.767 \times 10^{-4}\,\text{m}^2$$
$$A_{\text{pipe}} = A_{\text{outer}} - A_{\text{inner}} = 0.777 \times 10^{-4}\,\text{m}^2$$

Mass per Meter

$$\text{Pipe mass per meter} = \rho_{\text{PVC}} \cdot A_{\text{wall}} = 1400 \times 7.77 \times 10^{-5} = 0.1088\,\text{kg/m}$$
$$\text{Water mass per meter} = \rho_{\text{water}} \cdot A_{\text{inner}} = 1000 \times 1.767 \times 10^{-4} = 0.1767\,\text{kg/m}$$
$$\text{Total load per meter} = 0.1088 + 0.1767 = 0.2855\,\text{kg/m}$$

Maximum Height Calculation

$$\text{Available payload capacity} = 10.8 - 4.5 = 6.3\,\text{kg}$$
$$h = \frac{6.3}{0.2855} \approx 22.07\,\text{meters}$$
$$h_{\text{feet}} = 22.07 \times 3.28084 \approx 72.4\,\text{feet}$$

Final Theoretical Height

$$\boxed{h \approx 22.07\,\text{m} \approx 72.4\,\text{feet}}$$

Note: - All these calculations are based on the Garden hose pipe we used during testing. These calculations also doesn't account for the Extra instabilities generated due to Vibrations and Higher wind speed. These are also based on the Maximum thrust provided by motor. However as the voltage of the Battery decreases due to power consumption, the current available to the motor would also vary during flight time, thus that also needs to be accounted and taken care of.

18 Theoretical Maximum Volume Flow rate and Velocity of water using a pump that can be supported by drone for Extinguishing Fire.

We know that the water will exert a thrust force on the Drone due to change in the Momentum experienced by the water and thus eventually by the drone.

The Thrust Force should be balanced by the Forward Thrust force Generated by the

Drone. As there is a limit to the Forward thrust force generated by the Drone, There is limit to the Volume Flow rate and velocity of water that can be used to extinguish fire by pumping the water.

An Important thing to note that this Forward/Backward (or rather thrust force in the X-Y plane,where Z axis is the altitude axis) is generated by tilting of drone, thus the Thrust force also has a component in the Horizontal plane, thus this Force is responsible for Forward, Backward or Sideways movement of the Drone.

For Stable Flight Operation the Tilt angle of the Drone shouldn't be more than 10 Degrees for Heavy lift drones , in common terms this tilt angle is often called Pitch angle of Drone.

The Thrust force due to Water jet can be found using Momentum conservation and takes the form as below

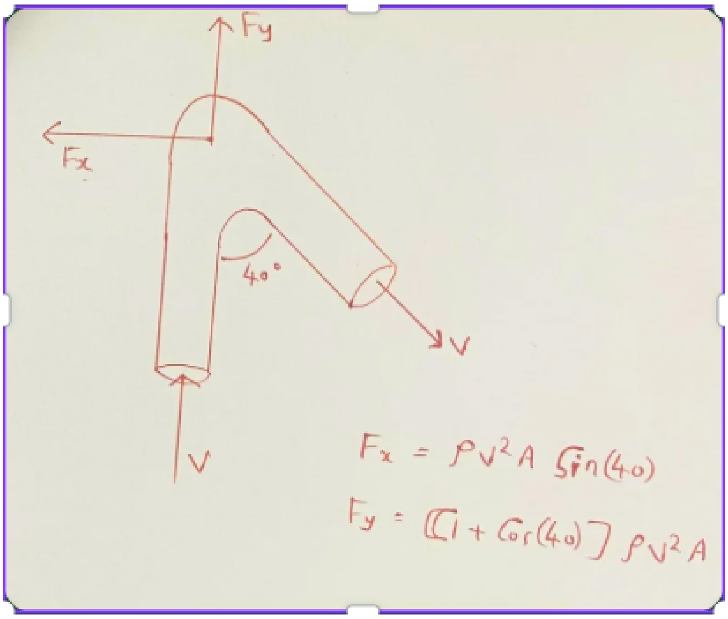

Figure 21: Thrust Force due to Water Jet Spraying

Now this Horizontal Thrust force due to water jet must be equated by Horizontal Thrust force that can be provided by the Drone.

Considering the Maximum Limit Scenario.

Known Parameters

We have chosen the maximum Upward thrust available for Stable Flight to be **80 % of the maximum thrust that can be provided by the Motors**, because some amount of thrust is needed for stabilizing the drone along each rotatory axis, thus not all Motor's Thrust can be utilized.

- Thrust per motor at 80 % Throttle: 1.8 kgf
- Number of motors: 6

- Total thrust: $1.8 \times 6 = 10.8\,\text{kgf} = 10.8 \times 9.81 = 105.948\,\text{N}$
- Total Horizontal Plane Thrust: $105.948 * Sin(10) = 18.4\,\text{N}$
- Pipe inner diameter: $D_i = 15\,\text{mm} = 0.015\,\text{m}$
- Water density: $\rho_{\text{water}} = 1000\,\text{kg/m}^3$

Cross-sectional Area

$$A_{\text{inner}} = \pi \left(\frac{D_i}{2}\right)^2 = \pi(0.0075)^2 = 1.767 \times 10^{-4}\,\text{m}^2$$

Equating the Forces to find Maximum Velocity

$$\rho_{water} * V_{max}^2 * A_{inner} = 18.4$$

$$V_{max} = \sqrt{\frac{18.4}{\rho_{water} * A_{inner}}}$$

$$V_{max} = \sqrt{\frac{18.4}{1000 * 1.767 * 10^{-4}}}$$

$$V_{max} = 10.2 \text{ m/s}$$

18.1 Maximum Volume Flow rate

$$Q_{max} = A_{inner} * V_{max}$$

$$Q_{max} = 1.767 * 10^{-4} * 10.2$$

$$Q_{max} = 0.0018\ m^3/s$$

$$Q_{max} = 1.8\ L/s$$

$$Q_{max} = 108\ L/min$$

Final Theoretical Maximum Volume Flow rate and Velocity

$$\boxed{Q_{max} = 108\ L/min}$$

$$\boxed{V_{max} = 10.2 \text{ m/s}}$$

Note: - All these calculations are based on the Garden hose pipe Diameter we used during testing. These calculations also doesn't account for the Extra instabilities generated due to Vibrations and Higher wind speed. These are also based on the Maximum thrust provided by motor. However as the voltage of the Battery decreases due to power consumption, the current available to the motor would also vary during flight time, thus that also needs to be accounted and taken care of.

An Important thing to note that the velocity of the Water jet can be changed by changing the Diameter of the Pipe, thus it is not a good bounding limit, Rather Volume flow rate is the main limitation for our drone, As it is controlled by the Pump Pressure that is being used to drive the water jet.

Also some drones could fly stable with higher Tilt Angle thus allow higher Volume Flow rates. Thus it is important to check the limitation of the drone as per the specifications of the components used.

19 Conclusion and Future Improvements

We were able to design the Drone capable of providing Reasonable sufficient Flight time of around 15-20 mins considering we have used a single 6S battery. The Drone was able to maintain stability while Flying under Loiter and Position Hold mode with inaccuracy within 1 m.

Though we can use the drone in semiautomatic flight modes like (position hold where the position is kept same if the user doesn't command to change it).If we want to fully automize the flight path and altitude and all coordinates, launch point, land point, speed, we need to provide more safety mechanisms.

For ensuring safety from collision due to object in path, ultrasonic sensor, IR sensor or other obstacle detection mechanisms coupled with the flight controller can be implemented to ensure no collisions occur during the preprogrammed flight path.

The Fire detection and extinguishing mechanisms can also be fully automized by using Thermal camera and image processing which would detect the fire and automatically extinguish the fire.

Another improved could be to use Lighter but stronger (Higher Strength-to-weight ratio) can be used to minimize weight while not compromising on structural integrity.

We would be using Carbon Fiber Rods instead of PVC pipe along with better Flight controller and Motor that could provide higher thrust and try to implement better Fire extinguishing mechanisms and automize the process as much as possible.

20 Acknowledgement

We would like to express our sincere Gratitude to our Project Manager **Mr.Anirudhh Mali**, Project Supervisor **Prof. Pratik Mutha**, Maker Bhavan TA **Mr. Dvijit**, **Maker Bhavan Lab @ IITGn** and **Tinkerers Lab @ IITGn** for Providing Insights,Assitance and Facilities for Making the project, we would also to extend our special thanks to **Professor Rakesh Singhai** for providing insights and possible improvements during the Final Review of the Project

21 Reference Links for images

- figure-1
- figure-2
- figure-7
- figure-16
- figure-17
- figure-11 (connectors
- figure-11 (power-module)
- figure-11 (base plate soldering with ESCs
- figure-20
- figure-9
- figure-10
- figure-19
- figure-7
- figure-18