DESIGN OF VARIABLE RATE SPRAYER FOR AGRICULTURAL DRONES

Final Year Project Report

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of the Requirements for the Degree of
Bachelor of Mechanical Engineering

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ABSTRACT

Pest outbreaks in agricultural landscapes are growing more common as climate and farmland ecological conditions change, increasing the demand for enhanced crop production equipment and methods. UAV-based agricultural spraying is expected to be a significant new technology for offering efficient and effective crop protection product applications.

Furthermore, for a developing country, such as Pakistan, it is important that we provide an indigenous, economical, and effective spraying system that works on variable rate spray for controlling the discharge and saving the wastage of pesticides.

This report illustrates the theoretical solution of our final year project, that is design and fabrication of a variable rate sprayer for agricultural drones.

ACKNOWLEDGMENTS

We would like to express our gratitude to our parents and our project supervisor, Dr. Zaib Ali, for their moral, social, and financial support throughout this project. We would also like to thank Dr. Jawad Khan for his assistance in developing our control mechanism for our variable rate sprayer and providing valuable feedback throughout this project.

ORIGINALITY REPORT

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ABBREVIATIONS

UAV	Unmanned Aerial Vehicle
TPU	Thermoplastic Polyurethane
CPVC	Chlorinated Polyvinyl Chloride

CHAPTER 1: INTRODUCTION

The world population will reach around 10 billion by 2050, according to the "Agriculture in 2050 Project." As a result, food production will need to be increased by 70%. Hence there is dire need of increasing agricultural crop yield by using new advanced farming methods. As climate and farmland ecological conditions change, insect outbreaks in agricultural landscapes become more common, posing new hazards to crop productivity. Hence, farmers have resolved this issue by using pesticides that are inorganic chemicals used to kills pests such as Jassids and American Bollworm (refer to Appendix A). Unfortunately, excess use of pesticides not only hinders crop growth but also harms human and animal habitats. To sort out this issue, many farmers all over the world have moved to aerial spraying using aircrafts and UAV drones.

Agricultural aerial spraying, both manned and unmanned, is frequently the most cost-effective and time-efficient technique of providing efficient and effective crop pest control applications, allowing for quick reactions to abrupt pest outbreaks. Furthermore, when compared to ground plant-protection technology, it can cover a broad area without destroying the crop or soil physical structure, which is very important.

Although, the state of Pakistan always considers the short comes of ground pesticide spraying, no advancement has been made to manufacture UAV spraying system locally. Hence, this project focus on designing such a system that is not only economical and more effective but also addresses the problem of pesticide wastage using variable rate spraying technology.

1.1 Motivation for work

Agriculture is the backbone of the Pakistani economy. It accounts for 24 percent of GDP and employs 48.4% of the labor force. Agriculture helps to growth by serving as a source of raw materials for industry as well as a market for industrial products, accounting for

60% of Pakistan's export revenues. Approximately 67 percent of the country's population lives in rural areas and is directly dependent on agriculture for a living. Farmers have been encouraged to employ contemporary practices such as insecticides and fertilizers to improve agricultural yields due to population growth and climate change.

To resolve the problem of pests such as aphids and whiteflies, farmers use pesticides to kill pests and save their crop. However, in some cases, farmers use extra dosage per acre of pesticides thinking that it will increase crop yield. This not only results in damaging crop yield and harming human and animal life, but it is also followed by wastage of useful pesticides.

Therefore, we have sorted to use Aerial Variable rate spraying technology by UAV drones. This not only resolves the issue of wastage of chemicals and saves crops but also prevent direct contact of humans and farm animals.

1.2 Problem Statement

The agriculture fields face dramatic losses due to the diseases. These diseases come from the pests and insects, which reduce the productivity of the crops. Hence fertilizers and pesticides are used to enhance the growth and quality of crop.

Pesticides are an essential aspect of modern agriculture, contributing to the productivity and quality of many agricultural goods. It is believed that the usage of agrochemicals avoids up to 45 percent of the world's food supply from being lost. Manual air-pressure and battery-powered knapsack sprayers are the most common spraying equipment used in conventional farming.

However, the World Health Organization (WHO) projected one million incidents of adverse effects from manually spraying pesticides in crop fields. Furthermore, conventional sprayers can result in significant pesticide losses and environmental damage.

Therefore, this is a need to develop a system by which we can spray pesticides or fertilizers in effective way i.e., spraying them without direct contact and in required amount as per crop requirement.

UAV-based agricultural spraying is anticipated to be an important new technology for providing efficient and effective applications of crop protection products

1.3 Objectives of the Project

The objectives of the project can be set forth as:

- To have a local indigenous system for UAV agricultural spraying.
- To save resources by providing a variable rate spraying mechanism as continuous spraying causes wastage of chemicals.
- To make a prototype for future research

CHAPTER 2: LITERATURE REVIEW

2.1 Classification of UAV drones

Over the last two decades, there has been a tremendous increase in the production and sale of remote-control flying vehicles known as Unmanned Aerial Vehicle (UAV) drones. There are different types of drones based on their use and number of rotors.

2.1.1 Based on Design

Unmanned Aerial Vehicles (UAVs) were first developed in the twentieth century for military missions that were too "dull, dirty, or dangerous" for humans, and by the twenty-first century, they had become critical assets to most forces. Control technology progressed and costs fell, allowing them to be used in a wide range of non-military applications. Among them include aerial photography, product delivery, agriculture, law enforcement and surveillance, infrastructure inspections, science, smuggling, and drone racing. Our project will centre on agricultural UAV drones. In 1985, Yamaha produced the Model Rmax, the world's first agricultural UAV, for pesticide spraying. It was a medium-scale unmanned helicopter with a payload capacity of 5 kg. In addition, the business has created a line of unmanned helicopters (KG-135, YH300, and AYH3, among others) (shown on the right for pesticide spraying over crop fields. Many countries throughout the world have used Yamaha helicopters as a research platform. However, the export of Yamaha helicopters was prohibited in 2007 in order to protect the company's technology. Recently there are two major agricultural drone manufacturers:

Figure 1 Yamaha's Fazar, R

- *DJI Agriculture Co. Ltd*
- *XAG Agricultural company*

2.1.2 Based on number of rotors

Multi-rotor UAVs, which include four, six, and eight-rotor platforms (shown in the figure below), have surpassed helicopters as the most often utilized UAV platforms for agricultural applications.

Figure 2 Multi rotor drones

2.2 Main Components of a UAV drone

For better **i**llustration**,** we will consider a quadcopter and briefly discuss each of its main parts.

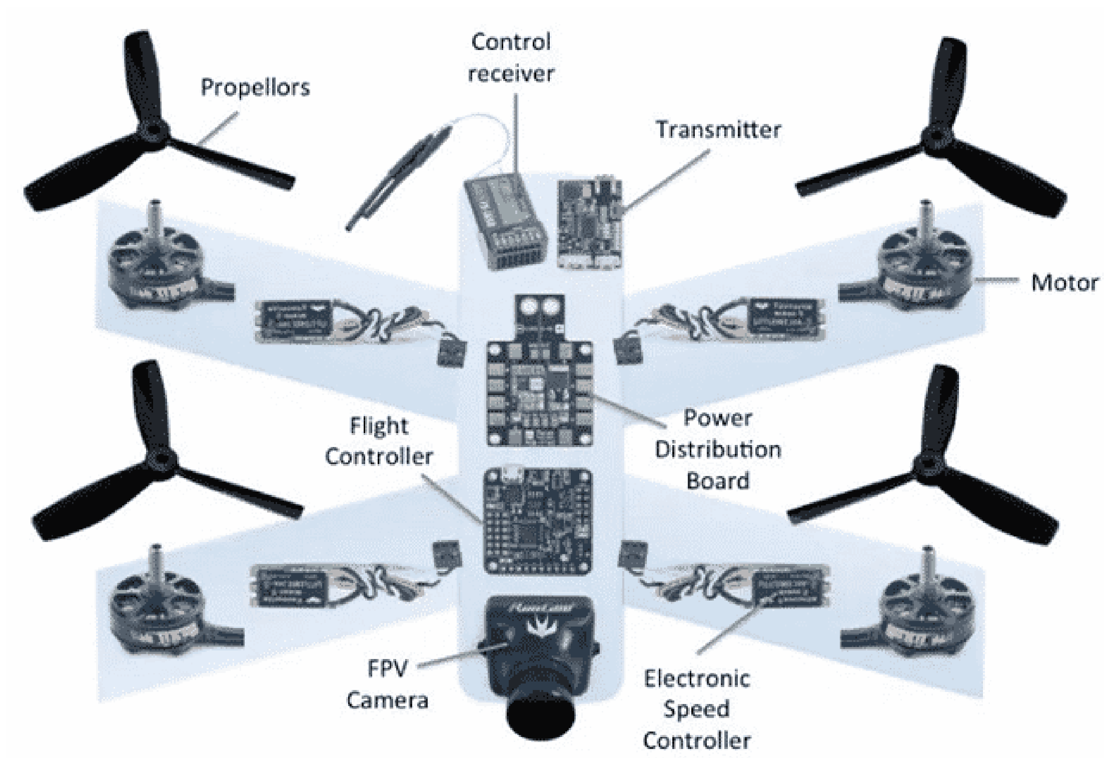


Figure 3 Main components of a UAV quadcopter

Electronic Speed Controller

Electronic speed controllers (ESC) are electronic circuits that control the speed of direct current (DC) motors. It also has dynamic braking and reversing capabilities.

DC Motors

High torque motors are required to keep the drone aloft for an extended period of time. The high torque also aids in adjusting the speed of the propellers. Brushless DC motors are favored over brushed motors because they are lighter.

Propellers/ Wings

Drones/UAVs are guided by propellers, wings, or both (depending on availability). Drones powered by propellers have two types of propellers onboard for direction and force. There are Standard propellers and Pusher propellers.

Chassis

This is the primary body of the quadcopter that houses all the other components.

Flight Controller

The flight controller is often known as the drone's brain. The flight controller controls the power supply to the electronic speed controller. It is also used to detect changes in the drone's orientation. It controls the motors and keeps the drone airborne.

Landing Gear

Small drones do not require landing gear. Larger drones, on the other hand, require landing gear to prevent damage when landing. The necessity of the landing gear changes according to the drone functionality. For example, delivery drones that transport packages require a large landing gear to accommodate the contents

Transmitter

The transmitter transfers messages from the controller to the drone to create direction and thrust commands.

Receiver

The receiver takes signals from the transmitter and forwards them to the Flight Controller PCB.

GPS Module

The GPS module transmits navigational information to the Controller (longitude, latitude, and elevation). This module assists the controller in detecting the taken path and safely returning to the initial point in the event of a lost connection.

Battery

It gives the drone power. In most cases, rechargeable batteries are employed in drones.

2.3 Main Components of Pesticide Sprayer

Pesticide sprayer is mounted either below or above the frame of UAV depending on the weight carrying capacity and material of the drone. The sprayer generally consists of a sprayer tank, a pump, pipes or tubes, several nozzles, and a control mechanism for adjusting discharge rate of the nozzles according to the crop and pesticide used.

2.3.1 Sprayer Tank

It is used to store pesticides to be sprayed in the fields. It is available in different shapes but the preferable one is funnel type. In a funnel type sprayer tank, the fluid flows under the action of gravitational force and the shape ensures that all the liquid is drained.

Figure 4 A sample hexacopter drone with pesticide sprayer

All pesticide application equipment should be made of corrosion-resistant materials. Fiberglass and stainless steel, as well as plastic coatings, resist corrosion induced by most chemicals; however, the endurance of these materials is diminished if cracks or chips in the coating occur and expose the base metal to corrosive forces. Untreated metal can be used to apply noncorrosive pesticide solutions, although care must be taken to avoid rust and scaling. As a result, all tanks should be built to prevent leaking and burst. The following table describes the impact of several chemicals on storing equipment.

Table 1 Material performance in commercial fertilizers after two years of service life

Material	***Penetration (μm)***
304 stainless steel	0,253
Carbon steel	282
5052 aluminium	132

2.3.2 Sprayer Pump

A pump is characterized by its pump head and volume flow rate. The size and weight of the pump depends on the thrust capacity of the drone. The discharge rate of the pump and type of pump used depends on the pesticide and crop application.

a) <u>Centrifugal Pump:</u> A centrifugal pump is a mechanical device that moves fluids by transferring rotational energy from one or more impellers, which are driven rotors. Fluid enters the rapidly rotating impeller along its axis and is expended along its circle by centrifugal force via the vane tips. The action of the impeller increases the velocity and pressure of the fluid and guides it toward the pump exit.

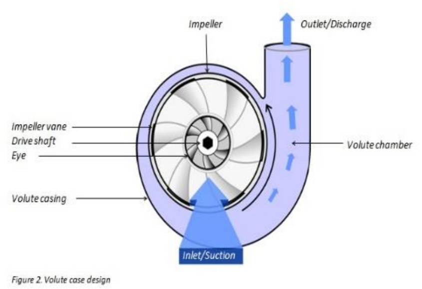


Figure 5 Major components of a centrifugal pump

b) <u>Axial Flow Pump:</u> Another type of pump is axial flow pump. Here, water flows in and flows out axially. The pump converts rotational kinetic energy of the impeller blades to kinetic energy of water resulting in increase in pressure and flow rate of water.

c) A positive displacement (PD) pump moves a fluid by confining and mechanically moving a fixed volume across the system on a regular basis. Pumping is cyclic and can be powered pistons, screws, gears, rollers, diaphragms, or vanes. Although there are many different types of pumps, majority of them fall into two categories: reciprocating and rotary.

2.3.3 Sprayer Nozzle

2.3.3.1 Importance of Nozzle selection for pesticide spraying

The nozzle has a large influence on the amount of spray sprayed to an area, the uniformity of application, the amount of coverage received on the target surface, and the amount of potential drift. Spraying system nozzles divide the liquid into droplets, which produce the spray pattern. The nozzles at a given operating pressure, travel speed, and spacing define the application volume. Drift can be reduced by choosing nozzles with the biggest droplet size while still providing appropriate coverage at the intended application rate and pressure. As a result, selecting the optimal nozzle type and size is crucial for correct and accurate pesticide application.

2.3.3.2 Sprayer Nozzle Types

As indicated in the image below, the most frequent varieties for ground application of agricultural chemicals include flat fan, even flat fan, cone nozzle, hollow cone nozzle, and flood nozzle.

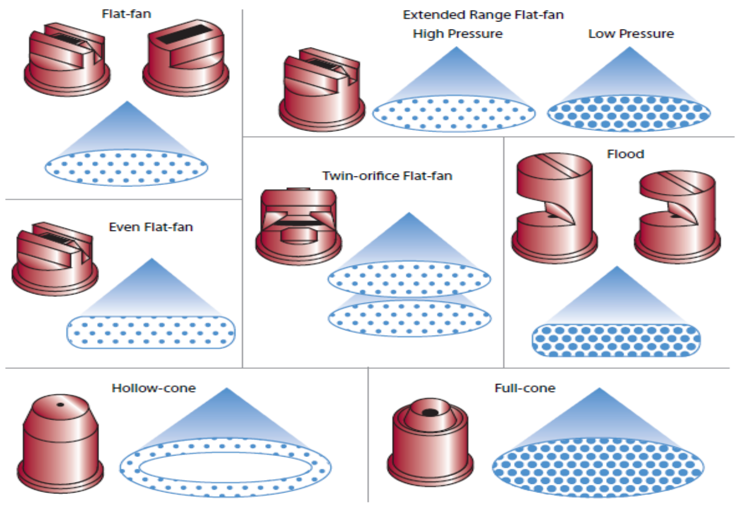


Figure 6 Different Types of Sprayer Nozzles

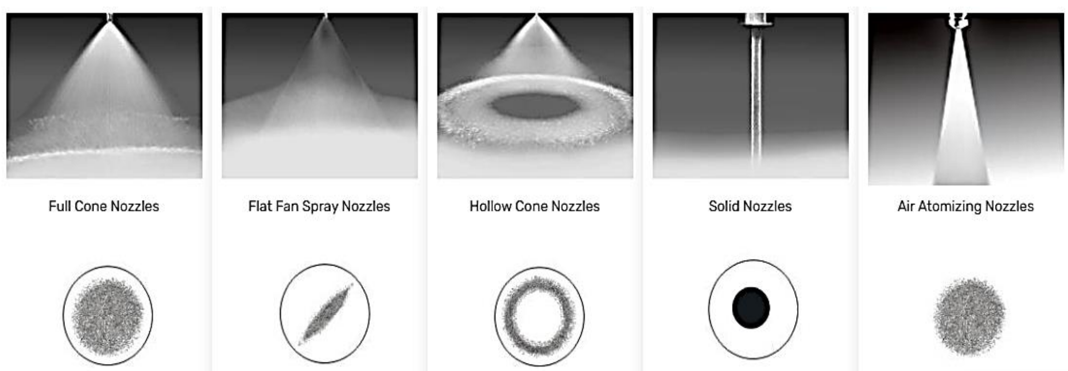


Figure 7 Spray pattern of different nozzles

The fan nozzle is the most commonly used type of nozzle in agriculture. Pesticide spraying using a fan nozzle is typical in both banding (over and between rows) and broadcast applications.

These nozzles produce a tapered flat-fan spray pattern (Figure 6). Broadcast boom sprayer nozzles are positioned so that their output overlaps. There are various types of fan nozzles, such as:

• standard flat-fan.

• even (E) flat-fan;

• low-pressure flat-fan; and

• extended-range (XR) flat-fan;

and some special types such as

• off-center (OC) flat-fan; and

• twin-orifice (TJ) flat-fan.

Other designs include flood nozzles, turfjet nozzles, hollow-cone nozzles and full-cone nozzles.

2.3.3.3 Nozzle materials

Nozzles are produced from a variety of materials. Brass, nylon, stainless steel, toughened stainless steel, tungsten carbide, thermoplastic, and ceramic are the most prevalent. Ceramic and tungsten-carbide nozzles are exceptionally durable and corrosion-resistant. Nozzles made of stain-resistant steel endure longer than those made of brass or nylon and generate a more consistent pattern over time.

2.3.3.4 Nozzle Nomenclature

Most firms assign a four- or five-digit number to their flat-fan nozzles (Figure below). The first values represent the spray angle, and the other numbers represent the discharge rate at the rated pressures. An 11002 nozzle has a 110-degree spray angle and applies 0.2 GPM at 40 psi. Additional designations are "**BR**", brass material; '**SS**" stainless steel; "**HS**" hardened stainless steel; "**VP**", polymer with color coings; **"VK**" ceramic with color coding; "**VH**" Hardened steel with color coding and "**VS**" stainless steel with color coding

Nozzle Type

Spray angle

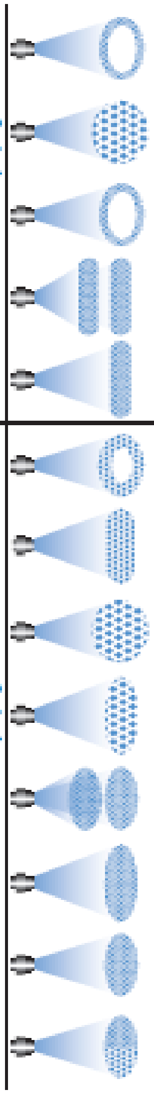
Nozzle discharge GPM

Figure 8 Nozzle Identification

2.2.3.5 Nozzle Selection and Sizing

Sprayer nozzles are selected based on their application or using nozzle catalogues.

Table 2 Nozzle Guide for Spraying



	Broadcast Spraying								Band and Direct Spraying				
	Extended Range Flat Fan	Standard Flat Fan	DriftGuard Flat Fan	Twin Flat Fan	Turbo Flood Wide Angle	FullCone	Flood Nozzle Wide Angle	Raindrop Hollow Cone	Even Flat Fan	Twin Even Flat Fan	Hollow Cone	Full Cone	Disc and Core Cone
Herbicides													
Soil-Incorporated	Good		Very Good		Very Good	Very Good	Good	Good					
Pre-emerge	Very Good (on low pressure)	Good	Very Good		Very Good	Very Good		Good	Very Good	Good		Good	
Post-emerge Contact	Good	Good		Very Good					Good	Very Good	Very Good		
Post-emerge Systemic	Very Good (on low pressure)	Good	Very Good		Very Good			Good	Very Good	Good			
Fungicides													
Contact	Very Good	Good							Good		Good		Very Good
Systemic	Very Good (on low pressure)		Very Good		Very Good				Very Good				Good
Insecticides													
Contact	Good	Good		Very Good						Very Good	Very Good		Very Good
Systemic	Very Good (on low pressure)		Very Good		Very Good				Very Good				Good

2.4 Control system for variable rate spraying

This is the brain of the whole system. It is responsible for changing the spray discharge as desired for different crops and different landscapes. Some areas of field are required to be left untouched. Spraying on such fields will not only hinder crop growth but will also result in wastage of chemicals.

2.5 Operational Parameters for improving Spraying efficiency

A thorough study was conducted by a team of engineers on the effects of operating parameters such as flight speed, droplet drift, and effective spray width on Spraying efficiency.

The study's findings revealed that the operation parameters are strongly related to the Effective Spray width, Droplet deposition uniformity, flight speed, flight height, Droplet Penetration Rate, and even spraying efficiency. The simulations showed that by optimizing the aerial spraying parameters, the acquired control effects for aphids, powdery mildew, and head blight could fulfil the actual needs in general. As a result, the combined operation parameters employed in the real application are deemed inappropriate. To achieve good prevention and control results, it should be paired with agronomic needs to select the suitable parameters based on crop types, growth time, pests and diseases characteristics, and even environmental circumstances. For further details on the research study, refer to [16].

2.6 Agricultural study

Pakistan has an area of 80 million hectares. 22 million hectares are used for crop cultivation. Around 18 million acres (80%) of farmed land is irrigated, with the remainder being dry farmland. Agriculture is the backbone of the Pakistani economy. It accounts for 24 percent of GDP and employs 48.4% of the labor force. Agriculture contributes to growth by providing raw materials to industry as well as a market for industrial products, accounting for 60% of Pakistan's export revenues.

2.5.1 Different types of crops grown in Pakistan

There are two primary crop seasons in Pakistan: "Kharif," which starts in April and ends in April-May, and "Rabi," which starts in October-December and ends in April-May. Rice, sugar cane, cotton, maize, and millet are Kharif crops, whereas wheat, jute, tobacco, rapeseed, barley, and mustard are Rabi crops. The table below outlines the crops grown in various regions of Pakistan, as well as the various irrigation systems used.

Table 3 Crop Production regions in Pakistan

No.	Region	Cropping pattern	Agricultural area (million ha)	Source of Irrigation	Rainfall mm (1966-2002)	
					Average	Range
1.	Punjab I	Cotton-wheat	5.5	Canal, tubewell	156	55-247
2.	Punjab II	Rice-wheat	2.8	Canal, tubewell	800	600-1 100
3.	Punjab III	Mixed crops	4.1	Canal, tubewell	446	240-688
4.	Punjab IV	Pulses-wheat	1.9	Canal, rainfed	300	200-550
5.	Punjab V	Maize/wheat-oilseeds	1.2	Rainfed	900	700-1 200
6.	Sindh I	Cotton-wheat	1.6	Canal	50	43-70
7.	Sindh II	Rice-wheat	1.1	Canal	58	40-78
8.	Sindh III	Mixed crops	1.3	Canal, dry	123	62-200
9.	NWFP I	Maize-wheat	0.9	Rainfed	1050	240-1700
10.	NWFP II	Mixed crops	0.53	Canal	520	400-670
11.	NWFP III	Pulses-wheat	0.36	Canal, dry	500	300-600
12.	Balochistan I	Mixed crops	0.40	Tubewell, Karez	180	65-3405
13.	Balochistan II	Orchards/vegetables-wheat	0.30	Tubewell, Karez	115	27-290
14.	Balochistan III	Rice-wheat	0.35	Canal	-	-
15.	Balochistan IV	Peri-urban	0.02	Tubewell, Karez	167	167

2.5.2 Major Pesticides used on crops

Among all the crops, cotton has the highest production rate in the country. It also consumes a large percentage of fertilizers and pesticides. Therefore, we will only consider pesticides used on cotton crop.

In Pakistan, 80% of the total pesticides sprayed are used on cotton crop. Pesticides such as Acetamiprid come in soluble powder and are mixed with water or other liquid to be sprayed in the cotton fields. It is used to protect the protects from pests such as Aphids and White fly.

Appendix I: Pesticides used on cotton contains detailed information about pests and their recommended pesticides. It also contains information about what pesticide to use on cotton crop under different pest conditions.

2.5.3 Effect of Pesticides on Environment

Farmers use more pesticides by increasing the number of sprays/dosages which they believe increases crop production, however, these poor preventive measures not only damage the crops but also puts farming communities, including women and children at risk.

How and why Pesticides are hazardous to human health

Pesticides are dangerous by design: they are chemicals designed to kill, repel, or impede the growth of living organisms by interfering with biological processes essential to life. Pesticides are used in numerous instances. not only influence the physiology of the pest species they are meant to suppress, However, they also have an impact on the well-being of human adults and children. This occurrence is especially linked to pesticides, many of which are designed to wreak havoc on biological systems found throughout much of the world such as the neurological and reproductive systems of animals Of course, the 201 agrochemicals categorized by the WHO as 'Extremely', 'Extremely', 'Extremely', 'Extremely', 'Extremely', Insecticides are by far the most dangerous, whether classified as 'very' or ‘moderately' dangerous. grouping (52%). In comparison, the percentages of herbicides (15%), fungicides (14%), and rodenticides (10%) included in these hazard groups are significantly smaller.

2.6 Entrepreneurial aspects of using aerial spraying technology

Drones' application in agriculture has skyrocketed in recent years. Soil and field analysis, mapping and animal identification, irrigation, crop spraying, and planting are some of the applications. According to a quantitative survey of professional drone users in Switzerland done in 2017 (Klauser et al., 2017), 90 percent of farmers who use drones would not use the airspace without the technology, and 88 percent expect other farmers to employ the technology in the future.

Although aerial spraying technology is not new, its use in agricultural spraying has been restricted to a few crops due to complex terrains and crop nature. Even in the developed parts of the world such as Europe, until 2019, only Switzerland had permitted its states to use aerial farming. Hence, businesses have to go through a lot of hardships to convince their customers and the government that their product can prevent wastage of chemicals and ensure proper spraying in the fields. Hopefully, soon, with the rise of variable rate technology, aerial spraying using UAV drones will replace ground spraying as more safe and efficient method for pesticide and fertilizer spraying.

CHAPTER 3: METHODOLOGY

3.1 DJI F550 Hexa-copter

For our project, we have used a DJI F550 Hexa-copter. The drone comprises of:

- 5200mAh LiPo Battery
- PIXHAWK Flight Controller
- 1045 Propellers
- 6 sets of 1000 kV A2212 BLDC motors
- 6 sets of 30A ESCs
- Hexa-copter F550 Frame
- Other accessories include transmitters, receivers

Figure 9 Hexacopter Sprayer Assembly

3.2 Construction of UAV Pesticide Sprayer

The prefix hexa-copter implies a drone configuration with six arms ("hexa" = six). The main frame is made of carbon fiber composite material. A motor will be fixed at each free end of the arm, and a propeller will be mechanically coupled to the motor. The output side of an ESC will be connected to the flight controller for all six motors, and the input side of the Electronic Speed Controller (ESC) will be connected to the flight controller. The ESC's other input will be connected to the power distribution board, which will be powered by the Li-Po battery. All of the other ESCs, motors, and propellers are linked in the same way. To receive signals from the transmitter remote, a receiver will be connected to the Flight controller. The sprayer tank is mechanically coupled to the frame, and the tank's bottom has a slope to allow the entire tank to be drained completely. A meter long plastic tube with two nozzles spaced is used. A pump is powered by a power distribution board, and its inlet is connected to a storage tank, while its outlet is connected to a plastic tube in which nozzles are fixed. The landing frame of height 18mm is connected to the main frame so that the landing of the drone will be safe, and the sprayer tank will not touch the ground.

3.3 Working of UAV Pesticide Sprayer

The signals will be sent by the Transmitter and received by the Receiver in the drone. The signal is sent from the receiver to the flight controller, where it is processed using accelerometer and gyroscope sensors. The processed signal is sent to the ESC, which allows the motor to receive a specific amount of current based on the signal it receives. The propellers are mechanically coupled to the motors, causing them to rotate and generate thrust. The pump draws power from the Li-Po battery and pressurizes the liquid in the storage tank before it goes through the pipeline and into the nozzle, from where it is sprayed. The pump's flow rate can be regulated by altering the input current, which is controlled by the transmitter

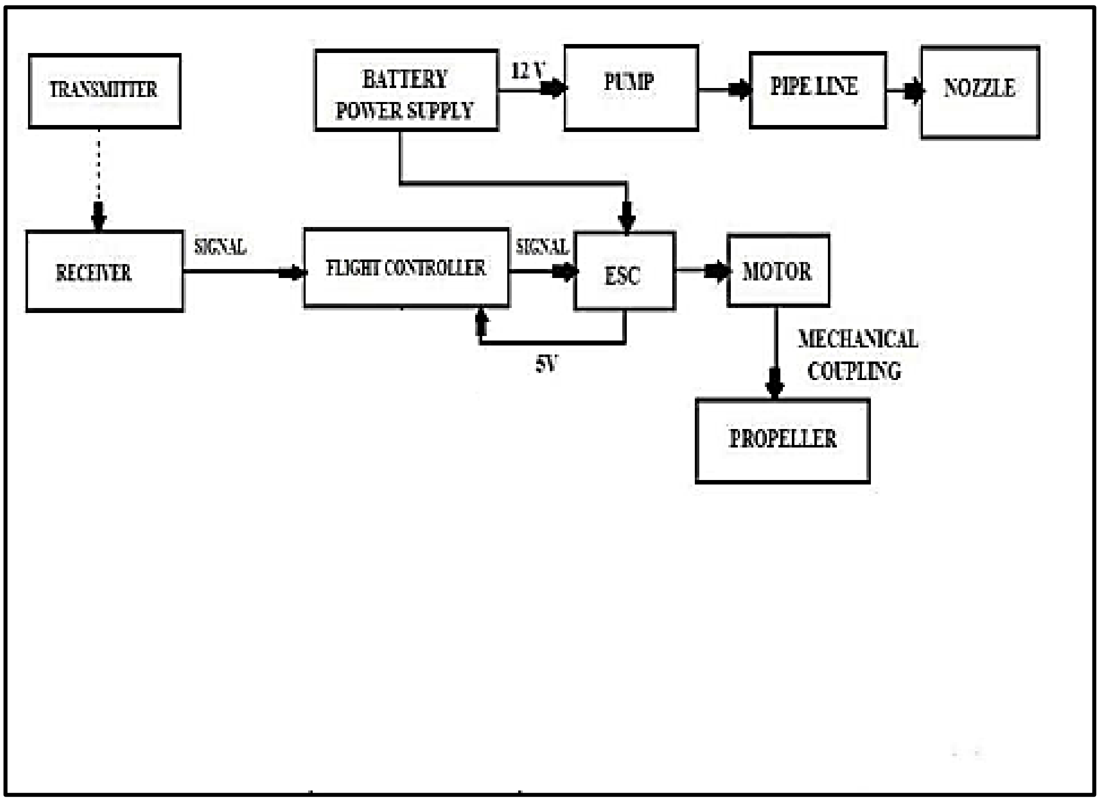


Figure 10 Block Diagram of Hexacopter and Sprayer Assembly

3.4 Drone Payload calculations

3.4.1 Mass of sprayer assembly

Take density of water = 998 kg/m^3

Volume of water in sprayer tank = 600 ml = 0.6 L = 0.0006 m^3.

Mass of water = 998*0.0006 = 0.59 kg

Mass of tank = 20 g = 0.02 g

Mass of pump = 550g = 0.55 kg

Mass of nozzles = 2*5= 10 g = 0.01kg

Mass of other accessories including elbows, T-joint, pipes and Arduino circuits
= 400 g = 0.4 kg

Total mass = 1.58kg

3.4.2 Calculated payload of drone on basis of thrust force

The thrust force of the selected electric motor and propeller pairs was calculated with the following formula.

T=[((ηxP) ^2)$x2\pi x$ (r^2)xρ]^(1/3)

Here;

η: propeller efficiency (between 0.7-0.9), preferred:0.8

P: electric motor power (Watt),

Voltage applied = 12V

Rated Current = 10 A

Electric motor power = 120 W

r: radius of propellers (m), = 12.7 cm = 0.127 m

ρ: air density (1.22 kg/m3)

Calculated thrust from single motor is =10.44 N

With 6 motors, total thrust force provided by the motors = 10.44*6 = 62.64 kN

Lifting capacity of motors = 62.64/9.81 = 6.38 kg

Applying a factor of safety of 2, we have lifting capacity = 6.38/2 = 3.19 kg

Conclusion: As lifting capacity of motors is greater than mass of sprayer assembly, therefore, it is proved that our drone will lift our sprayer assembly.

3.5 UAV Pesticide Sprayer CAD Designs

3.5.1 Pesticide Sprayer

The sprayer consists of a sprayer tank made of ABS (acrylonitrile butadiene styrene) plastic. It is followed by a pump that increases the flow rate of water. For different operating conditions, flow rate can be varied with the help of Arduino micro-controllers and servomotors. Water from the sensor flows through pipes into each of the two nozzles. Water is then sprayed to the ground.

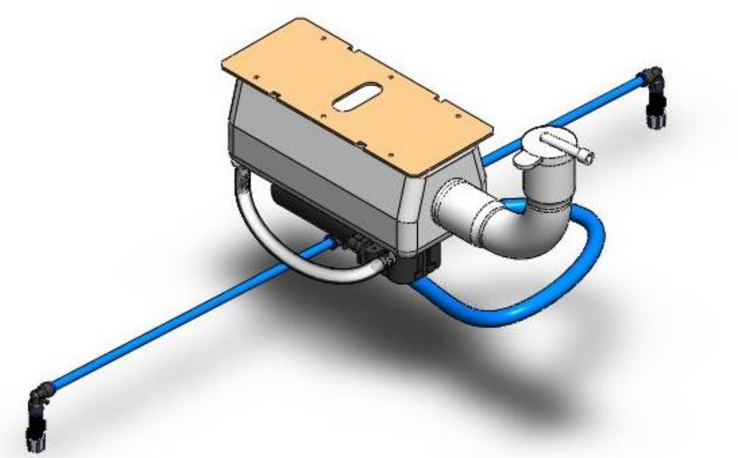


Figure 11 Pesticide Sprayer

3.5.2 Sprayer Tank

The sprayer tank is a horizontal cylinder with a funnel opening as shown in the figure below. Before spraying, water plus pesticide is injected in the tank from the inlet.

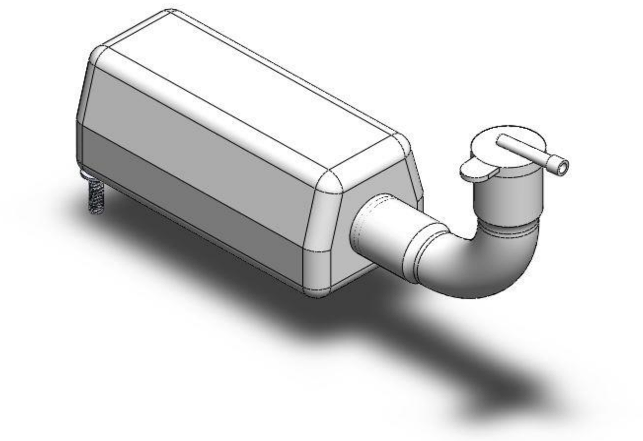


Figure 12 Sprayer Tank

3.5.3 Water Pump

It is used to increase the pressure and flow rate of water. We have used positive displacement pump with a discharge pressure of 450 kpa and flow rate of 2.6 L/min.

Figure 13 Water Pump

3.5.4 Spray Nozzle

A plastic water spray nozzle of outlet diameter 0.8mm and discharge flow rate of 0.675 L/min when connected with our pump is used for our sprayer.

Figure 14 Plastic Nozzle

3.6 Pesticide Selection

After a thorough market survey of available pesticides for cotton with a discharge rate suitable for our selected nozzle and pump, we have chosen **Chlorpyrifos** with a flow rate of 1000 ml/acre. Considering our drone speed, it could take 1.5 to 2 min to cover an acre. This speed is suitable for our flow rate of 675 ml /min.

Details of Chlorpyrifos pesticide, and its usage on cotton crop has been provided in **Appendix 1.**

3.7 Pipe Length Calculations

Data:

Tank inlet diameter: d_i = 2.5 cm = 0.025m

Tank outlet diameter: d_1 = 0.5 cm = 0.005m

Pipe inlet diameter for Pump inlet/outlet: d_2 = 0.84 cm = 0.0084m

Pipe inlet diameter for nozzle entry = d_3 = 0.4 cm = 0.004m

Nozzle outlet diameter (plastic water sprinkler nozzle) = 0.8 mm = 0.0008 m

Pump flow rate (experimental) = 0.675 L/ min = 1.125×10^{-5} m/s^3

Pump head = 4.5 bar = 450 kpa

Pressure on the tank surface: P_1 = 1 atm = 101.325 kpa

Pressure at nozzle exit = P_4 = 101.325 kPa

Height of water level in the tank with respect to ground = 18 cm = 0.18 m

Objective

1. To determine maximum pipe length for spray water to flow through the sprayer assembly without flow blockage due pressure generated from nozzle.
2. Use the maximum pipe length and drone length parameters to determine optimum pipe length for sprayer.

Procedure

1. Apply mechanical energy equation in its head form for steady incompressible fluid flow.
2. Use the mechanical energy equation to determine maximum length for the pipe through which fluid can flow steadily.
3. Compare maximum pipe length to drone size and determine most suitable pipe length for sprayer.

Calculations

Objective 1: Maximum Pipe Length

Apply mechanical energy equation for steady incompressible fluid flow for two different locations in the pipe.

$$\frac{p_{out}}{\gamma} + \frac{V_{out}^2}{2g} + z_{out} = \frac{p_{in}}{\gamma} + \frac{V_{in}^2}{2g} + z_{in} + h_s - h_L$$

where

$$h_s = w_{shaft\ net\ in}/g = \frac{\dot{W}_{\substack{shaft\\net\ in}}}{\dot{m}g} = \frac{\dot{W}_{\substack{shaft\\net\ in}}}{\gamma Q}$$

Here,

P_{in}, $V_{in,}$ and z_{in} represent fluid properties at the surface of the pipe as P_1, V_1, and z_1.

P_{out}, V_{out} and z_{out} represent fluid properties at the nozzle exit as P_4, V_4, and z_4.

h_L = head losses due to pipe friction and other pipe components such as T-joints and elbows

h_s = shaft work or pump head.

γ = specific weight of water at 20^0C = 9789 N/m^3

g = acceleration due to gravity = 9.81 m/s^2

Using our data,

P_1 = 1 atm = 101.325 kPa (free surface)

P_4 = 1 atm = 101.325 kPa (free jet)

z_4 = 0 (reference)

z_1 = 18 cm = 0.18 m

V_1 = 0

From flow rate, Q = 0.675 L/ min = 1.125 x 10^{-5} m/s^3, we can calculate fluid velocities at different sections of pipe using the formula:

$$Q = \frac{\pi}{4} D^2 * V$$

For D_2 = 0.0084 m, we have V_2 = 0.203 m/s

D_3 = 0.004 m, we have V_3 = 0.895 m/s

D_4 = 0.0008 m (nozzle exit), we have V_4 = 21.04 m/s

Pump head

Pump head can be calculated using the formula:

$$h_p = \frac{P}{\gamma}$$

P = 4.5 bar = 450 kPa

γ = 9789 N/m^3.

Putting the values in the above equation, we get

h_p = 45.96 m

Minor head losses

Minor head loss ($h_{L,minor}$) is given by the equation:

$$h_{L\,\text{minor}} = K_L \frac{V^2}{2g}$$

where K_L stands for loss coefficients at pipe components. The loss coefficients for different pipe components have been calculated below:

1. At sharp entrance of pipe at tank outlet, K_L = 0.5
2. At T-joint, K_L = 1.0 (branch flow, flanged)
3. At pipe elbows just before nozzle entry, K_L = 0.3 (regular 90^0, flanged)
4. Nozzle: Loss due to sudden contraction.

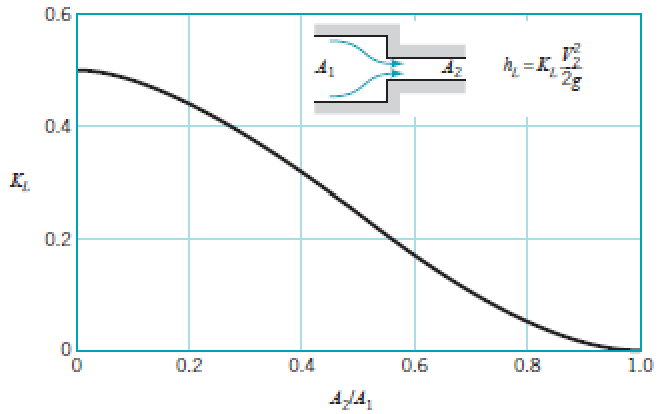


Figure 15 Loss coefficient for a sudden contraction

$A_2/A_1 = \frac{Nozzle\ exit\ area}{Nozzle\ entrance\ area} = \left(\frac{D4}{D3}\right)^2 = \left(\frac{0.0005}{0.004}\right)^2 = 0.0156$

From the graph, $K_L = 0.49$.

$h_{L,minor} = \sum K\ \frac{V^2}{2g} = \frac{0.5(0.203)^2}{2(9.81)} + \frac{1(0.203)^2}{2(9.81)} + \frac{2(0.3)(0.895)^2}{2(9.81)} + \frac{2(0.5)(21.04)^2}{2(9.81)} = 22.59$

Major head losses

Major head losses occur due to fluid friction and can be calculated using the formula:

$$h_{L\ major} = f\frac{\ell}{D}\frac{V^2}{2g}$$

Where *f* = friction factor.

L = pipe length

D = pipe diameter

V = fluid velocity

We need to account for pipe lengths from pump exit to T-joint and then from T-joint to nozzles. Let these lengths be denoted as L_2 and L_3.

For *f*, we need to find whether flow is laminar or turbulent for both D_2 and D_3.

Using the formula,

$$Re = \frac{\rho V D}{\mu}$$

ρ = 998 kg/m^3

$\mu = 1.002 * 10^{-3}$

For D_2 = 0.0084 m and V_2 = 0.203 m/s. Re = 1696.7 (laminar flow).

For laminar flow,

$$f = \frac{64}{Re}$$

f = 0.0377

For D_3 = 0.004 m and V_3 = 0.895 m/s. Re = 3562.15 (transitional flow)

For transitional flow,

As Re<4000, we can use the same formula for previous calculations

$$f = \frac{64}{Re}$$

f = 0.018

Putting all the values in major head loss equation, we get

$$h_{L,major} = \frac{0.0377(L2)(0.203)^2}{(0.0084)(2(9.81))} + \frac{0.018(L3)(0.895)^2}{(0.004)(2(9.81))} = 0.00942L_2 + 0.183L_3$$

<u>Total Head loss</u>

$$h_L = h_{L\,major} + h_{L\,minor}$$

$h_L = 0.00942L_2 + 0.183L_3 + 22.59$

<u>Maximum Pipe length</u>

Finally, putting all values in the energy equation, we get

$$\frac{101.325}{9789} + \frac{21.04^2}{2(9.81)} + 0 = \frac{101.325}{9789} + 0 + 0.18 + 45.96 - (0.00942L_2 + 0.183L_3 + 22.59)$$

Solving and simplifying the equation for unknowns, we get

$0.00942L_2 + 0.183L_3 = 0.642$

$L_2 + 19.42L_3 = 68.23$

Now, we have two variables and one equation. Thus, we need to compromise a less significant value. In our case, it is length between pump exit and T-joint (L_2)

Assuming, L_2 = 2 ft = 60.96 cm ≈61 cm = 0.61 m and putting in the above equation, we get

L_3 = 3.482 m

Note L_3 is length between one nozzle to the other. Therefore,

- ⇨ **Maximum Pipe length = 3.482 m ≈ 3.48 m**

Objective 2: Suitable pipe length with respect to drone parameters

The above calculations focused entirely on pump head flow rates. In the end, we calculated, that for our given spraying system the boom length of our pipe should not exceed 3.48 m. This value is independent on type of drone but sets an upper limit.

For our case of DJI 550 hexacopter drone, distance between propellers at opposite ends is equal to 55 cm or 0.55 m. Hence, we take desired pipe length as 0.6 m

Desired Pipe length = 0.6 m. Nozzle 1 to T-joint should be 0.3 m and T-joint to nozzle 2 should be 0.3 m. Nozzles should be placed directly below propellers to ensure thrust transfer for effective spraying.

3.8 Variable Rate spraying mechanism through electronic circuits and Arduino Programming

3.8.1 Electronic Components

3.8.1.1 Arduinos:

Uno:

Arduino UNO uses the Atmega16U2 microcontroller that helps to increase the transfer rate and contain large memory compared to other boards. The Arduino UNO contain SCL and SDA pins and also have two additional pins fit near to RESET pin.

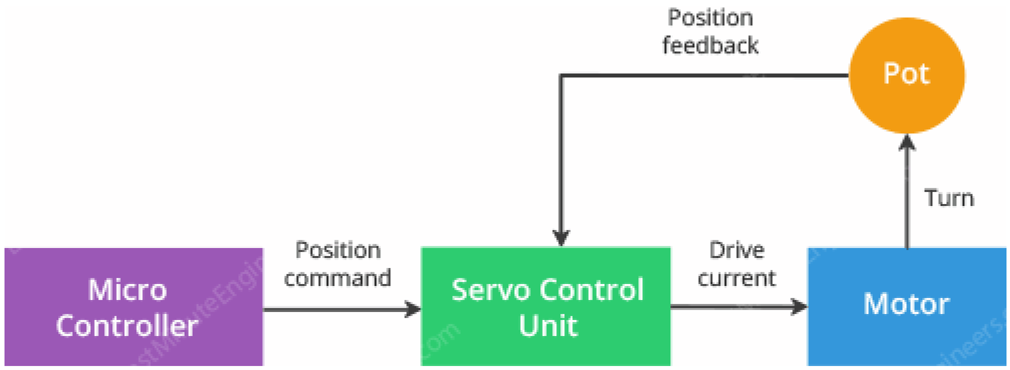
The board contains 14 digital input pins and output pins in which 6 pins are used as PWM, 6 pins as analog inputs, USB connection, reset button and one power jack. The Arduino UNO board can be attached to computer system buy USB port and also get power supply to board from computer system. The Arduino UNO contains flash memory of size 32 KB that is used to the data in it.

Nano:

Arduino Nano is a small breadboard-friendly version of Arduino UNO. It has more or less functionality of the Arduino UNO but in a small form factor. The only major differences from UNO are the lack of a DC power jack, the usage of a Mini USB port instead of a USB B port, and the USB-TTL converter chip. Nano uses an FT232, a dedicated USB-UART bridge chip from FTDI instead of an ATMega16U2. It is also a very popular choice among the developers just like UNO because of its small size.

3.8.1.2 Servo SG90:

Servo is a general term for a closed loop control system. A closed loop system uses the feedback signal to adjust the speed and direction of the motor to achieve the desired result.



RC servo motor works on the same principal. It contains a small DC motor connected to the output shaft through the gears. The output shaft drives a servo arm and is also connected to a potentiometer (pot).

The potentiometer provides position feedback to the servo control unit where the current position of the motor is compared to the target position. According to the error, the control unit corrects the actual position of the motor so that it matches the target position.

3.8.1.3 Ultrasonic Sensor:

At its core, the HC-SR04 Ultrasonic distance sensor consists of two ultrasonic transducers. The one acts as a transmitter which converts electrical signal into 40 KHz ultrasonic sound pulses. The receiver listens for the transmitted pulses. If it receives them it produces an output pulse whose width can be used to determine the distance the pulse travelled.

It all starts, when a pulse of at least 10 µS (10 microseconds) in duration is applied to the Trigger pin. In response to that the sensor transmits a sonic burst of eight pulses at 40 KHz. This 8-pulse pattern makes the “ultrasonic signature” from the device unique, allowing the receiver to differentiate the transmitted pattern from the ambient ultrasonic noise.

The eight ultrasonic pulses travel through the air away from the transmitter. Meanwhile the Echo pin goes HIGH to start forming the beginning of the echo-back signal.

3.8.1.4 NRF24l01 Transceiver module:

The nRF24L01+ transceiver module is designed to operate in 2.4 GHz worldwide ISM frequency band for data transmission. The data transfer rate can be one of 250kbps, 1Mbps and 2Mbps. The operating voltage of the module is from 1.9 to 3.6V, but the good news is that the logic pins are 5-volt tolerant, so we can easily connect it to an Arduino or any 5V logic microcontroller without using any logic level converter.

There are a variety of modules available based upon the nRF24L01+ chip. The used version uses on-board antenna. This allows for a more compact version of the breakout. However, the smaller antenna also means a lower transmission range. With this version, you'll be able to communicate over a distance of 100 meters.

The nRF24L01+ transceiver module transmits and receives data on a certain frequency called Channel. Also in order for two or more transceiver modules to communicate with each other, they need to be on the same channel. This channel could be any frequency in the 2.4 GHz ISM band or to be more precise, it could be between 2.400 to 2.525 GHz (2400 to 2525 MHz).

Each channel occupies a bandwidth of less than 1MHz. This gives us 125 possible channels with 1MHz spacing. So, the module can use 125 different channels which give a possibility to have a network of 125 independently working modems in one place.

3.8.1.5 Relay KY-109:

The KY-019 relay module has two contacts, normally open (NO) and normally closed (NC) that are operated by pulling the signal pin HIGH. This allows low voltages devices such as the Arduino or Raspberry Pi to safely control high voltage devices. The high voltage side of the relay can operate up to 250V AC or up to 30V DC.

This module has six pins, Normally Open, Normally Closed, Common, GND, Vcc+, and Signal.

The normally open and normally closed contacts operate opposite of each other. Normally closed will pass current until the signal line is activated. Normally Open will not pass current until the signal line is activated. The common terminal is shared between the two contacts. You can use either the NC or NO terminals, or both at the same time.

3.8.1.6 DC Motor speed controller HW-687:

HW-687 is one easy module for adding speed regulation to DC motor-based project. It is a simple pulse-width–modulated speed controller providing smooth control with almost no jerks. There is no soldering involved, so it is perfect for quick prototyping and modeling, especially for those not having easy access to requisite raw materials.

In the module, the tiny timer chip NE555 is used to drive an N-channel power MOSFET D4184. With the help of the onboard 100K potentiometer (with on/off switch), we can control the duty cycle of the 20-KHz pulse-width modulation (PWM) from 1% to 100% (as claimed by the maker). The module's proclaimed input voltage range is DC 4.5 V to 35 V. There's also a "cryptic" 5-V linear regulator chip marked as M5350B included to cater stable DC supply to the NE555 chip. One red LED is also powered by the same 5-V line for power-on indication. The module has a single connector with four screw terminals, so all electric connections can be made simply by using the screw terminals without any sort of soldering.

3.8.1.7 100k ohm rotary Potentiometer:

A potentiometer has three terminals. It is very easy to understand the purpose of these terminals by looking at the diagram below.

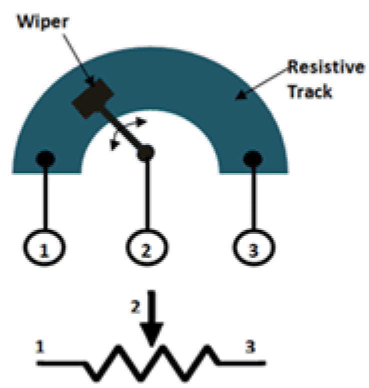


Figure 16 Potentiometer

The diagram shows the parts present inside a potentiometer. We have a resistive track whose complete resistance will be equal to the rated resistance value of the POT.

As the symbol suggests a potentiometer is nothing but a resistor with one variable end. Let us assume a 10k potentiometer, here if we measure the resistance between terminal 1 and terminal 3 we will get a value of 10k because both the terminals are fixed ends of the potentiometer. Now, let us place the wiper exactly at 25% from terminal 1 as shown above and if we measure the resistance between 1 and 2 we will get 25% of 10k which is 2.5K and measuring across terminal 2 and 3 will give a resistance of 7.5K.

So the terminals 1 and 2 or terminals 2 and 3 can be used to obtain the variable resistance and the knob can be used to vary the resistance and set the required value.

3.8.2 Circuit Diagram

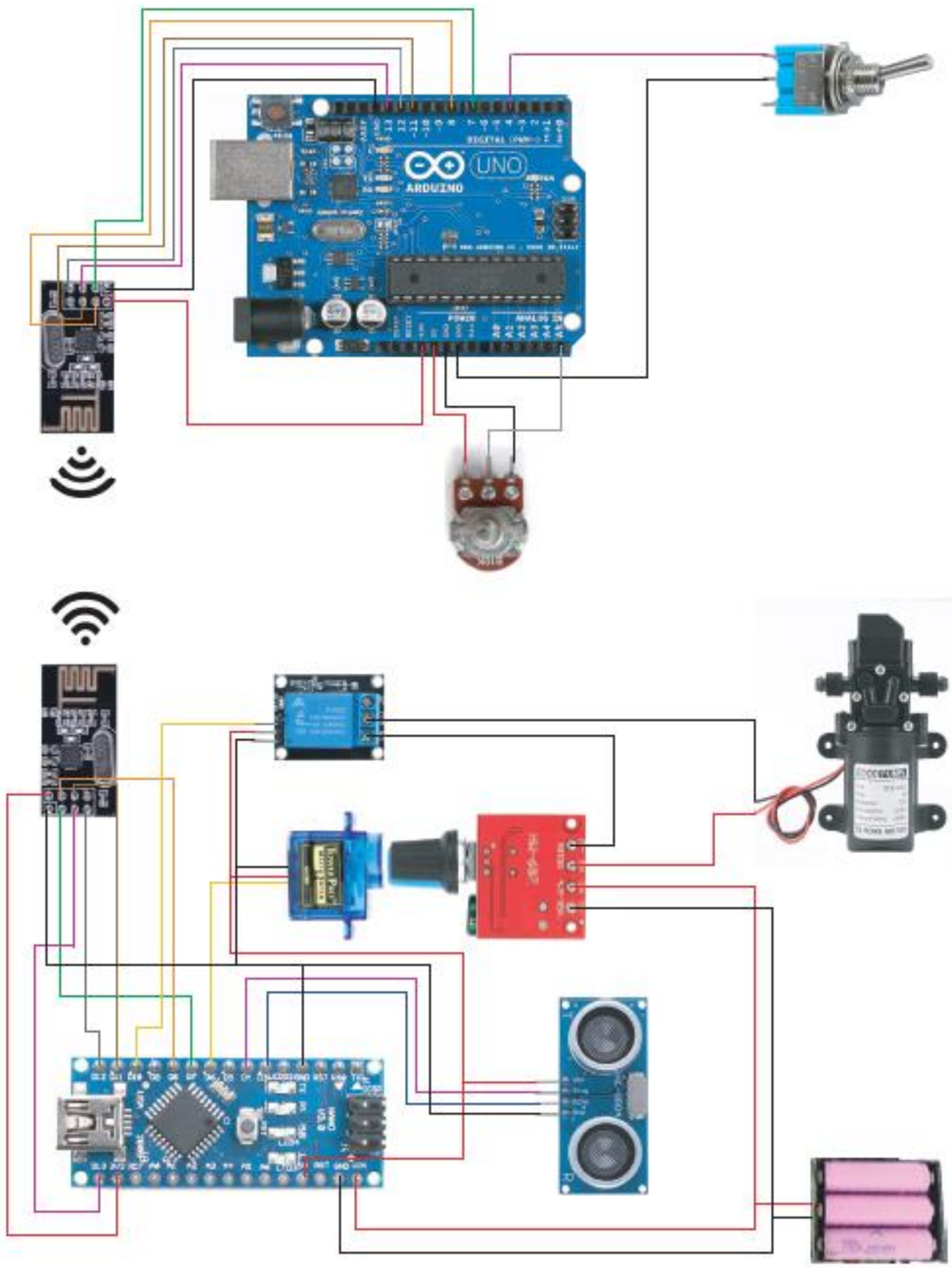
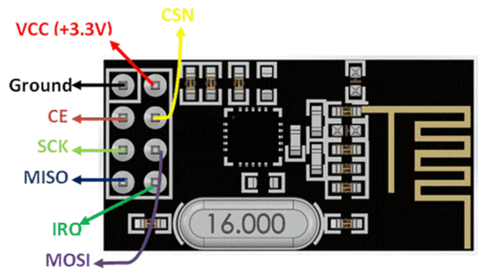


Figure 17 Circuit

3.8.3 Working of Electronic Circuit

NRF24l01 module pinout is connected as



CE - 7
MISO - 12
MOSI - 11
SCK - 13
CS - 8

Whereas the numbers are the pins of the both Arduino Uno and Nano since both of them are using NRF module to connect with each other. NRF wireless transceiver module is connecting the Arduino Uno and Arduino Nano as transmitter and receiver respectively.

The servo SG90 is connected to pwm 6th pin of the Arduino Nano. It acts as actuator which responds to the wireless transmitted signal of the 100k ohm potentiometer attached to the analogue A5 pin of the Arduino Uno. Servo further rotates potentiometer of the HW-687 DC motor speed controller module to vary the flowrate of the pump.

The ultrasonic sensor hc sr-04 has its trigger and echo pin connected to 3 and 4 pins of the Arduino Nano. It works with OR logic along with the toggle switch attached to the pin 4 of the Arduino Uno to actuate the KY-019 relay module connected to the pin 10 of the Arduino Nano.

Grounds of the sensors and actuators at the Arduinos are common but the power of NRF24l01 is derived from 3.3V pin while the rest of the components are commonly powered from 5V pin.

3.8.4 Arduino Code

Transmitter code:

```
#include <SPI.h>
#include "RF24.h"
RF24 myRadio (7, 8);
struct package
{
  int msg = 0;
  int btn = 0;
};
byte addresses[][6] = {"0"};
typedef struct package Package;
Package data;
void setup()
{
  myRadio.begin();
  myRadio.setChannel(115);  //115 band above WIFI signals
  myRadio.setPALevel(RF24_PA_MIN); //MIN power low rage
  myRadio.setDataRate( RF24_250KBPS ) ;  //Minimum speed
  pinMode(4,INPUT_PULLUP);
  delay(500);
}
void loop()
{
  int state = digitalRead(4);
  int Read_ADC = analogRead(A5);
  char servo_value = map (Read_ADC, 0, 1023, 0,180);
    data.btn = state;
    data.msg = servo_value;
    WriteData();
    delay(50);
}
void WriteData()
{
  myRadio.stopListening();  //Stop Receiving and start transminitng
  myRadio.openWritingPipe( 0xF0F0F0F0AA); //Sends data on this 40-bit address
  myRadio.write(&data, sizeof(data));
  delay(300);
}
```

Figure 18 Transmitter code

Receiver Code:

```
#include <SPI.h>
#include "RF24.h"
#include <Servo.h>
Servo myservo;
RF24 myRadio (7, 8);
int distanceThreshold = 0;
int cm = 0;
struct package
{
  int msg;
  int btn;
};
typedef struct package Package;
Package data;
byte addresses[][6] = {"0"};
long readUltrasonicDistance(int triggerPin, int echoPin)
{
  pinMode(triggerPin, OUTPUT);  // Clear the trigger
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);
  pinMode(echoPin, INPUT);
  return pulseIn(echoPin, HIGH);
}
void setup()
{
  myRadio.begin();
  myRadio.setChannel(115);  //115 band above WIFI signals
  myRadio.setPALevel(RF24_PA_MIN); //MIN power low rage
  myRadio.setDataRate( RF24_250KBPS ) ;  //Minimum speed
  myservo.attach(6);
  pinMode(10,OUTPUT);
  delay(500);
}
```

```
int Servo_value;
int state;
int servo;
void loop()
{
  ReadData();
  state = data.btn;
  servo = data.msg;
  Servo_value = abs(servo);
if (Servo_value == 0){
  myservo.write(0);
}
if (Servo_value > 0 && Servo_value < 60){
  myservo.write(90);
}
if (Servo_value > 60){
  myservo.write(180);
}
distanceThreshold = 5;
  // measure the ping time in cm
  cm = 0.01723 * readUltrasonicDistance(4, 3);
  if (cm <= distanceThreshold || state == 1){
  digitalWrite(10,1);
}
else {digitalWrite(10,0);}
}
void ReadData()
{
  myRadio.openReadingPipe(1, 0xF0F0F0F0AA); //Which pipe to read, 40 bit Address
  myRadio.startListening(); //Stop Transminting and start Reveicing
  if ( myRadio.available())
  {
    while (myRadio.available())
    {
      myRadio.read( &data, sizeof(data) );
    }
  }
}
```

Figure 19 Receiver code

CHAPTER 4: RESULTS AND DISCUSSIONS

ANSYS Simulations and Results

4.1 Flow through Pipes, T-joint and elbows

4.1.1 Geometry

We created a separate geometry in design modeler for our analysis of pipe flow.

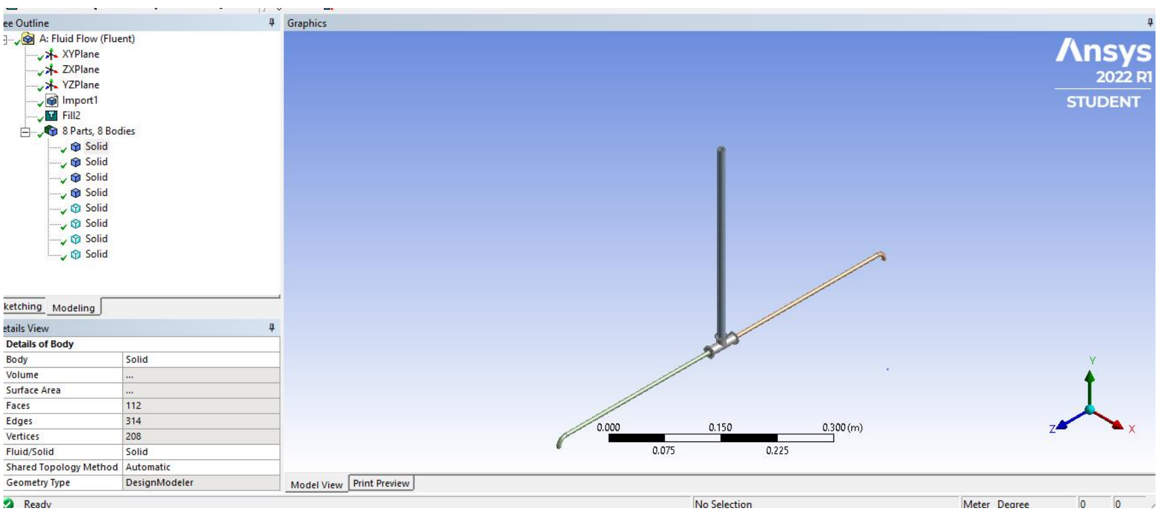


Figure 20 Geometry in Design modeler

4.1.2 Mesh Generation

Separate domains for solid bodies and fluid domain were created.

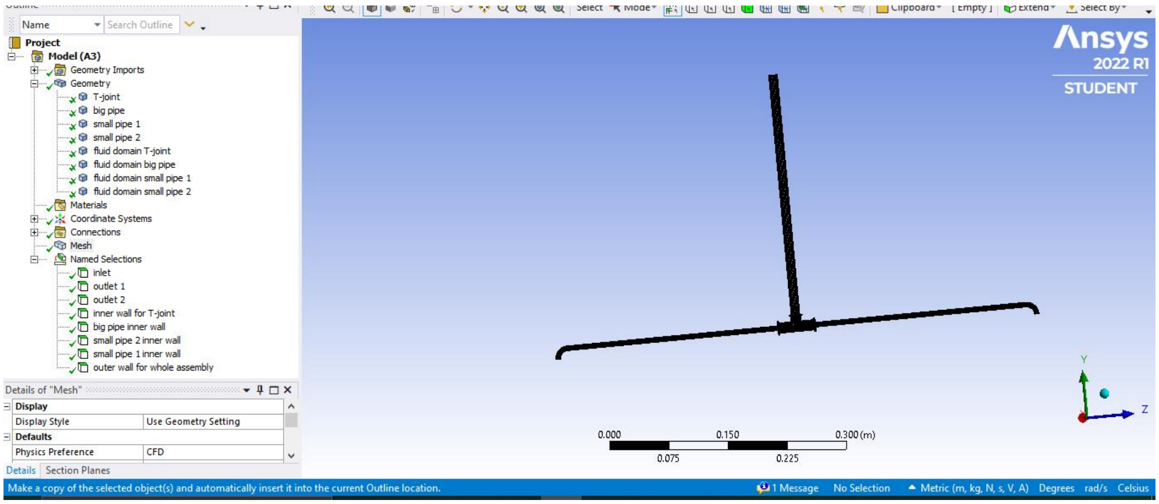


Figure 21Mesh Generation

4.1.3 Setup and Design Solution

A steady and fully developed viscous laminar pipe flow model is selected for analysis of the design. Inlet velocity is given as 0.203 m/s and pressure is set as pump discharge pressure as 450 kpa (guage). Fluid is given as liquid water while pipe material was chosen as TPU (Thermoplastic Polyurethane) with a density of 1179 kg/m^3.

4.1.3 Graphical Results

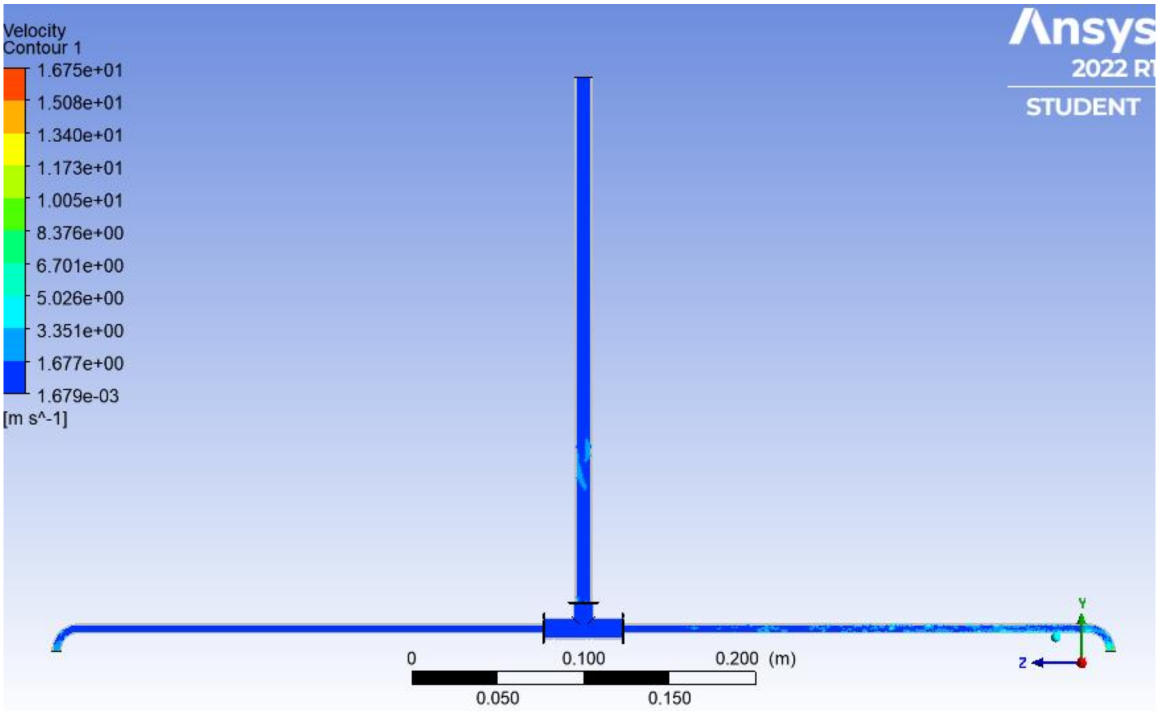


Figure 22Velocity Contour for pipe flow

4.2 Nozzle spray Analysis

4.2.1 Geometry

A gradual contracting pipe of length 15 mm with inlet diameter of 2mm(inner diameter of small pipe) and outlet diameter of 0.8 mm(outlet diameter of our sprinkler nozzle) is used to model our nozzle. A cylinder block enclosing the nozzle is used for simulating our fluid flow as water jet.

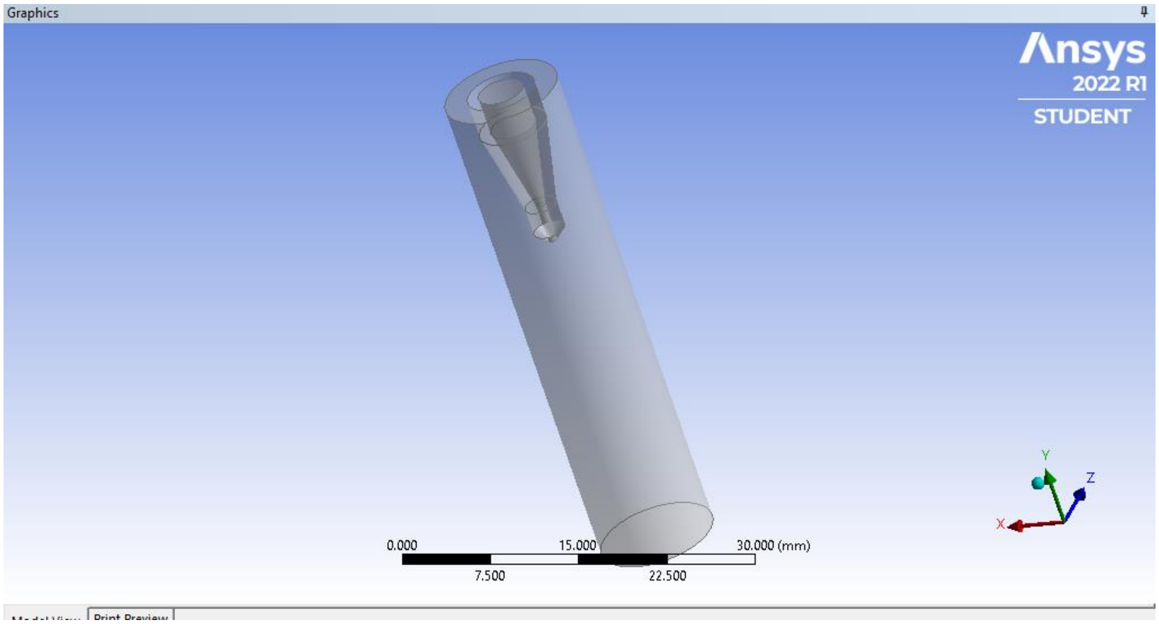


Figure 23 Nozzle geometry

4.2.2 Mesh Generation

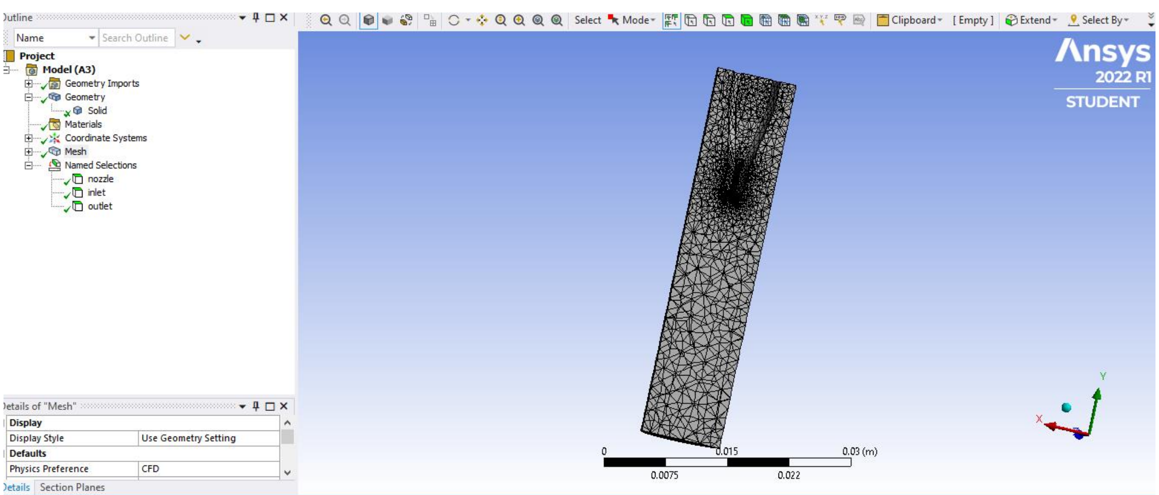


Figure 24 Nozzle Mesh Generation

4.2.3 Setup and Design Solution

A steady and fully developed viscous flow model is selected for analysis of the design. k-epsilon CFD model with energy equation is used for turbulence modelling.

4.2.4 Graphical Results

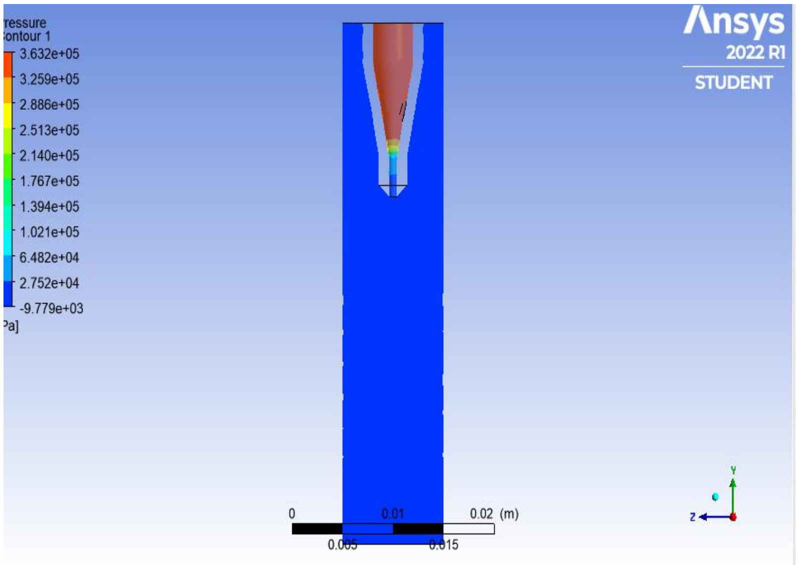


Figure 26 Nozzle Pressure Contour

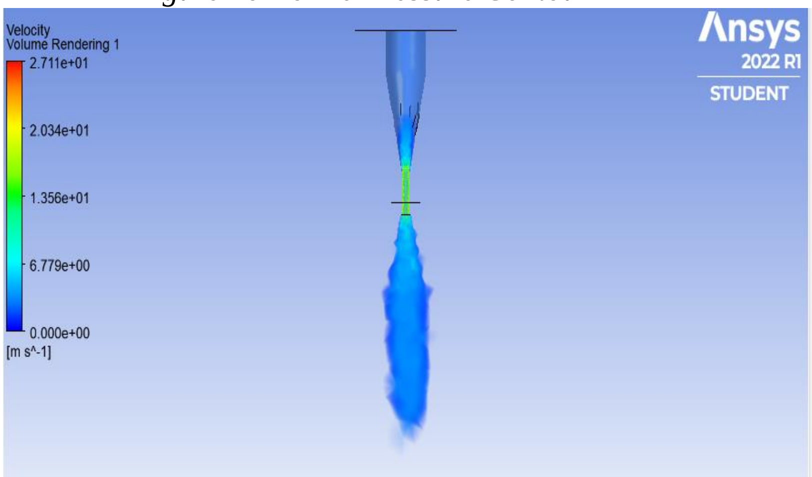


Figure 25 nozzle Velocity spray simulation

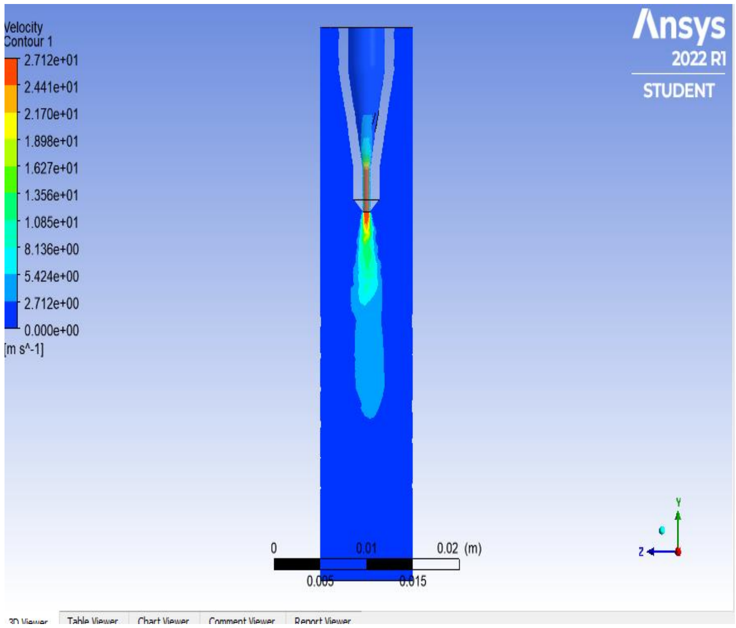


Figure 27 Nozzle Velocity Contour

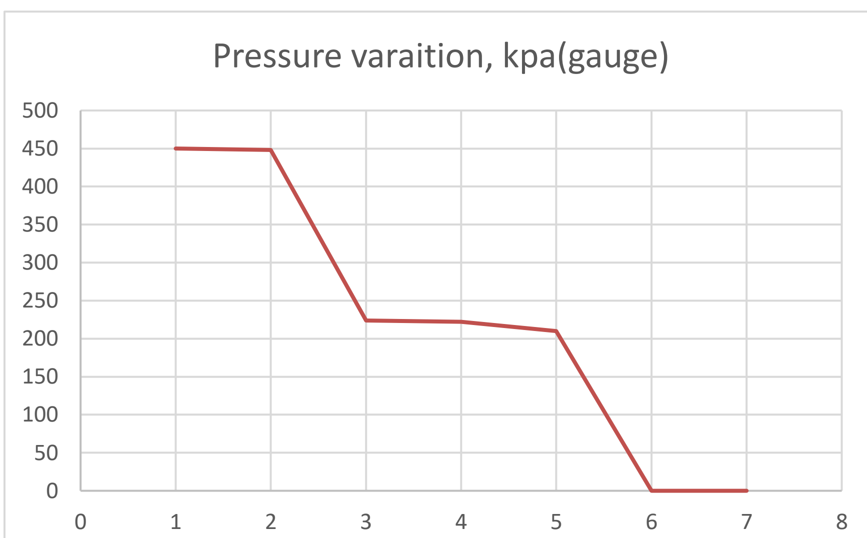
4.3 Pressure and Velocity Plots

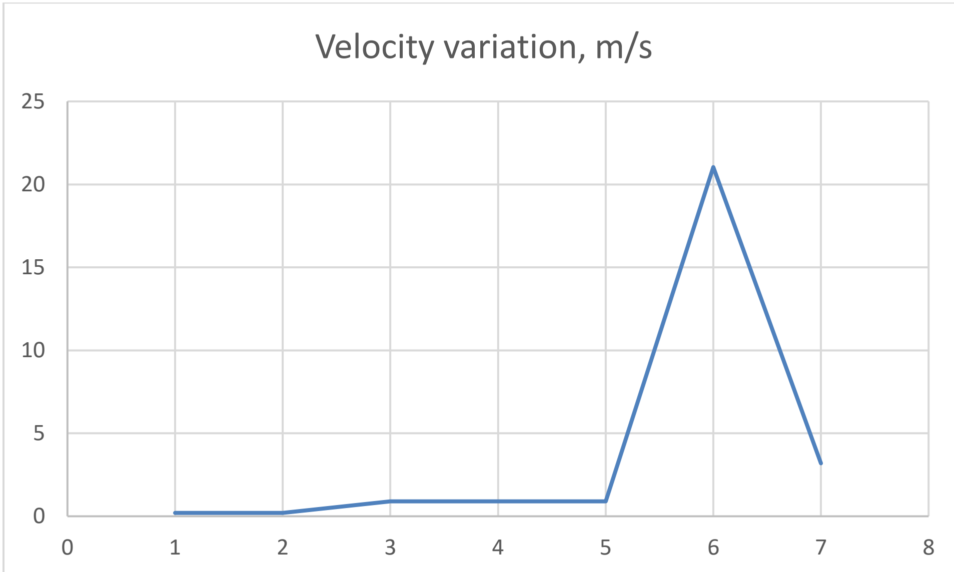
From Ansys simulations, we gather pressure and velocity values at different locations throughout the fluid flow as it enters the pipe from pump and exits at the nozzle.

Let P1 represent Pipe of internal diameter 8.4mm

Let P2 represent each of the two pipes with internal diameter 4mm

Sr. No.	Description	Pressure (kpa) (gauge)	Velocity (m/s)
1	Pipe P1 entry	450	0.203
2	Pipe P1 exit	448	0.203
3	Pipe P2 entry	224	0.895
4	Pipe P2 exit	222	0.895
5	Nozzle entry	210	0.895
6	Nozzle exit	0	21.04
7	5m away from nozzle exit	0	3.2




Velocity variation, m/s
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In our drone payload calculations, the motors thrust force turned out to sufficient to lift 3 kg. However, considering air drag and motor efficiency, this load can drop to 2 kg or below. Therefore, we should prefer experimental results over theoretical calculations for ensuring that our drone can lift our sprayer. In our case, the thrust force provided by our motors could lift the sprayer up to 5m above the ground.

Due to losses in the nozzle and the pipe, the discharge rate from pump reduced significantly from 2.6 L/min to 0.675 L/min showing the effect of nozzles over pressure head.

The electronic circuit and Arduino program works successfully, and we were able to change the flowrate according to requirement of crops

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APPENDIX I: PESTICIDES USED ON COTTON

Pests and farm chemicals on Cotton

Pest	Time of attack	Remedy (common Name)	Dosage/Acre
American Bollworm 	Starts attack with flower formation and last till the end	Endosulfan	600 ml
		Chlorphrifos	1000 ml
Jassid 	Attacks the crop during the whole period.	Endosulfan	1000 ml
		Bromophos	400 ml
		Chlorphrifos	1000 ml
		Dimethoate	400 ml
		Fenitrothion	500 -700 ml
		Isothioate	1300-1500 ml
		Methamidophos	400 ml
Whitefly 	Attacks the crop during the whole period.	Endosulfan	1000 ml

APPENDIX II: FLUID MECHANICS FORMULAE FOR PIPE FLOW CALCULATIONS

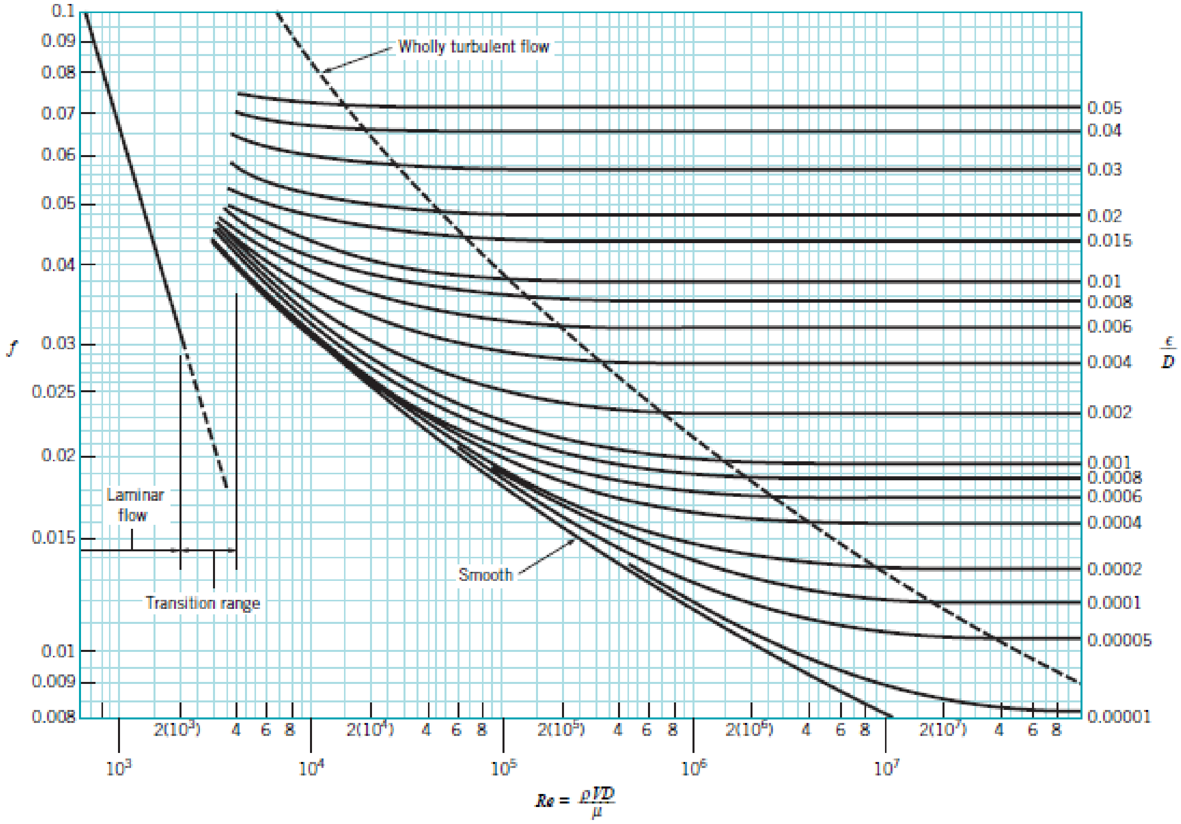
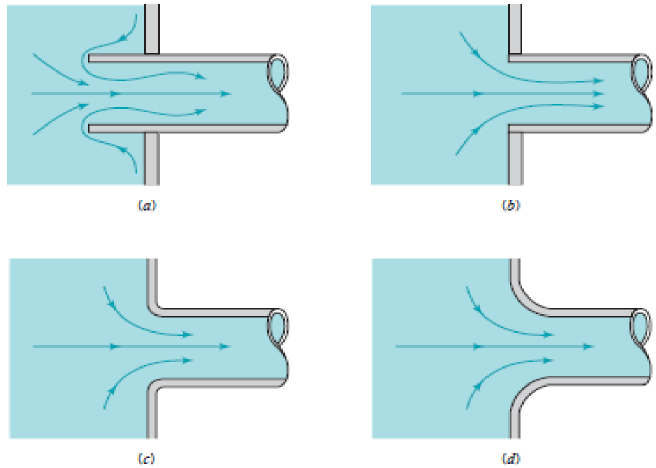
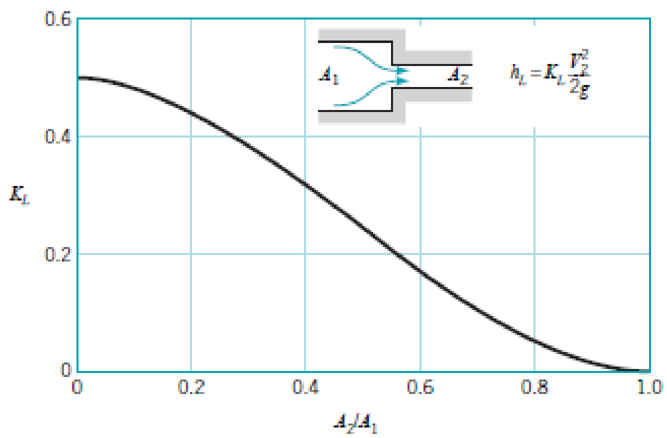


FIGURE 8.20 **Friction factor as a function of Reynolds number and relative roughness for round pipes—the Moody chart. (Data from Ref. 7 with permission.)**

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$



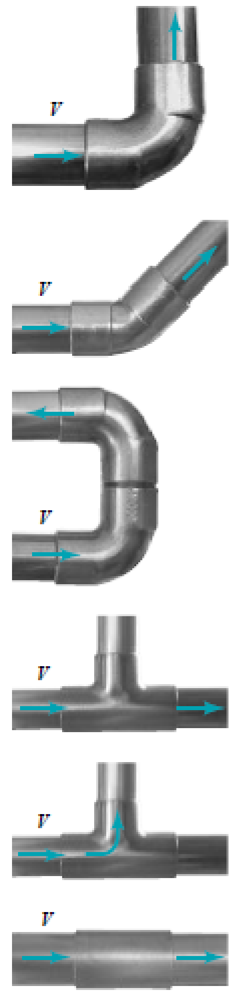
■ **FIGURE 8.22** Entrance flow conditions and loss coefficient (Refs. 28, 29). (*a*) Reentrant, $K_L = 0.8$, (*b*) sharp-edged, $K_L = 0.5$, (*c*) slightly rounded, $K_L = 0.2$ (see Fig. 8.24), (*d*) well-rounded, $K_L = 0.04$ (see Fig. 8.24).



■ **FIGURE 8.26** Loss coefficient for a sudden contraction (Ref. 10).

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ (Data from Refs. 5, 10, 27)

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210



Payload calculation formula:

Surface roughness and loss due to pipe bend:

TABLE 8.1

Equivalent Roughness for New Pipes [From Moody (Ref. 7) and Colebrook (Ref. 8)]

	Equivalent Roughness, ε	
Pipe	**Feet**	**Millimeters**
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Wood stave	0.0006–0.003	0.18–0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

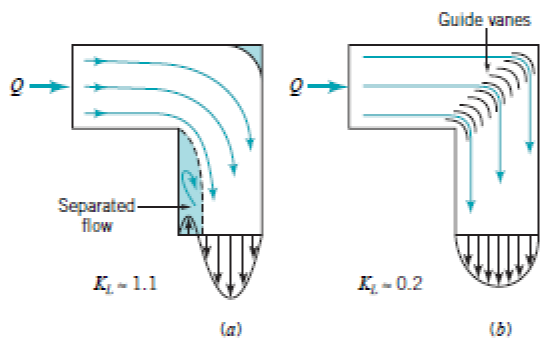


FIGURE 8.31 Character of the flow in a 90° mitered bend and the associated loss coefficient: (*a*) without guide vanes, (*b*) with guide vanes.