DESIGN OF A LOW-COST UAV FOR AGRICULTURAL PURPOSES

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by

Ali Kamran Gohar

Hammad Farooq

Mahrukh Malik

Muhammad Unes

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EXAMINATION COMMITTEE

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

ALI KAMRAN GOHAR	00000138959
HAMMAD FAROOQ	00000175292
MAHRUKH MALIK	00000180828
MUHAMMAD UNES	00000175310

Titled: "DESIGN AND DEVELOPMENT OF LOW-COST UAV FOR AGRICULTURAL PURPOSES" be accepted in partial fulfillment of the requirements for the award of B.E. Mechanical degree with grade A

Supervisor: Dr. Zaib Ali, Assistant Professor Department of Mechanical Engineering	Dated: 8-8-2020
Committee Member: Dr. Jawad Aslam, Assistant Professor Department of Mechanical Engineering	Dated: 8-8-2020
Committee Member: Dr. Aamir Mubashar, Associate Professor Department of Mechanical Engineering	Dated: 08/08/2020

12-Aug-2020

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________

____

(Dean / Principal

ABSTRACT

Unmanned air vehicles are a promising technology having a wide range of applications. In this technologically evolving world, numerous new precision farming technologies have emerged to optimize crop productivity and to combat the food crisis of the ever-rising world population with limited land resources. Particularly, in a developing agro-economy like Pakistan, over 42.02% of the total employable population are employed in agribusinesses. This sector contributes 25% to GDP and makes up 65% of the total exports. Despite the immense importance of this sector in the economy of Pakistan, owing to the absence of state-of-the-art farm technologies, the agribusinesses face drastic losses, especially due to pest attacks and diseases, for example, Pakistan cannot produce more than 14 million bales of cotton a year because of pest attacks only. To combat pest attacks and diminish pest-related diseases chemicals called pesticides are utilized to kill pests and insects to increase crop yields. These chemicals are typically toxic to humans as well. The World Health Organization estimated as many as one million instances of illnesses due to exposure to pesticides during manual spraying of crops. Unmanned aerial vehicles are becoming increasingly popular in pesticides spraying to limit human exposure to pesticides to alleviate associated health problems. UAVs also reduce the time and effort needed to complete the task, consequently increasing crop productivity. However, despite the advantages that the use of UAVs offers in the pesticide spraying process, UAVs require high initial investment due to the high cost of commercially available UAVs. This cost is further increased for Pakistani farmers due to the absence of local manufacturers of agricultural UAVs. In a fragile economy like Pakistan, this discourages the use of UAVs in agribusinesses. Therefore, the objective of this work is the design of low-cost UAV for farming application. To make the flying process of UAV easier for untrained farmers in rural Pakistan, we are aiming to produce an autonomous UAV that requires minimum

input from the controller to complete the tasks. Our UAV has onboard cameras, flight controllers, GPS, sensors, and Computer System. It has a direct connection with the Ground Controller and has a virtually unlimited range.

ACKNOWLEDGMENTS

We have made a lot of efforts in bringing this project to life. However, it would not have been possible without the support of our kind teachers. We are hugely thankful to our supervisor Dr. Zaib Ali and Co-Supervisors Dr. Jawad Aslam and Dr. Aamir Mubashar for their constant guidance and supervision and always providing us the required information regarding this project. They helped a lot during the process of making this project and all of its intricacies.

Our Head of Department Dr. Emad-ud-din as well as our Principal Dr. Shahid Ikram-ul-lah Butt are also be thanked who gave us the golden opportunity to do this wonderful project on the topic of Design of a Low-Cost UAV for Agricultural Purposes.

We would also like to thanks many of our fellow students who also helped us in doing a lot of research. Along the process, we came to know about so many new things and found new and interesting interconnection among various fields of engineering with our own.

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ABBREVIATIONS

UAV	Unmanned air vehicle
EP	Expanded polypropylene
FEM	Finite Element Method
ESC	Electronic Speed Controller
RPi	Raspberry Pi

Table 1: Abbreviations

NOMENCLATURE

F_D	Drag Force
V	Velocity
P	Density
F_L	Lift Force
A	Area
C_D	Coefficient of Drag
C_L	Coefficient of Lift
M	Meter
Kg	Kilogram
Ft	Feet
m^2	Meter squared

Table 2: Nomenclature

CHAPTER 1: INTRODUCTION

1.1 Motivation

The motivation for selecting this particular project is to offer a cost-effective solution for Pakistani farmers, to make the agricultural processes more efficient.

1.1.1 Large Consumer Base

Pakistan has a well-integrated agriculture sector. 25% of the total area of Pakistan is cultivated. As much as 42.3% of Pakistan's labor force is directly or indirectly employed in this sector. 113 million people in Pakistan live in rural areas only and have some involvement in agriculture. Therefore, we have a large consumer base that we can target and pitch our product to. It is a 555-million-dollar market that is yet to be introduced to Pakistan[1][2].

1.1.2 Government as Stakeholder

The agriculture sector is the mainstay of Pakistan's economy as it contributes around 20 percent in the overall gross domestic product (GDP) and makes up 65% of the exports. Given the importance of agriculture in the Pakistani economy, the government has always incentivized farming solutions and helped boost the mechanization of farming practices in Pakistan. Very recently, the government has allowed the use of drones for agricultural purposes, hence opening a window of opportunity for this industry to grow. We wanted to exploit this opportunity[2].

1.1.3 Improving Agricultural Practices

It is also the need of the hour. Pakistan is the 4^{th} largest producer of cotton in the world[2], however, it cannot produce more than 14 million bales a year because of pest attacks only. The population of Pakistan is also on a rise, increase the demand for food more than ever. At a time like this, Pakistan needs to make its agricultural practices more efficient to compete in the world and to sustain itself. Drones save time and money for everyone involved in the process. A human worker can only cover 0.65 acres[3] of land in a full day while the drone can cover the same area in just 2mins! Moreover, it will also reduce the cost of production by reducing the cost of labor employed to spray pesticides.

1.1.4 Alleviate Health Problems

Pesticide spraying drones also have a lot of social benefits. Using them reduces the health and safety risk to farmers due to exposure to toxic chemicals and the risk of falling off the trees and bug and snake bites. It also rids the farmers from having to perform dull repeated tasks in uncomfortable, hot, and humid working environments.

1.1.5 Reduce Pesticide Wastage

Moreover, the use of the drone will allow for wastage reduction of about 30% because of the high degree of atomization, saving the country's resources, and reducing the amount of pesticide sprayed in the atmosphere.

1.1.6 Farming in Remote Areas

It also makes farming in difficult terrains easier making use of most of Pakistan's cultivatable land and also reduces crop damage due to human workers stepping on them accidentally.

1.1.7 Sustainability

It is also a sustainable solution as it uses rechargeable batteries rather than the fuel.

- Local development of UAV designed according to Pakistan's Agricultural needs
- Find a low-cost solution for local farmers
- Reducing the operating cost to increase ROI on agricultural yield

1.2 Problem Statement

Our problem revolves around four foci which are described below.

1.2.1 Low Cost

The UAV will be manufactured using materials and components which would incur the lowest cost without compromising the performance. Cost-cutting would be done by optimizing the structure and using a self-designed avionic system.

1.2.2 Local Manufacturing

The UAV fixtures and structure will be manufactured and assembled locally to reduce the manufacturing cost and give a local option for the Pakistani farmers. It will reduce the cost incurred and also save shipping charges and customs.

1.2.3 Low Operating Cost

The UAV will incur a low operating cost and will reduce the cost of pesticide spraying manifolds.

1.2.4 Autonomous Flight

The UAV will not require to be controlled by a remote on the ground. It will fly on its own by getting data from a computer chip that will help the UAV to decide its course of motion. During actions in case of surveillance and the UAV will decide on its own, by gathering data from the computer chip.

1.3 Objectives

The objectives of the project are described below:

- Designing the unmanned aerial vehicle in a 3D modeling software. After the design, performing the analysis of the 3D model by giving close to real-world conditions on Ansys.
- Finding low-cost solutions and options for the manufacturing of the UAV.
- Manufacturing the prototype based on the results from software analysis and theoretical calculations.
- Ground testing of the aerial vehicle to ensure that all the parts are working accurately.
- Initial flight of the UAV to make sure it is flying without significant errors.
- Implementing the automation with the autopilot flight controller.
- Initial flight of the UAV after the implementation of Automation
- Field testing the UAV in variable weather and other environmental conditions.
- Testing for spraying mechanism in variable weather and other environmental conditions.
- Debugging and finalizing the product.

CHAPTER 2: LITERATURE REVIEW

The focus of our literature review was based on the deliverables proposed. Overall, it included applications of UAV in agriculture, construction of the UAV, implementation of the control systems, and automation using autopilots other techniques.

Research Papers Used

Research Paper	**Abstract**
[4]Design and trajectory control of universal drone system	Proposed universal drone simulations to benchmark trajectory performance. The effect of different arm lengths on this performance. Effect of number of rotors on performance under disturbance effects
[5]Review on Application of Drone Systems in Precision Agriculture	Technical analysis of UAVs in precision agriculture research involving technologies, methods, systems, and limitations of UAVs Techniques and crucial components involved to build an unmanned rotorcraft vehicle
[6]Numerical analysis and validation of spray distributions disturbed by quadrotor drone wake at different flight speeds	Simulation of the downwash flow field of a quad-rotor drone using computational fluid dynamics method based on the lattice Boltzmann method (LBM) The dependence of the droplet movement on the flight speed and altitude of a quad-rotor drone and the nozzle spacing

[7]Control Design for Unmanned Aerial Vehicles with Four Rotors	Control system design in the combination with the quadcopter dynamic model The PI-D control algorithm for simplified quadcopter dynamic model Reference trajectory tracking with added periodical disturbances
[8]CFD Analysis of Quadcopter	The impact of the effect of airflow on the quadcopter frame and proper stress analysis of the main structural components of the quadcopter frame and propeller.
[9]Quadcopter: Design, Construction, and Testing	The proposed system for design, construction and testing procedure of quadcopter
[10]Dynamic Modeling and Simulation of a Quadcopter with Motor Dynamics	Development of an adaptive dynamic model for battery voltage for a quadcopter platform by conducting experiments for determining motor dynamics Development of the state-space model in linear time-invariant condition for designing a controller for simulation purposes. The system was flight tested and parameter estimation was performed on the thrust and torque motor coefficient.
[11]Quadcopter Flight Dynamics	Angular maneuvering scheme along with standard flight operations such as taking-off, landing, and hovering Determination of total thrust using the inputs of altitude, pitch and roll angles The procedure on varying the thrust direction of rotors for flight operations.

[12]Structural Analysis of Quadcopter Frame	The overall design of the quadcopter frame model Determining the dynamics of the quadcopter Analyzing the static and dynamic characteristics of the frame with commercial Finite element code ANSYS Procedure for selecting the suitable materials that meet the strength and stiffness of requirement of the system
[13]Design and development of FOLLY: A self-foldable and self-deployable quadcopter	Studying the design of self-harm management using a four-bar crank-rocker mechanism that is actuated by a single servo motor and coupled with spur gears to allow for easy folding and unfolding of arms. Numerical analysis and dynamic simulation of torque characteristics of the mechanism are analyzed numerically.
[14]Towards a Framework of Key Technologies for Drones	A publication to minimize the design and verification effort for complex drone applications and ease the integration and customization of drone systems Puts forward an integrated multi-vendor and compositional UAV embedded architecture solution and a toolchain complementing the compositional architecture principles.

Table 3: Research Papers Used

2.1 Quadcopter Flight Dynamics

A quadcopter is operated and maneuvered by controlling the RPM of rotors which further controls the lift, torque, and thrust of the rotors. The small size of quadcopters relative to other fixed-wing and single rotor UAVs enables it to perform complex aerial maneuverability. To perform such complex flights precisely, angles are required to be handled very carefully. Mainly, the standard flight operations include[11]:

- Take off
- Landing

- Hovering

2.1.1 Thrust:

When the propeller is rotated at a certain speed, an orthogonal force is produced that is termed as thrust. The copter is accelerated in the direction of this thrust force. The equation of thrust is given as:

$$\boldsymbol{T = \rho A v^2}$$

Where ρ is the density of the surrounding air which is a very important parameter to calculate the thrust. The value of the air density must be taken in real-time. v is the velocity and A is the cross-sectional area of the propeller. This equation shows that the thrust produced by the propeller depends upon the environmental conditions and if we take the air density as constant, it will compromise the rotor performance.

2.1.2 Taking off and Landing:

While taking off and landing, all the four rotors of quadcopter rotate in the same direction at the same speed. For taking off the thrust must be higher than the total weight to be lifted, so as the speed of propellers goes on increasing, it increases the thrust and when it becomes equal to the total weight, it starts lifting the copter in the upward direction. For landing, the speed of the rotors is just reduced so that the thrust becomes less than the weight of quadcopter, this will result in the landing of the copter smoothly. The net thrust on the copter is given as:

$$\boldsymbol{T = W - \rho A \sum_{i=1}^{4} v_i^2}$$

Where "i" represent the number of propellers and W is the net weight of the copter.

2.1.3 Hovering:

When the net thrust becomes equal to zero, it means that the copter will remain standing in the air at a certain altitude. This phenomenon is termed as hovering. The direction of the propellers' rotation is still in the same direction.

$$\boldsymbol{T = W - \rho A \sum_{i=1}^{4} v_i^2 = 0}$$

2.1.4 Orientation:

The maneuverability of the quadcopter involves the following three types of orientation:

- Roll (θ)
- Pitch (φ)
- Yaw (ψ)

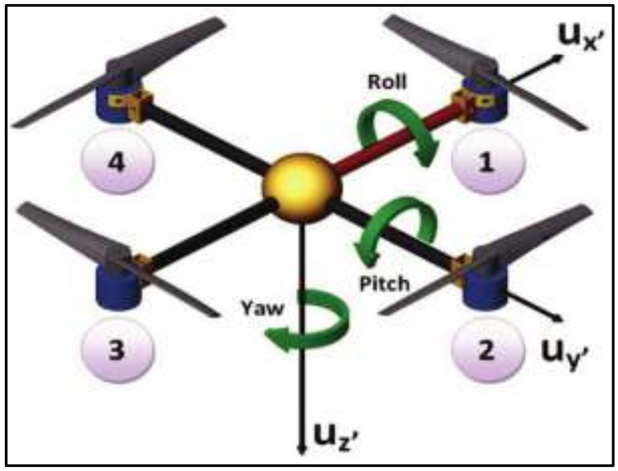


Figure 1: Roll, pitch and yaw rotations of quadcopter[15]

Roll: The rotation about X-axis is termed a rolling of the quadcopter.

Pitch: The rotation about Y-axis is termed a pitch of quadcopter.

Yaw: The rotation about Z-axis is termed a Yaw motion of quadcopter.

2.1.5 Front and Back Motion:

The quadcopter can be moved in the forward direction by increasing the speed rear end rotors while by increasing the speed of front-end rotors, backward motion can be achieved. This will affect the pitch angle of the quadcopter.

2.1.6 Left & Rightward motion:

This motion can be achieved by changing the yaw angle which can be done by increasing or decreasing the speed of CCW rotors along with decreasing or increasing the speed of CW rotors.

2.2 Design and trajectory control of universal drone system

Two different configurations of drones i.e. “Dodecacopter” and “Octa-copter” were used for the autonomous flight simulation to study the effect of disturbance on trajectory tracking. The simulation results of intentional disturbance show that the stability of the dodecacopter flight is higher than that of octocopter as with the increasing effect of disturbance. While in case of no disturbance, the performance of trajectory tracking was almost the same for both of the copters. Another aspect that was studied is the effect of arms-length on the performance of the flight. The purpose of changing arm length is to use propeller of different sizes which is ultimately supposed to affect the flight performance. The results of simulations showed that there is no effect on flight performance by changing the arm length. So, it can be concluded that flight performance goes on to be improved by increasing the number of rotors since it improves the stability of the flight but the arm length has no effect on it so it can be set based on other design considerations[4].

2.3 Review on Application of Drone Systems in Precision Agriculture

Technical analysis of the application of UAV technology in precision agriculture needs to be done to study their applicability in agriculture operations like crop surveillance, pesticide spraying, and field and soil analysis. Although the hardware components of UAVs are majorly dependent on physical aspects such as weight, required flight range, total payload, and structure configuration, the size, and auxiliary components can depend on the type of use of UAV.

Designing and building of UAV require the design of the structure, aerodynamic modeling, manufacture of hardware components, integration of software system, and flight controlling.

For crop surveillance, vision systems like thermal and multispectral cameras can be incorporated. The reflectance of plantation canopy can be recorded. Pictures can be processed based on NDVI to denote the crop conditions.

$$\mathbf{NDVI = (R_{INR} - R_{RED})/\ (R_{INR} + R_{RED})}$$

Where, R_{INR}= Reflectance of the near-infrared band
R_{RED}= Reflectance of the red band

The value of NDVI ranges from -1 to +1 where values close to zero indicate no vegetation while values close to 1 suggest the highest density of green leaves. Field conditions can be identified based on these values.

For pesticide spraying, a sprayer system assembly can be mounted on UAV along with a pesticide tank. This can aid in pest control while limiting human interaction. It can potentially increase the efficiency of the spraying process.

Problems like some areas of field not being covered pesticides, sprayed areas overlapping and less spraying on the edges of the field can be resolved by designing autonomous UAV with planned trajectories. This can be done by adjusting the route of an unmanned aerial vehicle to changes in wind speed.

For the spraying mechanism, the pressure and discharge rate of pesticide, density, and size of droplets, spray uniformity needs to be studied. The sprinkling system comprises of, which are the spraying components and the controller used to activate the nozzle. Another component is a pressure pump which is used to pressurize the pesticide before it is expelled through the nozzle. The pump is controlled by a motor-driven integrated circuit.

Different spraying systems are analyzed in the paper, for example, to diminish pesticide wastage an electrostatic spray technology can be incorporated. Particle image velocimetry method can be utilized to determine the movement of downwash flow field droplets at varying rotor speeds.

In place of this, crop surveillance and pesticide spraying processes can be automated by using a drone with a sprinkling assembly and a multispectral camera[5].

2.4 Numerical analysis and validation of spray distributions disturbed by quadrotor drone wake at different flight speeds

The droplet movement depends on flight speed, UAV altitude, and the spacing between the nozzles. Wind tunnel tests and numerical simulations can be used to determine the optimal spray conditions. To reduce droplet, drift the flight speed and altitude of the drone are significant factors. The spacing between nozzles and their position will have a very small effect on the droplet deposition and drift. Consequently, the flight speed and drone altitude will result in eddy current shaped like a horseshoe in the downwash flow field that will result in the uneven deposition and drift of droplets ultimately[6].

2.5 Control Design for Unmanned Aerial Vehicles with Four Rotors

A control system design is aimed at stabilizing the state of the system about a reference state or varying the state according to some relation or law, eliminating any disturbances to the system. This is achievable through a feedback loop system. The control system of any system should be designed keeping in mind its dynamic model.

There are six degrees of freedom for a quadcopter and a total of four control variables, which suggests that the system is dynamically unstable and under-actuated. Propulsor propellers are the only moving components that rotate w.r.t a fixed axis. As the frame of the quadcopter is assumed as rigid, the only variable that influences the quadcopter movement is the revolutions per minute of the propeller.

A controlled quadcopter system's behavior is dependent upon the control algorithm as well as the dynamic model of the quadcopter. The inputs of the control algorithm input are the values specified for the task to be achieved and the output values of the dynamic model. The control algorithm outputs make the four control variables that are inputs to the dynamic model. That means outer control loop outputs are inner control loop inputs so the parameters for the outer-loop are to be selected in a way that in amalgamation with inner-loop parameters, it gives suitable control variables. The paper also includes mathematical equations for the design of a dynamic model of the quadcopter that is to be used for the design of the control system[7].

2.6 Quadcopter: Design, Construction, and Testing

2.6.1 Frame

A quadcopter's frame mainly comprises of four arms, a base plate, and landing gear. The structural design needs to be rigid to host the electronic components of the drone, but low in weight to keep the thrust requirement low. To increase stability the center of gravity would be as low as possible and the weight on each arm should be balanced. The wheelbase should be big enough to prevent any kind of aerodynamic interaction between propellers.

2.6.2 Motors

Owning to the superior thrust-to-weight characteristic of brushless DC motors, they are widely used in drones. In Quadcopters, an independent variation of the speed of each rotor is used to control the system by creating a desired total torque or turning force due to difference in rotor speeds and subsequently thrusts. Each motor's commutator is electronically commutated using the speed controller. BLDC motors have two defining ratings: current ratings and Kv ratings. The current rating is a representation of the maximum current drawn by the motor while the Kv rating indicates the relationship between the RPM and the applied voltage. Kv rating can be used to determine the torque constant (Kt) of the motor, therefore Kv rating can be used as the selection criteria for motors.

2.6.3 Propellers

The spinning of propellers provides the thrust to lift the quadcopter, therefore, selecting the right propeller is critical to yielding appropriate thrust without overheating the motors. The size and material of the propeller can vary depending on application and thrust requirements. The size of the propellers is defined by their diameter and their pitch sizes. Propellers are coupled with motors. In a quadcopter, two propellers spin clockwise while the other two spins anti-clockwise.

2.6.4 Electronic Speed Controllers

Electronic Speed Controllers have two major functions in radio-controlled quadcopters. They act as Battery Elimination Circuit, connecting the motors and receivers to the same battery. They also interpret the flight controller's signal received by the receiver and apply the right current to the motors to produce the correct combination of thrust to allow for maneuvering of the copter. The controller's commands are given as PWM signals, which are received by the ESC of each motor, which then outputs the appropriate motor speed. Every ESC has a current rating which indicates the maximum current that an ESC can provide to the motor without overheating. ESC current rating is always higher than the maximum current draw of the motor.

2.6.5 Design

A Quadcopter's motion is dependent on the resultant forces and moments about the center of gravity. Normally an X shaped frame used for a quadcopter because it allows for a thin yet strong design that can endure deformation resulting from loads applied during operation. The frames are defined by their shape, the size of the wheelbase (which is the motor to motor distance), or the diameter of the frame area. Deformation due to bending and twisting that the frame is subjected to is related to the cross-sectional shape section. For quadcopter, typically a closed cross-sectional, hollow tubular frame is used to reduce weight. The stiffness of the design can be varied by altering cross-sectional profile dimensions and wall thickness.

The control of a quadcopter is achieved by sending an input signal by a control board through a gyroscope in the microcontroller. Gyro gain for the three-axis (roll, pitch, and yaw) is measured and controlled via three adjustable potentiometers. According to the code built-in microcontroller, it processes these signals through an actuator, which is an ESC. Using these signals as a reference, ESCs make adjustments to the rotational speed of the motors to stabilize the quadcopter. Signals from the radio system receiver are also interpreted by the control board which passes on these signals to the microcontroller as the elevator, aileron, throttle, and rudder inputs. The microprocessor processes this information and sends control signals to the ESCs which will make adjustments to motors' rotational speeds to induce controlled maneuverability during flight.

2.6.6 Mechanism and Motion

The six major operations for a drone are takeoff, landing, moving forward, moving backward, turning right, and turning left.

Takeoff and landing movements are controlled by respectively increasing and decreasing the speed of all four rotors simultaneously. This changes the direction of vertical movement. To move forward, the speed of the front two rotors is increased more than the two rear rotors, whereas to move back the speed of rear rotors is increased more than the front rotors. Similarly, to move in the left or right direction, the speed of two rotors in the direction is to be increased. To turn, however, the speed of clockwise or anti-clockwise rotors is altered.

2.6.7 Numerical Analysis

The forces acting on propeller are transferred to the frame via rods to the fixtures to the base plates. To perform static structural analysis, the forces to be considered are the motor thrust, the centrifugal force, and the moment created due to the turning of propellers.

$$\boldsymbol{F_c = mR\omega^2}$$

Where F_c is the centrifugal force in N

m is the mass of propeller in kg

R is the radius of the propeller in meters

ω is the angular speed of the propeller

$$\boldsymbol{M = x * F_c}$$

Where, M is the moment due to the propeller in N.m and x the perpendicular distance in meters

The propeller is defined by its diameter and its pitch. The thrust generated by a propeller and motor combination is as follows:

$$\boldsymbol{T} = \frac{\boldsymbol{\pi} * \boldsymbol{D}^{\boldsymbol{4}} * \boldsymbol{\rho} * \boldsymbol{v} * \Delta\boldsymbol{v}}{\boldsymbol{4}}$$

Where T is thrust in N, D is the diameter of propeller, ρ is the air density in kg/m^3, v is the velocity of incoming air (m/s). Then, the total mass lifted by the quadcopter is

$$\boldsymbol{M} = \frac{\boldsymbol{Thrust}}{\boldsymbol{acceleration\ due\ to\ gravity}\ (\boldsymbol{m}/\boldsymbol{s}^{\boldsymbol{2}})}$$

The lift capabilities of flight system can be defined by the following relationship

$$\boldsymbol{Lift}\ (\boldsymbol{kg}) = \frac{\boldsymbol{W} * \boldsymbol{D}^{\boldsymbol{4}} * \boldsymbol{N}^{\boldsymbol{2}} * \left(\frac{\boldsymbol{\rho} * \boldsymbol{24}}{\boldsymbol{C_f} * \boldsymbol{29.9}}\right)}{\boldsymbol{2.2}}$$

Where C_f is lift co-efficient, W is the weight of the quadcopter, N is the rpm of motors or propellers

Total Flight time is given by:

$$\boldsymbol{Flight\ time}\ (\boldsymbol{minutes}) = \frac{\boldsymbol{Maximum\ Capacity\ of\ Battery}\ (\boldsymbol{Ah})}{\boldsymbol{Maximum\ current\ draw\ of\ the\ motor}\ (\boldsymbol{A})} * \boldsymbol{60}$$

2.6.8 Testing

The structure is analyzed on simulation software. To ensure the safety of quadcopter during flight, several tests are conducted on components in isolation and the whole system. For example, motors are tested at various speeds and thrust settings. This is done through a spring arrangement with known spring stiffness, where one end of the spring is restricted and the other end is attached to the motor. The motor thrust can be determined by measuring the deflection[9].

Typically, tests are carried out in two definitive stages.

Unit Tests

All the components including motors and sensors are tested separately.

Flight Tests

This is done in a further three stages:

- For pre-flight testing (tethered), where checklists are used to ensure that everything is in place.
- In-flight testing to check stability by flying the Quadcopter

2.7 CFD Analysis of Quadcopter

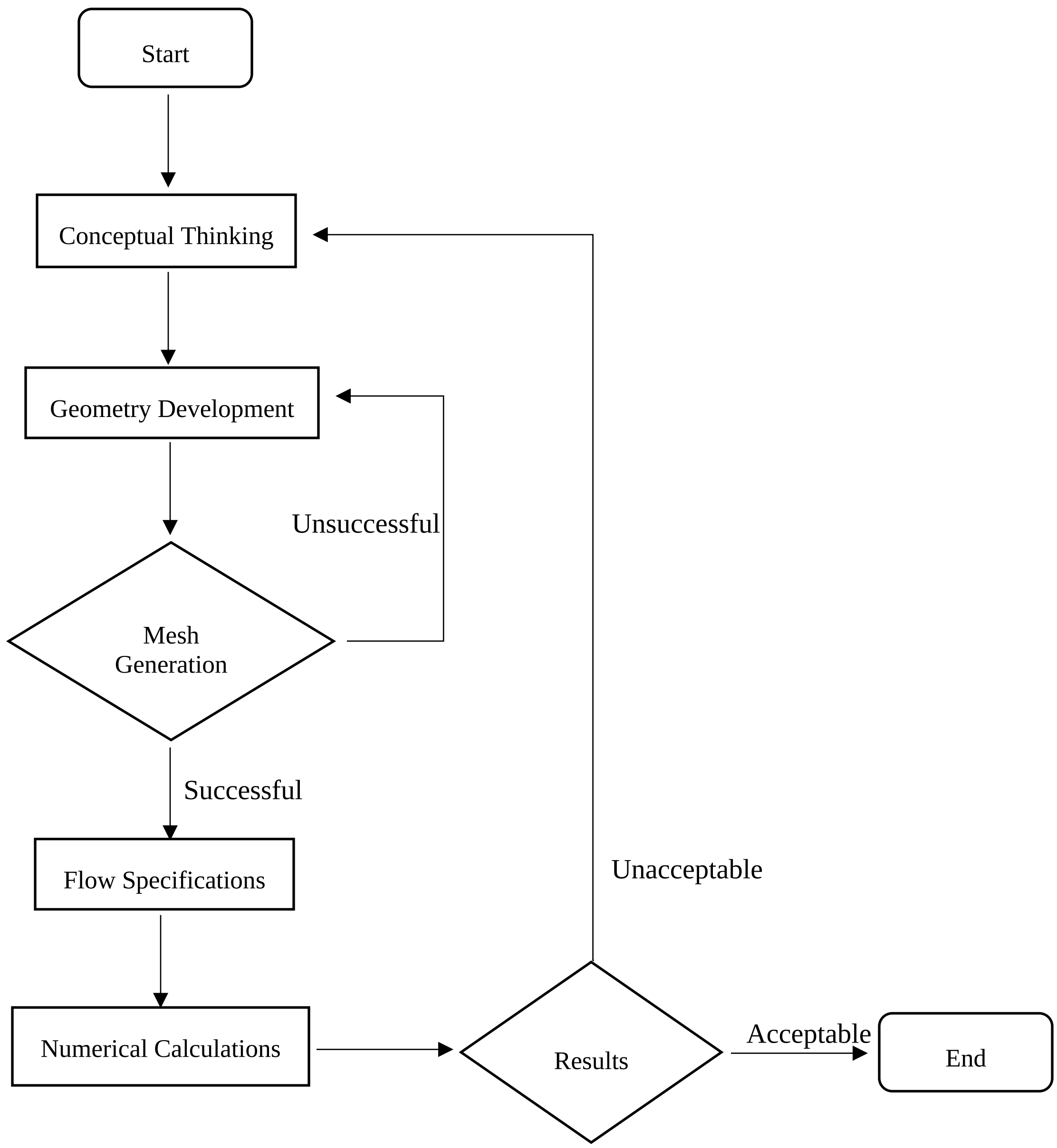


Figure 2: Schematic for CFD

To study the impact of airflow on the propeller and quadcopter frame, a simulation software like ANSYS is used. It is done in four steps. The first step is to import the geometry from 3D software like Solid Works. The second step is to do meshing for the entire structure. Thirdly, the conditions similar to real-life situations are applied. Finally, the fourth step is to obtain the results after running the simulation. The effects of the forces acting on the quadcopter frame and the total deformation, elastic stress, and stain can be determined through CFD analysis. This can help in designing the structure and deciding the materials to be used[8].

2.8 Thrust vs Copter Speed

The relationship of trust with the speed of quadcopter, the diameter of propeller, the pitch of propeller and RPMs of propeller is given as:

$$\boldsymbol{T = 1.225 \times \frac{\pi(0.0254 \times d)^2}{4}\left[\left(RPM_{prop} \times 0.0254 \times p \times \frac{1}{60}\right)^2 - \left(RPM_{prop} \times 0.0254 \times p \times \frac{1}{60}\right)v\right]\left(\frac{d}{3.2954 \times p}\right)^{1.5}}$$

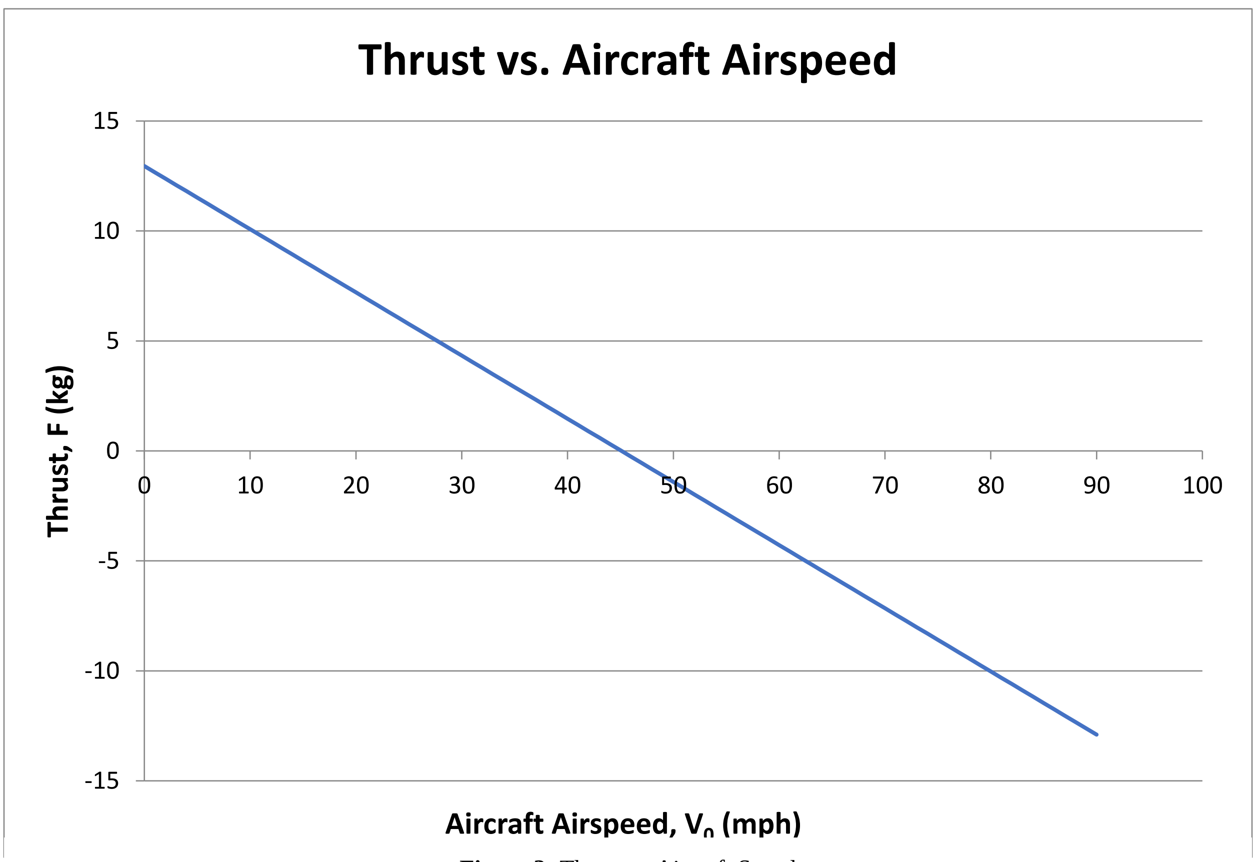


Figure 3: Thrust vs Aircraft Speed

The graph shows that as the speed of the quadcopter goes on increasing, the value of thrust is decreased. It means when the quadcopter is moving in some direction, more thrust is required as compared to when it is hovering[16].

2.9 Types of drones used

Drones used for agricultural purposes are mainly divided into three types[18]

2.9.1 Fixed Wing Drones

A fixed-wing drone resembles an airplane in design, they are characterized by one rigid wing. Fixed-wing drones cannot stay in one place with vertical lift rotors but instead, they glide along a defined path. This means they can be far more efficient compared to the two other main categories of drones. Advantages of using a fixed-wing drone are

Advantages:

- The average flight time is a couple of hours and can go up to an impressive 16 hours or more if the drone is gas engine powered
- Fixed wings can fly at a high altitude so have increased advantages if used surveillance purposes.
- They have greater endurance against higher airspeeds.
- And have the ability to carry more weight.

Disadvantages:

- Fixed-wing drones are expensive.
- Specific training is usually required to pilot them.
- They are more difficult to land than the two other categories of drones.
- Fixed winged drones are not capable of hovering and can only move in the forward direction.

2.9.2 Single Rotor Drone

Single rotor drones are strong and as the name implies look similar in structure and design to actual helicopters. These drones are characterized by one big rotor at the center and a small-sized rotor for direction and stability on the tail.

Advantages:

- Unlike fixed-wing drones, single rotor drones can hover vertically in the air.
- These drones are built to be more durable and stronger
- They have a long-lasting flight time, which increases if the drone is gas-powered.
- Because of increased strength and rotor power, they have a heavy payload capability.

Disadvantages:

- Compared to multirotor drones, a single rotor is hard to fly.
- These drones are expensive and have greater complexity compared to multirotor drones
- Because of the heavy spinning blade, single rotor drones are considered more dangerous and are to be handled with extreme caution.

2.9.3 Multi-Rotor Drones

The third and most common type of drones is Multi-rotor drones. They are easier to manufacture and the cheapest among all the types. As the name suggests, such drones carry several rotors and can be further classified based on the number of rotors installed on the drone. Tri-copters (3 rotors), quadcopters (4 rotors), hex copters (6 rotors), and octocopters (8 rotors) are the types based on the number of rotors. Quadcopters are the most popular multi-rotor drones.

Advantages:

- These drones are easy to control and maneuver and are considered to be stable
- Unlike fixed-wing drone multirotor drones can hover
- Multirotor drones have the VTOL capability

Disadvantages:

- Due to a greater number of motors Multi-rotors have a limited flying time (usually 15-20 minutes)
- They have small payload capabilities

2.10 Applications of UAVs in agriculture

Drone technology has various applications in agriculture such as[19]:

2.10.1 Pesticides Spot Spraying

The fertilization and pesticide spraying are very important for the high yielding of crops. This is usually done manually, using vehicles like tractors or even airplanes but this is very inefficient ways not only with respect to time but also in terms of costs. After getting approval from Aviation authorities of the regional or local governments, drones can be used for spraying of pesticides, herbicides as well as fertilizers. This is a very cost-effective method as well as a safer way to complete the task. These drones can be automated or semi-automated to run on the specified routes and schedules.

Spot spraying is another very important benefit of using drone technology for this purpose because now instead of spraying the whole acreage due to some issues with some specific crop but using spot spraying, not only the time and monetary resources will be saved but also the environment will have far less exposure to chemicals used in pesticides.

2.10.2 Field/Soil Analysis

The soil can be analyzed using drones before, in the middle, and after the crop cycle to collect useful data about the quality of soil or dead zones in the field that can help the farmer to take necessary measures to increase the yield. This will help the farmer in the determination of a more effective pattern for the plantation of seeds, management of soil and crops.

2.10.3 Used in Seed plantation

Plantation of seeds is a new concept in the field of agricultural UAV and the design of the injection of seeds into the prepared soil is under consideration. New startups are working on innovative drone technologies to bridge the gap and solve agricultural problems. This technology has reduced the need for ground planting and helped in saving cost, time, and effort. This technology has a wide scope and its application are wide and can be used to an extensive range of farms and this not only results in reducing planting time but also it reduces the cost of labor.

2.10.4 Used in Surveying of Crops

Drone technology is advantageous in the sense that it provides efficient monitoring of crops. In the past plane/satellite images were used in spotting potential issues and besides being not very clear these images were very expensive. But with the new drone technology decisions can be easily made based upon real-time information. Using a near-infrared drone sensor, it is easy to determine plant health based upon light absorption, giving a proper idea about the health of the farm. With this drone technology it is easy to collect information like 1) plant health 2) distribution of land-based on crop 3) life cycle of crop 4) GPS images of the crop area.

2.10.5 Used in the monitoring of Livestock

The farmers can easily monitor their livestock daily with less staff and investment. The drone will help to identify injured animals and animals giving birth. The use of thermal image also helps to keep an eye on the predators which are a huge advantage concerned with the number of life-stock.

2.10.6 Used in monitoring and management of irrigation

Drone with thermal cameras can be used in locating issues in irrigation like areas that are receiving very low or high moisture. The irrigation of water is very costly and can damage the yield of crops. With drone technology, such issues can easily be located before these become troublesome. And due to this storage of water in large pools can also be avoided since required water can easily be provided using drone technology[20].

2.11 Spraying Techniques

2.11.1 Low-pressure sprayer

Used due to relatively very less cost it has the following types[21]:

(a) Tractor mounted

The tank is attached to a tractor ranging with a capacity from 150 to 500 gallons and the pump is attached to the shaft and is driven hydraulic motor. The sprayer's booms can be attached either in the front, back, or on the belly of the tractor.

(b) High clearance sprayer

These sprayers are derived from tractor attached sprayers and these a tall frame that can clear corn, cotton, and tobacco plus all other tall crops. High clearance sprayers' boom height can be adjusted depending on the height of the crop.

(c) Trailer-mounted Sprayers

Trailer mounted sprayers are mounted on a trailer and dragged by an agricultural tractor, consists of a tank with a capacity of 3,785L. The pump is driven by the power hydraulic motor and is attached to the sprayer. These sprayers might contain a boom of a length of 3.7 to 15 m.

(d) Truck-mounted sprayers

It consists of a skid-mounted sprayer powered by an auxiliary engine. These are most useful in expansive areas or special applications. It is a large model that includes tanks that can hold up to 2,500 gallons.

2.11.2 High-pressure sprayer

High-pressure is used when spray needs to be driven through thick brush or tall trees. These sprays are heavier and expensive and these can operate under working pressures of 1,000 pounds per square inch. These are hydraulically operated and contains the same basic parts as low-pressure versions.

Air carrier sprayer

These machines are called air-blast sprayers or mist blowers. Pesticides confined in air-carrier sprayers are transported in an airstream ranging in speed from 129 to 241 km per hour. In these sprayers, concentrated pesticides are used because the air in which they are carried dilutes them considerably. Hence, the use of concentrated chemicals is, therefore, more efficient because it takes very little time to fill the tank when 80 percent less dilution water is required.

Hand operated sprayer

Hand-operated equipment is used for small scale application of pesticides such as greenhouses or small outdoor jobs on small farms or spot treatment on larger farms. Air is compressed into a tank in handheld sprayers and the mixture is pressurized.

The pressure drops as the liquid is sprayed. At low pressure, the nozzle spray pattern is poor. These sprayers operate at low pressures of 350 kPa (50 psi) or less and have small tanks of up to ten litters. Backpack sprayers are fitted with a harness so can be carried on the operators back. The tank capacity is up to 20 litters. The pressure is continuously developed using a handheld lever. A hand lever is continuously operated to maintain the pressure thus making the sprayer output more uniform than a hand-held sprayer[22].

CHAPTER 3: METHODOLOGY

To complete the objectives of the project mentioned in the previous section Development of LOW-COST UAV, the process needed to take on various aspects. The process includes the actual manufacturing of the UAV which included structural design, material selection, selection of control components. Autopilot modules were used which uses machine learning to achieve the procedure required to automate the UAV itself for mapping the landscape and routing itself for a spray period. For the control of the quadcopter, a circuit had to be set up for this module and how it responded to the many different flight variables and parameters that need to be controlled. The final aspect was to establish a network so the different aspects of the projects could communicate with each other with maximum efficiency and minimum latency. Specific pumps and nozzles had to be selected to achieve the desired efficient atomized spraying to minimize water, pesticide loss, and environmental hazards. Hence, the methodology was divided into following different aspects which were worked on:

3.1 Design of the UAV

The designing process of a multirotor drone can be summarized as follows;

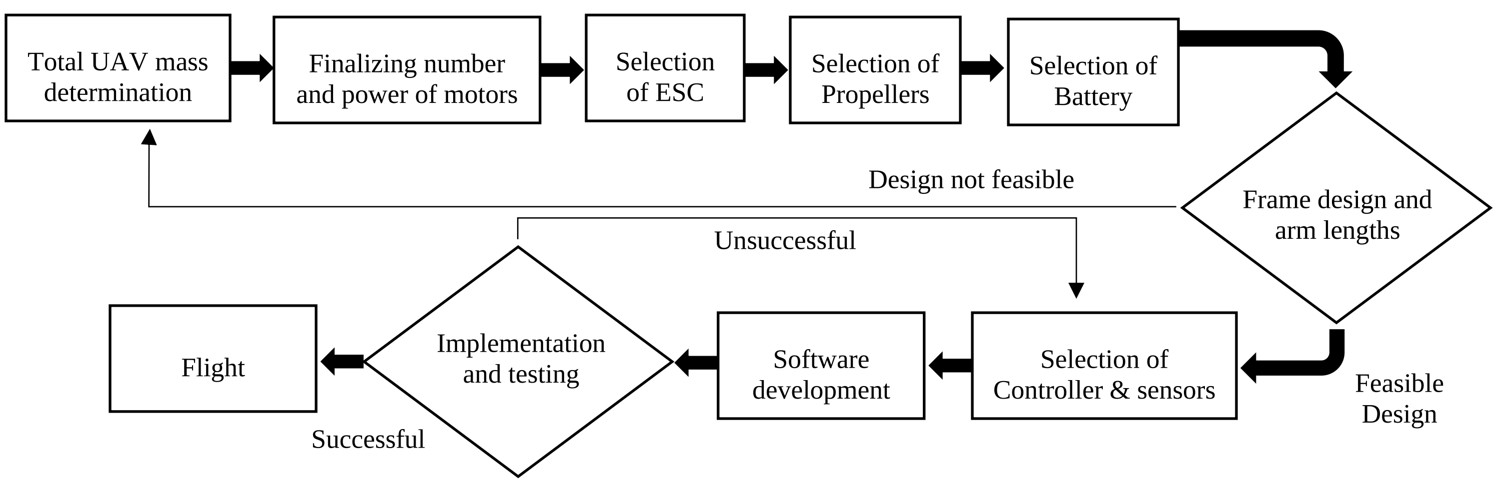


Figure 4: Design process of a multirotor drone

3.1.1 Payload finalization

The first step while designing an agricultural drone is to finalize the payload to be lifted. We intended to carry a payload of 5kg. Then the mass of structure, batteries, motors and other components was kept on adding roughly in the total mass and finally we get an estimate of the total mass of the vehicle including payload that came to be 11.8 kg so we took 12 kg for our calculations.

3.1.2 Selection of motor and propellers based on the market survey

Once the total weight was assumed motor and propeller selection was carried out based on required thrust and motors available in the market. Required thrust was calculated as follows:

Required thrust

$$\boldsymbol{Required\ thrust\ per\ motor = \frac{2W}{N}}$$

- W = Weight of drone
- N = number of rotors

$$\boldsymbol{Required\ thrust\ per\ motor = \frac{1.75\ x\ 12}{4}}$$

= 5.25 kg

For this calculation, we used a factor of safety of 1.75.

Based on this calculation and the availability of motors to provide such amount of thrust, four BLDC 6215 330kv motor was selected along with 2265 propeller. For XXYY propellers XX represent the propeller diameter and YY represents the propeller pitch. The fore mentioned datasheet represents the thrust produced by the motor.

Propeller inch	Voltages Volt	Throttle %	Load Currency Ampere	Pull gram	Power Watt
2265	22.2	40	6.4	1641	142.1
	22.2	45	8.55	2042	189.8
	22.2	50	10.95	2454	243.1
	22.2	55	13.75	2890	305.3
	22.2	60	17.05	3346	378.5
	22.2	65	20.65	3821	458.4
	22.2	90	43.3	6124	961.3

Table 4: Datasheet for 6215 330kv motors with 2265 propeller[23]

3.1.3 Structural design:

After the selection of the motor and the propeller, the wheelbase is selected, the wheelbase of a quadcopter is selected based on the fact that the minimum distance is to be maintained such that the flow of a propeller does not hinder the flow lines produced by the remaining propellers. Normally this length is 2 times the length of the propeller. So, for quadcopter the wheelbase calculated was:

$$\boldsymbol{Wheel\ Base = 2 * 22 * .0254}$$
$$\boldsymbol{= 1.117m}$$

After the selection of wheelbase, a proposed model was designed using a computer-aided designing software Solid works. Our proposed design is as follows:

Figure 5: Design CAD Model

Part drawings are attached in APPENDIX I – PART DRAWINGS.

3.1.4 Material Selection

Manufacturing of the UAV and making it as cost-effective as possible was the primary objective, Different properties were required given the usage and the timeframe we had set for this project which included low cost, high strength in the first place. Following materials were shortlisted to serve the purpose with their properties mentioned below:

BALSA WOOD[24]	**EXPANDED POLYPROPYLENE[25]**	**ALUMINUM[26]**	**CARBON FIBER[27]**
Balsa has excellent sound, heat, and vibration insulating	Lightweight, enhanced functionality, durability, and recyclability.	Heavier than the rest but has increased strengths	High strength to weight ratio.

properties, suitable for composite materials			
The density of dry balsa wood ranges 40–340 kg/m^3	, EPP density range, from 20 g/l through 200 g/l	Density of Aluminum = 2710 kg/m3	Density of Carbon fiber = 1800 kg/m3
UTS of Balsa Wood = 1 MPa	*UTS of 270 to 1930((kPa)*	UTS of Aluminum = 210 MPa	UTS of Carbon Fiber = 3.5 GPa
Requires extensive machining operations to fabricate different parts of the	Easy to machine	Easy to machine	Difficult to machine
CHEAP	MODERATE	CHEAP	HIGH COST

Table 5: Material Comparison

Based on this comparison aluminum and carbon fiber were selected for our drone fabrication.

3.1.5 FEM analysis:

FEM analysis was performed on this drone to calculate the deformation of a material under stress. Carbon fiber was selected for Propellers and wheelbase to achieve high strength to weight ratio, whereas for landing gear aluminum was selected to minimize cost. Material selection was made and verified using FEM analysis (Ansys) to check for maximum deflection under two conditions

- Static deflection due to weight.
- Arm deflection while hovering.
- Max deflection due to drop test.

Static deflection due to weight:

FEM analysis was performed to study deflection and stresses in quadcopter when at rest supported on its landing gear. Carbon fiber was used for the top structure and aluminum was used for the tubes below the landing gear.

The maximum deflection produced in this case was 0.19 mm and the maximum stress produced was 24.38Mpa.

The results of these simulations are added for references. The design was simplified and defeatured to simplify meshing.

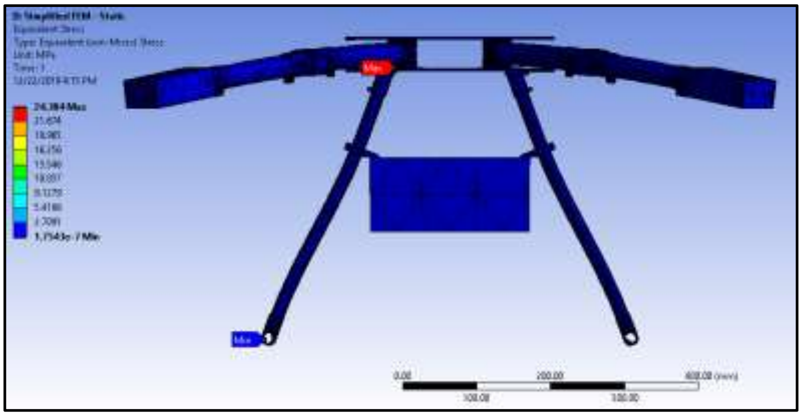


Figure 6: Equivalent stress model under static conditions.

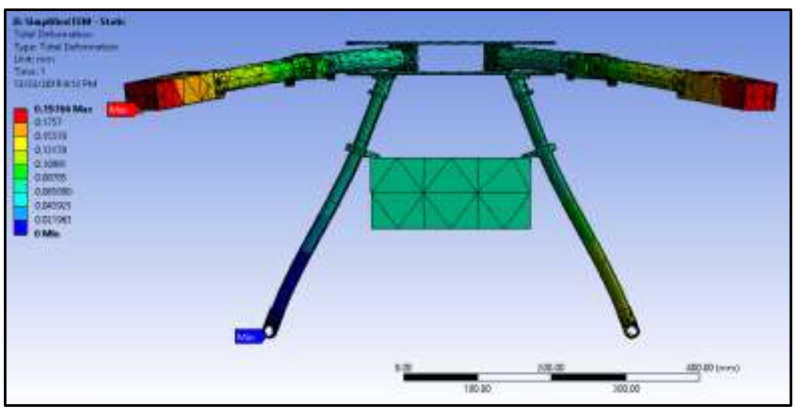


Figure 7: Total Deformation due to weight under Static condition

Arm deflection while hovering:

The analysis was carried out to study stress and deflection produced in the drone structure when hovering in the air

The maximum deflection produced in this case was 0.91mm and the maximum stress produced was 124.39 MPa.

Models to support the results are added,

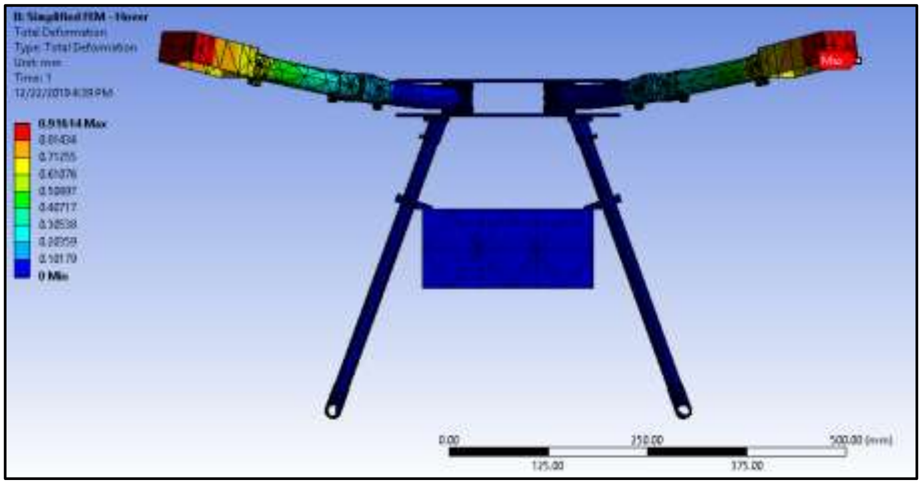


Figure 9: Total deformation while hovering

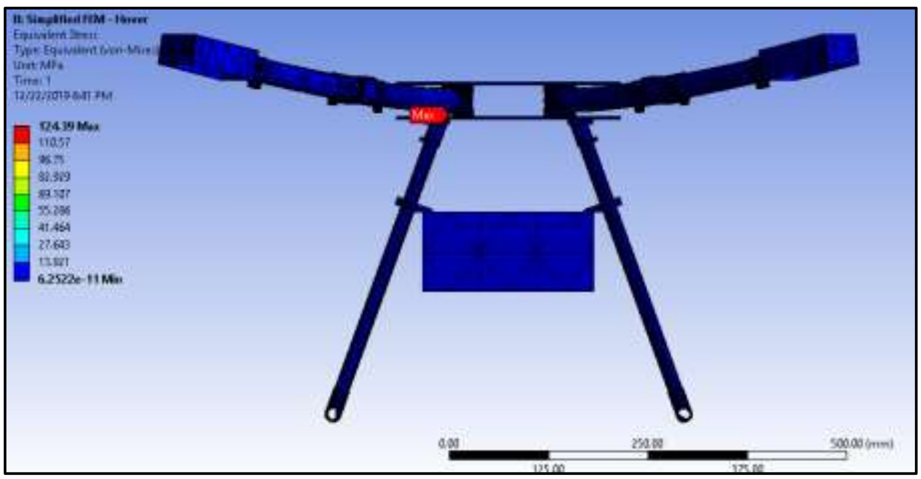


Figure 8: Equivalent Stress model while hovering

3.1.6 Innovative Design Concept

The Quadcopter used has an innovative design that supports folding arms reducing the 1.1m wheelbase to a mere 0.65m when required for efficient transporting. This reduced sized model with propellers removed can be transported with ease in a cushioned packed box and can be reassembled when required.

3.2 Electronic System Design

3.2.1 Electronic Speed Controller

Electronic speed controllers are used for BLDC motors. In a broader sense, ESC is PWM controllers for motors. A **32 bit 4-in-1 60A ESC** is used for our 6215 330kv motors. This speed controller can withstand a peak current of 70A. The maximum current drawn by our motor is 45A which is well within the control range.

3.2.2 Flight Controller

PIXHAWK PX4 version 2.4.8 an advanced autopilot is used to control the flight of quadcopter. PX4 is an open-source flight control software for drones. Pixhawk flight controller is assisted with the following electronic components:

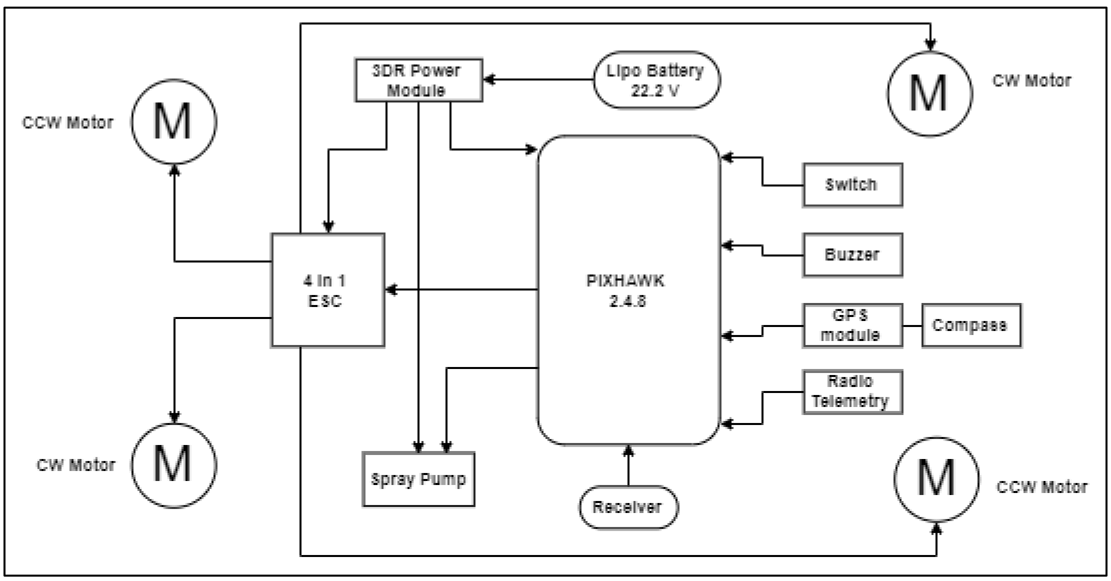


Figure 10: Schematic of Flight Controller

GPS module	Used to navigate and location tracking
Compass	Used by the **drone** to know its direction in space. If it is not calibrated, the GPS will not allow the **drone** to initiate a mission.
Radio telemetry	To transmit the radio signal back and forth from the drone to remote.
Ultrasonic sensor	To determine the elevation of a drone

3.2.3 Receiver and Transmitter:

Futaba FS-I6 controller is used to control the drone via radio telemetry, Radio telemetry 433 MHz is used to transmit signals from Ground Station (via Mission Planner) to the drone.

3.2.4 Power Supply

Lithium polymer (LiPo) batteries are used in quad-copter for their high weights and low capacities. LiPo batteries are available as 3.7V per cell. By series and parallel combination, desired power output can be achieved. These batteries have C-rating. C-rating indicates how fast a battery can discharge. For 12kg payload, 20000mAH 6s battery is used. Xs represents the number of cells used. For agricultural quadcopter drone 6 cells i.e. 22.2V battery is used.

The flight time of the drone is calculated from the amperage draw of motors.

$$\textbf{Flight time} = \frac{\textbf{Capacity}}{\textbf{Average ampere draw of Motors}}$$

$$= \frac{20000 \, x \, 60}{4 \, x \, 36 \, x1000}$$

$$= 8.33 \; minute$$

3.3 Spray System:

The spraying system is of vital importance for this project. Atomized spraying techniques were implemented to minimize water and pesticide waste reduction. Spraying system of an agricultural drone primarily consists of the following components

- Atomized nozzles 0.3mm diameter
- 12 V DC Diaphragm pump
- ESC variable flowrate Pump Controller
- Hosepipe

3.4 Component List:

Following is a detailed list of all the components used:

Sr.	EQUIPMENT	SPECIFICATION	QUANTITY	PRICE (PKR)
1	Pixhawk PX4 2.4.8	2.4.8 Flight Controller	1	11710.56
2	Carbo fibre Tubes	30x28x500(mm)	4	4661.54
3	Brushless Motors	6215 EA60 330KV	4	39119.14
4	Propeller	2265	4	5217.48
5	ESC	60A 3-8S 4 IN 1	1	8852
5	Base Seat Fixtures		4	6646.5
6	T- fixtures		4	1870.89
7	Battery Tray Fixture		4	4000
8	Propeller arm fixture		4	2815
9	Motor Fixture		4	11780
10	Bending Pipe Fixture		4	8443.73
11	Aluminium Pipes	18x16x3657.6	1	550
12	Pump	12V DC/(4.5L/min)/ 0.65Mpa	1	450
13	Nozzle	Nozzle Kit	4	960
14	Hose Pipes		1	140
16	Battery Tray		1	800/kg
17	Battery Slider		1	800/kg
18	Battery base		1	1000
19	Controller Housing (Top + Bottom)		2	1000
20	Pump ESC		1	3000
21	Tank	5 lit	1	**200**
23	5MP camera	5 MP	1	850
			Total	**113266.8**

Table 6: Component List

CHAPTER 4: RESULTS AND DISCUSSIONS

After performing design calculations, selection of materials, and all other components of drones, we started the actual construction of Quadcopter, and the research we did before the construction proved to be very useful. We started with the fabrication of landing gear that was manufactured with aluminum pipes. The fixtures required for the assembly were also manufactured using the billets of aluminum. Along with that, the foldable arms of the drone were manufactured using the carbon fiber pipes and aluminum folding fixtures. The mounting base for motors that were attached at the end of motors was also manufactured of aluminum. The base seat where all the four arms are connected and then attached to the landing gear was made of the aluminum composite sheet that was quite low weight sheet and we found it in the local market. Finally, the mechanical structure of the drone was ended up looking like:

Figure 11: Actual Base seat with arm assembly

Figure 12: Actual Bending Arm assembly

As a reference, the CAD model of the drone is attached below that was developed initially during the design phase of the project. In the cad model, the spraying system consisting of spray tanks and nozzles can also be seen that were to be installed after the completion of the mechanical structure.

Figure 13: CAD model of complete drone with spraying system

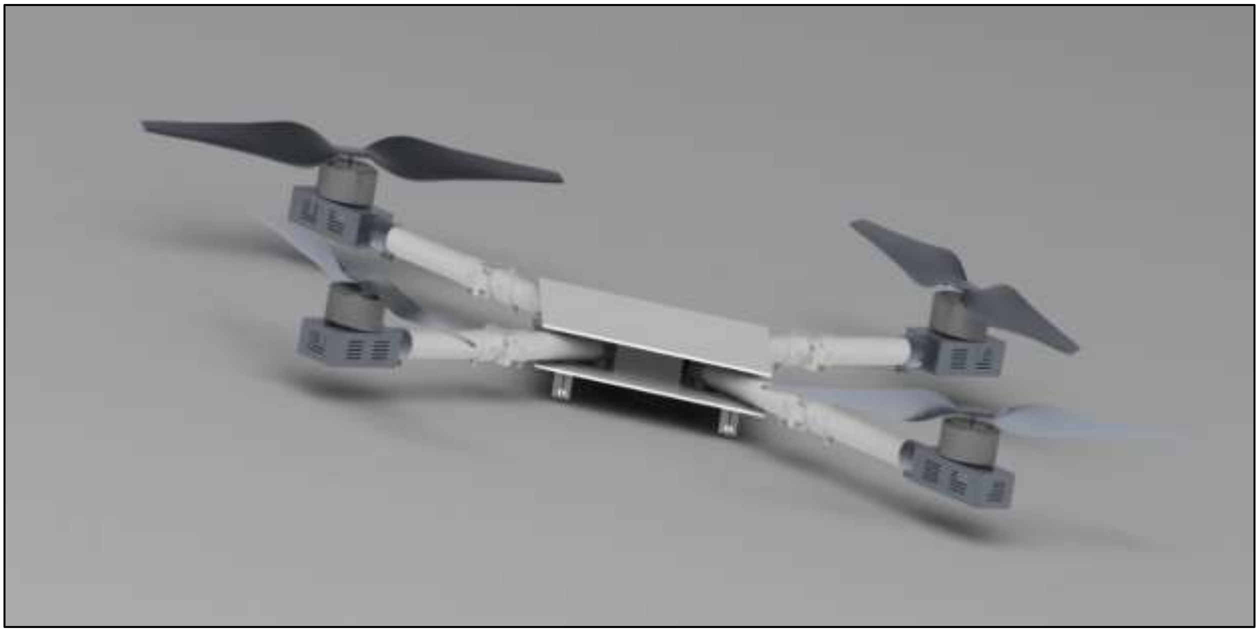


Figure 14: Base seat with arm assembly

Figure 15: Bending arm assembly

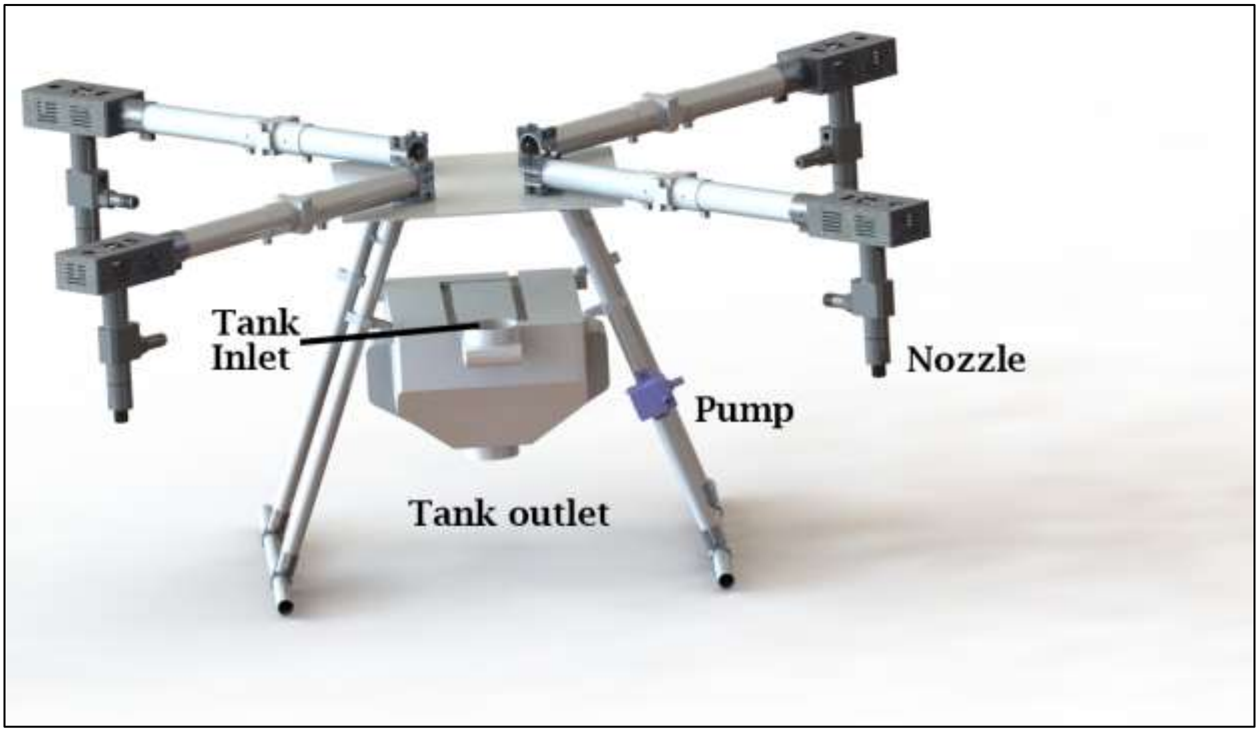


Figure 16: Spraying System

The landing gear was tested by applying enough load at the specified points to determine the actual validity of its strength and it came out to be well adequate. The results of this testing depicted that the initial choices made based on theoretical designs were correct.

The final constructed mechanical structure of the drone has specifications given below:

The material of landing gear	Aluminum
Material of arms	Carbon Fiber
Wheelbase/Boom length	1.1 m
Propeller Radius	11 in (279.4 mm)
Base seat plate thickness	2 mm
Empty Weight (including battery, motors, and control system)	8 kg
Payload	5 kg
Battery	20000 mAh (6S)

Table 7: Final Specifications of Drone

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In this project, the design of a low-cost SUV has been presented. The mechanical structure was constructed and tested to be safe according to the theoretical design expectations. Other components including motors, electronic speed controller, battery, Futaba Radio Controller, Pixhawk Flight controller, and pump for spraying system were acquired and tested to working fine. The facility of measuring thrust of the motor-propeller pair was not available so it can be measured only after completion of the drone.

Such an agricultural drone will bear fruits to the efforts of our farmers and will effectively prevent their crops from pesticides and insecticides that render a huge portion of their crops useless. By using such advanced agricultural techniques, the future of a farmer will be in secure hands. A strong farmer and livestock reflect a strong nation, thus such farmers using advanced tools, breaking the farming stereotypes, will contribute to a prosperous economically stable Pakistan.

The use of concept Internet of Things as a source to control the drone using smartphones using a WI-FI module chip would be one of the most important parts to focus upon as this would cut off a very hefty amount of the controller and the receiver and it would not only lower the manufacturing amount of the drone but would also help to strengthen the purchase ability of the farmers. Another important thing is that the mobile application synced with the WI-FI module chip is a user-friendly open platform software so it would give access to any user located in any part of the world compatible with any built-in smartphone software, so instead of taking several days and getting a thorough insight of the functionalities for operating the drone on a multi-button transmitter a layman would easily be able to operate the drone on his/her smartphones with where ever they want the controls on screen as per with what they are comfortable with.

5.1 Future Scope:

The use of spraying technology in agricultural-based drone helps to improve and increase the crop yield and also saves time but there are many other efficient irrigation and spraying techniques emerging in the market like drip irrigation system and efficient spray system attached to farming based vehicles not only is giving promising results in conserving water but also raise questions among farmers as they would be reluctant in investing more on something that would although save their time but not as much water and money. So to make the drone technology outstand among all other techniques in the agriculture sector in upcoming future the use of Artificial intelligence along with Computer Vision in agricultural drone technology would be a plus point for the farmers to help consume less water and fertilizers, reduce the planting cost and also to analyze the health of the crop. The use of computer vision provides images of the field the images are paired with artificial intelligence which provides important data regarding the health of the plant and which part of the part needs improvement and at the same instant speedy response can be taken by the spraying of pesticides or water whichever is required that not only can save a crop but the entire orchard. It is claimed the use of Artificial intelligence along with Computer Vision can boost the yield by up to 30 percent[29].

REFERENCES

[1] FAO United Nations. (2018). Pakistan at a glance | FAO in Pakistan | Food and Agriculture Organization of the United Nations. In Food and Agriculture Organization of the United Nations. http://www.fao.org/pakistan/our-office/pakistan-at-a-glance/en/

[2] Technology_ The Missing Link in Pakistan's Agriculture Sector. (n.d.). http://www.technologyreview.pk/technology-missing-link-pakistans-agriculture-sector/

[3] Articles _ Sprinkler Drones & Modern Day Farming. (n.d.). https://www.industrialautomationindia.in/articleitm/1220/Sprinkler-Drones-&-Modern-Day-Farming/articles

[4] [Yıldırım, Şahin, et al. "Design and Trajectory Control of Universal Drone System." *Measurement: Journal of the International Measurement Confederation*, vol. 147, no. December, 2019, doi:10.1016/j.measurement.2019.07.062.

[5] Mogili, Um Rao, and B. B. V. L. Deepak. "Review on Application of Drone Systems in Precision Agriculture." *Procedia Computer Science*, vol. 133, Elsevier B.V., 2018, pp. 502–09, doi:10.1016/j.procs.2018.07.063.

[6] Wen, Sheng, et al. "Numerical Analysis and Validation of Spray Distributions Disturbed by Quad-Rotor Drone Wake at Different Flight Speeds." *Computers and Electronics in Agriculture*, vol. 166, no. October, Elsevier, 2019, p. 105036, doi:10.1016/j.compag.2019.105036.

[7] Kotarski, Denis, et al. "Control Design for Unmanned Aerial Vehicles with Four Rotors." *Interdisciplinary Description of Complex Systems*, vol. 14, no. 2, 2016, pp. 236–45, doi:10.7906/indecs.14.2.12.

[8] Al-zogphy, Osama Jamal, and Osama Ibrahim Khalil. *CFD Analysis of Quadcopter*. no. August, 2019.

[9] Tatale, Omkar, et al. "Quadcopter : Design , Construction and Testing." *International Journal for Research in Engineering Application & Management (IJREAM),* vol. 04, no. AMET-2018, 2018, pp. 1–7, doi:10.18231/2454-9150.2018.1386.

[10] Kim, A. Ram, et al. "Dynamic Modeling and Simulation of a Quadcopter with

Motor Dynamics." AIAA Modeling and Simulation Technologies Conference, 2017, no. January, 2017, pp. 1–16, doi:10.2514/6.2017-1560.

[11] Khan, Mohd. "Quadcopter Flight Dynamics." *International Journal of Scientific & Technology Research*, vol. 3, no. 8, 2014, pp. 130–35.

[12] Singh, Rahul, et al. "Structural Analysis of Quadcopter Frame." *Materials Today: Proceedings*, vol. 22, Elsevier Ltd., 2020, pp. 3320–29, doi:10.1016/j.matpr.2020.03.295.

[13] Tuna, Turcan, et al. "Design and Development of FOLLY: A Self-Foldable and Self-Deployable Quadcopter." *Aerospace Science and Technology*, vol. 100, Elsevier Masson SAS, 2020, p. 105807, doi:10.1016/j.ast.2020.105807.

[14] Papa, Umberto, and Giuseppe Del Core. *Design and Assembling of a Low-Cost Mini UAV Quadcopter*. no. January 2015, 2014, doi:10.13140/2.1.3480.6088.

[15] Prem Kumar, N., Raj Kumar, A., Anand, S., Ganesh, E. N., & Prithiviraj, V. (2015). Quad band signal strength monitoring system using quadcopter and quad phone. Journal of Green Engineering, 5(1), 1–22. https://doi.org/10.13052/jge1904-4720.511

[16] Al, A., Dewi, A. Y., Bachtiar, A., & Harinita, D. (2019). An angle speed and thrust relationship of the quadcopter rotor. Indonesian Journal of Electrical Engineering and Computer Science, 13(2), 469–474. https://doi.org/10.11591/ijeecs.v13.i2.pp469-474

[17] ElectricRCAircraftGuy. (n.d.). https://www.electricrcaircraftguy.com/2013/09/propeller-static-dynamic-thrust-equation.html

[18] Andrew Chapman. (2020). Types of Drones: Multi-Rotor vs Fixed-Wing vs Single Rotor vs Hybrid VTOL - AUAV. In Auav. https://www.auav.com.au/articles/drone-types/

[19] Mazur, M., & PwC. (2016). Six Ways Drones Are Revolutionizing Agriculture - MIT Technology Review. In MIT Technology Review. https://www.technologyreview.com/s/601935/six-ways-drones-are-revolutionizing-agriculture/

[20] SenseFly. (2019). How Agricultural Drones Are Changing The Industry. https://www.sensefly.com/industry/agricultural-drones-industry/

[21] Agricultural Sprayers _ Basic Types, Uses and Advantages. (n.d.). https://www.farmpractices.com/agricultural-sprayers

[22] Hofman, V. (2018). Spray Equipment and Calibration Reviewed by. 73(March).

[23] JMRRC 6215 KV330 Brushless Motor for Agriculture UAV Drone. (n.d.). http://www.4fpv.com/ProductDetail/2467582.html

[24] G Newaz, M Mayeed, A Rasul 2014 in Sage Journals. Characterization of balsa wood mechanical properties required for continuum damage mechanics analysis.

[25] DPSpecDepronCore Retrieved from: https://dragonplate.com/Content/Images/uploaded/Weights%20and%20Specs/DPSpecDepronCore.pdf

[26] Expanded Polypropylene (EPP) Retrieved from: http://www.bpf.co.uk/plastipedia/polymers/Expanded_Polypropylene_EPP.aspx

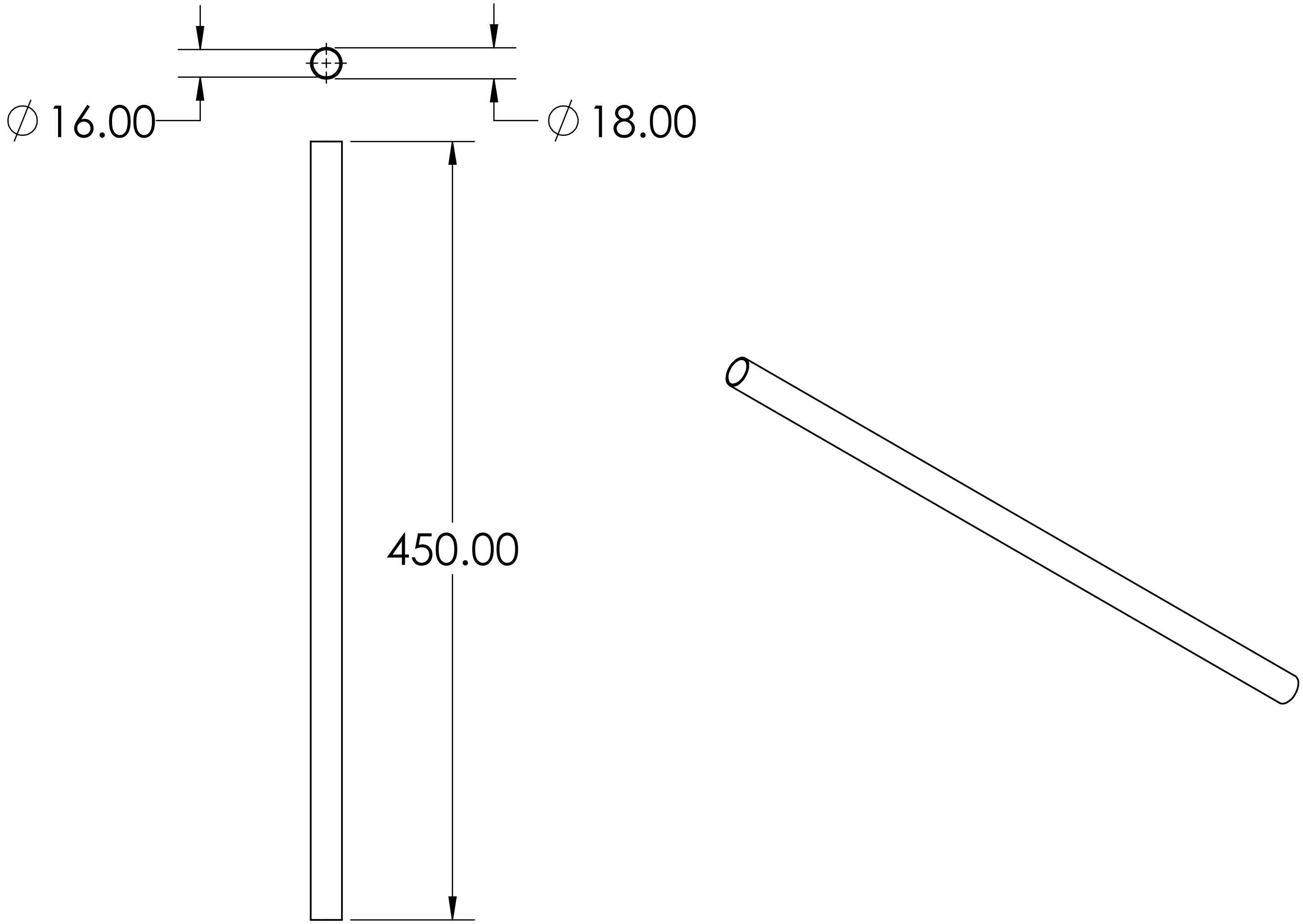
[27] What Drones Are Made Of_ Materials Selection For Drones. (n.d.). https://matmatch.com/blog/what-are-drones-made-of/

[28] Advanced Pixhawk Quadcopter Wiring Chart — Copter documentation. (n.d.). http://ardupilot.org/copter/docs/advanced-pixhawk-quadcopter-wiring-chart.html

[29] Jacob, A. (2017). How Drones, Computer Vision, and AI are Transforming the Agricultural Industry. https://www.ordermentum.com/blog/how-drones-computer-vision-and-ai-are-transforming-the-agricultural-industry

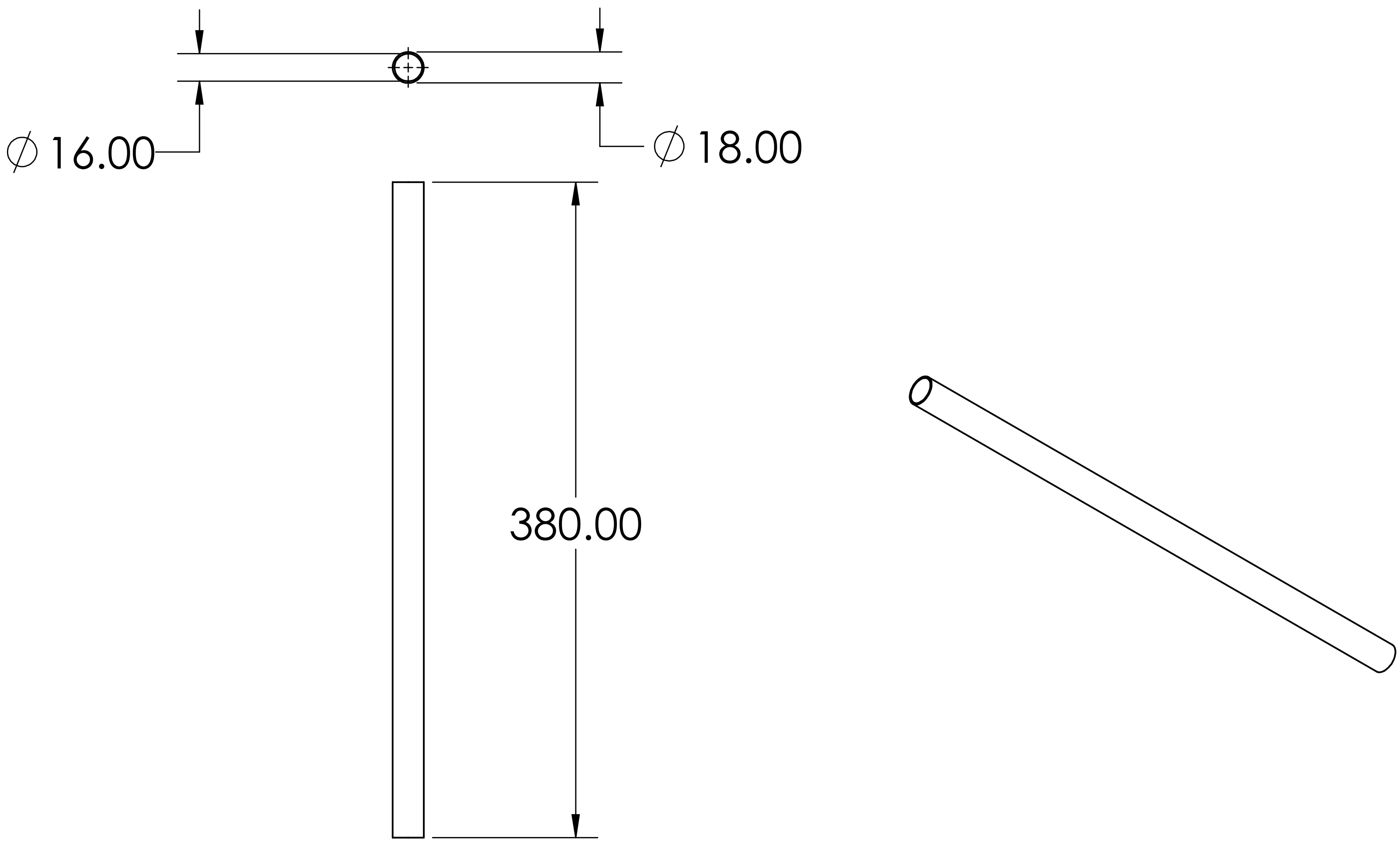
APPENDIX I – PART DRAWINGS

Sr. No.	**Part Name**
1	Ground Pipe
2	Leg Pipe
3	T-Joint
4	Tank holding fixture
5	Base Plate seat fixture
6	Base Plate
7	Arm Clamping fixture
8	Arm Pipe 1
9	Arm Pipe 2
10	Arm Folding fixture - Male
11	Arm Folding fixture – Female
12	Motor Mount



PROPRIETARY AND CONFIDENTIAL

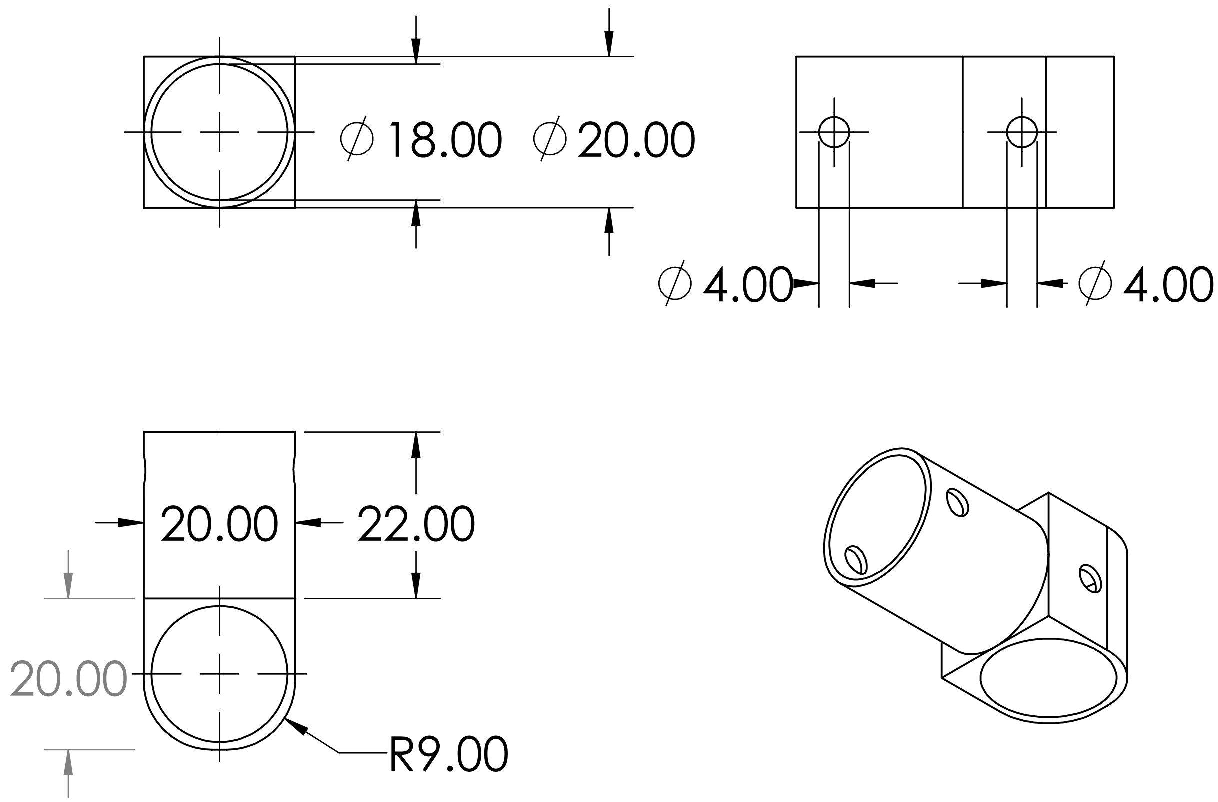
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN			
			CHECKED			TITLE: Copter Base Pipe
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminium	COMMENTS:			SIZE A — DWG. NO. 18x16x450 — REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 — WEIGHT: — SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN mm TOLERANCES: 0.1mm	DRAWN			TITLE:	Copter Leg Pipe
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Aluminum	COMMENTS:			SIZE A	DWG. NO. 18x16x360 / REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:4	WEIGHT: / SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN Millimeter
TOLERANCES: 0.1 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

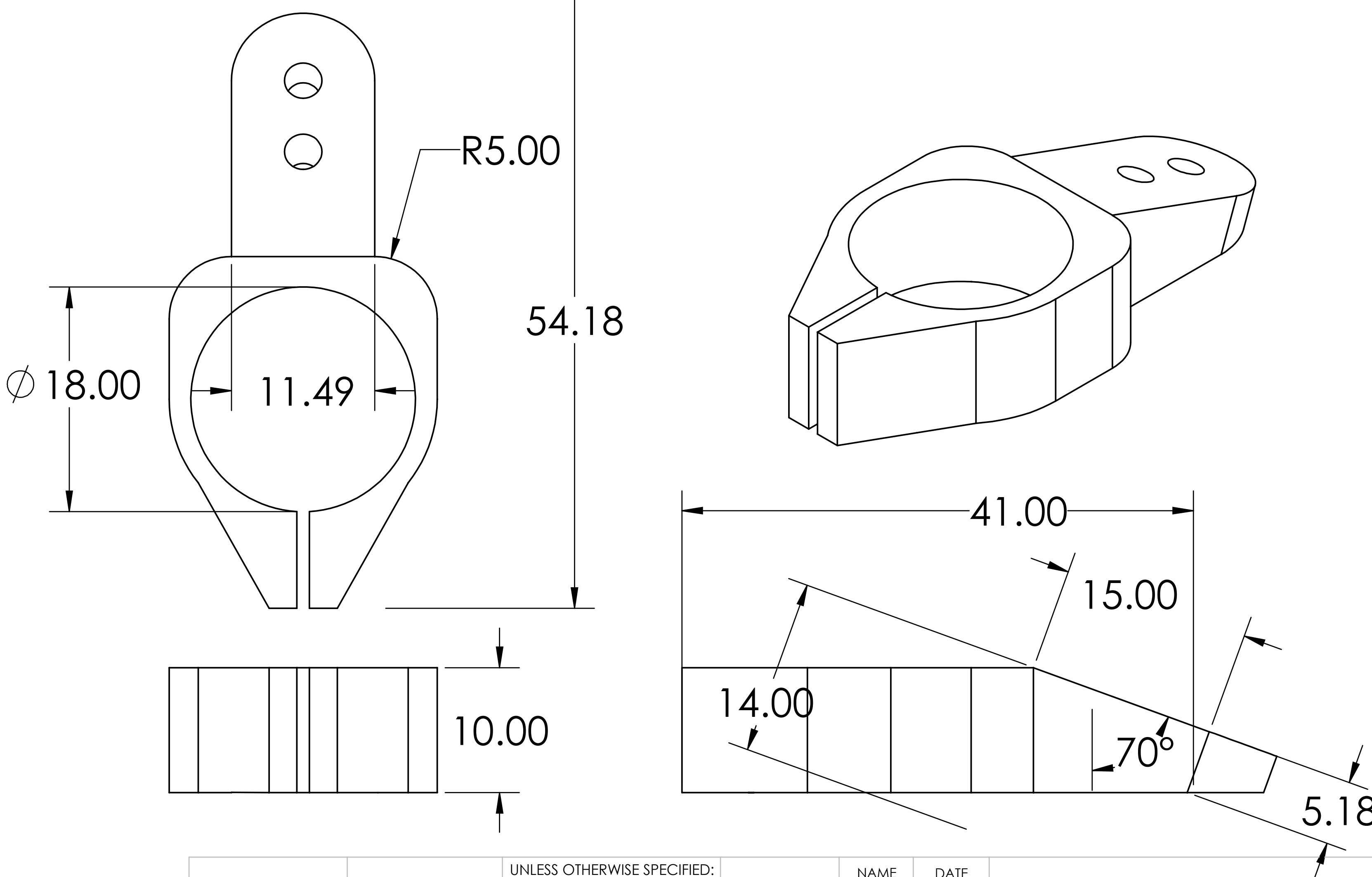
COMMENTS:

TITLE:

T-Joint

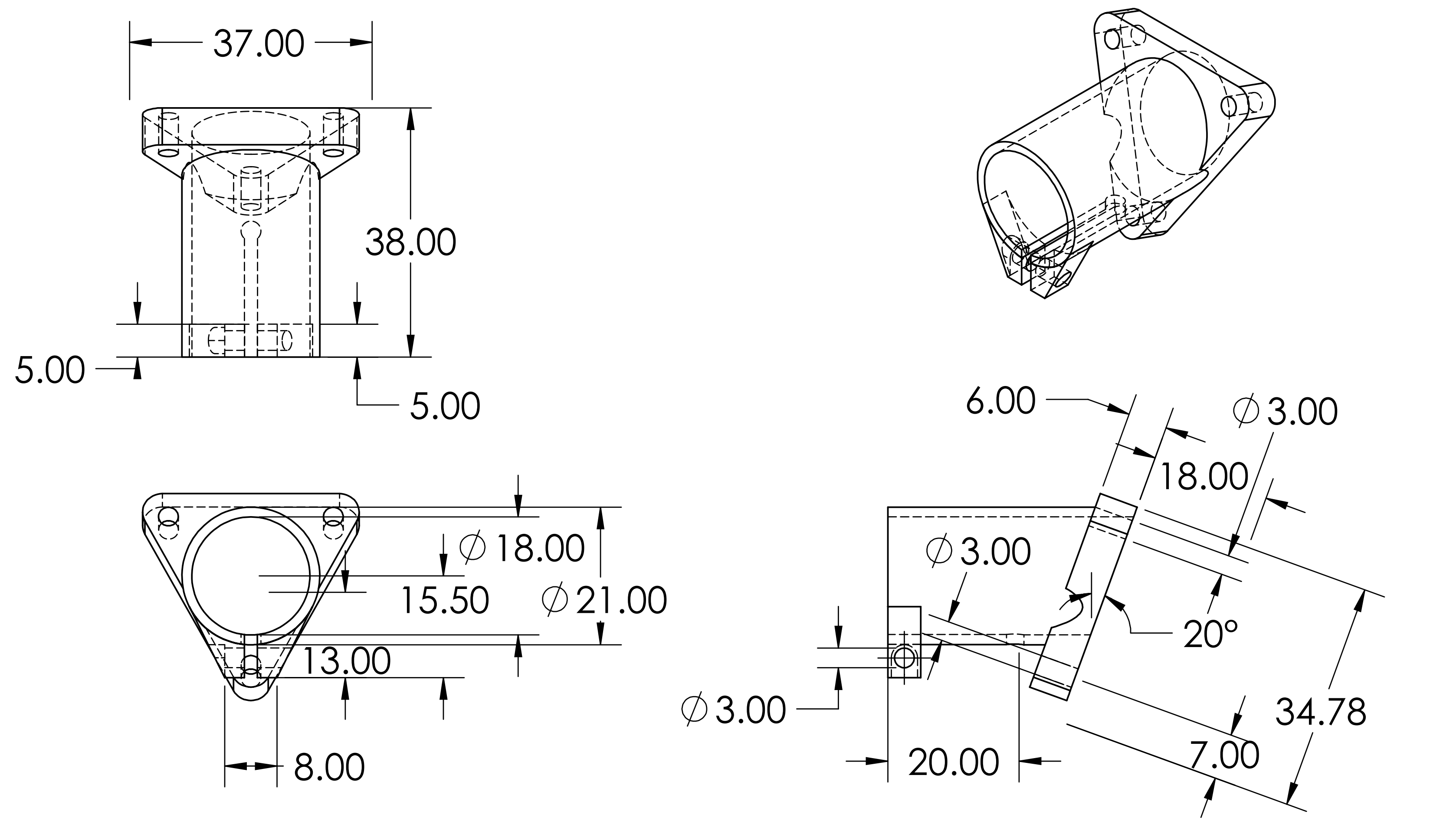
SIZE A | DWG. NO. T1 | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



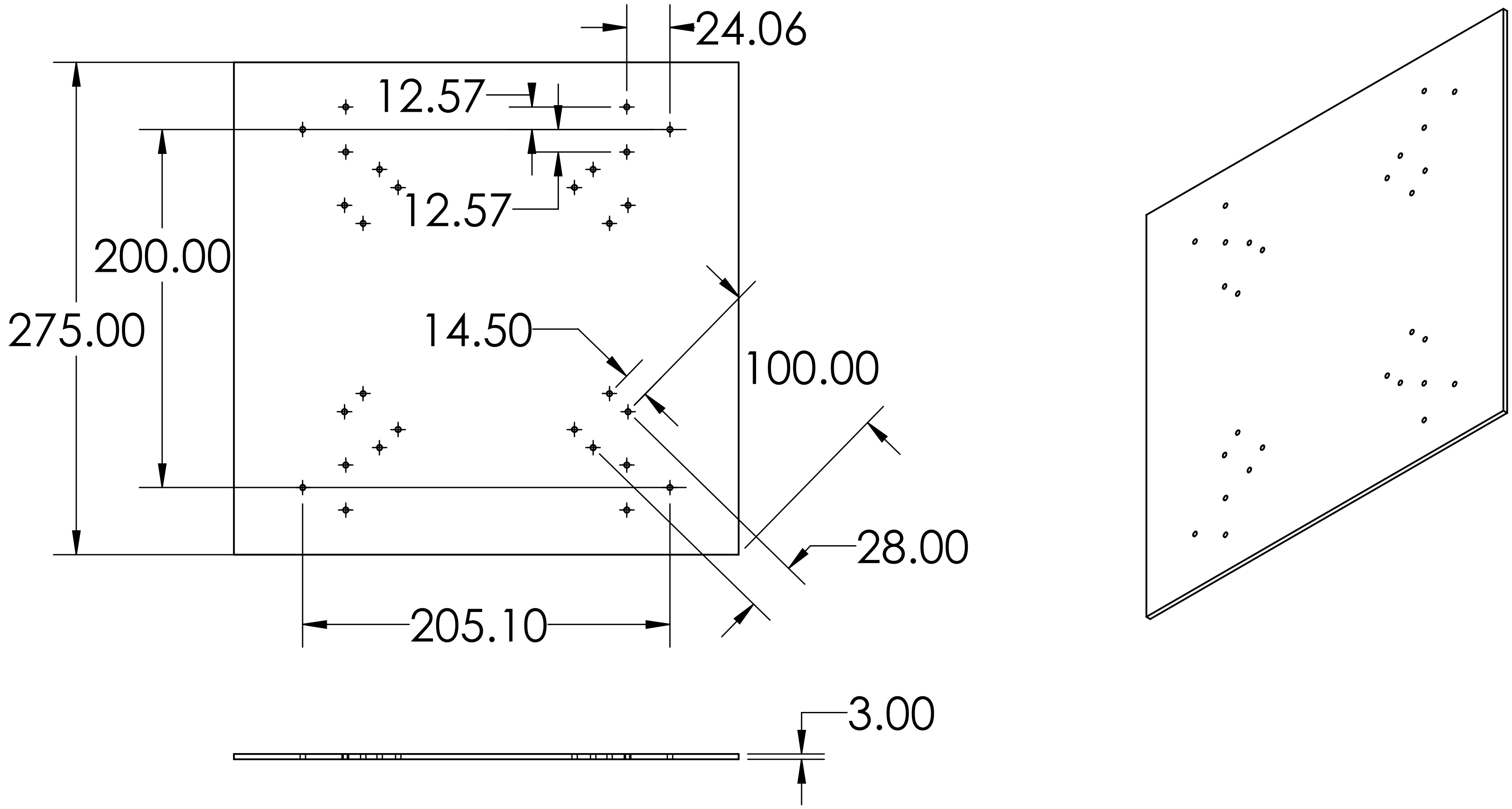
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN			TITLE:
			CHECKED			Tank Holder
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminium	COMMENTS:			SIZE A · DWG. NO. TH1 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1 · WEIGHT: · SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL



PROPRIETARY AND CONFIDENTIAL

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN			TITLE: Base Plate Seat
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminium	COMMENTS:			SIZE A · DWG. NO. B1 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON	
APPLICATION		

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN Millimeter
TOLERANCES: 0.1 mm
All holes have diameter: 3 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminium

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

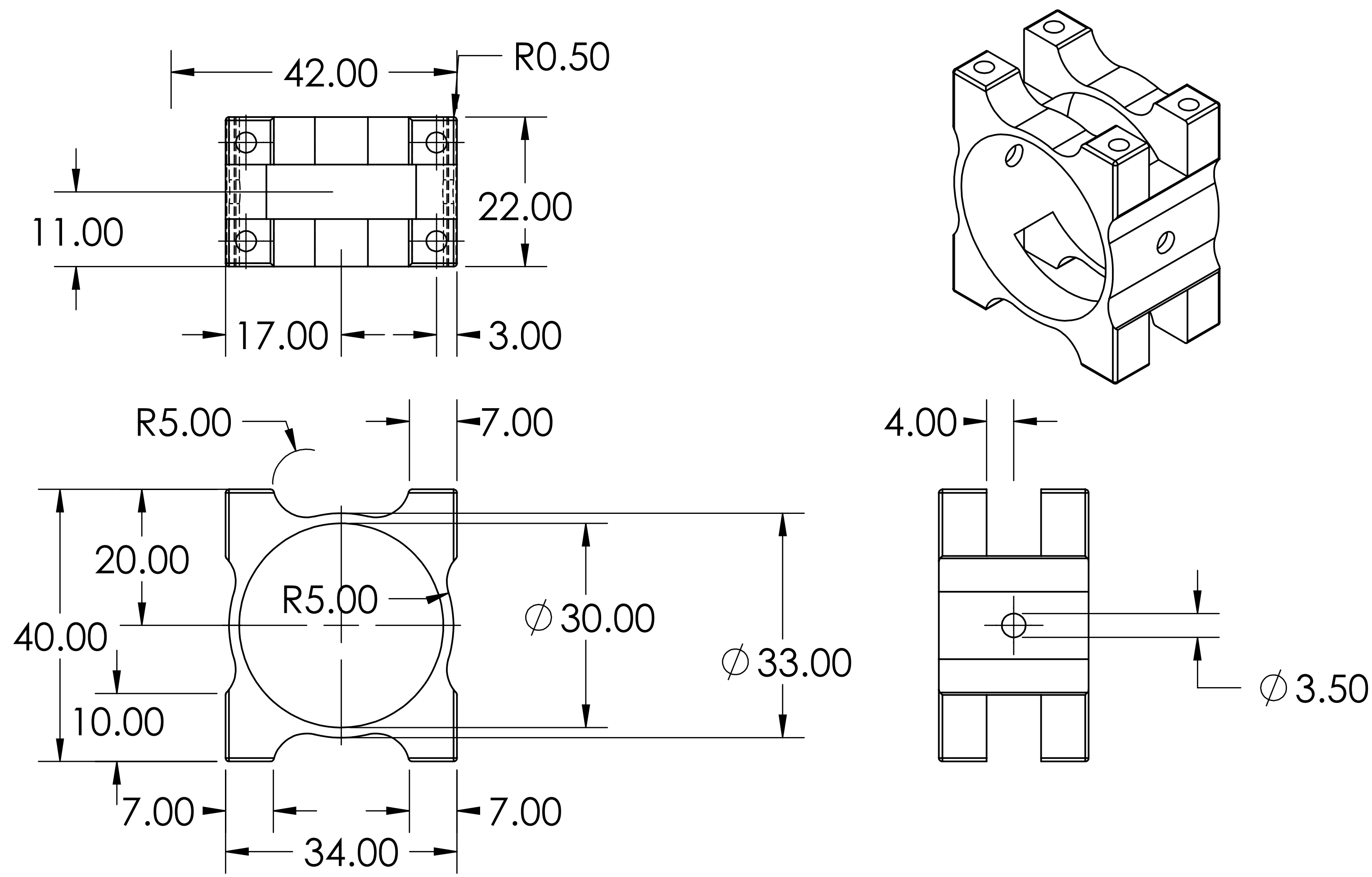
COMMENTS:

TITLE:

Base Plate

SIZE	DWG. NO.	REV
A	B2	

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm All Holes have diameter: 3 mm	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Aluminium	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

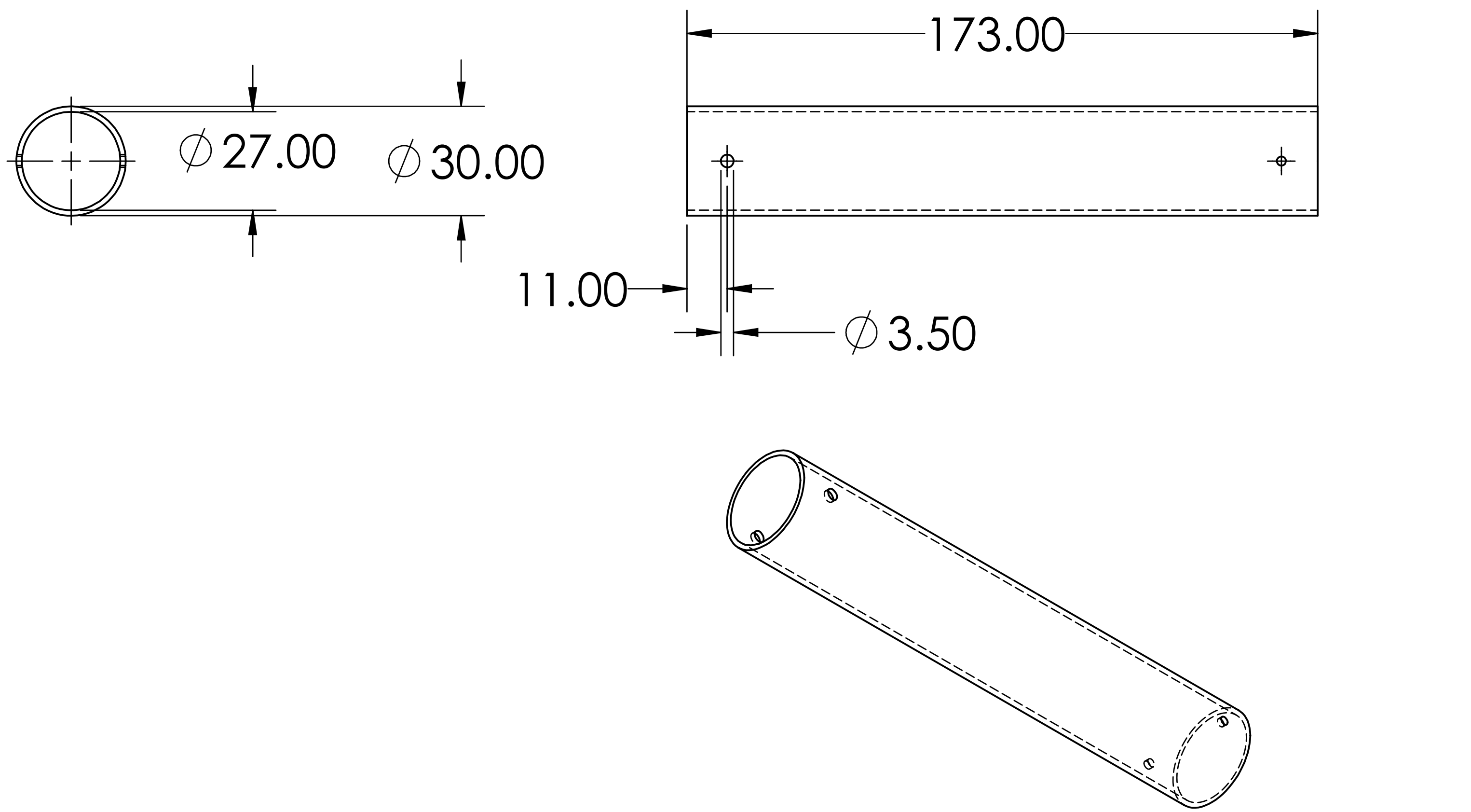
Arm Clamp

SIZE	DWG. NO.	REV
A	P1	

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

2 1

B B

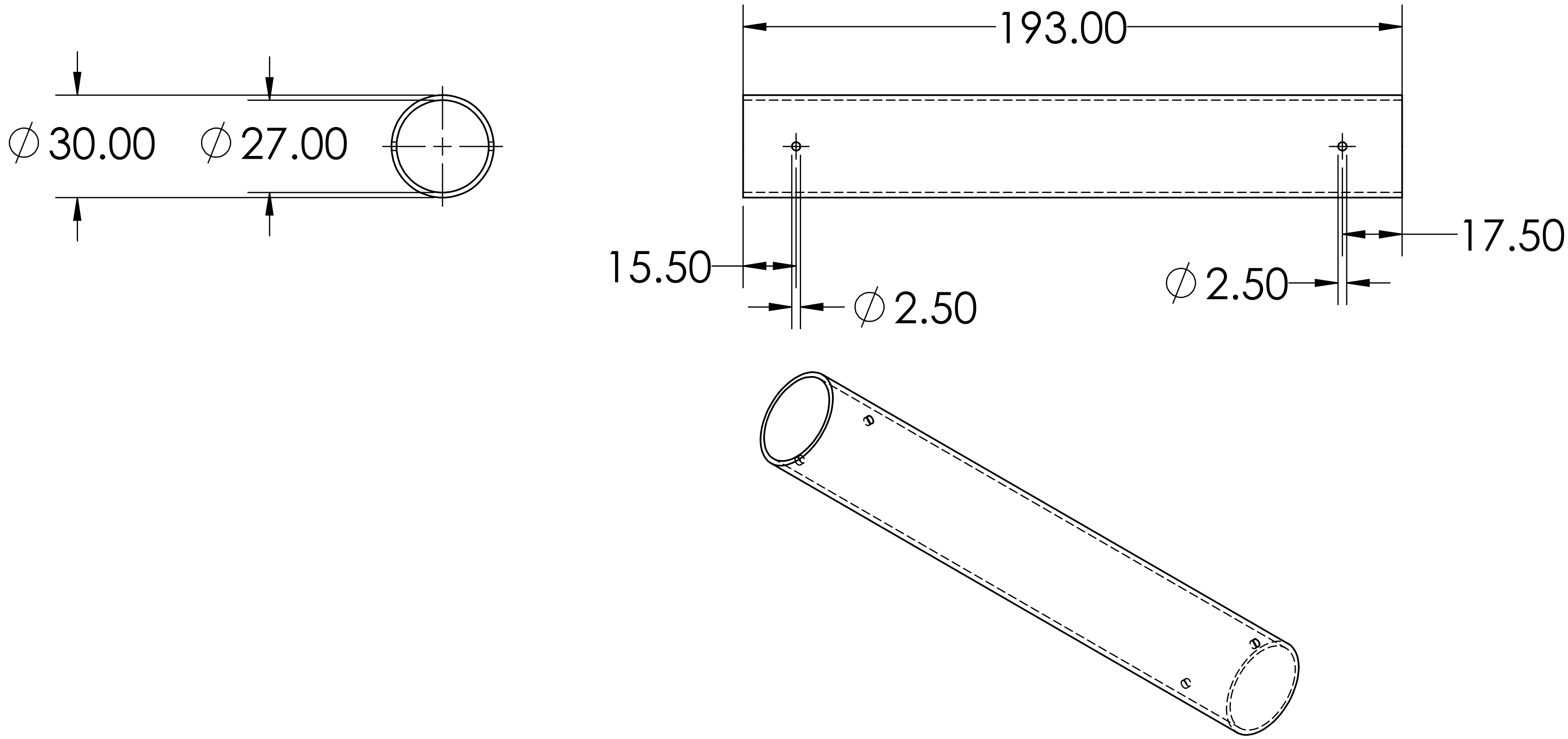


A A

2 1

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN			
			CHECKED			TITLE: Arm Pipe 1
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Carbon Fibre	COMMENTS:			SIZE A / DWG. NO. A1 / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 / WEIGHT: / SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN Millimeter
TOLERANCES: 0.1 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Carbon Fibre

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

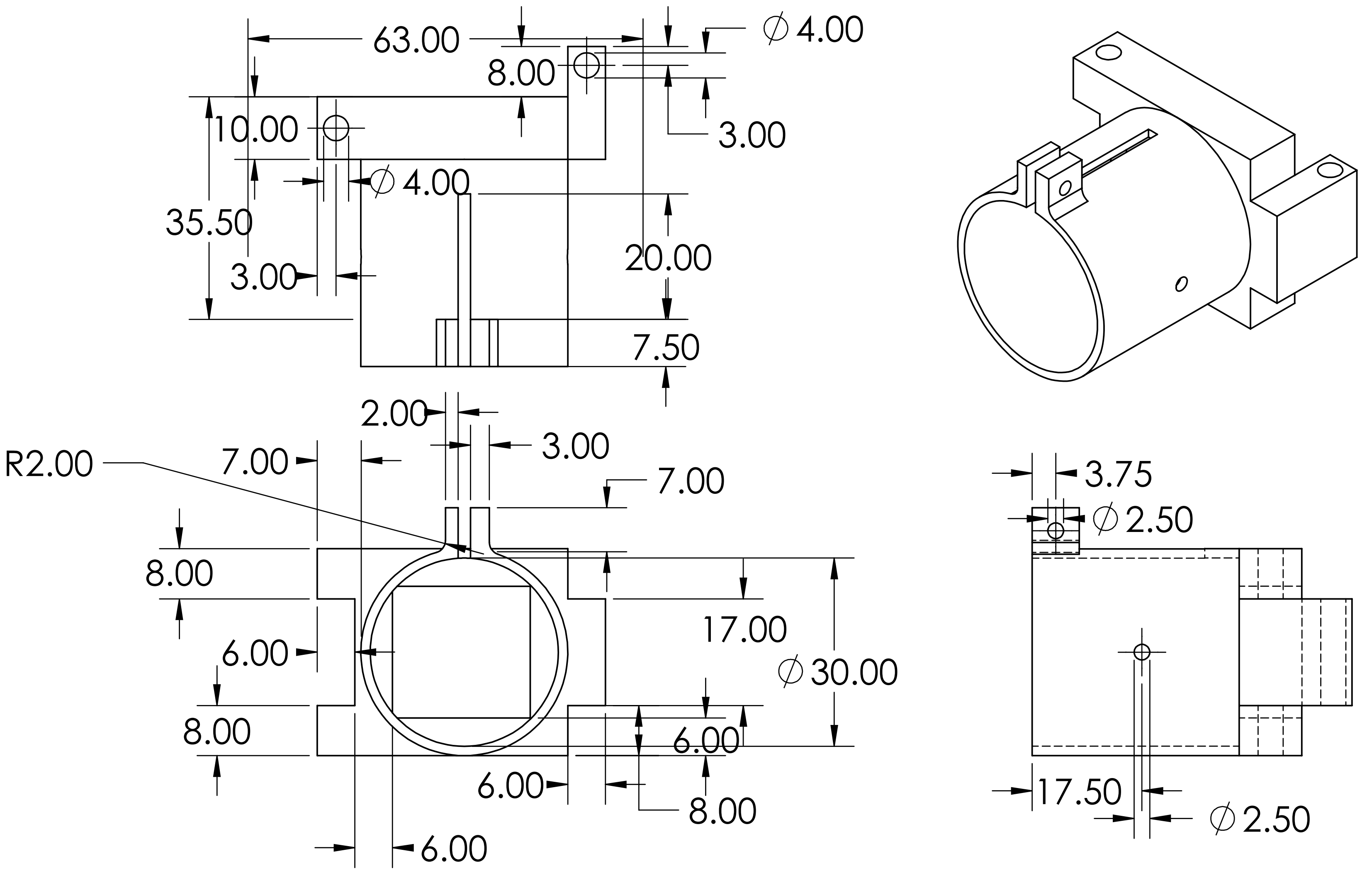
TITLE:

Arm Pipe 2

SIZE	DWG. NO.	REV
A	A2	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

B A

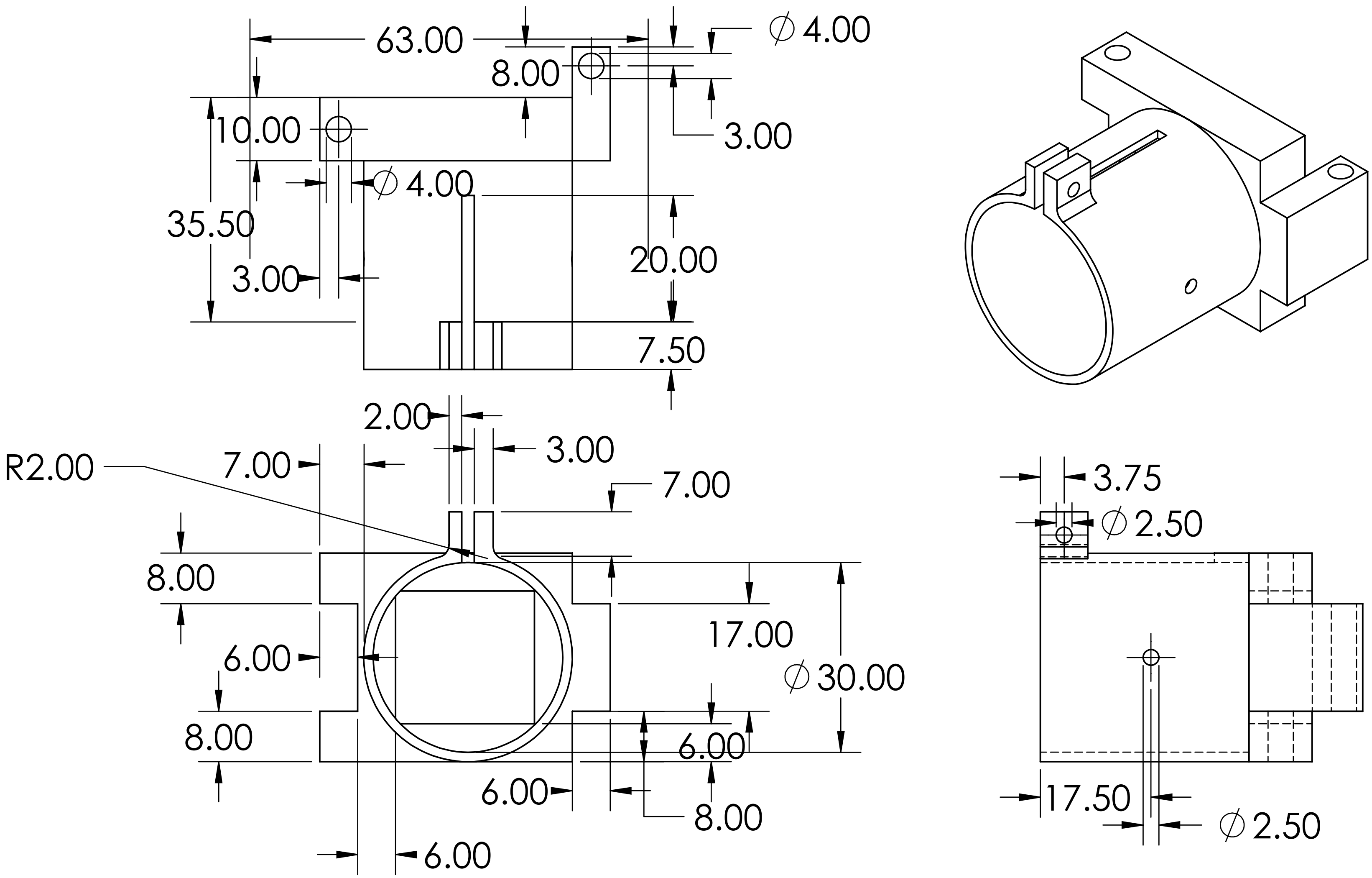


		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Aluminium	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

TITLE:
Bending Joint Male

SIZE	DWG. NO.	REV
A	BJ1	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN Millimeter TOLERANCES: 0.1 mm	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Aluminium	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

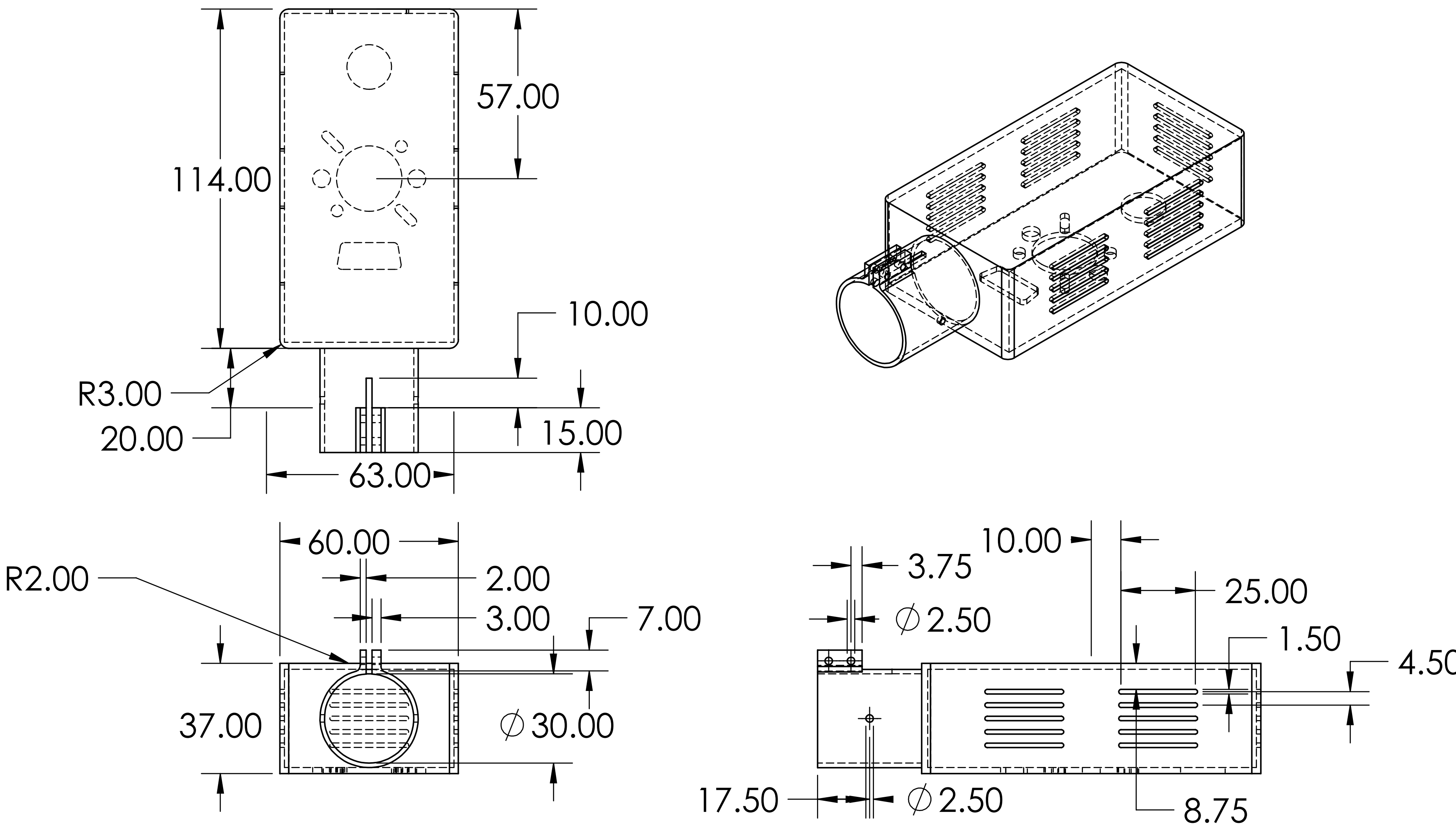
PROPRIETARY AND CONFIDENTIAL

TITLE:

Bending Joint Female

SIZE	DWG. NO.	REV
A	BJ2	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN Millimeter
TOLERANCES: 0.1 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminium

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Motor Mount

SIZE	DWG. NO.	REV
A	M1	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1