CZECH UNIVERSITY OF LIFE SCIENCES, PRAGUE

FACULTY OF ENGINEERING

Department of Agricultural Machinery

DESIGN OF SPRAYING EQUIPMENT FOR UAV

MSc. Thesis

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Engineering

DIPLOMA THESIS ASSIGNMENT

Saheed Adekunle Ojetimi

Agricultural Engineering

Thesis title

The design of the spraying equipment for UAV.

Objectives of thesis

The aim of the diploma thesis is to design the equipment of a specific UAV for spraying.

Methodology

The student will do a literature review on the topic of using UAVs to apply sprays. Based on the findings, the student will become familiar with the application of aerial spraying using UAVs. The student will design proposal for a spraying device for a drone.

The structure of the work will be as follows:

1) Introduction

2) Literature review oriented to aerial spraying

3) Analysis and synthesis of the literature review findings

4) Design proposal of a spraying device for a drone

5) Evaluation of the proposal

6) Conclusion

The proposed extent of the thesis

40-60 pages

Keywords

UAV, spraying, aerial spraying

Recommended information sources

Gibbs, J., Peters, T.M., Heck, L.P. 2021. Comparison of droplet size, coverage and drift potential from UAV application methods and ground application methods on row crops. Transactions of the ASABE 64(3): 819-828.

Scientific journal Biosystems Engineering

Scientific journal Computers and Electronics in Agriculture

Scientific journal Precision Agriculture

Scientific journals of ASABE

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Prague on 02. 05. 2024

I hereby declare that I have completed this thesis entitled "**The design of the spraying equipment for UAV**" independently, all texts in this thesis are original, and that all information sources have been quoted and acknowledged by means of complete references. I also confirm that this work has not been previously submitted, nor is it currently submitted, for any other degree, to this or any other university.

In Prague 31. 3. 2024

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Saheed Adekunle Ojetimi

Abstract

This piece of work explore and elaborate the development of a spraying device specifically designed for integration with a drone platform through addressing crucial design factors, objectives, process, equipment features, and leveraging innovative technologies. The primary goal is to create a reliable spraying equipment that maximizes efficiency and effectiveness in aerial agricultural operations that is open to further research work and improvement as time and technology demands.

It is done through reviewing, analyzed, and synthesized related literatures. The findings were utilized to propose an agricultural spraying equipment.

Key words: Unmanned Aerial Vehicle (UAV), Spraying, Aerial Spraying

Foreword

All praises be to Almighty ALLah (SWT) who has made this possible. It is with great pleasure and a sense of accomplishment that I present this Master's thesis, which reflects my passion for advancing knowledge in agricultural engineering field.

Undertaking this Master's degree program provides intellectual growth and scholarly development that I have experienced throughout my studies. It is the product of countless hours spent delving into literature, conducting experiments, analyzing data, and engaging in critical discourse with peers and mentors. This thesis explores, synthesizes, and proposes design of efficient spraying equipment, delving into its intricacies, complexities, and implications for aerial spraying operation. Through meticulous research, rigorous analysis, and thoughtful interpretation, I have endeavored to contribute meaningful insights and advance understanding within this domain.

I am deeply grateful to my thesis advisor, Professor Frantisek Kumhala, for his unwavering and fatherly guidance, support, and mentorship throughout this journey. His expertise, encouragement, and constructive feedback have been invaluable in shaping the direction, scope, and success of this thesis. Additionally, I would also like to express my sincere appreciation to Lucie Koreckova, and the whole employee of this great faculty most especially, all lecturers who impacted me with their scholarly expertise that have enriched the quality and depth of my knowledge and this work.

Furthermore, I extend my gratitude to my wife- Shukurah, sons- Mujahid and Musharraf, my parents– Alhaji (Engr.) and Alhaja A. A. Ojetimi, and siblings- Afis, Bayo, Yetunde, Eniola, and Lolade being there for me during this interesting and successful academic journey.

Finally, I acknowledge the unwavering support and encouragement of my family, friends, and loved ones throughout this academic endeavor. Their belief in my abilities and their steadfast encouragement and advice have been a constant source of motivation and inspiration.

I am presenting this thesis to the academic community, with humility, pride, and a sense of optimism for the future. It is my sincere hope that this work will contribute to the body of knowledge within agricultural engineering and inspire further research, innovation, and scholarly inquiry in the years to come.

Acronyms related to UAV aerial spraying.

1. UAV - Unmanned Aerial Vehicle
2. UAS - Unmanned Aircraft System
3. RPAS - Remotely Piloted Aircraft System
4. UAVS - Unmanned Aerial Vehicle System
5. UAVP - Unmanned Aerial Vehicle Platform
6. GPS - Global Positioning System
7. GIS - Geographic Information System
8. GCS - Ground Control Station
9. RTK - Real-Time Kinematic
10. VTOL - Vertical Takeoff and Landing
11. RTH - Return to Home
12. VLOS - Visual Line of Sight
13. BVLOS - Beyond Visual Line of Sight
14. ADS-B - Automatic Dependent Surveillance-Broadcast
15. EO/IR - Electro-Optical/Infrared
16. LiDAR - Light Detection and Ranging
17. GNSS - Global Navigation Satellite System
18. IMU - Inertial Measurement Unit
19. EO - Electro-Optical
20. IR – Infrared

Sprayer Equipment:

1. AS - Aerial Sprayer
2. APS - Aerial Spray System
3. ATS - Aerial Treatment System
4. AFS - Aerial Farming System
5. AES - Aerial Application Equipment
6. AET - Aerial Equipment Technology

Power and Control Systems:

1. FCU - Flight Control Unit
2. ESC - Electronic Speed Controller
3. PDB - Power Distribution Board
4. BMS - Battery Management System
5. FC - Flight Controller
6. ECS - Electronic Control System

Pumps:

1. PPP - Portable Pumping Power
2. HPS - Hydraulic Pumping System
3. PAP - Portable Agricultural Pump
4. IHP - Integrated Hydraulic Pump
5. PSP - Portable Sprayer Pump

Motors:

1. BLDC - Brushless DC Motor
2. PMDC - Permanent Magnet DC Motor
3. ACIM - Alternating Current Induction Motor
4. PMSM - Permanent Magnet Synchronous Motor
5. VFD - Variable Frequency Drive

Nozzles:

1. SPN - Spray Nozzle
2. AN - Aerial Nozzle
3. PSN - Precision Spray Nozzle
4. ASN - Aerial Spray Nozzle
5. MHN - Multi-Head Nozzle
6. DSN - Drop Size Nozzle
7. VSN - Variable Spray Nozzle
8. CSN - Controlled Spray Nozzle
9. SSN - Smart Spray Nozzle
10. ASN - Adjustable Spray Nozzle

Conversion factors related to aerial spraying equipment calculations.

1. Miles to Meters:
    - 1 mile = 1609.34 meters
2. Miles to Kilometers:
    - 1 mile = 1.60934 kilometers
3. Acre to Hectare:
    - 1 acre = 0.404686 hectares
4. Hectare to Acre:
    - 1 hectare = 2.47105 acres

5. Pressure:
    - 1 psi (pounds per square inch) = 6,894.76 pascals (Pa)
    - 1 bar = 100,000 pascals (Pa)
    - 1 atm (standard atmosphere) = 101,325 pascals (Pa)
    - 1 MPa (megapascal) = 1,000,000 pascals (Pa)
    - p.s.i. x 6.9 = kPa
    - 1 kPa (kilopascal) = 1,000 pascals (Pa)

1. Miles per hour (mph) to meters per second (m/s):
    - 1 mph ≈ 0.44704 meters per second
    - 1 mile per hour (mph) ≈ 1.60934 kilometers per hour ($km.h^{-1}$)
    - m.p.h. x 1.6 = km/h

2. Gallons per minute (gpm) to liters per second ($L.s^{-1}$):
    - 1 gpm ≈ 0.0630902 liters per second
    - gal./acre x 11.2 = $L.ha^{-1}$; gal./acre (US) x 9.35 = $L.ha^{-1}$

3. Liters per minute ($l.min^{-1}$) to liters per second ($L.s^{-1}$):
    - 1 $l.min^{-1}$ ≈ 0.0166667 liters per second
    - 1 liter (L) of water = 1 kilogram (kg)

4. Inches/Feet to meters:
    - 1 inch ≈ 0.0254 meters
    - 1 foot ≈ 0.3048 meters

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

According to history, "The first records of the use of drones date from 1849, when the Austrians attacked Venice with unmanned balloons filled with explosives fired from a battleship". (https://www.dronetechplanet.com). From this point, it soon becomes a military tool and was given different names such as Unmanned Aerial Vehicle (UAV), Miniature Pilotless Aircraft, or Flying Mini Robots. It was utilized and engaged in some war both convectional and cold wars. UAVs' application is not limited to the military sector, it has however, cut across and being utilized in other several fields that is not exhaustive, such as agriculture, health and safety, oil and gas, telecommunication, mining, hospitality, supply chain/logistics, transport. Nowadays, the application of small unmanned aerial vehicles (UAVs) is growing at a very fast rate in agribusiness (Vargas-Ramı´rez et al, 2017, Gayathri Devi, et al, 2020, Giacomo et al, 2018). UAVs are typically radio-controlled devices that is commonly operated by an individual stationed on the ground with various types based on design (fixed wings and rotors/blade). These days, drones are however, integrated with GPS guidance components which has made it autopilot aerial vehicles with more aerial operation capability. The mission of UAVs is fundamentally depending on attached equipment, component, and devices. The type of cameras, sensors, controlling devices depends on the application of a drone. Moreover, the development of powerful processors, GPS modules, and increment in the range of digital radios is a continuous process, and thus drone technology is also improving. This piece of work focusses primarily on usage of drone in agriculture. It is obvious that UAV application in agriculture can be in different operations – crop monitoring and management, precision agriculture, crop mapping and surveying, yield estimation and forecasting, drought and pest management, crop spraying and fertilization, livestock monitoring and surveillance, environmental monitoring, and conservation.

Utilization of Unmanned Aerial Vehicles (UAVs) in agricultural applications with regards to this thesis is streamlined to integration of a spraying equipment for optimization and enhancement of aerial activities in agriculture with focus on spraying of agricultural substances on plants, crops to protect, enhance growth of crops and as a result improve and increase yield quality

CHAPTER 2

2.0 LITERATURE REVIEW ORIENTED TO AERIAL SPRAYING

2.1 Abstract

Unmanned Aerial Vehicles (UAVs), also known as drones, have emerged as versatile tools in various industries, including agriculture. In agricultural applications, UAVs equipped with spraying equipment offer significant advantages over traditional manual or ground-based methods that have been employed in the past decades for spraying activities on the farm or agricultural field.

2.2 Literature Review Objective

This literature review aims to explore the design aspects of spraying equipment for UAVs, and its usage on the agricultural field. The goal of this section will cover key considerations, advancements, challenges, and innovation opportunities. By examining the existing body of research, this review provides insights into the current state of the art, identifies research gaps, and offers recommendations for future development.

2.3 Review Background

Unmanned Aerial Spraying Systems (UASS) have been developed rapidly during recent years as a spray tool for the application of plant protection products (Wang et al. 2022). The efficacy of the application of UASS made the technology to be welcomed globally. Their application overcome any field operation challenges such as terrain or topography that causes affect accessibility of farmland or manual operated sprayer operation. The UASS can spray in the hilly and steep slope areas without being restricted by field obstacles (Delpuech et al. 2022). In relative to other aerial techniques, physical damage to crops can be avoided. It can easily spray above high standing crops (bananas, corn, and rubber) and operate over complex terrain (steep slopes, terraces) where backpack sprayers are confronted to critical operator issues regarding tediousness and safety (Cavalaris et al. 2022). It is easy to deduce that Unmanned Aerial Vehicles (UAVs) equipped with spraying equipment offer significant advantages over traditional manual or ground-based methods that was famously and commonly practiced in the past. In the last few decades, pesticide application has mainly been performed in two ways: ground and aerial (Faiçal et al. 2017).

In developed countries, such as USA and Europe, various ground application equipment was developed for different spray needs, such as air-assisted sprayers for orchards, tractor-mounted or self-propelled boom sprayers for row crops, mist blowers for the ultra-low volume application, and knapsack sprayers for the manual application. Among these equipment, tractor-mounted boom sprayers with linear nozzles arrangement are widely used in treating large area of row crops with high working efficiency. Comparing knapsack to drone sprayer in term of speed, UAV is obviously many times faster that knapsack operated by man and faster than the vehicle driven boom sprayer. Furthermore, drone application for spraying will significantly reduce agricultural liquid wastage as this will translate to less exposing the soil to chemical. If properly applied, It will enhance soil preservation. On the contrary, in developing countries mainly in Africa and Asia, such as Nigeria, India, ground applications with the use of backpack knapsack sprayers, gasoline-powered sprayers with handheld long extended hoses or plastic pipes, or power mist-sprayers are employed and widely used most especially in the rural area. This kind of agricultural activity mostly require an individual known as operator or custom applicator to move through and within the farmland. This applicator ordinarily points the hose or pipe and sways it from side to side while walking within and through the field either in a define route or randomly. This spraying process is relatively stressful with human variation and requires footpaths in the field. Although it has undeniable benefit as the sprayed substances is closely aimed and relatively gets to the targeted point and crop. Moreover, this approach has relatively reduced drift and higher spray coverage in the regard of agricultural spraying application. Those approaches allow spraying close to the target crop with lower drift and higher spray coverage. At this point, the disadvantages of this method cannot be ignored, for instance, movements such as walking or driving through the agricultural field alongside knapsack and related component can make it easy for plants to be affected, stepped on or hit during the movement. In addition, it increases the soil compaction of the area which consequently reduces the productivity of the walked area. Another issue to mention is the exposure of the applicator to the harmful substance being sprayed. The small knapsack sprayer easily leads to higher operator pesticide exposure (Cao et al. 2017) and potentially compromised spray distribution resulting in applying the improper labeled rate per hectare. However, with unbalanced and excessive use, it has negative effects on both environmental health and human health, causing diseases such as cancer and neurologic disorders (Radoglou-Grammatikis et al. 2020, Dhouib et al. 2016). The chemical exposure could be hazardous affects the health of the operation and in the end influence and slow down the field operation which will also have an impact on overall productivity and profit.

In contrast, the aerial method sprays above the plants with no need for paths within the crop and removes applicator worker exposure risk. A possible alternative to improve the safety of the applicator and reduce health risk is to use unmanned aerial vehicles (UAVs) by remote control or in autonomous mode. Conventional aerial spraying includes manned helicopter and fixed wing aircraft. The high maneuverability, light weight and low cost are also advantages of UAVs when spraying crops in complex terrain and on small farms. Based on the prediction of the Association of Unmanned Vehicles Systems International, the legalization of commercial drones could create more than $80 billion in economic impact from 2015 to 2025 and agriculture could account for 80% of that total (AUVSI, 2013). In 2014, agricultural UAVs were awarded 10 breakthrough technologies by MIT (Massachusetts Institute of Technology in the USA) (https://www.technologyreview.com/lists/technologies/2014/). Since then, agricultural UAVs have undergone an explosive development trend and subsequent extensive commercial use in China. Performance of tiny sensors (accelerometers, magnetometers, gyros, and pressure sensors, etc.), used in drone technology, is continuously increasing and their size is reducing day by day (Barkunan et al. 2019, Adamchuk, et al. 2004, Wang, 2005). According to the 2018 statistics of the Chinese Ministry of Agriculture, the number of UAV sprayers in agriculture was close to 30,000, and the operating area was 17.3 million hectares. Before going further in this section, it is necessary to have a brief overview about UAVs. This will help with a good grasp of its integration with spraying equipment and their usage in agriculture sector. UAVs are radio-controlled aircraft capable of flight. Multi-rotor UAVs are the only type that may be further categorized by the number of rotors on their platform. In recent decades, numerous UAV model types have been deployed, compared to multi-rotor aircraft, the design of fixed-wing UAVs is drastically different, and the aerodynamic structure of their two wings makes them easier to fly. There are several models of drones, and the common ones are single-rotor helicopter with one large rotor on top and a smaller one in the tail of the UAV. Quadcopters, hexa-copters, and octocopters refer to multirotor aircraft with four, six, or eight rotors. Single-rotor, quadcopter, hexa-copter, and octocopter are subcategories of multi-rotors. A multi-rotor has a lower flight speed, distance, and duration than a fixed-wing drone since it requires an enormous amount of power to generate lift and maintain flight (Ghazali et al. 2022). The octocopter has all the advantages of the hexa-copter, but with increased power. These devices are not inexpensive but are generally obtain the best possible aerial footage, spray, mapping amongst many areas of utilization. These octocopter drones offer the same, or additional, advantages to the quadcopter, and the hexa-copter.

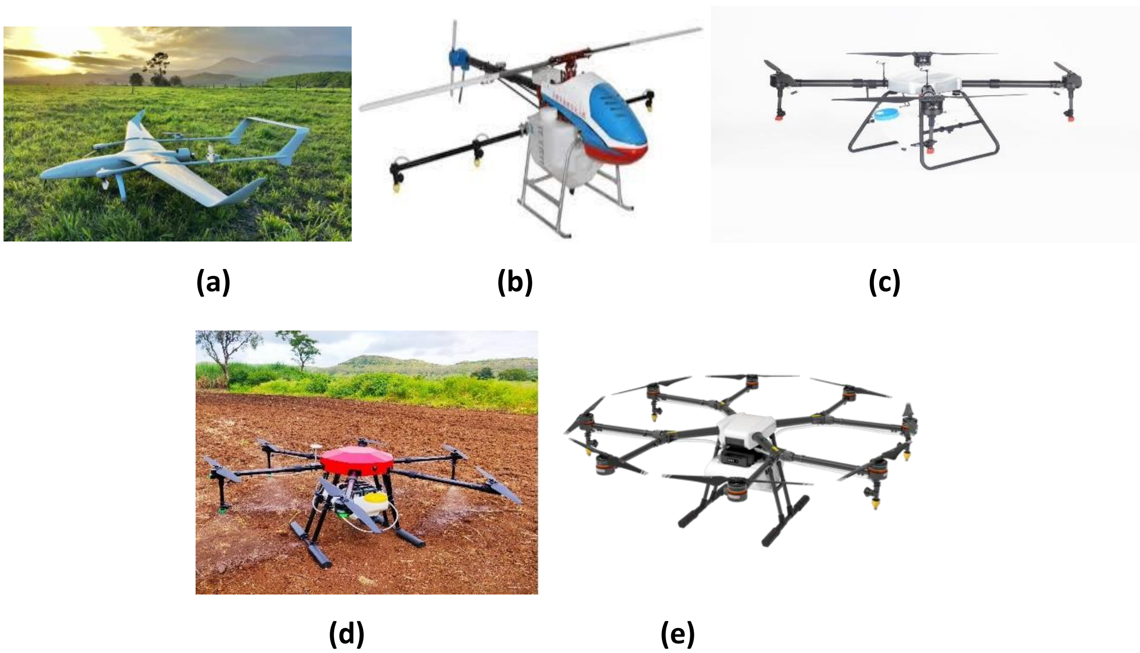


Figure 1. Examples of different types of drones. (a) Fixed wing, (b) Single rotor, (c) Quadcopter, (d) Hexacopter, and (e) Octocopter

Therefore, utilizing and combining the operation of Unmanned Aerial Vehicle (UAV) and the spraying equipment result in a unified name Unmanned Aerial Spraying Systems (UASS). This consist of a drone carrying a spraying device, operated by a control system and comprise sensors to spray agricultural substances such as fertilizer, herbicides, agricultural chemical products. However, as outdated plant protection machinery, they are being replaced by UAVs because of their higher work efficiency, lower operator exposure, and improved ability to apply chemicals in a timely and highly spatially resolved manner.

According to statistics from the Chinese Ministry of Agriculture, by May 2016, more than 178 types of agricultural UAVs were in use in the country. UAVs have an efficiency of up to 6 - 10 ha/hr. with a 5 - 20 L liquid tank and a 2 - 20 m spraying swath under different field chemical control application conditions. Because of their great value and potential, UAVs have been the subject of much research. In the field of spray application, (Faiçal et al. 2017) evaluated the impact of the number of communication messages between UAVs and the wireless sensor network (WSN) and concluded that use of feedback information from the sensors to adjust the flight routes could significantly reduce waste of pesticides and fertilizers. One of the most preferred precision agriculture applications lately is the use of UAVs for spraying applications. Agricultural chemical products sprayed on crops are aimed at increasing the yield of the crop and reducing possible plant diseases and pests. The near-precise performance for use with unmanned aerial vehicles has been a game-changer in the agricultural sector in recent years. The ultimate objective of establishing an autonomous spraying system that takes into consideration environmental and platform characteristics is to spray a precise amount of pesticide on plants without affecting the quality of the plant nor area of exposed land that could be due to excessive pesticide use. Pesticides are substances that, when applied in excessive quantities, are detrimental to both the environment and humans (Kundak et al. 2007, Valenti et al. 2006). Pesticides, on the other hand, can be the most effective solution if applied correctly, especially when paired with high precision agricultural equipment such as UASS.

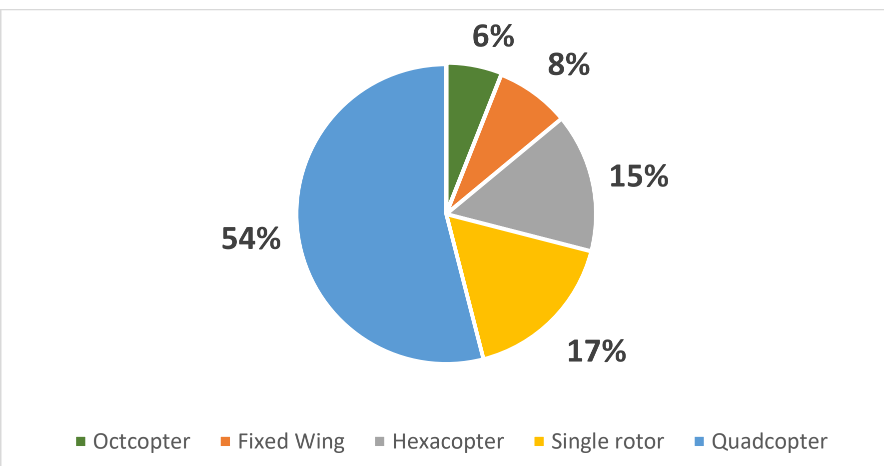


Figure 2. Type of drones utilized agricultural research.

Source: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 04, April 2022).

However, there are also many problems with conventional aerial spraying. Application close to the plants (approximately 3 m high) increases the odds of fatal accidents. In addition, the higher vehicular speed and water droplet release height, and large spray volume dispersed by multiple nozzles on extensive booms (10–20 m long) compared to those of a ground application may increase the risk of spray drift. Compared with manned aerial vehicles, UAVs can spray lower with smaller crops at slower spraying speeds, which may be beneficial for reducing drift. Compared to a fast and unbalanced sprayer, UAVs can reduce pesticide use and maximize plant health and yield (Radoglou-Grammatikis et al. 2020, Kim, 2019). The chemical pesticide is sprayed on the plants, usually with a spraying system mounted on the UAV. With techniques such as image processing and artificial intelligence, the condition of the soil or plant is predicted, and spraying is performed accordingly. In a sample study on spraying, Martinez-Guanter et al. 2020 carried out a low-cost and high-efficiency UAV spraying application for olive and citrus orchards. Giles et al. 2015, analyzed the technical and economic feasibility of RMAX helicopter (Yamaha Motor Co. Ltd, Iwata, Japan) deployment in a commercial vineyard spray application. With the rapid development of UAVs, scientists have also conducted many studies on the operating parameters with regards to deposition and drift. Zhang et al. 2018 analyzed the effect of citrus tree-shape and UAV spraying height on droplet distribution and found that a working height of 1.0 m performed better than 0.5 and 1.5 m. Wang et al. 2021, developed a test system based on spatial spraying deposition quality balance (SSDQB) to evaluate the characteristics of tracer deposition and drift distribution, and the test results showed that regardless of the flight direction, height and crosswind, all these factors influenced the tracer deposition distribution by weakening the intensity of the downwash airflow field perpendicular to the ground. To further evaluate the effect of the downwash airflow field, the China National Center for International Collaboration Research on Precision Agricultural Aviation Pesticides Spraying Technology (NPAAC) and Nanjing Research Institute for Agricultural Mechanization of Chinese Ministry of Agriculture respectively tested the relationship between different UAV working parameters and droplet deposition on rice, maize, and citrus. NPAAC measured the effect of wind field below the rotor of an unmanned helicopter and multi-rotor UAV on the droplet deposition distribution of aerial spraying and evaluated the effective spray width for different types of UAV.

The entire operating cost of an agricultural UAV is relatively less compared to a knapsack sprayer. The only operation cost will be the operator and to replace the faulty components (IATA, "Best Practice for Component Maintenance Cost Management", International Air Transport Association, 2, 3 (2015)). Most of the components are low cost and easy to obtain therefore it is very easy to conduct any repair works. It also does not need to pay any airport taxes as it is able to land almost anywhere. Agricultural UAVs have a huge advantage in terms of mobile capability over ground vehicles (Phang et al. 2014). Many academic research institutes have a growing interest in such vehicles due to its high research value and application potential (Kundak et al. 2007, Valenti et al. 2006, Waslander et al. 2005). In addition, it can be utilized to spray farm or agricultural field with plants such as vegetables that are relatively weak to withstand the movement of human and machine on the farmland during spraying exercise. Moreover, exploitation costs are reduced by shortening the time of spray application and by lowering the amount of plant protection products applied (Morales-Rodríguez et al. 2022). With the rapid development of UAVs, scientists have also conducted many studies on the operating parameters with regards to deposition and drift.

Artificial Intelligence (AI) is another aspect integrated to spraying system. The system coupled with various available high-tech components like sensors, cameras enable It to make its own decision. As a result, UASS has its own decision-making power, which has made it a useful tool for real-time data analysis. This decision-making power of AI is based upon previous training through machine learning (ML), neural network (NN), internet of things (IOT), AI. With these, flowrate, tank level, temperature, obstacles and so many factors that the system may encounter during flight are taken care of. This means, if properly integrated, decisions can be made autonomously. Real-time data analysis has improved farm productivity through mapping spatial variability in the field. The crude data (of crops in agricultural fields) collected using drones are fed to the analytical models for analysis and further remedial actions are taken to improve the yield. Drones can perform soil health scans, assistance in irrigation, fertilizers application, crops health monitoring.

Moreover, it provides useful data analysis to estimate farming yield (Geetharamani 2019). Spraying of crop is done for different purposes, either to protect the crop, get rid of weed or add nutrient to the plants to enhance their growth. This is a vital aspect in agriculture sector.

Water, fertilizers, and pesticides can be sprayed with the equipment from aerial as a position by the aid of drone. Recent research has been conducted actively and extensively on variable quantity spray technology. Cruvinel et al. 2016 established relationships between operating velocity, nozzle height, and spray flow. To achieve consistent spraying, this approach only modulates the flow rate based on speed and altitude. Nevertheless, environmental conditions and spray system characteristics impact the spray effect (Hewitt 2008). Temperature, relative humidity, and wind speed influence droplet deposition by causing droplet drift and evaporation. The spacing between nozzles in the fuselage's structural characteristics has an effect on spray uniformity (Aissaoui 2015). Furthermore, the rotor's pitch changes its airflow field and influences droplet deposition (Zhang et al. 2018). Deng et al. 2016, built a constant-pressure sprayer governed by a proportional integral derivative algorithm with a closed-loop. This sprayer's pressure was altered by manipulating the solenoid valve's opening, hence altering the spray volume increase the discharge rate. In the same field, crops are affected by pests and diseases of varying severity, whereas environmental factors and flight characteristics affect spraying efficiency. Implementing this system, farmers can access land that is either too wet or otherwise inaccessible by humans. Other benefit of this application is the noninvolvement of humans from pesticide spraying operation, which greatly reduce the risk of chemical contamination. Also, the spraying heights by this means are usually higher than conventional ground sprayers, where fragile crops might experience some damage if the spraying height is too low. The major downsides of this approach are the limited flying time and amount of liquid (spraying content) that the drone can lift while in aerial operation. Drone spraying system typically consists of spray tank to store the liquid and nozzle for spraying. Pressure pump is usually applied in pesticide spraying but not in fertilizer spraying. Yallappa et al. 2017, use a hexa-copter type of drone, equipped with spraying mechanism, which consists of 5l capacity spray tank and 4 flat fan nozzles, among other equipment. Findings showed that the drone is capable of spraying 1.15 and 1.08 hectares per hour for groundnut and paddy crop, respectively. Qin et al. 2018, analyzed the effects of different spraying heights and concentrations on the deposition of droplets on the wheat canopy and the prevention of powdery mildew.

A single rotor UAV-N3, equipped with 25 l spray tank was used to spray the pesticide through two rotary atomizer nozzles at a flow rate of 850 $ml.min^{-1}$. It was found that spraying the pesticide from 3.5 m height gives the best droplets coverage rate and uniformity on wheat canopy, which is higher than ground spraying. For the prevention against powdery mildew, reducing the original dosage (450 g/hm2) by 20% will provides the best effect. To increase the usage efficiency of pesticide during spraying, Yanliang et al. 2017, introduced an electrostatic spray system with 0.3 MPa pressure and 10 l tank capacity and applied it to the hexacopter-type drone. Based on the results, this system gives a more concentrated droplet deposition compared to the non-electrostatic spray. Tang et al. 2018, analyzed the influence of quadcopter type drone's operational height and crop shape on the droplet deposition. It was discovered that the best spraying performance is at 1.2m operation height and droplet deposition can be improved when applied to the inverted triangle crop shape.

CHAPTER 3

3.0 Analysis and Synthesis of the Literature Review Finding

Thorough analysis has been carried out on several works on this theme of designing spraying equipment that can be attached to Unmanned Aerial Vehicle (UAV). Many of these works such as Journals, Thesis, Literature Review points to application of drone in agriculture especially, in spraying, monitoring, farm field mapping, soil and crop analysis and many more. Amongst all the application the area that align with this thesis is crop spraying. Application of drone for crop spraying will lead this work towards designing of effective and efficient spraying equipment that can be integrated with drone. The thesis will synthesize the main primary focus with factors to be considered for the design. These factors are and not limited to spray drift, payload, spray system, precision and decision, safety measures relating to usage of drone.

3.1 Scope of the study

With their versatility and capabilities, drones have revolutionized various sectors. One significant application of drones is in agriculture, where they are used for tasks such as crop monitoring, mapping, and spraying. The design of spraying equipment for drones is a crucial aspect of maximizing their effectiveness in agricultural operations. This piece of work aims to explore the scope of design considerations for spraying equipment in drone technology, highlighting key factors, challenges, and potential solutions. Unmanned aerial vehicles (UAVs) have emerged as valuable tools in modern agriculture, offering benefits such as increased efficiency, reduced labor costs, and improved precision. UAV-based spraying involves the aerial application of pesticides, fertilizers, and other agrochemicals over agricultural fields. This approach offers several advantages over traditional ground-based spraying methods, including better coverage, reduced chemical drift, and the ability to access challenging terrain.

This literature review focuses on the design of a sprayer that would be integrated or attached to a UAV for the purpose of spraying or discharging agriculture related substances. The following factors are to be considered when designing the spraying equipment, Payload Capacity, Spraying Rate and Coverage, Spray Nozzle and Distribution System, Tank Capacity, Flight Time and Range, Navigation and GPS Accuracy, Autonomous Operation. Taken all these into account ensures effective and efficient operations of the equipment which is the primary focus of this literature review.

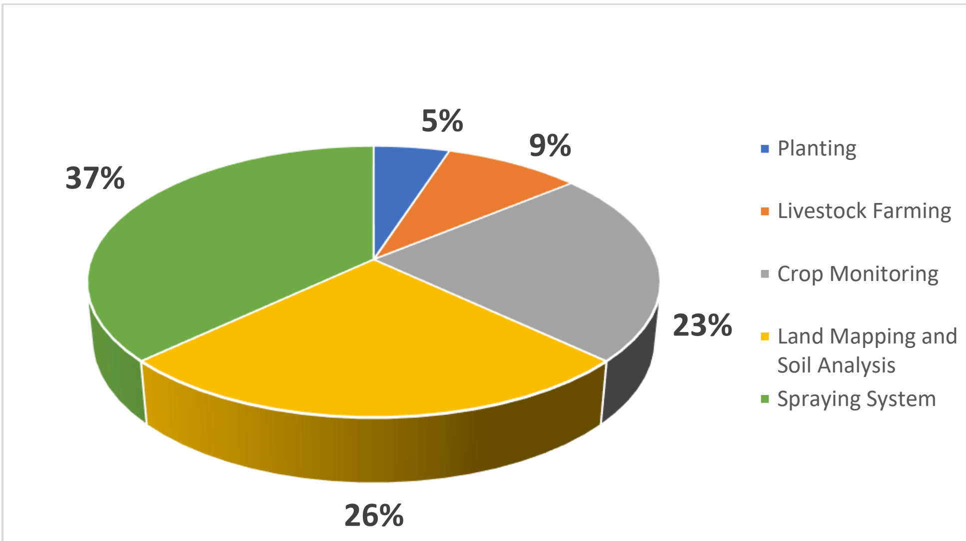


Figure 3. Agricultural area where drones have been used.

Source: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 04, April 2022)

3.2 Design Considerations for Spraying Equipment

The following factors are to be considered when designing the spraying equipment. Payload Capacity, owing to the limitation of flight time due to high payloads, attempts are being made to develop an octocopter drone with lower weight spraying systems (Vimalkumar 2020). Striking a good deal of balance between drone's pay load and its aerial operation in regard to flight time will improve UAV usage in agriculture. If a drone can carry more payload weight, the chance of adoptability will increase which is also the observation made (Koshta et al. 2022).

Spraying Rate and Coverage, using drone will significantly increases the spraying rate and coverage and ultimately eliminate stressful manual labour employed by human. Adopting agro-drones for pesticide spraying, farmers can overcome issues like excessive chemical application, uneven distribution, airborne pesticide dispersion, and the significant reliance on manual labor, thus revolutionizing agricultural practices (Hafeez et al. 2022, Sinha 2020). A Quadcopter mounted with sprayer helped minimize the resources required and to ensure controlled spraying over the chosen farm (Spoorthi et al. 2017). Spray Nozzle and Distribution System, Tank Capacity, Flight Time and Range, Navigation and GPS Accuracy, Autonomous Operation. Additionally, this study seeks to explore the potential benefits of UAV-based spraying, including reduced labor costs, increased operational efficiency, and improved crop yields. Challenges in Designing UAV Spraying Equipment such as Weight and Size Constraints, Flow Control and Liquid Distribution, Integration with UAV Platform. This leads to another part of the study which is the Solutions to Design Challenges, and this includes Development of Lightweight and Compact Systems, Optimization of Flow and Distribution, Integration with UAV Platform and not exhaustive. This study will wrap it up exploring the Opportunities for Innovation relating to drone use in agriculture with focus on Precision Agriculture and Environmentally Friendly Solutions. By examining the performance of different spraying equipment configurations and methodologies, the study aims to identify optimal design parameters and operational practices for maximizing the effectiveness of UAV-based spraying in agriculture. Atomizing the discharge from the spraying equipment's nozzle is crucial to the design of the spraying device. The atomization factor caused by the structural design of the spraying system includes the selection of nozzles, the layout of nozzles and rotors, and the properties of the liquid (Chen et al. 2021).

Importance of Design in UAV Spraying Equipment

The design of spraying equipment plays a crucial role in the effectiveness and efficiency of UAV-based spraying operations. Several factors need to be considered during the design process to ensure optimal performance and functionality. These factors include spray volume, spray pattern, droplet size, payload capacity, power requirements, and system integration. Additionally, considerations such as weight distribution, aerodynamics, and durability are essential for ensuring safe and reliable operation.

Key Design Considerations

a. Spray Volume: The spray volume refers to the amount of liquid sprayed per unit area and is determined by factors such as nozzle size, flow rate, and operating pressure. Designing spraying equipment with adjustable spray volume capabilities allows for flexibility in application rates, enabling precise control over chemical usage and minimizing waste. The wider the orifice of the nozzle the more volume of liquid or agricultural substance s flows out from the spraying equipment. There is need to maintain normal operating pressure to make the discharge reach expected unit area during application.

b. Spray Pattern: The spray pattern refers to the distribution of spray droplets over the target area and is influenced by nozzle design, spacing, and orientation. Designing equipment with uniform spray patterns ensures consistent coverage and effective pest control, reducing the risk of under or over-application. Spray pattern is essential to the design of spraying equipment to maintain expected even spray of chemical, pesticide, fertilizer, or other agricultural liquid or substances. This will manage the issue of under or over-application of agricultural substances.

c. Droplet Size: Droplet size plays a critical role in the effectiveness of pesticide application, with smaller droplets providing better coverage and penetration. Designing equipment capable of producing fine droplets with controlled size distribution enhances spray efficacy while minimizing drift and environmental impact.

d. Payload Capacity: The payload capacity of the drone determines the amount of spraying equipment and chemicals that can be carried during each flight. Designing lightweight yet durable spraying equipment allows for increased payload capacity, maximizing operational efficiency and reducing downtime. One of the effective ways to reduce payload of UAV is choice of material for the spraying equipment. The material should be a light weight to mitigate the overall weight of the combined system – Drone and the spraying equipment altogether.

e. Power Requirements: The power requirements of the spraying equipment depend on factors such as pump efficiency, motor performance, and battery capacity. Designing energy-efficient systems and optimizing power management techniques extend flight endurance and operational range, enhancing overall productivity.

f. System Integration: Effective integration of spraying equipment with the drone platform is essential for seamless operation and control. Designing modular and compatible components facilitates easy installation, maintenance, and upgrades, ensuring scalability and adaptability to different drone models and configurations.

3.3 Precision and Accuracy

The spraying equipment is to be designed to achieve precise and accurate spraying as this is vital to optimize the effectiveness of agricultural applications. This can be achieved by critical design and right sprayer nozzle selection, positioning, and calibration. Different nozzle types, spray patterns, and droplet size control mechanisms to improve coverage uniformity and minimize drift. Integration of real-time monitoring systems, including sensors and imaging technologies, GPS (Global Positioning System) are necessary to provide feedback for adjusting spraying parameters during operation. Dongyan et al. 2015, experimented on effective swath width and uniformity of droplet distribution over aerial spraying systems like M-18B and Thrush 510G.These agricultural planes flew at height of 5 m and 4 m respectively and with this experiment they reach to conclusion that flight height leads to the difference in swath width for M-18B & Thrush 510G. Huang et al. 2015, made a low volume sprayer which is integrated into unmanned helicopters. The helicopter has a main rotor diameter of 3 m and a maximum payload of 22.7kg. It used to require at least one gallon of gas for every 45minutes. This study paved the way in developing UAV aerial application systems for crop production with higher target rate and larger VMD droplet size. Yallappa et al. 2017, developed an hexacopter with 6BLDC motors and two LiPo batteries of 6 cells- 8000 mAh. Their study also involves performance evaluation on discharge and pressure of spray liquid, spray liquid loss and determination of droplet size and density. Through their project, they finally made a drone capable of carrying 5.5 L of liquid with an endurance time of 16 min. Kurkute et al. 2018, worked on quadcopter UAV and its spraying mechanism using simple cost-effective equipment. The universal sprayer system is used to spray for both liquid and solid content. In their research, they have also compared different controllers needed for agricultural purposes and concluded that quadcopter system with Atmega644PA is the most suitable due to its efficient implementation. Rahul et al. 2019, described an architecture based on UAV that could be employed for agricultural applications. Their UAV was designed not only for spraying but also for monitoring agricultural fields with the use of cameras and GPS. Their design was optimized for cost and weight. They used a microcontroller kk 2.1.5 which has inbuilt firmware. Balaji et al. 2018, developed an hexacopter UAV with the purpose of spraying pesticides as well as crop and environment monitoring using Raspberry Pi that run on python language. Their UAV also contains multiple sensors like DH11, LDR, Water Level Monitoring sensors. From this experiment, they finally concluded that with proper implementation of UAVs in the agricultural field almost 20%-90% savings in terms of water, chemical maltreatments and labor can be expected.

3.4 Payload Capacity and Efficiency

The payload capacity is very crucial to flight efficiency of a UAV. A good consideration for material selection for the spraying equipment can enhance optimizing the design for efficient spray delivery. The total payload of a drone can be achieved by considering the weight of the agricultural substance (pesticide, granules, liquids, fertilizers, herbicide, or disinfectant), storage tank, pump, nozzles and any additional sensors or equipment. These significantly impacts UAV flight duration and coverage capabilities. To maximize payload capacity, minimize energy consumption and optimize operation efficiency various techniques such as lightweight materials, compact designs, and efficient pumping systems should be explored as this will also enhance the spraying rate and coverage. Lightweight and compact design solutions to minimize weight and space requirements. The higher the payload the more the volume especially, UAV with the larger tank - larger payloads can accommodate more liquid, granular substances, or other materials, allowing for a higher coverage area per flight, the higher the coverage area, the lesser the number of flights. There will be higher coverage rate - A UAV with a larger payload capacity can typically deliver a higher coverage rate, as it can carry more material in a single load. When the payload is high it reduces mission - A UAV with a higher payload capacity may require fewer missions to cover a given area compared to a UAV with a smaller payload. This can lead to increased efficiency, especially in large-scale agricultural or industrial applications.

The increased weight requires more power from the UAV's propulsion system to stay airborne. Due to the design limitations, they cannot handle missions with agile and complex manoeuvres. In contrast, Monocopter drones enable vertical take-off and landing (VTOL) and do not require a runway or operational space (Dhanya et al. 2023). They offer higher maneouvre flexibility by controlling the propeller speed thereby enabling agile movements during missions. However, they do not offer sufficient stability and control during missions, particularly at higher and payloads. In the recent times, multirotor drones are designed to overcome the challenges of fixed wing and monocopter drones (Hassanalian et al. 2017). They are equipped with multiple propellers at calculated geometrical locations on the drone body. Changing the speed and direction of rotation of these propellers enables the users to maintain the required stability as well as agility in manoeuvring them. They can be engineered to carry various payloads (Hassanalian et al. 2017). Deployment of a drone over agricultural farms helps farmers to experience aerial views of the harvest. The data thus obtained help to derive information on the efficiency of the water system, soil characteristics, and presence/absence of pests (Hafeez et al. 2022). Drones with payloads such as multispectral cameras can also aid in determining crop health at a large scale, which is challenging to the naked eye. Despite all these applications with significant influence on how operations are nowadays carried out in agriculture, payload is still a constraint to achieve full potential of the UAVs in this regard. In addition, as the UAV expends more energy to carry the heavier payload, its flight time is generally reduced. The additional weight increases power consumption and decreases the UAV's overall endurance. This as well decreased Operational Efficiency of the UAV. Shorter flight times due to heavy payloads can reduce operational efficiency, as the UAV may need to land more frequently for refueling or recharging or battery replacement. As a result, this piece of work is to strike balance in the design of storage capacity, material of the spraying equipment and other attachments to the UAV to achieve a relative efficient machine.

3.5 Challenges and Future Directions

a. Battery Technology and Endurance

One of the primary challenges in UAV spraying equipment design is the of battery power limitation, which affects flight endurance and altitude. Drones lose altitude and endurance once it experiences low power, and this consequently impacts efficiency and time frame of the spraying operation. Hence, developing advanced battery systems with higher energy densities, longer lifespans, and faster charging capabilities is crucial to operability of spraying equipment attached to UAVs. Integration of emerging battery technologies, such as solid-state batteries or hydrogen fuel cells, holds promise for significantly extending UAV flight durations and reducing downtime.

b. Hybrid Power Systems for Spraying

Battery limited power is one of the many challenges faced in UAV spraying operation. Relatively, the limitations of battery life pose challenges to extended spraying flight operation flight for UAVs. Putting this in mind, it is highly recommended to develop hybrid power systems that combine conventional batteries with alternative power sources such as solar panels or fuel cells. This is important simply because hybrid power systems offer increased endurance, allowing UAVs to cover larger areas without frequent battery replacements or recharging during operation.

c. Swarming and Cooperative Systems

Swarming is a concept that involves coordinating multiple drones to perform collaborative tasks. In the context of spraying, swarming allows for synchronized and efficient operations over larger agricultural areas. Further research should focus on communication and control mechanisms that enable swarm-based spraying, ensuring coordination, avoiding collisions, and optimizing coverage. Cooperative spraying systems demonstrate improved efficiency, reduced operation time, and redundancy for increased reliability. This enhances mission capabilities and cost-effective Operations as swarming reduces the cost per task or mission by distributing the workload among multiple UAVs.

d. Environmental Considerations

As UAVs become increasingly prevalent in agricultural spraying tasks, environmental considerations are of utmost importance. More work is to be done to exploring ways to minimize the environmental impact of spraying operations. This includes the development of eco-friendly spraying formulations with reduced chemical usage, improved targeting mechanisms to minimize overspray with regards to quantity and getting beyond the targeted area, and strategies to mitigate the impact on beneficial insects and non-target organisms. In addition, the adoption of sustainable practices, such as precision agriculture techniques and data-driven decision-making, helps optimize resource usage and minimize ecological footprints.

e. Regulatory Frameworks

The widespread adoption of UAVs for spraying purposes necessitates the establishment of robust regulatory frameworks to ensure safe and responsible operations. Regulatory Restrictions - Strict regulations and airspace restrictions govern drone operations in many countries, limiting where and how drones can be flown. Compliance with regulatory requirements, such as registration, licensing, and airspace authorization, can be complex and time-consuming for drone operators. Limited Payload Capacity: Most commercial drones have limited payload capacity, restricting the types of sensors, cameras, or equipment that can be carried. This limits their suitability for certain applications requiring heavy or bulky payloads. Security Concerns -Drones pose security risks, including unauthorized surveillance, privacy infringements, and potential misuse for malicious purposes such as smuggling, espionage, or terrorist attacks. Safeguarding against unauthorized access, hacking, or tampering with drones and their data is a significant concern. Safety Risks - Drones can pose safety hazards to people, property, and other aircraft if not operated responsibly. Collisions with obstacles, buildings, or manned aircraft, as well as loss of control, signal interference, or mechanical failures, can result in accidents, injuries, or damage. Data Privacy and Security - Drones collect vast amounts of data through sensors, cameras, and other onboard equipment, raising concerns about data privacy, security, and ownership. Unauthorized access to sensitive data or breaches in data storage and transmission can lead to privacy violations and legal liabilities.

It is necessary for all concerned parties such as engineer, scientists, environmentalists, researchers, and policymakers to working together to develop guidelines and standards that address airspace management, certification requirements, flight restrictions, and operational safety protocols for the usage of drones in agriculture and other field of life. Continual collaboration between industry stakeholders, regulatory bodies, and researchers is essential to adapt regulations to the evolving technological landscape and facilitate the integration of UAV spraying systems into existing agricultural practices.

f. Automation and Intelligent Systems

Incorporating automation and intelligent systems in the operation of spraying system plays a pivotal role in enhancing the capabilities of UAV spraying equipment. This literature will assist in the future project of making an autonomous spraying system that can independently and intelligently collects plant and flight data. These can be used to plan flight paths, monitor crop conditions, and optimize spraying parameters based on real-time data collected. This can be achieved through Integration of artificial intelligence (AI) and machine learning algorithms that will enable UAVs to learn from previous operations and improve decision-making to optimize spraying efficiency. The control system and environmental sensing sensors are the fastest elements of the drone update iteration, evolving from the initial manual control mode, semi-automatic (ex. Trajectory from Point A to Point B mode) control mode to fully autonomous mode. Positioning sensors have evolved from the Global Navigation Satellite System (GNSS) with meter-level errors to Real Time Kinematic (RTK) with centimeter-level errors. In addition, air pressure sensors, ultrasonic sensors, radar, binocular vision, and other sensors used for altitude determination, distance measurement, and obstacle avoidance are constantly updated (Wang et al. 2019, Chen et al. 2021).

g. Universal Spray System

Use of single spraying equipment on different types and sizes of UAVs has become a challenge. Integrating spraying equipment onto UAVs poses challenges relating to weight distribution, stability, and compatibility with different UAV makes and sizes. Although, this work will not go into details on this issue. Nonetheless, it will address the issue, of pressure and nozzle discharge for optimum spay system. It is, however, important to note that designing a universal spraying system that can be attached to any drones is very important in the field of agriculture. Hence, there is room for more work to investigate methods to ensure seamless integration, considering factors such as mounting mechanisms, structural modifications, and compatibility with flight control systems. Additionally, the ease of installation, maintenance, and removal of spraying equipment is also considered during the design process. The spraying equipment need to be designed in such a way that the pressure and atomization of the discharge especially, agricultural liquid substances should be moderate enough not to destroy the crop or plant being applied it to. The goal of aerial application is to achieve satisfactory crop protection by proper selection of the application parameters including application timing, pesticide type, tank mix partners, environmental parameters, and proper selection of spray system equipment. This sprinkler system, which is often located at the bottom of the UAV, employs a nozzle connected to the pesticide tank to spray pesticide solution over crops. The two components of a sprinkler system are the spraying control and nozzle systems. The spraying system includes both spraying material (pesticides or fertilizers) and a spraying nozzle. The second component is a controller that regulates the nozzle of the sprayer. A pressure pump is a sprinkler system component that forces insecticide through the nozzle using pressure.

h. Safety Measures

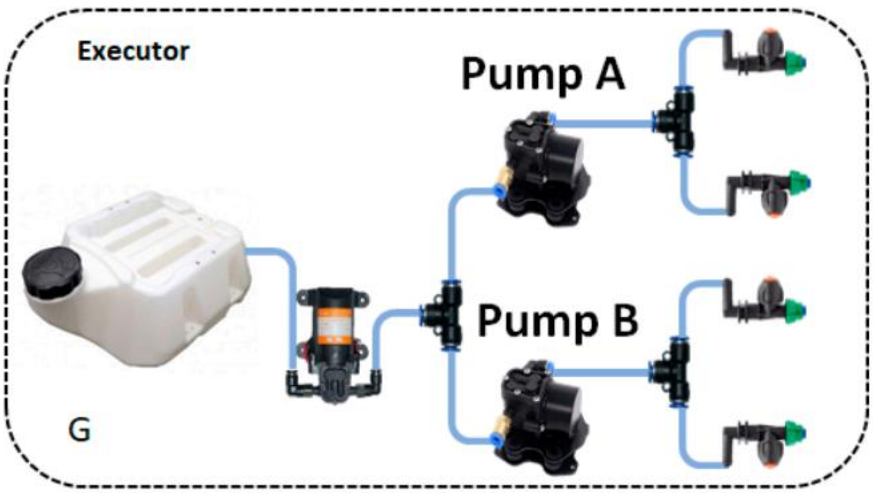
Safety has been an important aspect of engineering projects and design. Fundamentally, all equipment and accessories attached or integrated to the drone must be firmly fixed in such a way that it is not in a loose condition nor fall or drop while in operation most especially during flight. Thus, it is crucial to ensuring safety during UAV spraying operations. Considering and designing safety measures to protect operators, bystanders, and the environment is a paramount aspect of spraying equipment development. There is need to focus on incorporating fail-safe mechanisms, emergency procedures, and obstacle detection systems to minimize risks associated with collisions, equipment malfunctions, and chemical exposure. In addition, improvements in geofencing technology and collision avoidance systems contribute to safer operations. Weather Sensitivity is to be considered as drones are sensitive to adverse weather conditions such as high winds, rain, snow, fog, and extreme temperatures. Unfavorable weather can affect flight stability, reduce operational efficiency, and pose safety risks to both the drone and surrounding environment.

CHAPTER 4

4.0 Design Proposal of a Spraying Device for a Drone

Aerial spraying of farm and crops can be achieved through usage of drones equipped with spraying devices. It offers a precise and efficient method for applying pesticides, fertilizers, and other agrochemicals to agricultural fields. It has the potential to revolutionize agriculture. In addition, the design points at optimizing spray efficiency, accuracy, and increasing coverage. This chapter will explore and elaborate the development of a spraying device specifically designed for integration with a drone platform through addressing crucial design factors, objectives, process, equipment features, and leveraging innovative technologies. The primary goal is to create a reliable spraying equipment that maximizes efficiency and effectiveness in aerial agricultural operations that is open to further research work and improvement as time and technology demands.

Figure 4. Simple layout of an aerial sprayer system.



4.2 Design Objectives

A. Precision

All efforts will be pointing towards proposing and developing a spraying device capable of delivering precise and uniform spray coverage over the target area. This will aid minimizing chemical waste, herbicides, fertilizers, water, and other agricultural dischargeable substances and ultimately maximizing the effectiveness of agrochemical applications with less error.

B. Efficiency

To achieve a substantial efficiency with the proposed design, a lightweight material such as plastic, aluminum, durable inflatable rubber-like material should be considered.

In addition, energy-efficient components that will be coupled with the proposed spraying device is equally important. It will optimize payload capacity that mostly affect flight operations. In furtherance to that, it enhances and extends flight endurance, allowing for longer operational flights and increased productivity for the whole flight, spraying and farming operation combined.

C. Adaptability

In this regard, the proposal will be to create a modular and customizable spraying device that can be easily assembled with a wide range of drone platforms, accommodating different payload capacities, spraying requirements, and application scenarios. It is vital to know that this is different from universal design that fit all types of drones nor all aerial field and farm operations. The point here is that it will be relatively compactible with an appreciable number of drones with much ease of assemble and disassemble the spraying device.

D. Safety

Some recommendation will be put forward such as Implementation of safety features like component that senses obstacle or human presence with a given space of operation both aerial and on ground. Additionally, control device is expected to be integrated to the spraying system to identify and react spontaneously to fail-safe scenarios. This helps to mitigate any risks associated with chemical substance exposure, equipment malfunction, and flight disruptions, and ensuring compliance with regulatory standards and environmental regulations.

4.3 Design Features

a. Tank

Material such as Polyethylene which is the most common plastic tank material is recommended. Relatively, it has high resistance to salt water, non-hazardous liquid against damage. To add to this, it is much better for the tank material to be transparent materials that will easily and visibly show liquid level in the tank and serve as indicators to facilitate easy monitoring of chemical levels and refilling. Just like nozzle, the material for the tank must be durable to withstand weather condition, non-reactive to Agri-substances such as agricultural chemicals, fertilizer, herbicides, and other related agricultural substance that will be passing stored, filled into it. Centre of gravity need consideration when it comes to placement of spraying equipment tank.

It is highly recommended to place the storage tank at the center of gravity of the drone to support a perfect airlift and smooth flight during aerial operation. On the same hand, the storage tank should be designed in a form where the base (bottom) will slant on all sides towards the discharge point. This will avoid residual of Agri-substances to stagnate within the reservoir that could complicate cleaning for the next operation probably, with different agricultural liquid. Detachable which is otherwise means easily removable, refillable is preferred when designing the storage tank for this proposed spraying equipment. It is expected to be shaped whereby at least two of its sides will sit perfectly without slip on the frame of drone, sitting on the four sides will be the best. This will make to the tank to fit to appreciable numbers of drones for aerial spraying application.

b. Spray Nozzle System

The nozzle is the point of discharge for the spraying device. It discharges the agricultural substances in the form of spraying, directs the substance to the targeted point or area to be covered by the agro-substance. Selecting the right nozzle for spraying operation is one of the most important features to be considered with respect to related to agricultural spraying applications. This not only affects the amount of volume sprayed to a particular area, but also the uniformity of the sprayed agricultural substance, the coverage obtained on the sprayed surfaces, and the amount of drift that can occur while in operation. Various types of nozzle bodies and caps, including color coded versions, and multiple nozzle bodies are available with threads as well as quick-attaching adapters. Nozzle tips are interchangeable in the cap and are available in a wide variety of materials, including hardened stainless steel, stainless steel, brass, ceramic, and various types of plastic. Hardened stainless steel and ceramic are the most wear-resistant materials but are also the most expensive. Stainless steel tips, with corrosive or abrasive materials, have excellent wear resistance. Plastic tips are resistant to corrosion and abrasion and are proving to be very economical for applying pesticides. Brass tips have been common but wear rapidly when used to apply abrasive materials such as wettable powders and are corroded by some liquid fertilizers. Brass tips are economical for limited use, but other types should be considered for more extensive use. Figure 5 shows the increase in flow rate of spraying an abrasive material over a set period. Each of the nozzle type has specific characteristics and capabilities and is designed for use under certain application conditions. The types which are commonly used for application of agricultural liquids are flat-fan, even flat-fan, and cone nozzle. To enhance and utilize its precision, the nozzles to have adjustable flow rates and spray patterns that helps to optimize spray coverage and minimize drift during the aerial operation. Furthermore, to prevent clogging and ensure consistent performance throughout the spraying operation, incorporation of nozzle filters and anti-drip mechanisms will make the job done. Nozzles are connected to the spraying device pump with the aid of ducts or pipes. This serves as the channel for the passage of agro-chemicals and other agro-substances to flow from the reservoir to the nozzle for spraying. Material of the nozzle is another important area to address. The material plays a significant role in determining the drone's stability and efficient performance. Fundamentally, the material should be durable to withstand weather condition, non-reactive to agri-substances such as agricultural chemicals, fertilizer, herbicides, and other related agri-substance that will be passing through it. In spraying systems, there are various types of nozzles, each with its own efficiency, performance, and technical specifications. This sprinkler system, which is often located at the bottom of the UAV, employs a nozzle connected to the pesticide tank to spray pesticide solution over crops. The two components of a sprinkler system are the spraying control and nozzle systems. The spraying system includes both spraying material (pesticides or fertilizers) and a spraying nozzle. The second component is a controller that regulates the nozzle of the sprayer. A pressure pump is a sprinkler system component that forces insecticide through the nozzle using pressure. A motor driver integrated circuit is utilized to adjust the pump's pressure as required. Table 4 compares the flow rates and nozzles utilized by UAVs for spraying.

Table 1. Comparison of Selected Nozzle Types

Type	Droplets	Coverage	Drift	Pattern	Operation	Cost
Convectional	uniformly fine	wide	prone at wider angle	flat fan at 110˚	hydraulic pressure	low
Pre-Orifice	uniformly fine	wide	prone at hi-pressure	flat fan	hydraulic pressure	low
Low Pressure Air-induced	relatively fine	wide at hi-pressure	prone	flat fan	compressed air	medium
High Pressure Air-Induced	coarse	wide at hi-pressure	Less prone	flat fan	compressed air	high
Centrifugal	fine with limitation	wide	Less prone	cone-shaped	spinning disc/rotor	relatively low
Sprinkler	very coarse	wide	very prone	umbrella	sprinkler head	medium
Electrostatic	fine	wide	less prone	cone-shaped	Electric charge	high

NOZZLE TIP SELECTION

The correct nozzle tip size depends on an application rate in gallons per acre or litres per hectare ($l.ha^{-1}$), speed ($km.h^{-1}$), and effective spray width of each nozzle (W). The best method for choosing the correct nozzle tip size is to determine the discharge rate of the nozzle in litres per minute ($l.m^{-1}$) which is the output from the nozzle, then select a nozzle tip size that, when operated within the recommended pressure range, will provide this flow rate. It is important not to solely based the factor for nozzle selection on the "litres per hectare" of "gallons per acre" rating which some manufacturers give their nozzles as means of selecting nozzle tip size. This rating is correct only for standard conditions. The rating is meaningless if any variance from the standard occurs such as increase in pressure, or pressure drop or angle of spray. By determining the steps described below, choosing the right nozzle tip size can be achieved.

1. Calculate "GPA "- First select the application rate in gallon per acre (GPA) or litre per hectare ($l.ha^{-1}$). The application rate consists of the gallon of carrier (water, fertilizer, etc.) plus chemical applied per treated acre. The best guides for this decision on the quantity of substance to use, it highly recommended to check ranges listed on the label, the recommendation of a chemical dealer or county agricultural agent, and acquaintance with that chemical. This equally applies to litres per hectare label provided by manufacturer.

GPA can be converted to $l.ha^{-1}$ using the formular:

$$\textbf{GPA x 9.35} = \textbf{l.ha}^{-1} \text{ ------------------------} \textbf{[1]}$$

2. Calculate "MPH" - Select an appropriate aerial speed in miles per hour (MPH) or Kilometer per hour ($km.h^{-1}$) for the field to be sprayed. Experience is the best guide here. Generally, specific speed considered appropriate for aerial sprayers. There is not a universally agreed guidelines for speed of drones set by any official body or association for the UAV operation for spraying. The optimum speed of application for most multi-rotor spray drones defers from manufacturer to manufacturer for the various spray drone models. Therefore, it is best to operate a spray drone in the optimum conditions outlined in its operator manual. More to this, wind speed is very vital to consider when operating drone sprayer to avoid drifting of the agricultural chemical being sprayed.

$$\textbf{MPH} = \left(\frac{Distance(ft)\ x\ 60}{Time\ (Sec) x\ 88}\right)$$

km.h^{-1} can be derived from the above formular by multiplying the result by 1.609.

MPH x 1.609 = km.h^{-1} -------------------[2]

3. Calculate "W" - Determine the effective sprayed width per nozzle (W) in inches or meter or kilometer. For broadcast or aerial spraying, W is the distance between the two nozzles installed to discharge the chemical. The arrangement is basically in relative to operation or individual choice. This means that the nozzles can be in placed front, back or diagonal to each other regarding drone's flight direction.

W(inches) x 0.0254 = meter (m) or W(inches) x 2.54e^{-5} = Kilometer (KM) ----------[3]

4. Calculate Tip Size - Once the application rate, aerial speed, and spray width per nozzle have been determined, the flow rate required for each nozzle in litres per minute (LPM) can be determined by using a nozzle catalog, tables, or the following equation:

$$\textbf{GPM} = \left(\frac{GPA\ x\ MPH\ x\ W}{5{,}940}\right)$$

$$\frac{\textbf{GPM}}{\textbf{No of Nozzle}} = \textbf{GPM expected from each nozzle}$$

To convert GPM to l.min^{-1} the formular below is employed.

$$\textbf{GPM} = \left(\frac{GPA\ x\ MPH\ x\ W}{5{,}940}\right)\ \textbf{x 3.785 = l.min}^{-1}\ \textbf{(Litre Per Minute) ---------[4]}$$

Alternatively, l.min^{-1} can be directly calculated using this equation.

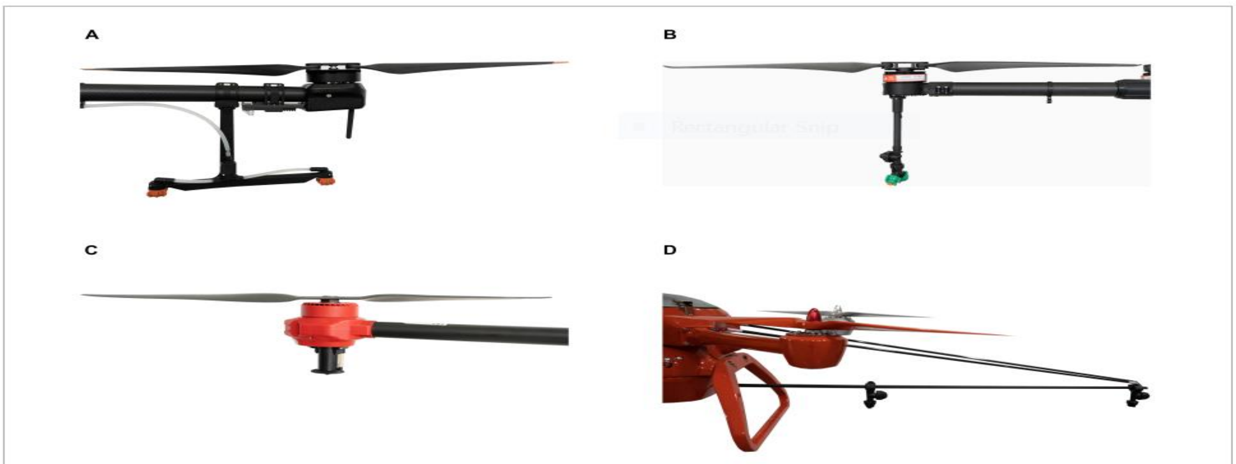
Q=d^2 x 0.00111 x $\sqrt{P}$ (l.sec^{-1}) **Q=d^2 x 0.0666 x $\sqrt{P}$ (l.min^{-1}) ------------------[5]**

Note: $l.s^{-1} \times 60seconds = l.min^{-1}$

Where:
Q = flow rate of liquid per sec or min for the operation (**$l.min^{-1}$**).
d = diameter of nozzle (m)
P = Pressure at nozzle (from the pump)
After determining the flow rate of the spraying nozzle, the next thing is to divide the flow rate by no of nozzles intended to use for the aerial agricultural spraying operation.

$$\frac{\text{Q (flow rate)}}{\text{No of nozzles}} = \text{LPM expected from each nozzle}$$

Figure 5. Different arrangements of nozzles under drone's rotor



The relative position of the rotor and the nozzle. **(A)** Inside under the rotor (T30, from DJI), **(B)** below the rotor (extended, 3WWDZ-16, from Tuogong), **(C)** below the rotor (P30, from XAG), **(D)** boom (kongzhongbaoma, from SCAU).

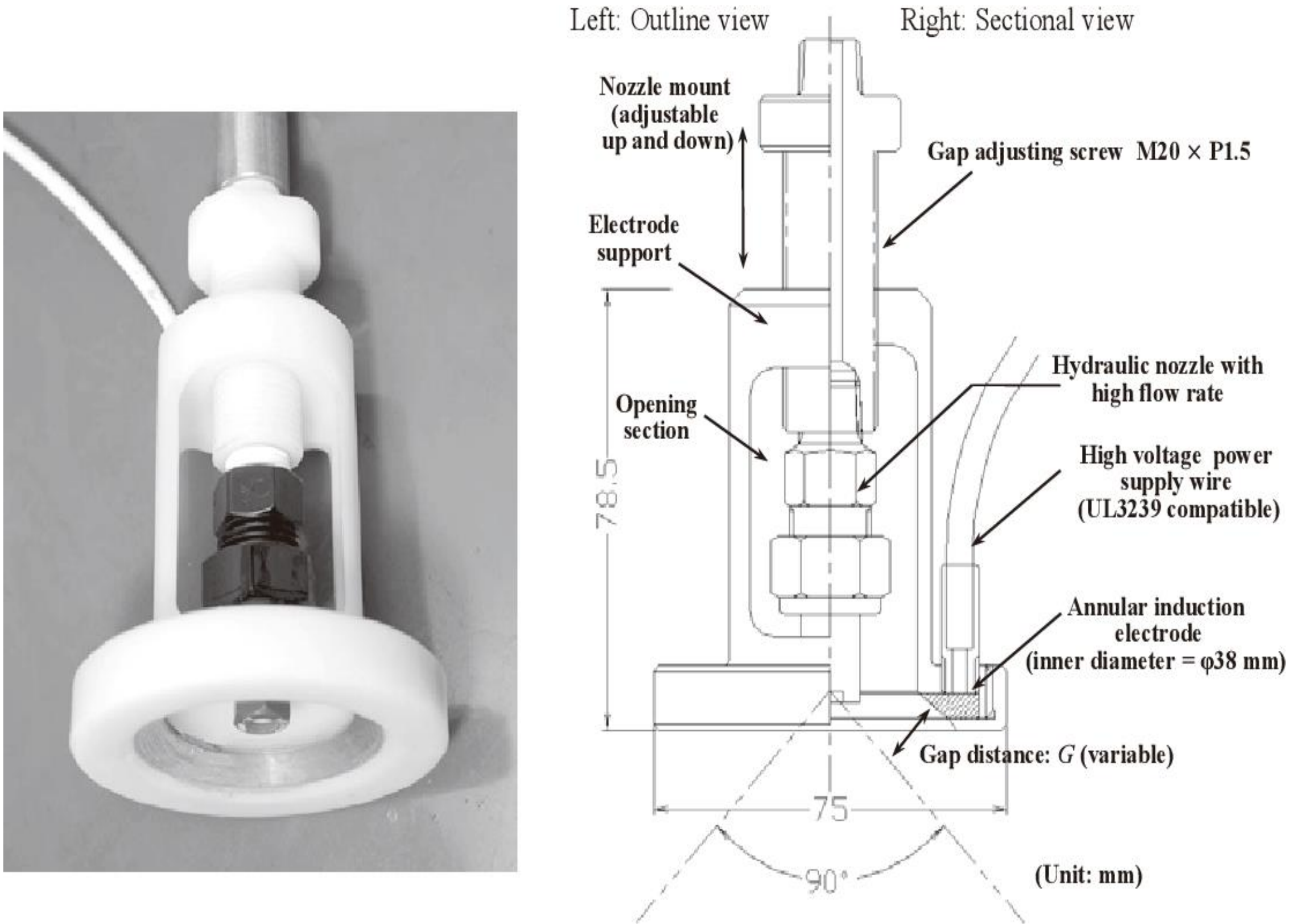
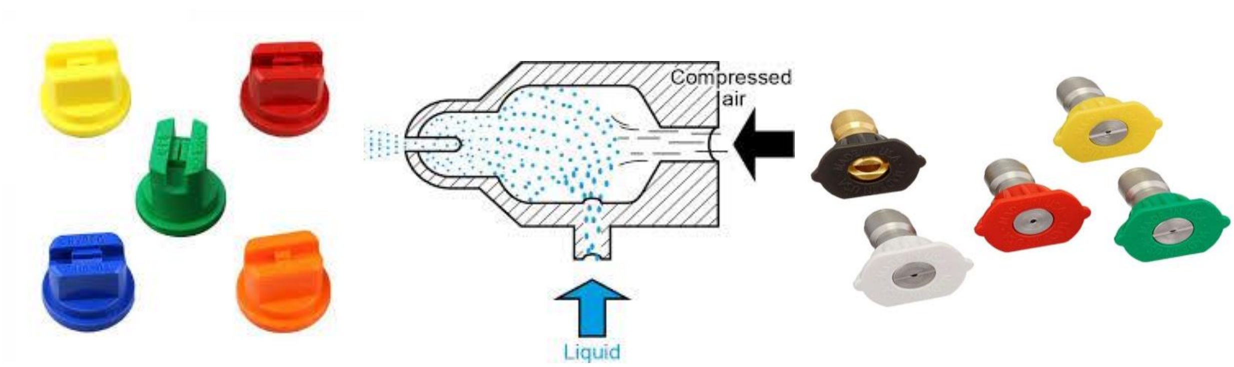


Figure 6. Electrostatic nozzle and its sectional view.



(a) **(b)** **(c)**

Figure 7. (a) Convectional nozzle tip. (b) Sectional view of air-induced nozzle tip. (c) Pre-orifice nozzle tip.

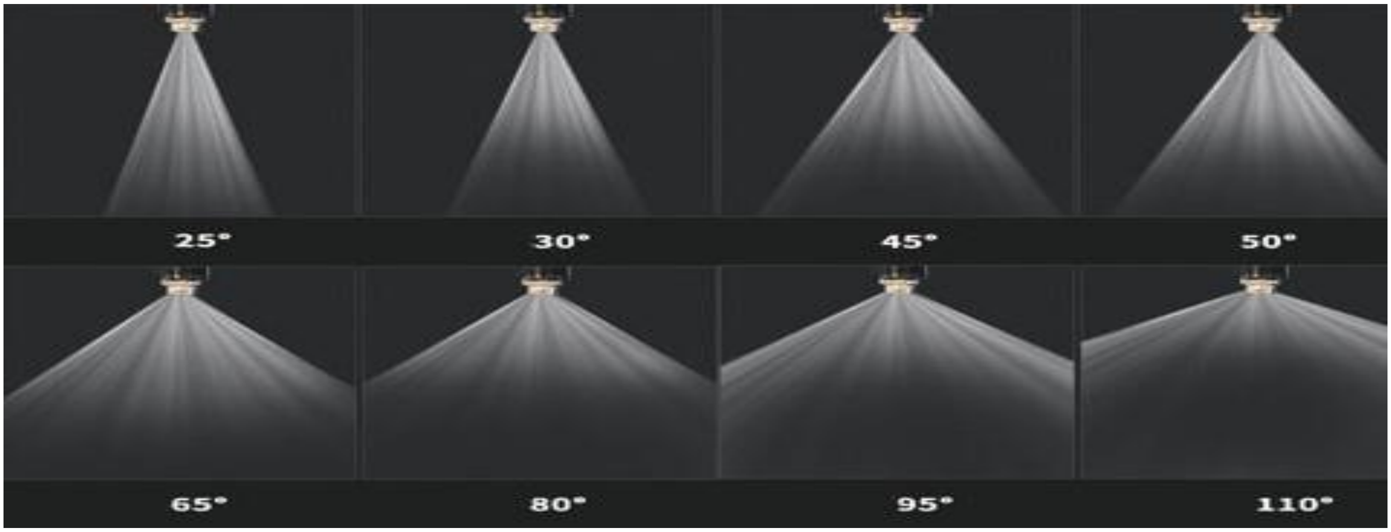


Figure 8. Different angles of convectional nozzle's discharge that define pattern, droplets characteristics.

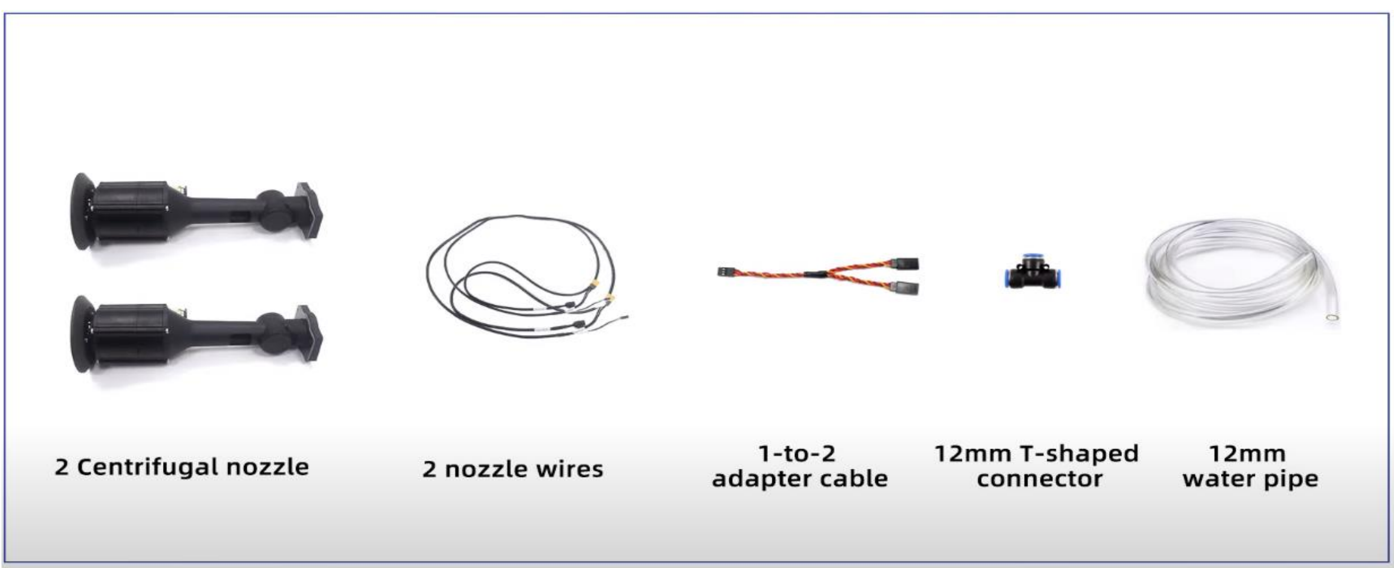


Figure 9. (above) Centrifugal Nozzle. (below) Centrifugal nozzle parts.

Figure 10. UASS with two centrifugal nozzles.

c. Pump

Pump- One of the main parts of any spraying system are the pump and its controlling system. The function of a pump is to basically generate appropriate pressure and transfer it to the desired point in the system. To pressurize the agricultural substance in the tank of the proposed spraying device and send it through the connected rubber hose to the nozzle as the discharging point in the spraying system, it is vital to selecting the right DC, appropriate voltage with a good discharge capacity of the pump. The pump is expected to be powered from a power distribution board while the inlet device of the pump is connected to the storage tank collect the liquid and transfer it to the outlet device that is connected via the flexible plastic tube/pipe/hose to the nozzles available in the system. Integrating this to the device will ensure a high-performance pump and reservoir system capable of delivering a consistent supply of agricultural material to the nozzles of the device. The pump assists to deliver regulated, and constant needed pressurize substance to the nozzle that collectively do the discharge operation in the form of spraying. The current supply to the pump will be from the UAV battery. The flow rate of the pump can be controlled by varying the input current which can be controlled from the transmitter.

Once flow rate has been determined, the right pump selection can be made with the aid of the formular below.

By manipulating the formular, the range of pressure needed for the operation can be deduced. This as a result, will guide for selecting the right pump for the spraying equipment.

$$\mathbf{Q=d^2 \times 0.00111 \times \sqrt{P}\ \ (l.sec^{-1}) \qquad Q=d^2 \times 0.0666 \times \sqrt{P}\ \ (l.min^{-1})}$$

From the equation [5], flow rate equation, the Pressure (P) is derived.

$$\mathbf{P = \left(\frac{Q}{d^2 \times 0.00111}\right)^2 \ (Pa)\ or\ P = \left(\frac{Q}{d^2 \times 0.0666}\right)^2 \ (Pa)}\ \text{--------------[6]}$$

(a) **(b)**

Figure 11. (a) A 3.8 $l.min^{-1}$, 24v brushless UAV liquid spraying pump. (b) Mounted pump on a UASS.

d. Power and Control System

Integrating power and control system component to the spraying equipment will upgrade its status from casual system to an advance one. Accessories such as Accelerometer, gyroscope, GPS are utilized when it come to drone flight control. It is highly recommended to employ brushless/DC motors. It is efficient and assist with power management, minimize energy consumption, and maximize flight endurance. In addition, the electronic component like flight controller effectively aids in the maneuvering aerial operations, and it provides Auto-level function for a smooth flight of the UAV. Sensors also play a crucial role to achieving a smooth and efficient flight combined with spraying operation. Sensors helps to gather and process data during flight, and this enhance decision making for both human and the system most especially, when artificial intelligence (AI) get involved. For instance, accelerometer and gyroscope sensors in the

Flight controller process the signals from the receiver and gives the output to the electronic speed controller (ESC). The KK 2.1.5 Flight controller board is one of the few available controllers that can be used in the drone as it has inbuilt firmware. The features of this Flight controller board are much easier for calibration. It uses ATMEL Mega 644PA 8-bit AVR RISC-based microcontroller with 64K of memory. Other sensors such as flow, liquid-level, obstacle to mention but a few can be integrated to the spraying system and optimize its overall performance.

It will be more interesting if the spraying equipment is upgraded from advance status to sophisticated level. This can be achieved by implementing AI. intelligent control algorithms, component, and onboard sensors to regulate spraying parameters, adjust nozzle settings, and ensure accurate application rates.

e. Mounting and Integration

This thesis primarily focuses on proposal to designing a lightweight, aerodynamic, and efficient mounting spraying system that firmly attaches to the drone platform and securely fly while maintaining stability and balance during aerial operation. Additionally, to ensure compatibility with standard drone mounting interfaces the individual devices are proposed to be detachable with ease. This means that all the spraying component is necessarily to be ergonomically designed in such a way that assembling and disassembling from the UAV should be as seamlessly as possible without any special training for the operators or farm worker. This will save precious time and cost of contacting servicemen. Furthermore, it is worthy to provide adjustable mounting options to accommodate different payload configurations and drone models. On this note, the spray system can fit to many drones and make it relatively universal. Although, it cannot fit all manufactured UAVs considering the evolvement and advancement of drone technology at an exponential rate. Nonetheless, it is proposed with an envisaged design that can fit appreciable number of drones with similar fabrication where the tank is placed or attached right in the middle of the UAV frame.

4.4 Design Process

Step 1: specifications and performance objectives

Clearly and concisely determine and list specifications such dimension, power output, discharge capacity, duration and many more, of all needed component for the spraying equipment. This should include their purpose, benefits, and performance in respect to the agricultural sprayer.

Step 2: Conceptual Design

Several conceptual designs are generated at this stage, multiple conceptual design proposals based on the identified requirements, considering factors such as size, weight, functionality, and manufacturability. Cut the options of the generated design to three then compared to make final decision on the best one that well align with the objectives of the design.

Step 3: Detailed Design

Refine and redefine the selected conceptual design through detailed engineering analysis, prototyping, and iterative testing to optimize performance and address any design constraints or limitations. This stage provides the opportunity to put final details to the design before construction, manufacturing, production, or purchase of component.

CHAPTER 5

5.0 Theoretical Evaluation of the Proposal

The design proposal for a spraying device for a drone represents a comprehensive approach to addressing the challenges and requirements of aerial spraying in agriculture. This section will evaluate the proposed design based on key criteria such as performance, functionality, feasibility, and potential impact on agricultural operations.

5.1 Performance Evaluation

a. Precision and Uniformity

After designing and construction of the proposed spraying equipment, the next step is to assess its ability to deliver precise and uniform spray coverage over the target area, considering factors such as nozzle design, spray pattern, and droplet size distribution. This can be done by conducting laboratory/indoor and field tests to measure spray deposition, coverage effectiveness, and application consistency under various environmental conditions and crop types. Combining the evaluation with process of data analysis, and performance measurements gives insight to the efficiency of the equipment. Here are some key steps to evaluate precision and uniformity in an aerial sprayer:

1. **Calibration:** Start by calibrating the aerial sprayer to ensure that it is delivering the desired spray volume and application rate. Adjust the sprayer settings as needed to achieve the desired application rate and uniformity.

2. **Field Testing:** Conduct field tests to evaluate the performance of the aerial sprayer under real-world conditions. Designate and mark area for testing purposes. Apply the spray using the calibrated sprayer, making sure to cover the designated test areas thoroughly.

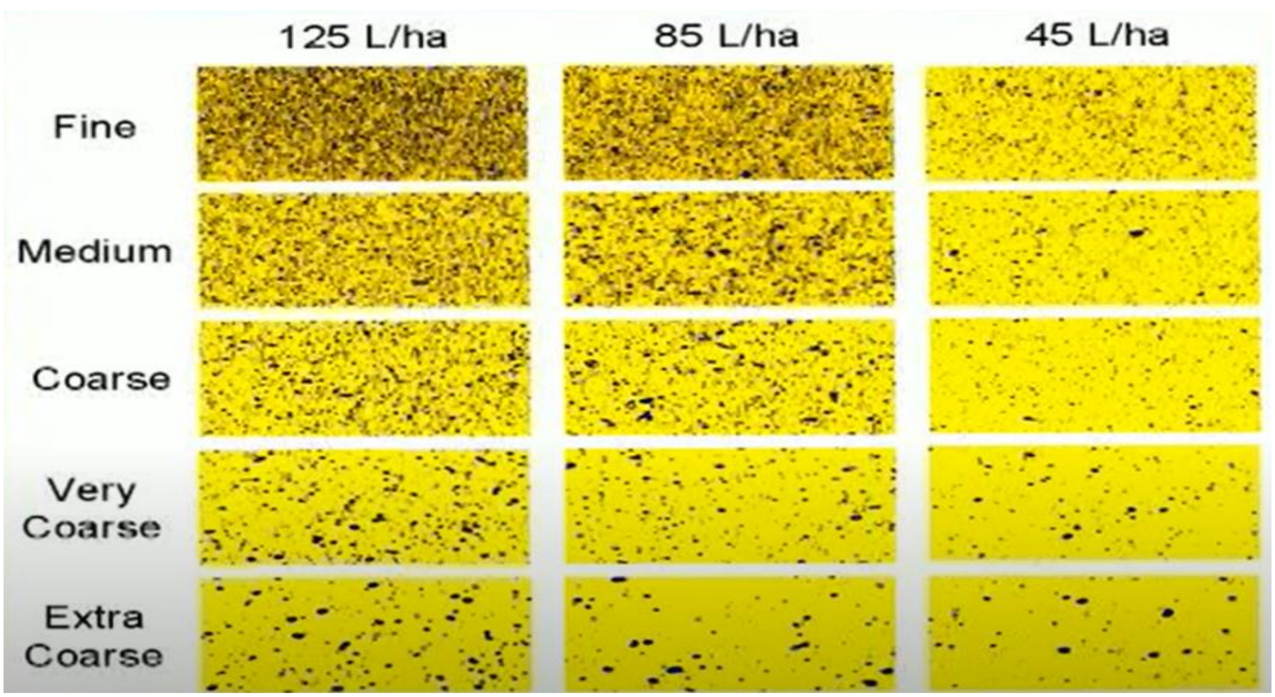
3. **Collection and Analysis:** Collect samples of the sprayed material from multiple locations across the test areas using catch cups, petri dishes, or other collection devices. Measure the volume and density of the collected spray material to assess the uniformity of application. Analyze the data to identify any variations or inconsistencies in spray coverage and distribution.

4. **Visual Inspection:** Conduct visual inspections of the treated areas to assess the uniformity of spray coverage. Look for signs of over-application or under-application, such as uneven crop growth, leaf burn, or missed spots. Document any areas of concern and note any patterns or trends observed during the inspection.

5. **Data Analysis:** The gathered data should be utilized using statistical analysis techniques to analyze the collected data and quantify the precision and uniformity of the aerial sprayer. Compare the observed spray distribution patterns with the intended target areas to identify areas of adjustment, improvement, or optimization.

6. **Adjustments and Optimization:** According to results from the evaluation, if necessary, make any modifications to the aerial sprayer device to improve precision and uniformity. This may involve fine-tuning sprayer settings, adjusting nozzle configurations, or optimizing flight patterns and application techniques. To verify improvements and ensure consistent performance over time, repeating the calibration, field testing, and evaluation process can be carried out as needed.

Figure 12. Spray result using water-sensitive paper.



Source: https://www.youtube.com/watch?v=NyOU6RtXcX4

b. Efficiency and Productivity. This can be achieved by evaluating the efficiency of the spraying device in terms of chemical usage, application rates, and operational throughput, and comparing it to conventional ground-based spraying methods. Measure the device's payload capacity, flight endurance, and operational range to determine its suitability for different agricultural applications and field sizes. Evaluating the efficiency and productivity of an aerial sprayer involves assessing its ability to effectively deliver spray materials while maximizing operational throughput and minimizing resource usage. Here are some key steps to evaluate efficiency and productivity.

1. **Spray Application Rate:** Measure the spray application rate of the aerial sprayer to determine the amount of spray material applied per unit area. Use calibration equipment such as catch cups, flow meters, or dye markers to collect and measure the spray material applied by the sprayer. Calculate the application rate based on the volume of spray material applied and the area covered during a specific period.

2. **Spray Coverage:** Assess the spray coverage provided by the aerial sprayer across the target area. Conduct visual inspections or use remote sensing techniques such as drone imagery or satellite data to evaluate the distribution and uniformity of spray coverage. Compare the observed spray coverage with the intended target areas to identify any gaps or areas of over-application.

3. **Drift Control:** Evaluate the effectiveness of drift control measures implemented by the aerial sprayer to minimize off-target movement of spray materials. Monitor weather conditions and wind speed during spray operations to assess their impact on drift potential. Use drift monitoring devices such as drift sensors or fluorescent tracers to quantify drift levels and assess the efficacy of drift reduction strategies.

4. **Operational Efficiency:** Measure the operational efficiency of the aerial sprayer by assessing key performance indicators such as spray application speed, flight duration, and turnaround time between spray missions. Track the time required for pre-flight preparation, loading of spray materials, flight operations, and post-flight maintenance to identify bottlenecks and inefficiencies in the spraying process.

5. **Resource Utilization:** Evaluate the utilization of resources such as spray materials, fuel, water, and manpower during aerial spraying operations. Calculate resource consumption metrics such as spray material usage per hectare, fuel consumption per flight hour, and labor hours per spray mission. Identify opportunities to optimize resource utilization and minimize waste through improved planning, scheduling, and operational practices.

6. **Data Analysis and Optimization:** Analyze the collected data on spray application rates, coverage, drift levels, operational efficiency, and resource utilization to identify trends, patterns, and areas for improvement. Implement adjustments, optimizations, and best practices based on the findings from the evaluation to enhance the efficiency and productivity of the aerial sprayer. Continuously monitor and evaluate the performance of the aerial sprayer over time, making iterative improvements and refinements to achieve optimal spraying outcomes.

c. Reliability and Durability

Assess the reliability and durability of the spraying device components, including pumps, nozzles, tanks, and mounting systems, through accelerated aging tests and long-term field trials.
Identify potential failure modes and develop contingency plans or maintenance procedures to minimize downtime and ensure continuous operation during spraying missions. Evaluating the reliability and durability of an aerial sprayer involves assessing its ability to perform consistently and withstand operational stresses over time. Here are some key steps to evaluate reliability and durability:

1. **Field Testing:** Conduct extensive field testing of the aerial sprayer under various operating conditions and environmental factors. Monitor the sprayer's performance during actual spraying operations, including flight missions, spray applications, and maneuvering in different terrain and weather conditions. Record any instances of malfunctions, failures, or operational disruptions encountered during field testing.

2. **Component Analysis:** Evaluate the reliability and durability of individual components and subsystems of the aerial sprayer, including pumps, nozzles, hoses, valves, and electronic systems.

Inspect components for signs of wear, corrosion, fatigue, or damage that could affect performance or service life. Conduct stress testing and accelerated aging tests on critical components to assess their resilience and longevity under simulated operating conditions.

3. **Maintenance Records:** Review maintenance records and service logs to track the frequency and nature of maintenance activities performed on the aerial sprayer. Assess the reliability of the sprayer based on its maintenance history, including any repairs, replacements, or upgrades conducted to address mechanical or technical issues.

4. **Endurance Testing:** Perform endurance testing to evaluate the long-term performance and durability of the aerial sprayer under continuous or extended operation. Subject the sprayer to prolonged use and repetitive spraying cycles to simulate real-world operating conditions and assess its resistance to wear and fatigue. Monitor the sprayer's performance and condition over time, observing any changes or degradation in performance that may occur with prolonged use.

5. **Environmental Factors:** Consider the impact of environmental factors such as temperature, humidity, UV exposure, and chemical exposure on the reliability and durability of the aerial sprayer. Evaluate the sprayer's resistance to environmental stresses and its ability to withstand harsh operating conditions without degradation or performance loss. Conduct environmental testing and exposure tests to simulate the effects of different environmental conditions on the sprayer's materials and components.

6. **Failure Analysis:** Analyze any instances of component failures, malfunctions, or breakdowns to identify root causes and failure modes. Determine whether failures are due to design flaws, manufacturing defects, material weaknesses, or external factors, and implement corrective actions or design improvements as necessary. Incorporate lessons learned from failure analysis into future design iterations and product development efforts to enhance the reliability and durability of the aerial sprayer.

5.2 Functionality Evaluation

a. Adaptability and Compatibility

Evaluate the compatibility of the spraying device with different drone platforms, considering factors such as mounting interfaces, payload capacities, and control systems. Assess the device's adaptability to varying spraying requirements, application scenarios, and agronomic practices, ensuring flexibility and versatility in agricultural operations. Table x format can be used to estimate the spraying system total payload. If added to the payload of the drone that will be utilized for the aerial spray task, it gives overall of the whole UASS weight. This helps to evaluate answer related questions such as is the drone is the right choice for the operation, will it have stable and smooth flight operation, can the battery last the flight duration? Evaluating the adaptability and compatibility of an aerial sprayer equipment involves assessing its ability to integrate with different drone platforms, accommodate various payload configurations, and meet the diverse needs of different agricultural applications. Here are some key steps to evaluate adaptability and compatibility:

1. **Drone Platform Compatibility:**
    - Assess the compatibility of the aerial sprayer equipment with different drone platforms, including fixed-wing drones, multirotor drones, and hybrid UAVs.
    - Verify that the mounting interface, weight distribution, and dimensions of the sprayer equipment are compatible with the designated mounting points and payload capacity of the drone platform.
    - Ensure that the aerial sprayer equipment does not interfere with the aerodynamics, flight characteristics, or stability of the drone during operation.
2. **Payload Flexibility:**
    - Evaluate the adaptability of the aerial sprayer equipment to accommodate different payload configurations and spray tank capacities.
    - Verify that the sprayer equipment can be easily adjusted or customized to accommodate varying application requirements, such as different spray materials, application rates, and coverage areas.
    - Assess the versatility of the sprayer equipment in handling different types of agrochemicals, including pesticides, fertilizers, herbicides, and fungicides.

Table 2. Spraying Component and Payload Data

Components	Weight (KG)
Liquid (15L)	15
Storage Tank	x
Pump	x
Nozzles	x
Total	x

3. **Modular Design:**
    - Look for modular design features that allow for easy integration, configuration, and customization of the aerial sprayer equipment with different drone platforms.
    - Evaluate the modularity of key components such as spray tanks, pumps, nozzles, hoses, and control systems, enabling quick assembly, disassembly, and replacement as needed.
    - Consider the availability of interchangeable parts, accessories, and upgrades that can enhance the versatility and adaptability of the sprayer equipment for different applications.
4. **Control and Compatibility:**
    - Verify that the control interface and communication protocols of the aerial sprayer equipment are compatible with the drone platform's flight control system and ground station software.
    - Ensure seamless integration and interoperability between the sprayer equipment and the drone's autopilot system, enabling synchronized operation and real-time monitoring of spraying activities.
    - Evaluate the compatibility of the sprayer equipment with other sensors, navigation systems, and payload payloads that may be integrated with the drone for additional functionality or data collection.
5. **Field Testing and Validation:**
    - Conduct field testing and validation of the aerial sprayer equipment under real-world operating conditions to assess its adaptability and compatibility with different drone platforms and agricultural applications.

- Evaluate the performance, reliability, and ease of use of the sprayer equipment in various field environments, including different crop types, terrain features, and weather conditions.
- Solicit feedback from end-users, drone operators, and agricultural professionals to identify any compatibility issues, usability concerns, or areas for improvement in the design and functionality of the sprayer equipment.

b. Ease of Use and Maintenance

Conduct usability tests and user surveys to assess the ease of installation, operation, and maintenance of the spraying device by farmers, agronomists, and drone operators.

Provide clear instructions, training materials, and technical support to facilitate successful deployment and utilization of the device in the field.

5.3 Feasibility Evaluation

a. Cost-Effectiveness

It is necessary to conduct a cost-benefit analysis to evaluate the economic viability of implementing the proposed spraying device compared to traditional spraying methods and other UAV-based solutions. Putting factors such as initial investment costs, operational expenses, labor savings, and potential yield improvements into consideration, it assists to determine the return on investment (ROI) and overall cost-effectiveness of the spraying device.

b. Regulatory Compliance

Ensure compliance with regulatory standards and environmental regulations governing aerial spraying activities, including restrictions on chemical usage, flight operations, and safety protocols. One of the main factors that influence the adoption of UAVs in various industries is the regulatory environment. Different countries and regions have different rules and standards for UAV operations, such as licensing, registration, certification, airspace management, safety, privacy, and liability. These regulations can either facilitate or hinder the use of UAVs for commercial purposes, depending on their clarity, consistency, flexibility, and enforcement. For example, some countries have more relaxed and supportive regulations for UAVs, such as Australia, Canada, and Rwanda, while others have more strict and restrictive regulations, such as India, China, and Brazil.

On this note, it is important to work closely with regulatory agencies, industry associations, and stakeholders to address any legal or compliance issues and obtain necessary permits or approvals for commercial deployment.

5.4 Potential Impact Evaluation

a. Environmental Sustainability

Assess the environmental impact of the proposed spraying device in terms of chemical usage, spray drift, and non-target exposure, considering factors such as pesticide toxicity, persistence, and bioaccumulation on plant and soil withing the targeted area of application.

Identify opportunities for minimizing environmental risks and maximizing ecological benefits through targeted spraying strategies, integrated pest management practices, and precision agriculture techniques.

b. Social and Economic Benefits

Evaluate the potential social and economic benefits of adopting the proposed spraying device, including increased crop yields, reduced labor costs, and improved farmer livelihoods. Consider the broader societal impacts, such as food security, rural development, and sustainable agriculture, resulting from the adoption of UAV technology in farming communities.

In addition, evaluation of the adoption of UAVs in various industries to measure its social acceptance is vital to its social and economic benefit. The perception and attitude of the public, the media, and the stakeholders towards UAVs can either support or oppose the adoption of UAVs in various industries specifically in agricultural sector. Social acceptance depends on the awareness, education, and engagement of the relevant parties, as well as the potential benefits and risks of UAVs, such as economic, environmental, social, and ethical impacts. For example, some of the factors that affect the social acceptance of UAVs in various industries include noise, privacy, security, safety, and ethics.

CHAPTER 6

6.0 CONCLUSION

The culmination of efforts in designing and evaluating a spraying device for drones heralds a transformative chapter in the annals of agriculture. In an age defined by exponential global population growth, dynamic climate patterns, and imperative sustainability goals, the imperative for revolutionary solutions in food production has never been more pronounced. Looking at the exponential growth of world population is crucial for engineers, agriculturalist, researchers, policy makers to proactively act to mitigate the envisaged impact. Part of the efforts to play a role in this is the design proposal for a spraying device, that is meticulously crafted with precision, efficiency, adaptability, and sustainability at it represents a quantum leap in agricultural methodologies and operations.

The envisioned spraying device emerges as a harbinger of change, promising to surmount the multifaceted challenges confronting farmers worldwide. By facilitating precise and uniform spray coverage across expansive agricultural terrains, the device serves as a conduit for optimizing the application of agrochemical liquids, thus curtailing wastage and curbing environmental contamination. To achieve this, it is important to take care of nozzle choice as it is vital for optimizing the operation of the spraying equipment. The right selection helps to mitigate drift, that divert agricultural liquid from reaching it target. This denies the aimed plant from the expected liquid. Sometimes, the drift allows more than enough agricultural substance to get to crop which can in the end harm it. The design proposal for a spraying device for drones epitomizes the transformative potential of technology, offering a beacon of hope for a more sustainable and equitable future. Integrating the equipment into agricultural operations will go a long way to eradicate the risk of being exposed to chemical substances which is common with knapsack operator and any other people around the sprayed area. The proposed equipment is envisaged to efficiently discharge appropriate amount of liquid to the plants and crops that is primary target. This operation is carried out without the presence of human that could be affected by the chemical. Beyond its technical ingenuity, the proposed spraying device embodies feasibility on myriad dimensions. Through exhaustive cost-benefit analyses and diligent engagement with regulatory authorities, stakeholders can discern the economic viability and compliance requisites essential for widespread integration. Moreover, its environmental stewardship and societal impact, including diminished chemical footprints, augmented crop yields, and enhanced rural livelihoods, underscore its potential to catalyze resilience and prosperity within agricultural ecosystems across the globe. By embracing innovation, fostering collaborative synergies, and championing sustainable practices, we can forge a trajectory towards a resilient and thriving agricultural sector that adeptly caters to the needs of both current and forthcoming generations. Moreover, its environmental sustainability and social impact, including reduced chemical usage, enhanced crop yields, and improved farmer livelihoods, underscore its potential to foster resilience and prosperity in agricultural communities worldwide.

In addition to its performance and functionality, the proposed spraying device demonstrates feasibility in terms of cost-effectiveness, regulatory compliance, and potential impact on agriculture that will enable stakeholders to assess the economic viability and legal feasibility of adopting the device in commercial farming operations. The design proposal for a spraying device for drones represents just one example of how innovation can drive positive change in agricultural practices. By embracing emerging technologies, adopting sustainable farming practices, and fostering collaboration between industry stakeholders, we can build a more resilient and sustainable food system that meets the needs of current and future generations.

In conclusion, the design proposal of a spraying device for a drone represents a significant opportunity to enhance the efficiency and effectiveness of agricultural spraying operations. By focusing on precision, efficiency, adaptability, and safety. This thesis aims to develop a versatile and reliable spraying solution that meets the diverse needs of farmers and agronomists. Through continued research, development, and collaboration with industry stakeholders, I am confident that the design proposal will contribute to the advancement of drone technology in agriculture and support sustainable food production practices. The evaluation of the design proposal for a spraying device for a drone provides valuable insights into its performance, functionality, feasibility, and potential impact on agricultural operations. By systematically assessing key criteria such as precision, efficiency, adaptability, cost-effectiveness, regulatory compliance, and environmental sustainability, we can identify strengths, weaknesses, opportunities, and threats associated with the proposed design. Through iterative refinement and validation, we can further enhance the design proposal to address stakeholder needs, market demands, and emerging trends in UAV technology and precision agriculture. Ultimately, the successful implementation of the proposed spraying device has the potential to revolutionize aerial spraying practices, promote sustainable farming practices, and contribute to global food security and environmental stewardship.

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