AGRICULTURAL UAV DESIGN
(AGRI-DRONE)

A Final Year Project Report

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of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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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

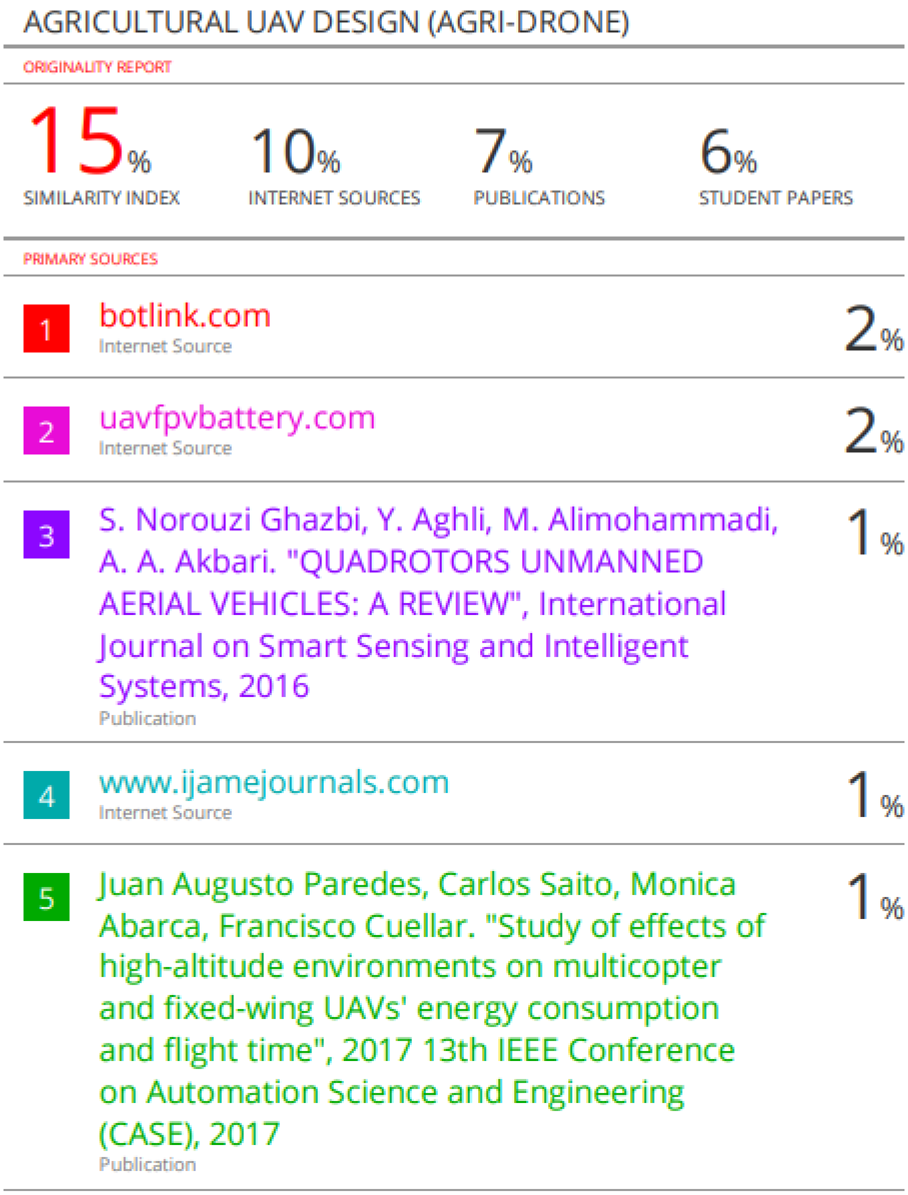
l praise to Allah Almighty who is the creator, maintainer, and regulator of the world. He is the one, who bestows and gives the power to us to think, utilize our expertise in knowledge in achieving remarkable solutions for mankind in every field of life. In the first place, therefore, we express our utmost thanks to Almighty Allah the omnipresent and creator of the worlds, who has endowed us with his blessings that enabled us to accomplish our work in the form of this project report. No words of thanks can be appropriate for His immense blessings.

We are also grateful to our loving and caring parents and siblings, who provided us full support through all possible resources with great patience throughout our project. We feel very lucky to have such parents. Without their confidence, we could not have reached our full potential.

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. Emad-ud-din 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.

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.

ORIGINALITY REPORT



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ABBREVIATIONS

UAV	Unmanned air vehicles
EP	Expanded polypropylene
FEM	Finite Element Method
ESC	Electronic Speed Controller
ABS	Acrylonitrile Butadiene Styrene
COG	Center of gravity
PID	Proportional Integral Derivative

NOMENCLATURE

V	Drag Force
P	Density
F_L	Lift Force
A	Area
m	Meter
Kg	Kilogaram
m2	Meter squared
Ft	Feet
Kg-F	Kilogram force

CHAPTER 1: INTRODUCTION

Chapter 1: Introduction

1.1 Motivation:

The main motivation behind the project selection is providing a cost effective and highly reliable solution for farmers settled in Pakistan, to make agricultural processes more effective and cheap.

1.1.1 Large consumer base in Pakistan:

Pakistan has a vast and well integrated agriculture base. 42.3% of labor force is directly employed in agriculture sector. More than 10% of labor force is indirectly associated with agriculture sector. Not to mention the fact that overall 113 million people live in rural areas and their confrontation with agriculture sector is inevitable. Therefore this sector has a large consumer base that we can target and pitch our project to. Overall, it is a 555 million-dollar market that is yet to be introduced to Pakistan.

1.1.2 Government-A stakeholder:

The agriculture industry is the backbone of Pakistan's economy, accounting for around 20% of the country's GDP and 65 percent of exports. Given the significance of agriculture in Pakistan's economy, the government has traditionally favored farming solutions and aided in the modernization of farming methods. The government has approved the use of drones for agricultural reasons, creating a chance for this business to flourish. We wanted to take advantage of this chance.

1.1.3 Improvement in agricultural practices:

It's also a pressing requirement. Pakistan is the world's fourth largest cotton grower, however it is unable to produce more than 14 million bales each year due to insect infestations. Pakistan's population is likewise growing, resulting in higher-than-ever food demand. At a time like this, Pakistan has to improve its agricultural methods in order to compete in the global market and stay afloat. For everyone engaged in the process, drones save time and money. In a whole day, a human worker can only cover 0.65 acres of land, but a drone can cover the same area in just 2 minutes! Furthermore, it will lower production costs by lowering the cost of manpower used to apply pesticides.

1.1.4 Alleviating health problems:

Drones that spray pesticides have several social advantages as well. Farmers' health and safety are improved by using them, as they are exposed to less harmful pesticides and are less likely to fall from trees or be bitten by bugs or snakes. It also frees farmers from having to do tedious, repetitive activities in hot, humid conditions.

1.1.5 Reducing pesticides wastage:

Furthermore, due to the high degree of atomization, the deployment of the drone will allow for a 30 percent decrease in waste, conserving the country's resources and lowering the quantity of pesticide sprayed in the atmosphere.

1.1.6 Farming in remote areas:

Furthermore, because of the high degree of atomization, the drone's deployment will result in a 30% reduction in waste, preserving the country's resources and reducing the amount of pesticide sprayed in the atmosphere.

1.1.7 Sustainability:

It's also a sustainable option because it runs on rechargeable batteries rather than gasoline.

Local development of unmanned aerial vehicles (UAVs) tailored to Pakistan's agricultural demands.

Finding a low-cost solutions for farmers.

Reducing the operating cost to increase ROI on agricultural land.

1.2 Problem statement:

Our problems revolves around four foci which are described below:

1.2.1 Low Cost:

The UAV will be built using the most cost-effective materials and components possible without sacrificing performance. The construction would be optimized, and a self-designed avionic system would be used to save money.

1.2.2 Local manufacturing:

To minimize manufacturing costs and provide a local option for Pakistani farmers, the UAV fittings and structure will be built and assembled locally. It will lower the overall cost as well as shipping and customs fees.

1.2.3 Low operating cost:

The UAV will have a minimal operating cost and will significantly lower the cost of pesticide spraying.

CHAPTER 2: LITERATURE REVIEW

For the construction of cost-effective agriculture drone the following techniques and methodologies were required:

1. Flight Mechanics and Design of multi-rotor wing Unmanned Aerial Vehicles
    a. Design Algorithm: Feasible Design Parameters
    b. Configuration Layout: Airfoil Selection
    c. Weight and CG Estimation
    d. Analytical Parameter Estimation
    e. Performance and Stability Analysis
    f. Estimation of inertial properties
2. Mechanics of Deformable Bodies
    a. Force-deformation Relationships and Static Indeterminacy

   b. Failure of Materials
   c. Pure Bending
   d. Beam Deflection
   e. Beam Bending, Buckling and Vibration
   f. Principles for Material Selection: Performance, Properties, and Constraints
3. Differential Analysis of Fluid Flow
4. DC-DC converter inclusion regarding input energy and flight-time

Table 1: Research paper Used:

Research Paper	Abstract
1. Design and analysis methods for UAV rotor blades	A method of preliminary design and analysis of propellers for small UAVs has been proposed, based on BEM theory. The design procedure has created the blade geometry in terms of the chord distribution along the radius as well as the distribution of the blade angle.
2. 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.

3. Control design model aerial vehicles with four rotors	Control system design in the combination with quadcopter dynamic for UAV. The PID control algorithm for simplified quadcopter dynamic model
4. Quadcopter design, construction and testing	The proposed for design, construction and testing procedure of quadcopter
5. 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
6. 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

7. 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.
8. Design, Analysis and Fabrication of Quadcopter	The paper focuses on the aerodynamic effects of quadcopter. It addresses all the aspects of quadcopter ranging from mechanical design to electronics used. It provides backup to the selection of different components with the help of various formulas from research papers.
9. Multistage Mass Optimization of a Quadcopter Frame	Explains how optimization is done for the shape of the frame using Design of Experiments (DoEs). Further, optimization can be carried out for mass using topology optimization
10. Quadcopter for Agricultural Surveillance	The aerial Quad copter used for agricultural surveillance is an unmanned vehicle used for proper and accurate surveying of the crops and leaves reducing the human effort. The paper gives an example of quadcopter design and the necessary design parameter

11. Study of effects of high-altitude environments on multi-copter and fixed-wing UAVs' energy consumption and flight time	Energy requirements increase as target altitude does, which decreases flight time; these can also be influenced by unforeseeable factors, like wind turbulence and temperature. Proper aeronautic design and choosing the right combination of propulsion elements will aid a UAV to fare better under these circumstances, which is crucial for industrial applications.
12. Efficiency Based Flight Analysis for a Novel Quadcopter System	An efficiency of 12.5% for the ducted quadcopter system over the ductless system was observed. Performs rigid body dynamics for analysis of quadcopter.
13. Vertical take off and landing with fixed rotor	The lift force generated by a wing reduce the required power of the motors to raise up the structure during horizontal forward flight. For airfoil selection and sizing of the wing, we consider the necessary weight to lift, the Lift coefficient (CL) characteristic of its geometry and the attack angle
14. Thrust efficiency of drones (quad copter) with different propellers and their payload capacity	This paper contains analysis of the different size of the propeller on manual and autonomous controlled QUAD – copter + TRI-copter separately. To check which propeller is more efficient to provide more thrust to carrying more

	Payloads at the same power supply and also find what is the thrust to weight ratio for same configuration models to increase performance

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:

2.1.1 Take off

A quadcopter must be formed to equate or exceed the force of gravity in order to get into the air. This is the fundamental idea behind the lifting of aircraft to manage up and down power. Quadcopters are now using the engine design and propeller direction to control the force of gravity against the quadcopter as a matter of principle.

The spinning of the quadcopter propeller blades push air down. All forces come in pairs (Newtons Third Law), which means for every action force there is an equal (in size) and opposite (in direction) reaction force. Therefore, as the rotor pushes down on the air, the air pushes up on the rotor. The faster the rotors spin, the greater the lift and vice-versa.

2.1.2 Hovering

To hover, the net thrust of the four rotors push the drone up and must be exactly equal to the gravitational force pulling it down.

2.1.3 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:

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

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.

Thrust, like lift, is generated by the rotation of the main rotor disk. In a helicopter, thrust can be forward, rearward, sideward, or vertical. The resultant lift and thrust determines the direction of movement of the helicopter.

The solidity ratio is the ratio of the total rotor blade area, which is the combined area of all the main rotor blades, to the total rotor disk area. This ratio provides a means to measure the potential for a rotor disk to provide thrust and lift. The mathematical calculations needed to calculate the solidity ratio for each helicopter may not be of importance to most pilots but

what should be the capabilities of the rotor disk to produce and maintain lift. Many helicopter accidents are caused from the rotor disk being overloaded. Simply put, pilots attempt maneuvers that require more lift than the rotor disk can produce or more power than the helicopter’s powerplant can provide. Trying to land with a nose high attitude along with

any other unfavorable condition (i.e., high gross weight or wind gusts) is most likely to end in disaster. The tail rotor also produces thrust. The amount of thrust is variable through the use of the antitorque pedals and is used to control the helicopter’s yaw.

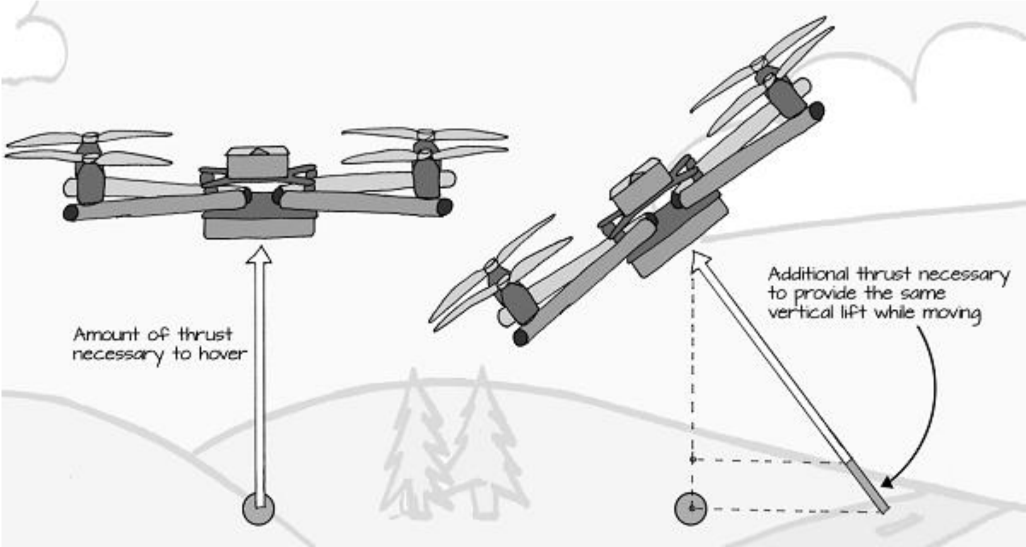


Figure 1: Thrust and Movement

2.1.4 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:

$$\boldsymbol{T} = \boldsymbol{W} - \boldsymbol{\rho A}\sum \boldsymbol{vi}\ 2$$

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.

$$\boldsymbol{T} = \boldsymbol{W} - \boldsymbol{\rho A \sum v i}\ \mathbf{2}$$

2.2 Types of drones used:

2.2.1 Single rotor:

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

2.2.2 Multirotor:

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. Can be further classified depending on the no. of rotors.

2.2.2.1 Tri rotor drone:

Tri-rotor UAVs are more efficient in terms of size and power demand than quadrotors, but they are more difficult to operate and stabilize. Tri-rotor vehicles are those that have three rotors. This design has been advocated as being less costly, with greater flexibility and agility. Tri-rotor UAVs are smaller in size, less complicated, less expensive, and have longer flying times than quadrotors due to the reduced number of motors, making tri-rotor vehicles excellent for deployment in various research projects and missions.

2.2.2.2 Quad copter:

Quadrotors are vertical take-off and landing aerial vehicles having a wide range of possible uses ranging from mapping to assisting with rescue missions. Quadrotors are tiny, nimble vehicles whose rotational speed is controlled by the four rotors. The position of the rotor arrangements in relation to the body coordinate system results in two types of quadrotor configurations: the "x" configuration and the "+" configuration, as shown in figures 3 and 4. An x-configuration quadrotor is said to be more stable than a + configuration quadrotor, which has a more acrobatic construction. The four rotors are arranged in such a way that the rotors on opposing ends revolve in the same direction while the other two rotate in the opposite direction.

Figure 2: Control System configuration for quadcopter: a) cross configuration. b) plus configuration

2.2.2.3 Hex copter:

A tiny remote-controlled aircraft, similar to a helicopter, with six rotating blades on top, used mostly to video or photograph objects from the air. A hex copter is a kind of drone.

2.2.2.4 Octocopter:

A tiny remote-controlled aircraft, similar to a helicopter, with eight rotating blades on top, used mostly for filming or photographing objects from the air. An octocopter is a type of drone.

2.2.3 Fixed wing UAV:

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

2.2.3.1 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.

2.2.3.2 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.

2.2.4 Hybrid UAV:

Merging the benefits of fixed-wing UAVs with the ability to hover is a new category of hybrids which can also take off and land vertically.

There are various types under development, some of which are basically just existing fixed-wing designs with vertical lift motors bolted on. Others are ‘tail sitter’ aircraft which look like a regular plane but rest on their tails on the ground, pointing straight up for take off before pitching over to fly normally, or ’tilt rotor’ types where the rotors or even the whole wing with propellers attached can swivel from pointing upwards for takeoff to pointing horizontally for forward flight.

2.3 Quadcopter design features:

2.3.1 Motors:

The movement of drones like quadcopters involves the movement of two motors in a clockwise direction while two others move in an anti-clockwise direction. This ensures a higher stability of the motors and effectiveness of the device.

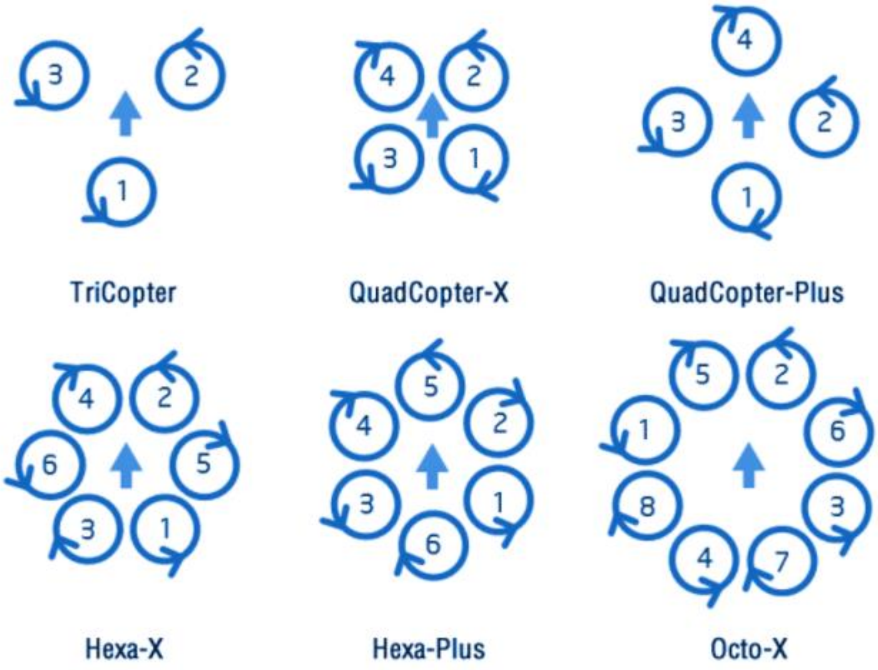


Figure 3: Direction of rotation for different multi-rotor drone

2.3.2 Propeller:

The purpose of your quadcopter propellers is to generate thrust and torque to keep your drone flying, and to maneuver. The upward thrust force generated by the propellers is usually measured in pounds or grams. To keep your drone flying at a hover, the upward thrust needs to equal the weight of your drone.

2.3.3 ESC:

Electronic speed controllers (ESCs) are devices that allow drone flight controllers to control and adjust the speed of the aircraft's electric motors. A signal from the flight controller causes the ESC to raise or lower the voltage to the motor as required, thus changing the speed of the propeller.

2.3.3 Batteries:

Drone flight time is largely depended by battery capacity, more capacity is mean more power and more energy.

Table 2: Common battery types and Drone

Drone Type	Lipo Batteries
Mini quad	lipo 80-800mAh 1s/2s
180mm	lipo 1000mah/1300mAh 3S/4S
210mm	lipo 1000mah/1300mAh 3S/4S
250mm	lipo 1300-1800mAh 3s/4s
280 / 290mm	lipo 1500-3300mAh 3s
330 / 360mm	lipo 2200-3200mah 4s
400mm	lipo 3200-3300mah 4S
450mm	lipo 3300mAh 4S
500mm	lipo 3300-5000mAh 4s
540mm	lipo 5000-5200mAh 4s
550 / 650 / 750mm	lipo 5000-8000mAh 4s/5s/6s
800mm or big	lipo 8000mah-30000mah 6s

Drone power is supplied by the Li-Po battery.

2.4 Quadcopter parameters:

The following parameter are to be considered when designing a quadcopter.

2.4.1 Flight time

Indicates the total duration of flight of drone at full capacity of battery:

time = capacity * discharge / AAD

where:

Time is the flight time of the drone, expressed in hours.

Capacity is the capacity of your battery, expressed in milliamp hours (mAh) or amp hours (Ah). You can find this value printed on your LiPo battery. The higher the capacity, the more energy is stored in the battery.

Discharge is the battery discharge that you allow for during the flight. As LiPo batteries can be damaged if fully discharged, it's common practice never to discharge them by more than 80%. If you'd like to change this default value, type the required discharge into the respective field of this drone flight time calculator.

AAD is the average amp draw of your drone, calculated in amperes. If you know this value, open the advanced mode to enter it directly into our calculator. If you're not sure how to calculate it, keep reading - we will help you determine the amp draw basing on parameters such as the quadcopter weight or battery voltage.

2.4.2 Thrust co-efficient:

The thrust force of a jet-propulsion engine per unit of frontal area per unit of incompressible dynamic pressure.

2.4.3 Drag factor:

The aerodynamic drag coefficient is a measure of the effectiveness of a streamline aerodynamic body shape in reducing the air resistance to the forward motion of a vehicle.

2.4.4 Wheelbase:

In both road and rail vehicles, the wheelbase is the horizontal distance between the centers of the front and rear wheels.

2.5 Propeller parameters:

The following parameter are to be considered when designing a propeller

2.5.1 Angle of Attack:

In fluid dynamics, angle of attack (AOA, α) is the angle between a reference line on a body (often the chord line of an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving. Angle of attack is the angle between the body's reference line and the oncoming flow.

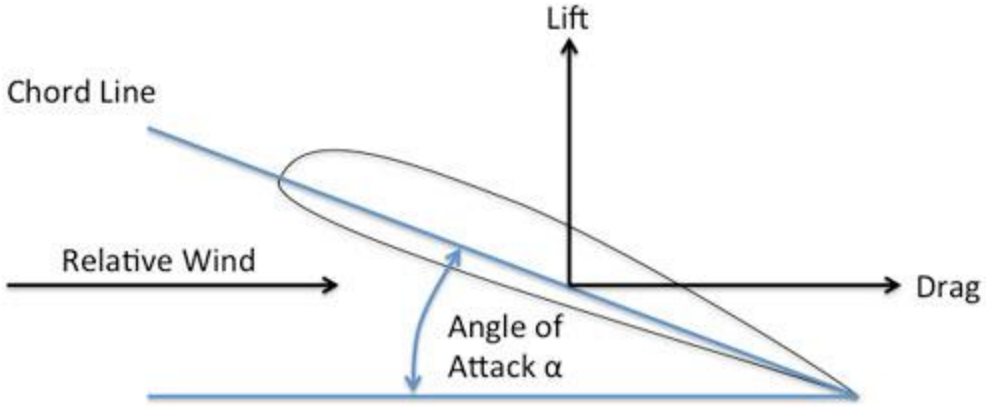


Figure 4: Angle of Attack

2.5.2 Camber:

Camber refers to curvature of the airfoil and may be considered as curvature of the mean camber line. The shape of the mean camber is important for determining aerodynamic characteristics of an airfoil section. Maximum camber (displacement of the mean camber line from the chord line) and its location help to define the shape of the mean camber line. The location of maximum camber and its displacement from the chord line are expressed as fractions or percentages of the basic chord length. By varying the point of maximum camber, the manufacturer can tailor an airfoil for a specific purpose. The profile thickness and thickness distribution are important properties of an airfoil section.

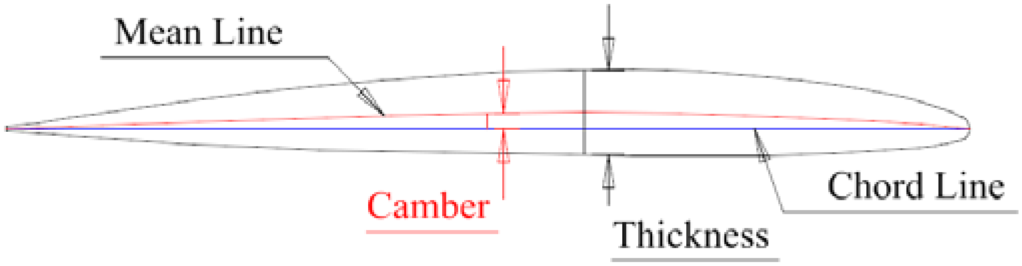


Figure 5: Propeller Profile Parameter

2.5.3 Blade Tip:

The part of a blade that is the farthest from the hub.

2.5.4 Blade Face:

The surface of a propeller or rotor blade that corresponds to the lower surface of a lifting airfoil. — called also driving face, thrust face.

2.5.5 Rake:

It is the distance at the blade tip between the generating line and the line perpendicular to the propeller axis that meets the generating line at the propeller axis.

2.5.6 Pitch:

This is the movement of quadcopter either forward and backward. Forward Pitch is achieved generally by pushing the throttle stick forward, which makes the quadcopter tilt and move forward, away from you. Backward pitch is achieved by moving the throttle stick backwards.

CHAPTER 3: METHODOLOGY

To complete the objectives of the project mentioned in the previous section Development of LOWCOST 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:

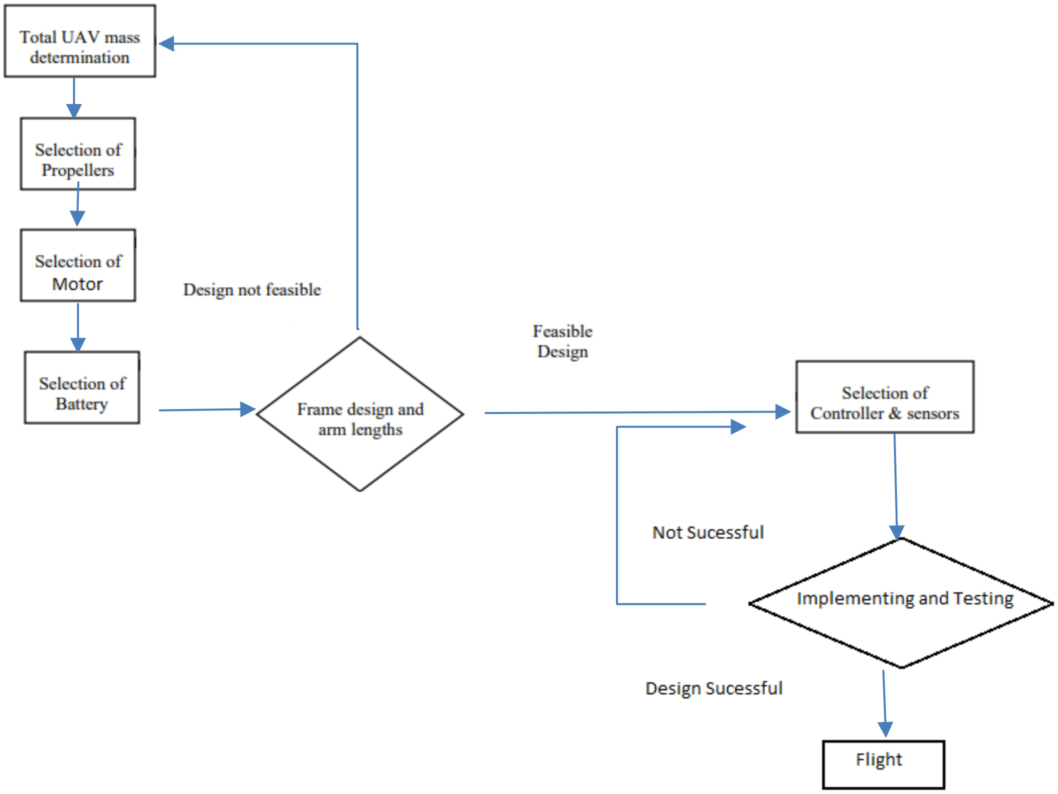


Figure 6: Solution Methodology

3.1 Payload Finalization:

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 Figure 4: Design process of a multirotor drone Total UAV mass determination Finalizing number and power of motors Selection of ESC Selection of Propellers Selection of Battery Selection of Controller & sensors Software development Frame design and arm lengths Implementation and testing Feasible Design Design not feasible Unsuccessful Successful Flight 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 13.4 kg so we took approximately 15 kg for our calculations

3.2 Selection of No. of arms of UAV:

Selecting no. of arms is the first step in design a UAV. Earlier in the literature review different advantages and disadvantages of difference drone design were discussed. Generally, the effects of no. of arms can be summarized as:

- With increase in number of arms the thrust increases
- With an increase in number of arms the weight increases

With these conditions it was favorable to use greater no. of arms. However, with increase in no. of arms it was observed that arm length is also to be increased which reduces thrust to weight ratio.

Also, with lower no. of arms more powerful motor were required which required bigger motor increasing weight and having larger losses.

For this process a generalization was required.

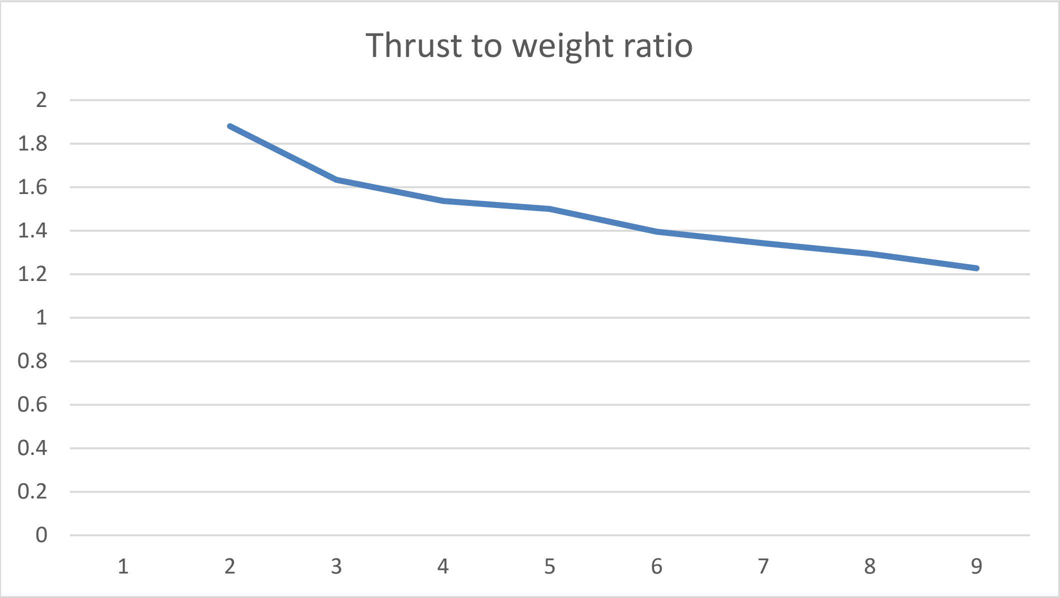


Figure 7: Arm vs thrust/weight

The above graph is constructed from the calculated excel file where each rotor is 5 unit in diameter producing 10 units of thrust each arm length was calculated. Now the weight was calculated using

Weight of an arm=Density*Cross area*Arm length

Actual weight = Weight of arm + (no. of arms*weight of fixtures)

This gives the table:

Table 3: Arm to thrust/weight relation.

no. of arms	Thrust to weight ratio	Total Thrust	Arm length required	weight of Arm	Total weight	Realistic weight
3	1.880406168	30	4.33	4.33	12.99	15.954
4	1.63345312	40	5	5	20	24.488
5	1.536475939	50	5.322	5.322	26.61	32.542
6	1.499430217	60	5.456	5.456	32.736	40.0152
7	1.395946172	70	5.868	5.868	41.076	50.1452
8	1.341777587	80	6.109	6.109	48.872	59.6224
9	1.293259531	90	6.342	6.342	57.078	69.5916
10	1.227174553	100	6.689	6.689	66.89	81.488

Using density=1unit and cross-sectional area=1unit square

According to this data rotors of 3, 4, 5 rotors can be used. However, for odd no. of arms and subsequently propellers cause major controlling issues. Therefore 4 no. of arms were selected.

3.3 Selection of Propeller:

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:

$$\textit{Required thrust per motor} = 2W/N$$

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

$$\textit{Required thrust per motor} = (13*12)/4 = 39\text{Kg-F}$$

For this calculation, we used a factor of safety of 1.3. Based on this calculation and the availability of motors to provide such amount of thrust. For XXYY propellers XX represent the propeller diameter and YY represents the propeller pitch.

Now different propellers were compared a selection was made on basis of maximum thrust to weight ratio.

Table 4: Propeller Selection

Name of Propeller	WEIGHT	DIAMETER	DIA TO WEIGHT RATIO	THRUST (N) AT 1unit	Thrust to weight ratio	Material
SportProp 8040L Pusher	10.15	8	0.78817734	15.18	1.4954	nylon
Carbon Fiber 8x6	6	8	1.333333333	11.918	1.98632	carbon fiber
HY-1047	7.8	10	1.282051282	26.64	3.415384616	plastic

According to man to our requirement total thrust produced will be for HY-1047

Thrust = 26.64*no. of arms = 26.64/4 =106.56N

Newton to Kf-F conversion: 106.56N = 106.56*0.101972 = 10.87N

Keeping rpm constant for all propellers.

Where thrust is :

$$F = 1.225\frac{\pi(0.0254\cdot d)^2}{4}\left[\left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1}{60}\right)^2 - \left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1}{60}\right)V_0\right]\left(\frac{d}{3.29546\cdot pitch}\right)^{1.5}$$

According to Data HY-1047 is selected due its high weight to thrust ratio.

3.4 Wheel Base:

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:

$\boldsymbol{Wheel\ Base} = \mathbf{2} * 10 *. \mathbf{0254} = 0.508$ m

After the selection of wheelbase, a proposed model was designed using a computer-aided designing software Solid works.

3.5 Arm Length and base plate Selection:

The area increase in base plate increases the weight considerably how ever the increase in arm’s length increases the stresses on the arm and the structural integrity and sturdiness is reduced. The minimum required space on the base for addition of battery, ESCs, GPS module, Flight controllers and Ultraviolet sensors is 125000mm square.

Priority:

- For base plate we wanted to have minimum size to reduce the weight
- Smaller arm length to reduce the stresses which enable smaller cross section and weight.

Issue:

- Since the wheel base is constant at 0.508m both cannot be possible and a compromise is required.

Solution Criteria:

- We require a combination of base plate which is not heavy and is rigid.

Solution:

- AN orthodox solution was achieved by using a non conventional base plate design.

3.6 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:

Table 5: Material Selection Criteria

BALSA WOOD[24]	EXPANDED POLYPROPYLENE[25]	ALUMINUM[26]	CARBON FIBER[27]
Balsa has excellent sound, heat, and vibration insulating properties, suitable for composite materials	Lightweight, enhanced functionality, durability, and recyclability.	Heavier than the rest but has increased strengths	High strength to weight ratio.
The density of dry balsawood 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	MODERAT	CHEA	HIGH COST

3.7 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:

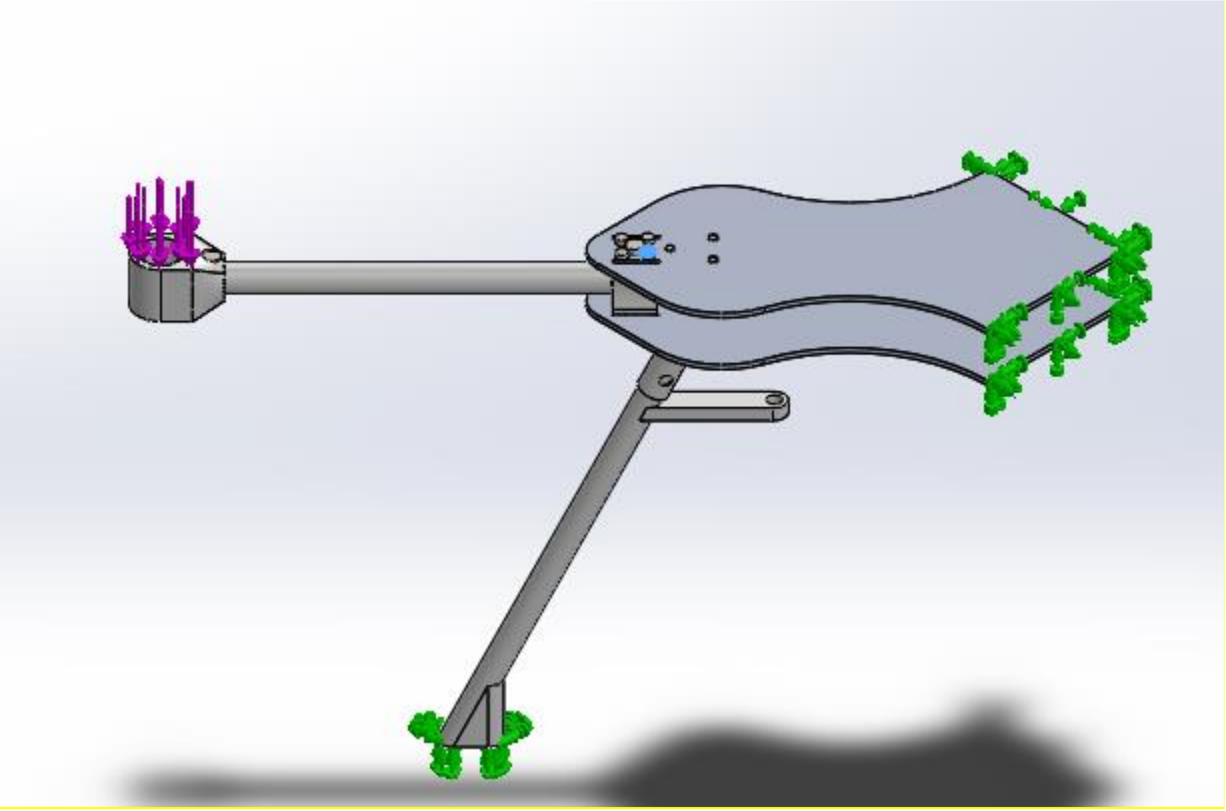


Figure 8: FEM, static deflection configuration

3.7.1 Static deflection due to weight:

3.7.2 Arm deflection while hovering

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. For this configuration the base was fixed the static deflection was calculated, without applying an downwards force by the propellers.

For the hovering condition; (The analysis was carried out to study stress and deflection produced in the drone structure when hovering in the air). The force applied by the propellers on the drone were added while all other conditions were set the same. For, this analysis Solid Work – Simulation was used.

3.8 Fluid Flow analysis:

In order to validate our results, we had two approaches one was using actual tabulated experimental data The Other was through computerized fluid dynamics.

Fluid flow analysis to validate this design, the total thrust provided by the five EDFs, τ, should exceed the sum of the weight of the design and the resistive forces it experiences:

$$\tau > mg + FR$$

Here m is the mass of the drone and g is the gravitational field constant. FRdenotes the air drag in the vertical direction. We cannot rely on the thrust values provided by the manufacturers for the thruster fans as the air flow is directed through an air multiplier, and additional losses and thrust augmentation due to inducement needs to be accounted for. A thrust factor (specific to air multiplier geometry) is to be determined and optimized. Moreover, the aerodynamic drag on the dome also needs to be determined and subsequently minimized. For these purposes, the following CFD analyses are conducted. All simulations are performed using Ansys Fluent. 1. A preliminary thrust analysis for the central to validate values provided by the manufacturer and determine the difference.

- Propeller Parameter calculations
- Combine drone flow simulation

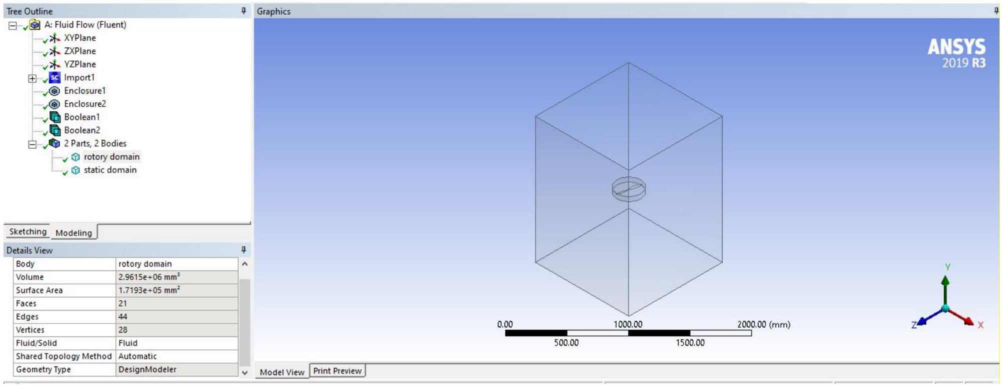
3.8.1 Propeller Parameter Calculations:

The following parameters were calculated using ANSYS workbench:

- Thrust
- Pressure Contours
- Velocity Profile

3.8.1.1 3D Geometry:

The unsteady simulation was run until convergence and the thrust produced were noted. The velocity streamlines for air movement around the fan are shown below. This simulation was performed for the central EDF to determine lift coefficients that are to be used to validate the design and model its control.

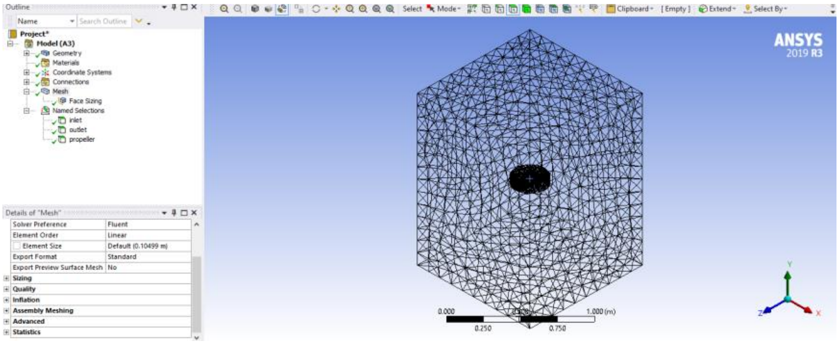


Body	rotory domain
Volume	2.9615e+06 mm^3
Surface Area	1.7193e+05 mm^2
Faces	21
Edges	44
Vertices	28
Fluid/Solid	Fluid
Shared Topology Method	Automatic
Geometry Type	DesignModeler

Figure 9: Geometry

3.8.1.2 Mesh Generation:

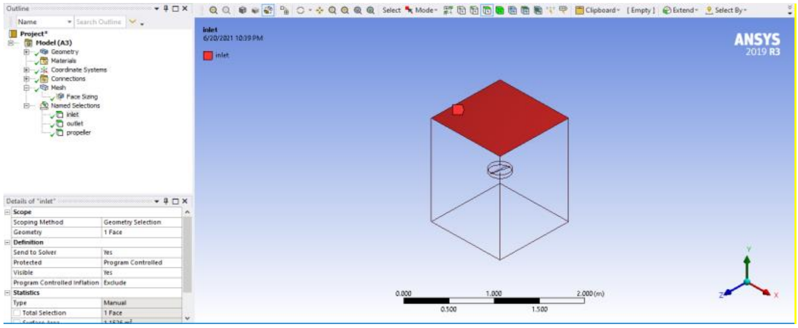
The boundary conditions comprise a pressure inlet and two pressure outlets (top and bottom boundary, with reverse flow expected at the top and also tabulated). A pressure inlet is favored over a velocity inlet because the compressible flow is further entrained at the nozzle, which may decrease the velocity at the inlet (which otherwise a velocity inlet boundary condition will enforce). The side faces (left, right, front, and back along with the air multiplier faces are set as walls). Figure 22 shows the mesh alongside boundary conditions (not all faces shown).



Details of "Mesh"

Solver Preference	Fluent
Element Order	Linear
☐ Element Size	Default (0.10499 m)
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Assembly Meshing	
Advanced	
Statistics	

Figure 10: Mesh Generation



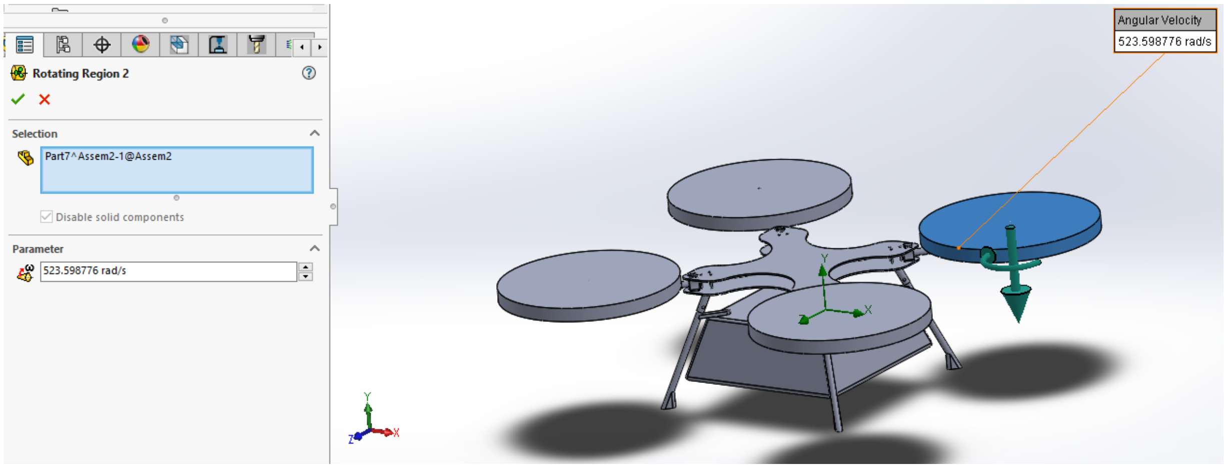
Details of "inlet"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Send to Solver	Yes
Protected	Program Controlled
Visible	Yes
Program Controlled Inflation	Exclude
Statistics	
Type	Manual
☐ Total Selection	1 Face

Figure 11: Inlet Configuration

3.8.2 Combined drone flow simulation:

Solid works Fluid flow was used to carry out the combined effect of the four propeller. To find the multiple flowing streams effect on each other. Moreover the tank was included in the calculation so that the near actual result could be found out. The simulation was done for RPM just when it was about to take off. For this configuration four regions were defined where the main motion occurs These regions were given the desired movement directions and angular velocities Meshing was done and results were calculated.



Rotating Region 2

Selection

Part7^Assem2-1@Assem2

☑ Disable solid components

Parameter

523.598776 rad/s

Angular Velocity

523.598776 rad/s

Figure 12: Solid Work Flow Simulation, configuration

3.9 Electronic System Design

3.9.1 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.

3.9.2 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:

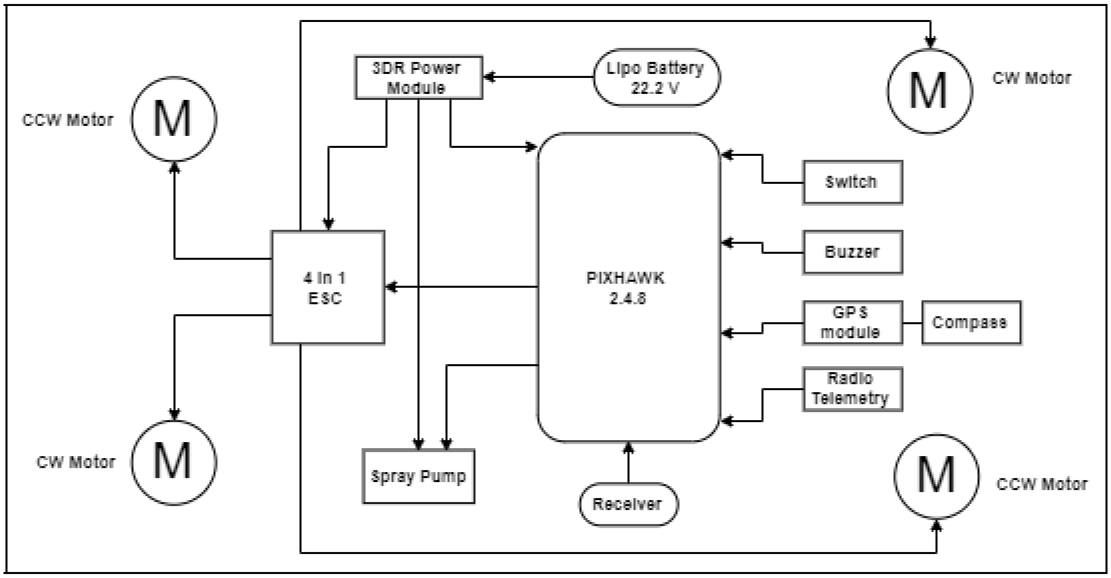


Figure 13: Flight controller schematic

GPS Module	Used to navigate and location tracking
Compass Radio	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.
Telemetry	To transmit the radio signal back and forth from the drone to remote.
Ultrasonic Sensor	To determine the elevation of drone

3.10 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

3.11 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 as:

$$\boldsymbol{Battery\ life} = \boldsymbol{Capacity}/(\boldsymbol{Consumption}*(\mathbf{1}-\boldsymbol{discharge\ safety}))$$

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Parametric Results:

4.1.1 Propeller and motor selection:

The required thrust upon the final design was the required thrust was 9.6 Kg-F. To fullfill the requirement the following were selected:

PROPELLER SELECTED:	HY 1047 CARBON FIBER
MOTOR SELECTED:	Turnigy2836 1000KV

The combined effect of the selected motor and propeller are listed in the following table:

Table 6: HY1047 Thrust VS RPM

PWM throttle signal (µs)	Rotation speed (rpm)	Thrust (N)	Voltage (V)	Current (A)	Electrical power (W)	Mechanical power (W)
1900	10992	26.11	11.63	26.25	421.7	327.2
1821	10949	25.96	11.64	25.17	409.2	322.2
1742	10053	23.32	11.64	16.16	304.6	242.7
1663	9146	20.9	11.65	9.24	224.2	179
1584	8233	18.746	11.66	4.03	163.5	128.1
1506	7338	16.831	11.66	0.914	115.6	87.85

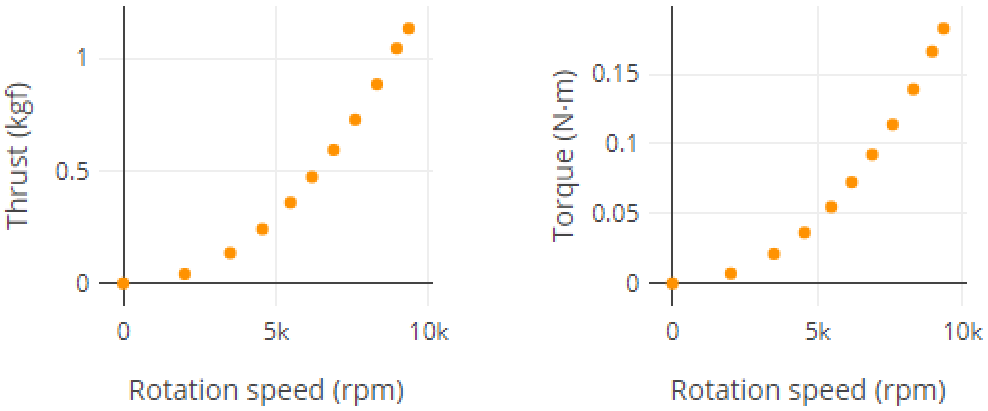


Figure 14: Propeller results: a) RPM vs Thrust b) RPM vs Torque

The thrust in the above table is for one arm. Converting required thrust to Newtons from KgF

1KgF = 9.8 N

Required Thrust: 9.6KgF = 94.1438N

Thrust Required per Arm = 94.143/4 = 23.53 N

The required thrust can be achieved easily and is at 60 percent throttle value for the selected motor.

4.1.2 Structure Results

The following are the final structural results as calculated by the sections calculated in the methodology.

Table 7: Structural Parameters

Parameter	Value
The material of landing gear	Aluminum
Material of arms	Carbon Fiber
Wheelbase/Boom length	0.506m
Arms dimensions	16mm dia, 125mm length
Base Plate Dimensions (base geometry)	258mm x 258mm x 2mm
Propeller Diameter	10 in (254mm)
Base seat plate thickness	2 mm
Empty Weight (including battery, motors, and control system)	4.6 kg
Payload	5 kg
Battery	20000 mAh (6S)

4.2 Final Design:

After iterative process the final design of Agri-Drone was developed using CAD techniques in Solidworks:

Figure 15: Final Design

4.3 Computational Results:

Following are the computational results for the propeller parameters and the combined drone fluid flow.

4.3.1 Thrust:

Thrust for single propeller was calculated using the set-up from section 3.8. The results obtained were in five percent error to analytical calculations. For output sample we have shown two velocities profiles, pressure profiles and xy plane fluid flow profile at 6000RPM.

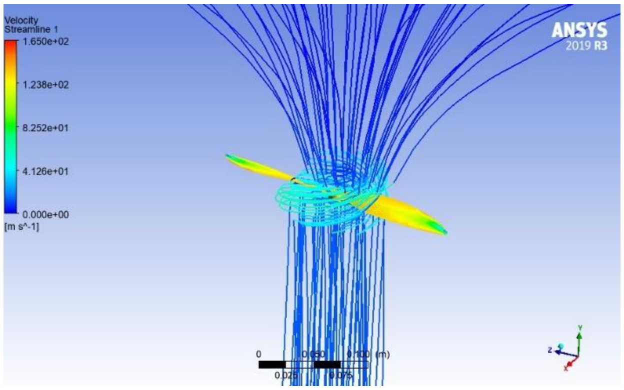


Figure 17: Thrust Profile A

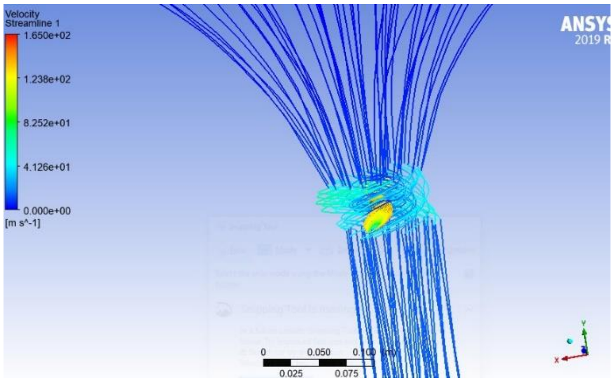


Figure 16 Thrust Profile B

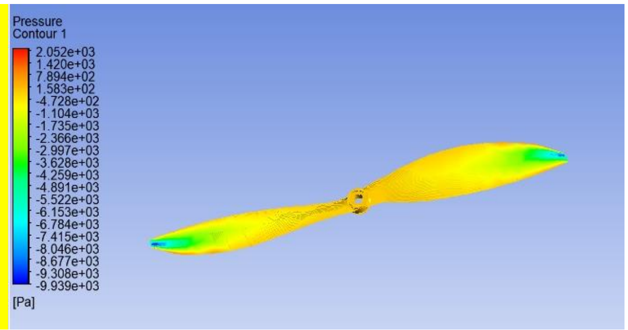


Figure 19 Pressure Profile

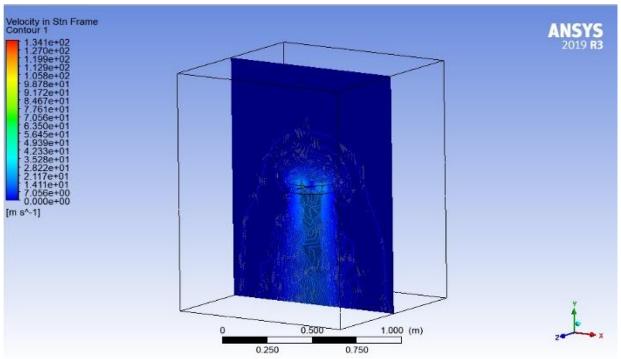


Figure 18: Velocity Profile XY plane

4.3.2 Fluid Flow inspection in SolidWorks assembly

A fluid flow inspection was done in solid work using the whole drone, including four propellers and tank. The result is shown in the fig. below.

Figure 20: Fluid flow over final design

This shows the interaction of different flow regions. As it is observed that the interaction of fluid flow is independent to other propeller how ever it depends on the geometry of the tank. In our case we observe minimal to no effect. Indicating good selection of wheel base.

4.4 Cost analysis:

Since a major Constraint of our project was total cost and we used off-shelf components the cost was calculated according to the market survey done online and physically. However, most component used were only available through online market. Following is the total list of components and the estimated cost of individual components:

Table 8: Cost Analysis

Component	Specifications	Quantity	Cost
Pixhawk PX 2.4.8	2.4.8 Flight Controller	1	11710
Carbon Fiber Tubes	16mmx15mmx1000mm	4	2800
Brushless Motors	Turnigy2863 1000kv	4	13,308
Propeller	HY 1047	4	4886
ESC	60A 3-8S 4 IN 1	1	8852
Propeller arm fixture	D16 CNC Aluminium Auto Folding Arm Joint Fitting	4	2366.12
Motor mounts		4	10000-12000
Pump	12V DC/(4.5L/min)/ 0.65Mpa	1	450
Nozzle	Nozzle kit	4	960
Hose Pipes		1	140
Tank	235*235*90mm shell 5mm with inlet and outlet custom.	1	300
Landing pipe	Phi 9mm*185mm	4	3200
Controller Housing (Top + Bottom)	300mm*300*2mm with countours	2	1200
Pump ESC		1	3000
Battery	6s LiPo (20000mAh)	1	30,000
Total Cost			93172 +/- 10%

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In this project, design of low cost UAV and its optimization is proposed. The design was constructed and tested according to be reliable through theoretical design experimentation. In addition to this, other components of agriculture-drone like motors, electronic speed controller, batteries and pumps for spraying were tested according to the theoretical design study.

Our main objective was to obtain performance optimization of the design through weight reduction and increment in flight time. To go along with this, we also aimed to achieve cost reduction through off-shell material, economical fabrication and low cost machining. After comprehensive analysis and optimization, the weight was reduced from 13 kg to 9.8 kg. This reduction in weight is directly related to cost reduction. There was clear increment in the flight time. The flight time is increased from 8 minutes to 12 minutes. Initially the cost of the primary design was 1.2 lakhs which was diminished to 93.13 thousands.

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 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 wherever they want the controls on screen as per with what they are comfortable with.

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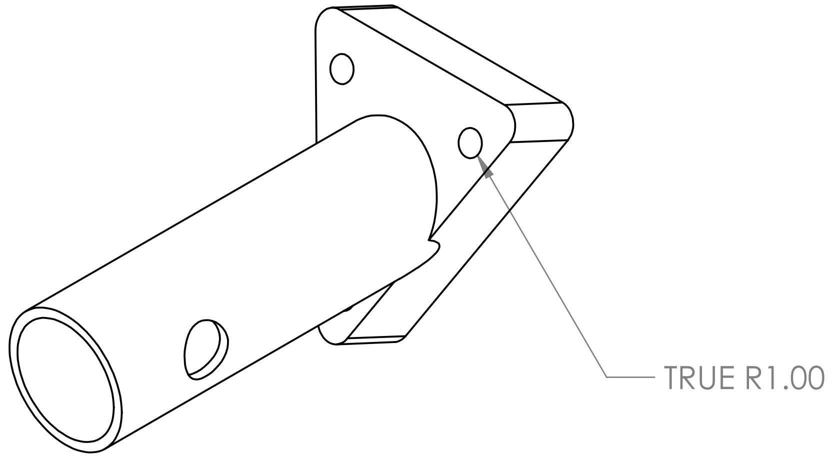
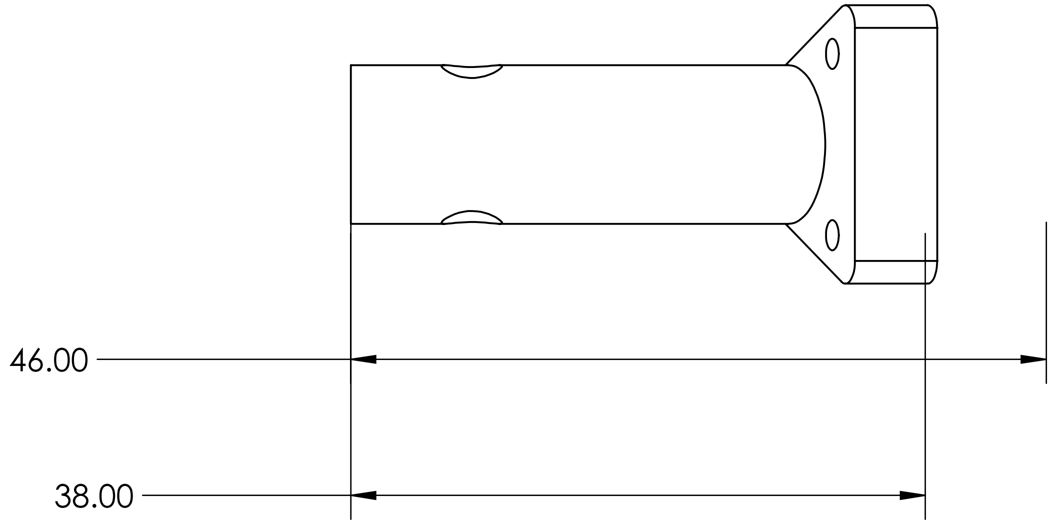
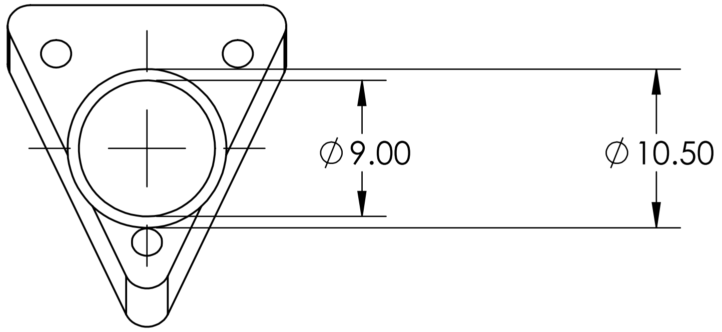
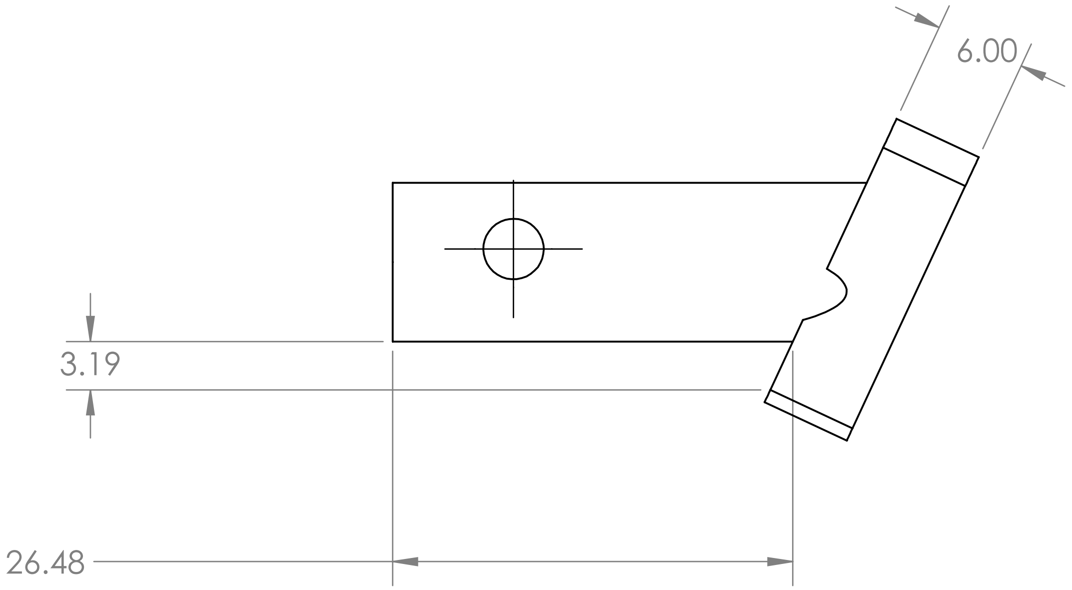
APPENDIX I: PART DRAWINGS

Sr. no	Part name
1	Base Seat
2	Base Plate
3	Arms
4	Clamps
5	Motor Mount
6	Leg









NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

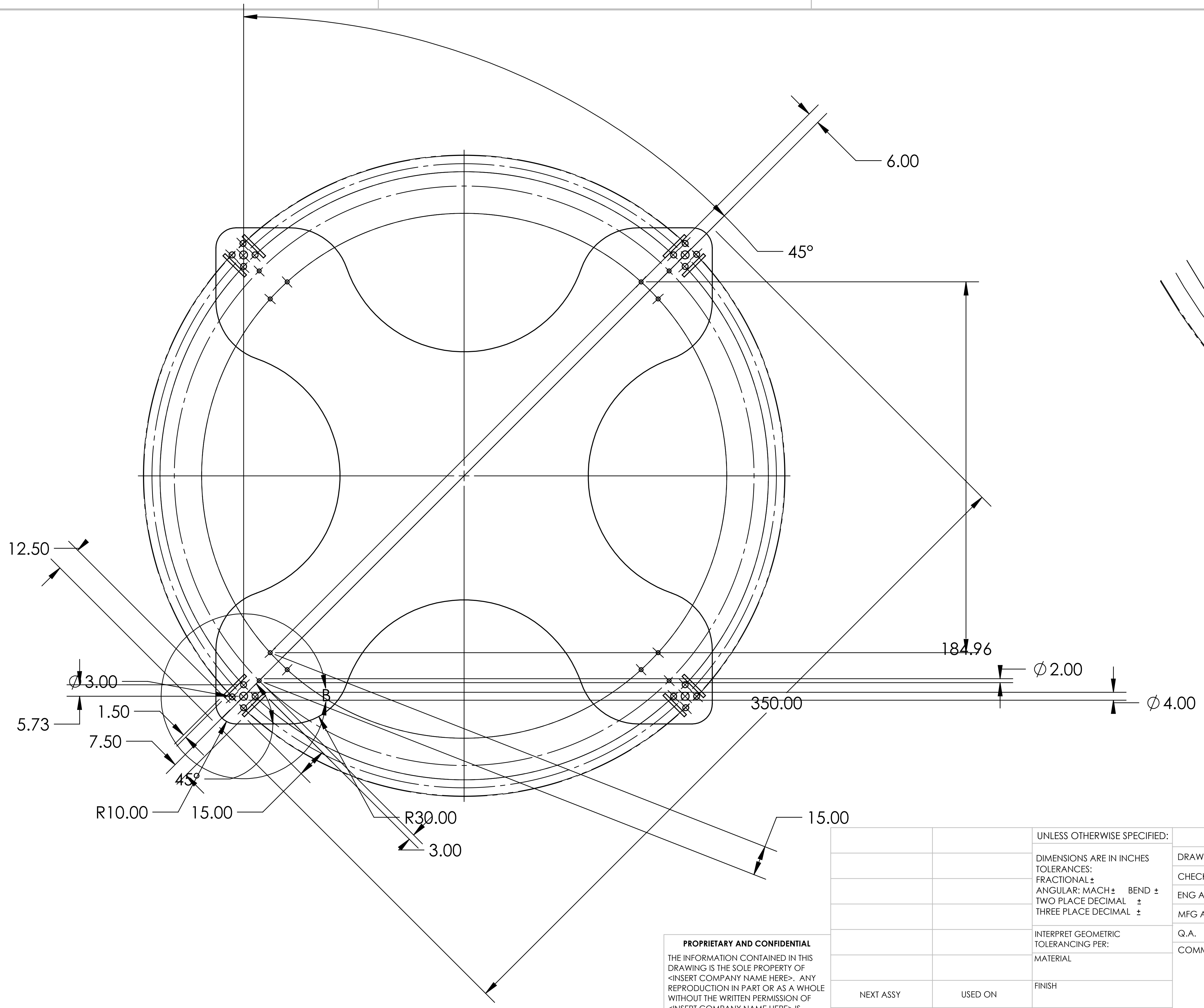
COMMENTS:

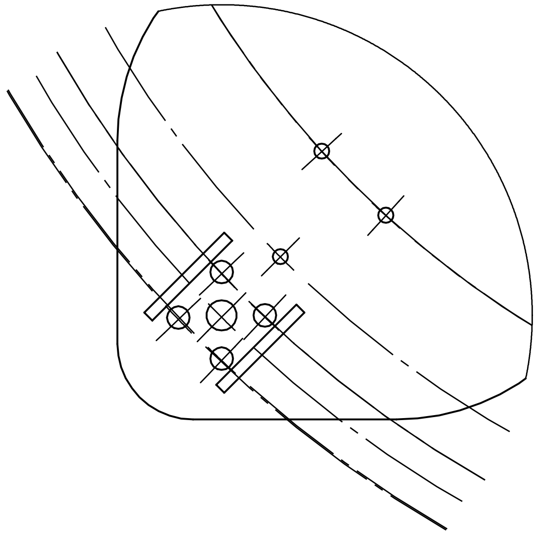
TITLE:

SIZE B
DWG. NO. 0001base seat
REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

B





DETAIL B
SCALE 1 : 1

B

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A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

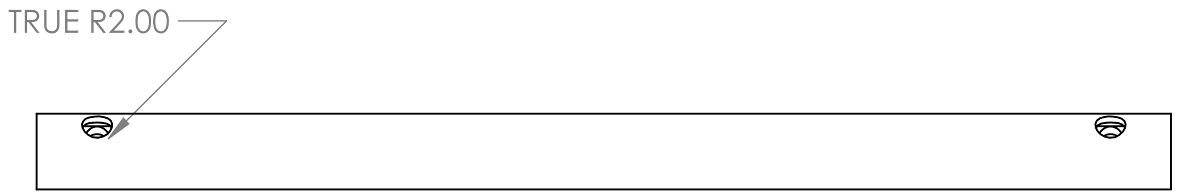
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

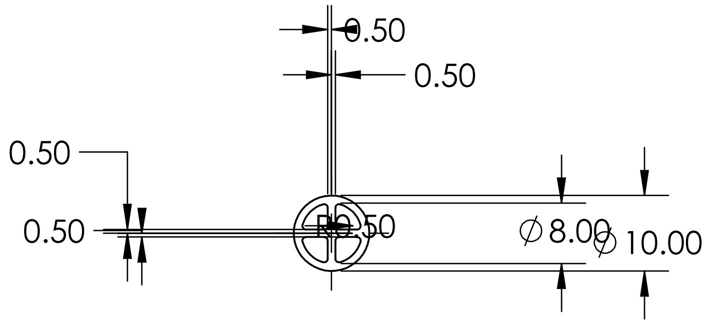
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	baseplate 1	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

B





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NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

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

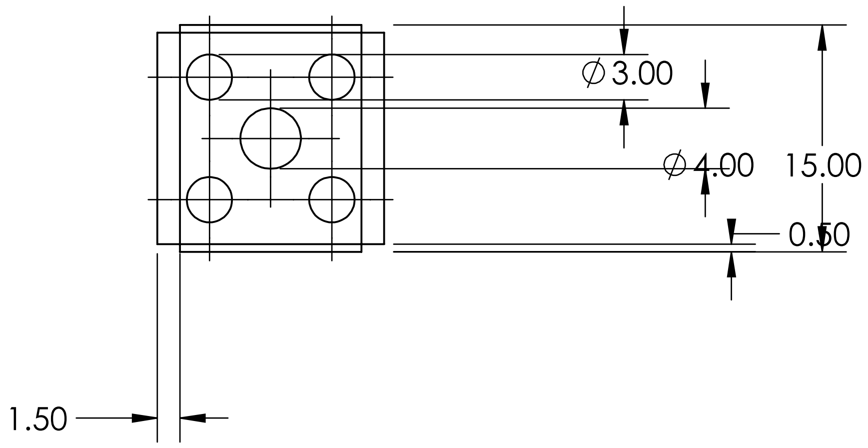
COMMENTS:

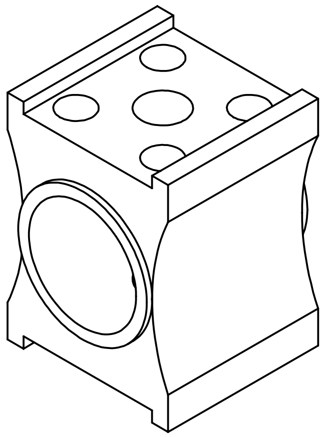
TITLE:

SIZE
B
DWG. NO.
arms
REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

B





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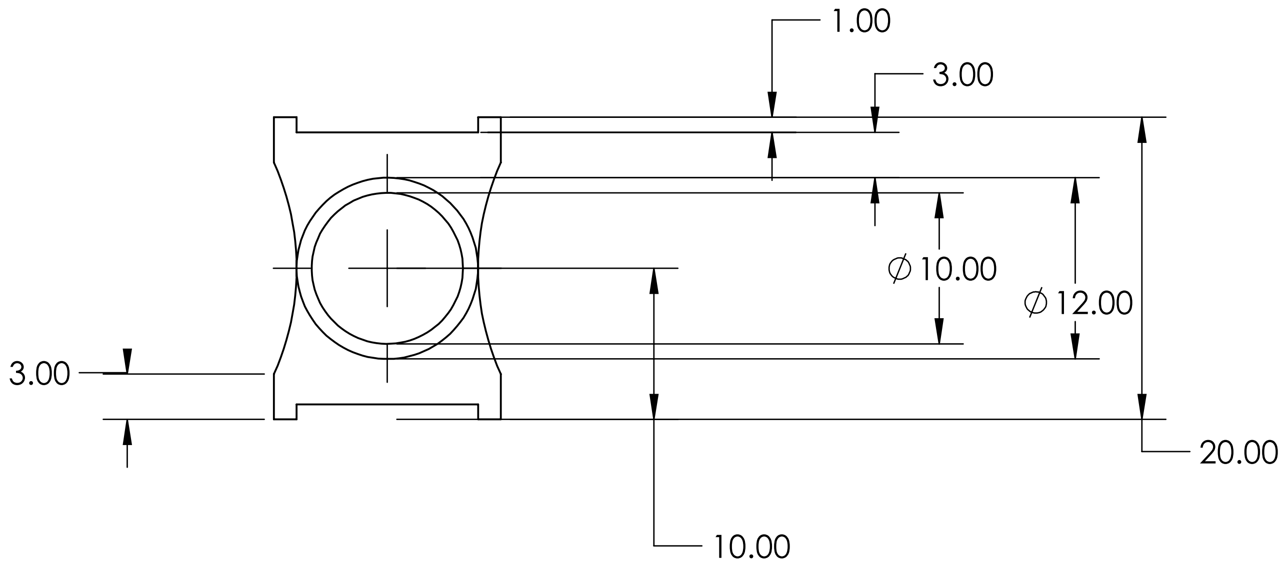
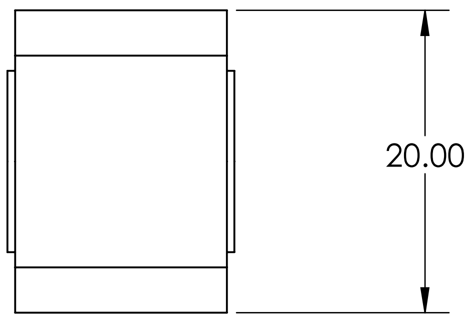




A

A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

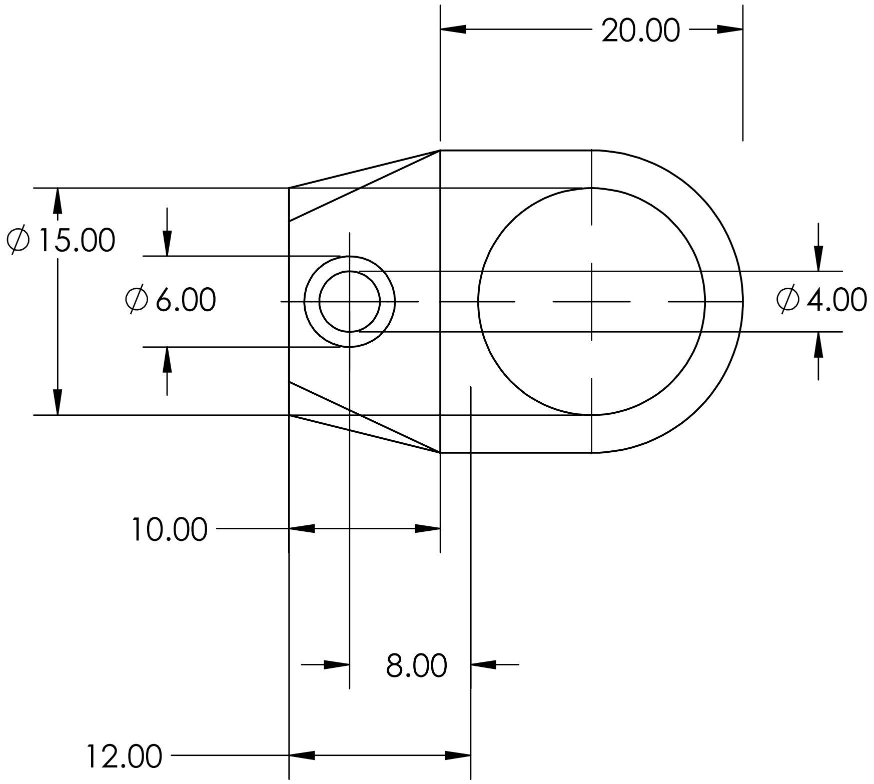
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

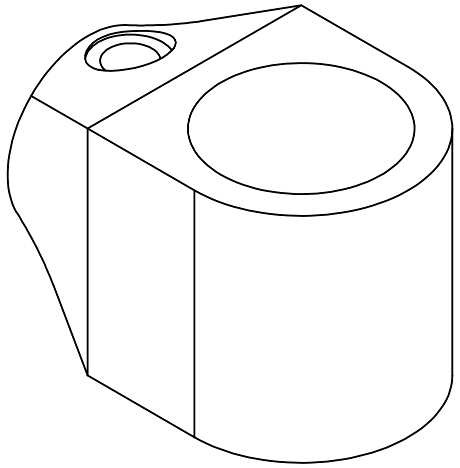
COMMENTS:

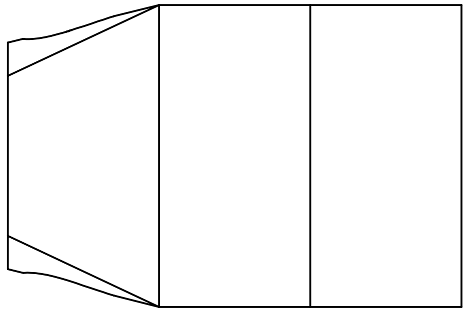
TITLE:

SIZE **B** DWG. NO. clamp 2 REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1







NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

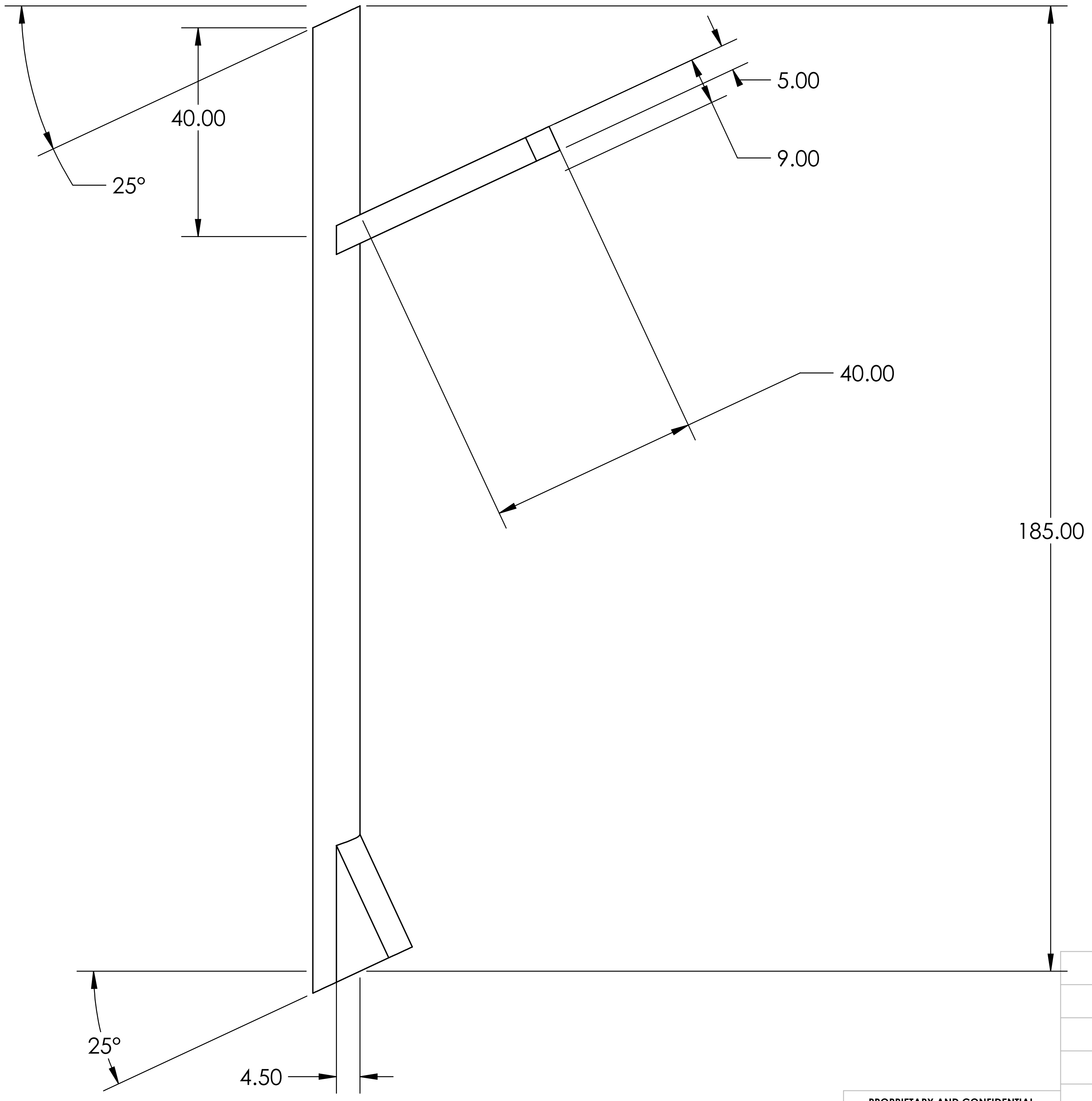
COMMENTS:

TITLE:

SIZE **B** DWG. NO. motor mount REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

B



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	leg	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1