UNIABUJA Journal of Engineering and Technology
https://ujet.uniabuja.edu.ng/
ISSN: 2714-3236 (Online); 2714-3228 (Print)
Volume 2, Issue 2, 2025; 188-199

Development of Unmanned Aerial Vehicle-Mounted Sprayer for Spraying Pesticides and Fertilizer

Babawuya ALKALI[1], Abdulrahman B. GAMBO[2], Tanimu YAMAJIN[3], Kabir KOLAWALE[4], Nassamu YUSUF[5], Abduljabar G. OYELEKE[6]

[1]*Department of Mechatronics Engineering, Federal University of Technology, Minna, Nigeria*
[2]*Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria*
[3]*Department of Mechanical Engineering, Federal Polytechnic, Bida, Nigeria*
[4]*Department of Aircraft Engineering Technology, Airforce Institute of Technology, Kaduna, Nigeria*
[5]*Department of Mechanical Engineering, Auchi Polytechnic, Auchi, Edo State, Nigeria*
[6]*Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria*

[1]babawuya@futminna.edu.ng, [2]danbauranborgu@gmail.com, [3]tanson37@gmail.com, [4]kabirolawole@gmail.com, [5]yusufnassamu@auchipoly.edu.ng, [6]medsabdulgbenga@gmail.com

Abstract
This study presents the design, fabrication, and performance evaluation of a hexacopter unmanned aerial vehicle (UAV) developed for precision agricultural applications, specifically pesticide and fertilizer spraying. The UAV integrates a lightweight Aluminium frame, six brushless DC motors, a custom sprayer mechanism with dual nozzles, a 5V submersible pump, and a flight control system supported by the APM 2.8 controller. Design processes involved 3D modeling with SketchUp and structural analyses using SolidWorks to assess motion and static stress responses on critical components such as motor arms and tank mounts. MATLAB was employed to model system dynamics, confirming system stability with a critically damped step response and adequate phase margins. The fabricated UAV was equipped with a 5-liter fluid tank, 336,000 mAh battery configuration, and LoRa-based wireless communication for ground control. Test results showed a battery endurance of 16.3 minutes and a total thrust capacity of 2600 grams per motor, achieving a total power requirement of 266.4 W. Although initial flight trials faced mechanical and calibration challenges, the final integrated UAV system successfully demonstrated aerial spraying capability, providing a low-cost and efficient solution for targeted agrochemical application in precision farming.

Keywords: *UAV, spray system, flight testing, remote control, payload, pump, agriculture.*

1.0 Introduction

Over the years, systems of controlling pests and applications of fertilizer on crops have been a major challenge globally in agricultural field. Various methods of agricultural inputs have been employed for large scale productions and protection of crops, (Cai *et al.*, 2010). Typical methods employed for the controlling of pests for instance, are through the use of manual sprayers such as knapsacks power sprayer, backpack sprayer etcetera. Pesticides fumigations and fertilizer applications are also done manually through similar means. Whereas these approaches remain some of the best practice employed even for large scale farming, it creates exposure effect to the users, requires long time and energy to cover wide area of farm, hence, the need for a precision agriculture, (Bending & Bolton, 2012). Precision agriculture is a field management technique that strives to increase the productivity of resources on agricultural fields through technological innovation and field management optimization. As a result, a new advanced strategy has emerged in which farmers offer optimum inputs such as water and fertilizer in order to boost productivity, quality, and output. (Agrawal & Arafat, 2024). Therefore, an unmanned aerial vehicle (UAV) can serve as an aerial sprayer by simply mounting a sprayer mechanism on it to curtail this challenge since it has the tendency of maneuvering, navigating and covering wider areas on the farm in limited time to effectively control pests and apply fertilizer on crops and other necessary disinfectants. Also, a UAVs is easy to operate as it provided with a simple control system which makes navigation easier to get the job done, (Anthony *et al.*, 204) and (Primicerio, 2012). In (Mogihl & Deepak, 2018) use a quadcopter UAV to monitor crops and spray pesticides. They highlighted problems encountered in agricultural fields, such as dramatic losses due to diseases caused by pests and insects, which reduce crop productivity, and cases of people becoming ill when spraying pesticides in crop fields manually. In defining their methodology, they state that they chose the quadcopter because of its stability, uniqueness, and flexibility in configuration, which can be divided into two categories. One is a plus (+) model, while the other is a cross (x) model. In comparison to the plus model, the cross model is more popular and more stable,

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025

https://doi.org/10.70118/ujet.2025.0202.18

(Gayathri, 2020).

(Koç, 2017) design a multi-rotor UAV prototype which was built for aerial pesticide applications. The UAV was created with the help of computer-aided design and manufacturing. The created hexacopter UAV has an aluminium frame and is powered by a 222 W battery. Also, it carries a 5-liter pesticide tank. The UAV is equipped with aerial camera, GPS, and electronics that allow it to fly independently. The properties of the designed UAV were successfully verified through laboratory and field trials. A hexacopter model of the UAV was designed and developed using computer aided design (CAD) (Catia v5 R20). Because of its small weight, aluminium was chosen as the frame material. There are six of them, each measuring 1120 mm in length. They used two sheets of hexagonal aluminium plates with a 300 mm edge length and a 2 mm thickness. The chassis of the UAV is consisted of four legs made of twisted aluminium pipe tubing with a diameter of 10 mm. The frame's height is 400 mm (Figure 1). Under the UAV frame, a 5-liter polyethylene tank was placed. The spraying was done with a 12 VDC electric pump.

(Devi Iet al., 2020) suggested the general review on the design of UAV for crop monitoring, pesticide and fertilizer application in precision agriculture. The Transmitter Channel, which consists of mode1 and mode2, controls the UAV. The raspberry pi was used to track the crops row by row. The camera attached on the UAV detects various diseases and damages in the crop. It is permissible to spray fertilizer and insecticides based on crop damage after monitoring the crops. The goal of developing this precision agriculture technology is to increase crop protection and productivity while also improving crop development by spraying fertilizer and insecticides based on crop damage.

(Karan et *al.,* 2020) design a drone mounted with spraying mechanism to carry 6 L storage capacity tank, using 12 V pump, 4 nozzles to atomize in fine spray, an octocopter configuration frame suitable landing frame, 8 Brushless Direct Current (BLDC) motors with suitable propellers to produce required thrust of 38.2 KG (at 100% RPM), and a suitable Lithium-Polymer (LI-PO) battery of current capacity 22000mAh and 22.2 V to meet necessary current and voltage requirements. The drone was also equipped with a First-Person View (FPV) camera and transmitter for monitoring the spraying operation as well as checking for pest attacks on plants. Pesticide application time, labor, and cost are all reduced with this pesticide spraying drone. By altering the flow discharge of the pump, this sort of drone can also be used to spray disinfectant solutions over buildings, water bodies, and densely populated regions.

2.0 Materials and Method

For a flying object like drones, materials with high strength to weight ratio are preferred. Therefore, suitable light weight components for this design was selected in design and production of the drone. The components used and their descriptions, characteristics, specifications are as follows:

2.1 DC Brushless Motors

A brushless DC motor is shown in Figure 1. (BLDC motor). Brushless DC motors are essentially electrically commutated DC motors meaning it rotate around the armature using a permanent magnet.

Figure 1. DC Propeller Motor - A2212/13T model, (Huang *et al.,* 2014).

Because of their high efficiency and thrust-to-weight ratio, brushless motors are ideal for airplane applications. By default, a BLDC motor should produce thrust in equation 1 equal to two times the weight of the frame plus all of its components (commonly referred to as All Up Weight (AUW)),

$$F_{thrust} = \dot{m}(v_e - v_o) \quad \text{(Artale \& Milazzo, 2013)} \quad (1)$$

where $\dot{m}$ is the mass flow rate of the air, (v_e and v_o) are the entrance and exit velocity of the air. The expression in equation 1 shows that each motor is expected to give a minimum thrust equal to that of total thrust produced.

i.e., $F_{motor\_thrust} = \frac{F_{thrust}}{6} = \frac{2\times \text{AUM}}{6}$ (2)

https://doi.org/10.70118/ujet.2025.0202.18

Therefore, assuming that the AUW is about 7.8kg (with inclusion of all the weight of each component added), equation (2) gives, (Mhetre *et al.*, 2020)

$$F_{motor\_thrust} = \frac{2\times 7.8}{6} = 0.26 \text{ Kg} = 2600\text{g} \quad (3)$$

The maximum power for all six motors can also be calculated by taking the maximum current and voltage of the motor, which is 11.1 divided by 10 A. Furthermore, assuming that the hexacopter's flight consumption is around 24 A for all six motors while in flight, power consumption for the known voltage can be calculated as stated in equation (4).

$$Power = I \times V \quad (4)$$

Therefore, for all six motors, 24× 11.1V = 266.4 W

2.2 Flight Controller

The flight controller is the decision unit of the system. An electronic board with embedded IMU. Its aim is to provide easy navigation using while the ESC guide the speed of each motor. The APM V2.80 Flight controller board was selected and used in the development of this drone, (Figure 2).

Figure 2: APM Flight Controller. Figure 3: ESCs and Propellers. Figure 4: Lithium ion Battery.

2.3 ESCs and Propellers

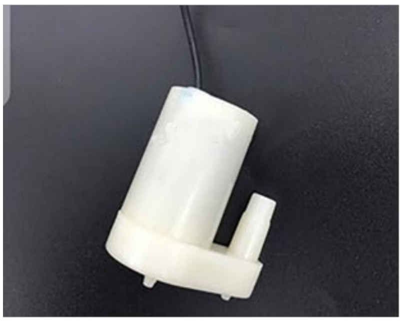
A propeller is a device that drives a vehicle. Figure 3 shows the propeller used. It has a spinning hub with fixed rotating blades that form a section of a helical surface. The Electronic Speed Controller (ESC) regulate the speed of the brushless motor. The flight controller sends a signal to the ESC, instructing it to deliver the appropriate voltage to the motor by simply increasing or decreasing the voltage of the motor, thereby adjusting the speed of the propeller. This build uses a 30A rated ESC based on the motor and battery specifications.

2.4 Battery

The battery is the system power source. Figure 4, shows the selected 18650 series type Lion battery having a output voltage of 3.7V. Four cells of 4200mAH is cascaded in parallel to give equivalent of 336000mAH.

2.5 Nozzle and Pump

A 5V DC water pump was used to pressurize the liquid, as shown in Figure 5 The fluid is shot through the nozzle. Figure 6, shows a plain fan nozzle. two of which were placed at a distance of 4.5m apart used for spraying the fluid which gives a desired offset angle for effective flow spraying and avoid overlapping of liquid interference.



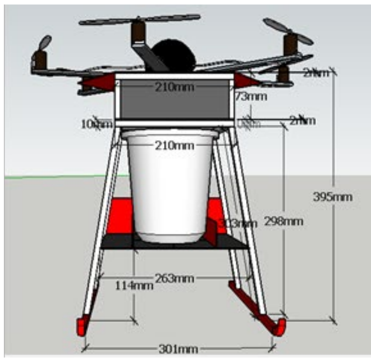


Figure 5: 5V DC Pump Figure 6: Nozzle Figure 7: Model Dimensions

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18

2.6 Fabrication Process

2.6.1 Frame and Landing Gear

In designing of the landing gear, the sketch-up software is used. Sketch-up is a computer aided design CAD used in the developments of 3D model and dimensioning of a system as shown Figures 7, shows the overall system model and dimension. The landing gear frame was built using a square-shaped hollow Aluminium pipe. Aluminium is the most common used material for aircraft framework due to its lightness and high tensile strength. It is readily available and inexpensive. It is also easy to machine, as machining processes that are possible with aluminium are not possible with other materials like the fibre material. Aluminium is an excellent electrical conductor; therefore, adequate care must be taken to not short out on board electronics on the hexacopter, or more importantly the battery used in powering the electronics.

Figure 8: Aluminium pipes

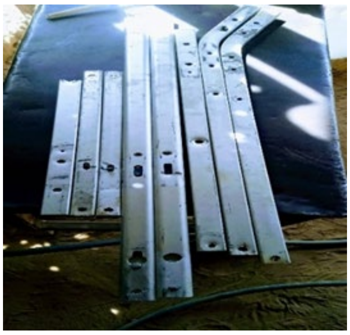


Figure 9: Landing Gear Frame

The Aluminium pipes were cut using hand tools to produce various parts of the hexacopter landing gear. The pipes were cut into desirable length using a hack saw. The gas welding was used for fabrication process. Aluminium flux is used to join the pipes together to allow firm grip. Hence, the hexacopter frame landing gear was successfully built and constructed locally as seen in the Figure 8 and 9.

2.6.2 F550 Hexacopter Frame Assembling

The accessories of the hexa frame which include the arm, ESCs, Motors, GPS, power module, flight controller, receiver and others connectors were incorporated in the correct order while the propellers were correctly placed in order of clockwise and counter clockwise configuration as shown in the Figure 10.

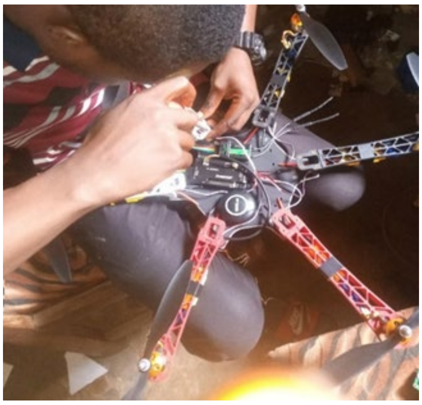


Figure 10: F550 Hexa Frame Assembling

Figure 11: Mission Planner environment

2.6.3 Design of software

The following are the different software tools for developing the hexacopter:

1. Mission Planner: This is used to write instructions to the flight controller for easy navigation.
2. Integrated Development Environment Arduino (IDE): This is used to program the Atmega 328 microcontroller (see Figure 11).
3. MATLAB: This environment used to write the code to determine the response of the system.
4. Sketch Up: This is used for the 3D design of the fluid tank and the landing gear.
5. SolidWorks: This is used to carry out the motion and static analysis of the system.

3.0 Design Results

The following design analysis were conducted:

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18

1. Motion Analysis – position, velocity and acceleration.
2. Static Analysis – including stress, deformation and strain analysis.

3.1 Motion Analysis

The recreations were performed by utilizing the CAD part's material properties to characterize the underlying properties of the system segment and naturally producing results that portrayed the component movement. The static examination, then again, produces results that stay consistent over the long run.

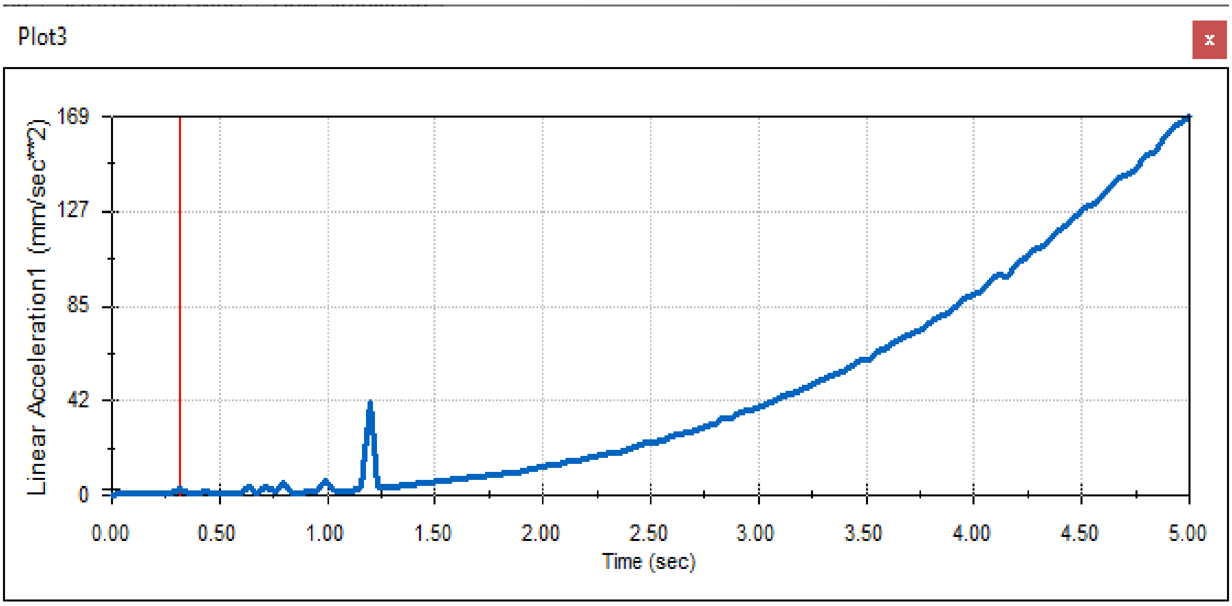


Figure 12: Time graph with linear acceleration

Figure 12 shows that the propeller arm accelerated in a quadratic profile.

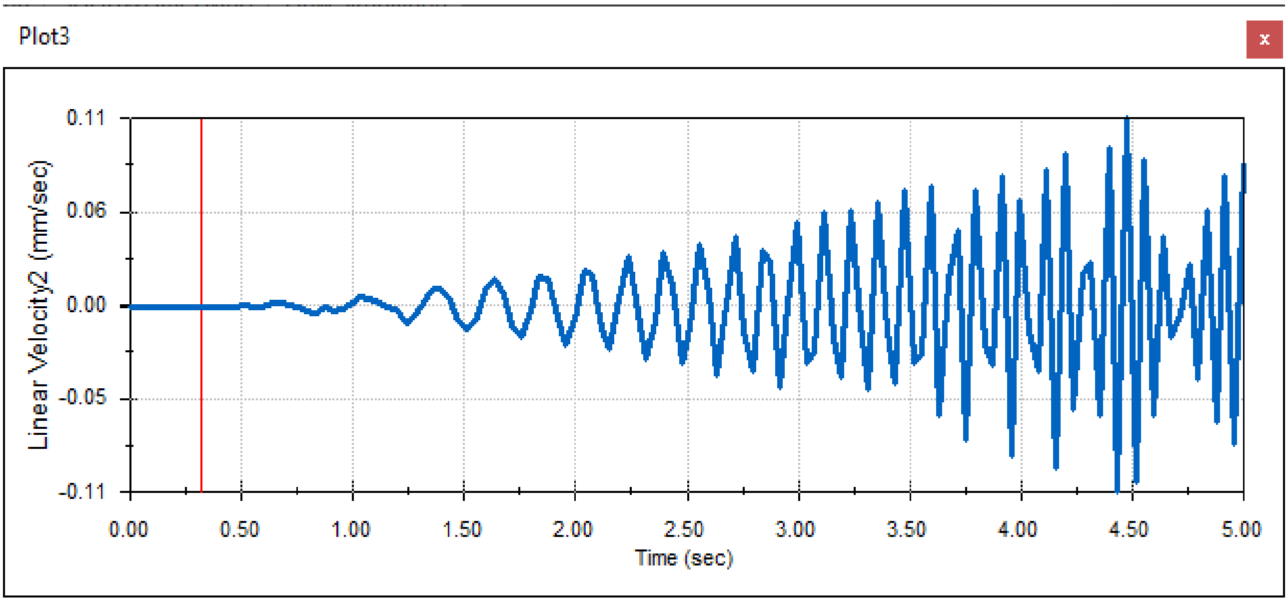


Figure 13: Graph of linear speed

Figure 13 illustrates the engine sequence as it is disembarked and moved. Tis illustrates that the engine does not move much during the start, but the shift can be noticed as the movement continues. Therefore, if the radius is known, the maximum speed capacity it reaches can be determined.

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18

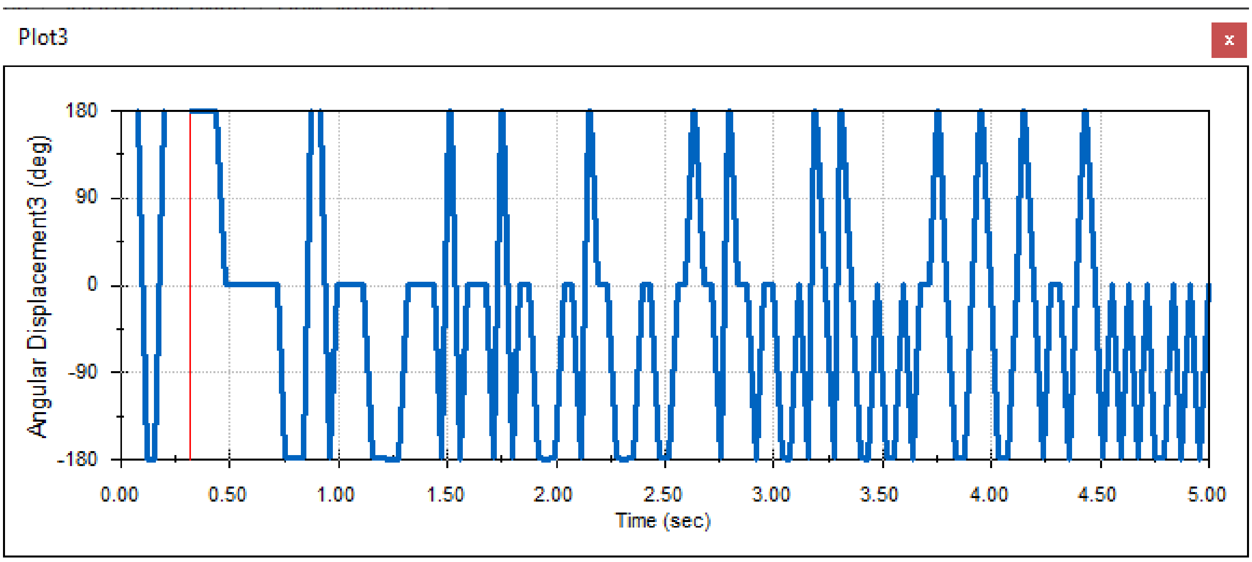


Figure 14: Angular time graph displacement

The motor displacement is shown in Figure 14. The chart illustrates motor movements between -180 t0 +180, equivalent to a whole cycle. A substantial variation can also be noted in the diagrams This means that when the engine is picking, it will take a rest in every quadrant, so that it will have a smoother move when it is steady in this quadrant.

3.2 Static Analysis

Static simulation is based on the load effect of the hexacopter that is able to maintain the stress conditions of the drone's structure, (Yanliang & Wei, 2017). Therefore, when subject to a load, the fitness of each structure may be anticipated. The structure of the holder of the liquid tank and of the motor arm for the UAV-assembled sprayer are considered when it is under pressure or stress.

3.3 Motor Arm Static Stress

Figure 15, demonstrates the motor arm design in SOLIDWORKS. The motor arm was stressed, and the following results was obtained:

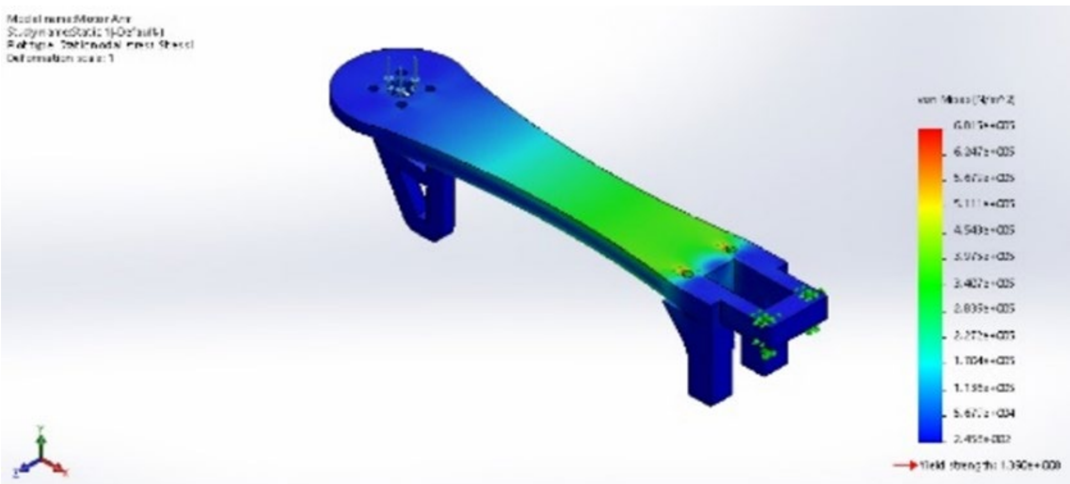


Figure 15: Motor Arm Tension

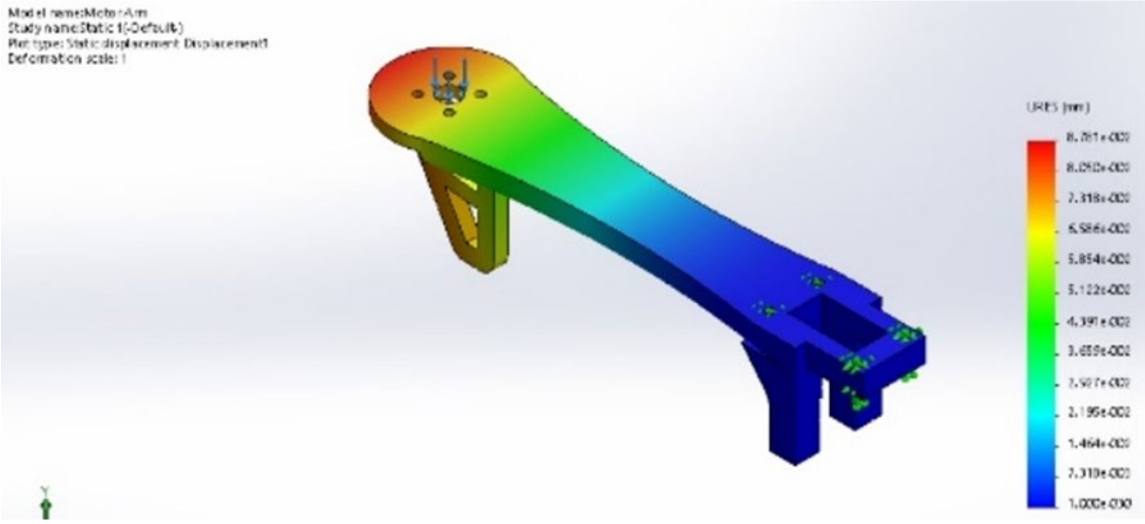


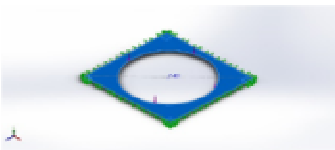
Figure 16: Displacement of the motor arm

Figure 16 shows that the yield strength of the motor arm produced is insignificant compared to the maximum stress produced. Thus, the motor arm withstand subjected load without failing. The displacement of the Motor Arm is demonstrated in Figure 16, which ranges from 8.781 x 10^{-2} maximum and minimum of less than 1mm. Comparison of both values shows insignificant results on the maximum displacement thus, the motor arm will not fail due to static load and this is close to the results found in (Sulaiman, et al., 2021).

3.4 Tank Seat Static Stress and Strain

Table 1 present the static stress and strain equivalent results and discussion on the fluid tank using the component specification.

Table 1: Static stress and strain

Model Reference	Properties	Components
	Name: **Nylon 101** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **6e+007 N/m^2** Tensile strength: **7.92897e+007 N/m^2** Elastic modulus: **1e+009 N/m^2** Poisson's ratio: **0.3** Mass density: **1150 kg/m^3** Thermal expansion coefficient: **1e-006 /Kelvin**	**SolidBody 1(Boss-Extrude1)(Tank Seat)**
Curve Data:N/A		

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18

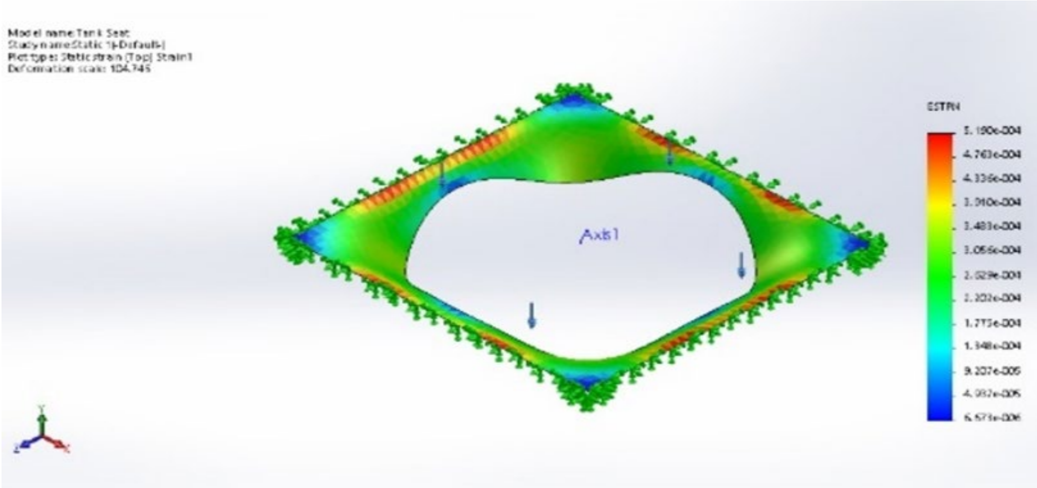


Figure 17: Strain tank seat

Figure 17, demonstrate the behavior of static strain displaying the range difference of 5.19 x 10^{-4} and 6.673x10^{-6} between maximum and minimum strain. The result shows the structural stress is considerable, hence the component may fail.

3.5 Fabrication Results

The following were achieved with the design analysis of the hexacopter system:

1. The landing gear frame was successfully designed and constructed.
2. As shown in Figure 15 and 16, the F550 hexacopter custom frame assembling, the landing gear designed and spraying system were integrated successfully.
3. The mounted sprayer mounted on the hexacopter UAV was successfully installed after the correct wireless input was exchanged between the control unit on-board and the ground station.

3.6 System of Spraying

The spraying integration consists of a base tank seat to accommodate the mounted fluid tank. A 5V submersible pump submerged into the fluid tank provides uniform pressure through a hose which connects the two sets of nozzles used for spraying. A lora module used to provide wireless communication between the on-board circuit unit and the ground station appropriately aid displays of the monitoring response produced by sensors on the LCD (see Figure 18).

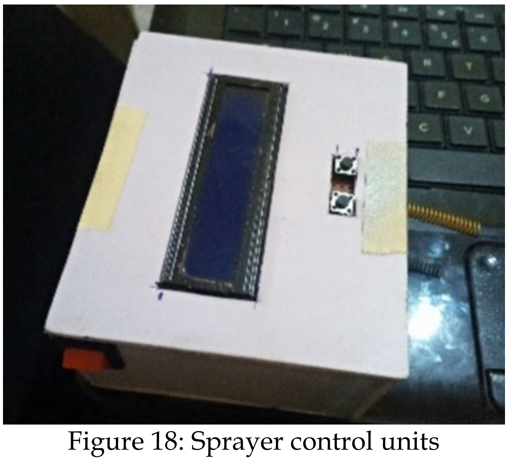


Figure 18: Sprayer control units

3.7 Performance Results

The performance results presented in Table 2, indicate that the system achieved a battery endurance of 16.3 minutes, demonstrating a reasonable operational time under continuous load. During operation, it drew a current of 123.8 A to produce a power output of 266.4 W, reflecting the electrical demand of the propulsion system. Notably, the system generated a thrust of 2600 grams, suggesting it has sufficient lifting capability for lightweight aerial or mobile applications. Overall, the results highlight a high current draw relative to power output, which may suggest the need for improved efficiency or battery management to extend endurance.

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025

https://doi.org/10.70118/ujet.2025.0202.18

Table 2: System Performance

Parameters	**Results Obtained**
Battery Endurance	16.3 min
Current	123.8 A
Power	266.4 W
Thrust	2600 grams

3.8 Description of UAV Test Flight

During the first flight test, the hexacopter was tested without mounting of the sprayer system, but the lifting performance wasn't satisfactory as the lifting pf the UAV from the ground was not successful. These propellers could not be traced to the correct setup thus the remote control could not be reacted to allow disengagement since this impedes motor stability. On the second attempt, the UAV lifted without the attached sprayer and crashed during the testing phase. The crash caused throttle damage to the flight controller and GPS in the process as a result of landing of the UAV failure. The GPS was unable to receive any new signal from the air controller as the aircraft controller appears to be damaged by the collision. To remedy this problem, the GPS is equipped and replaced by another flight controller with different models. The whole control flying system was calibrated by means of the mission planner. The air testing proceeded this time with the UAV sprayer that took off successfully, and the UAV was not able to return to landing as planned as previously experienced. Two of the six motor mounts of the hexacopter were broken on two of the test sessions. The hexacopter was protected by the hand to prevent UAV from flying high to prevent crashing, in order to address this problem.

3.9 System Response

MATLAB was used to calculate the system characteristic by deriving the BLDC transfer functions. The results obtained are shown in Figure 19.

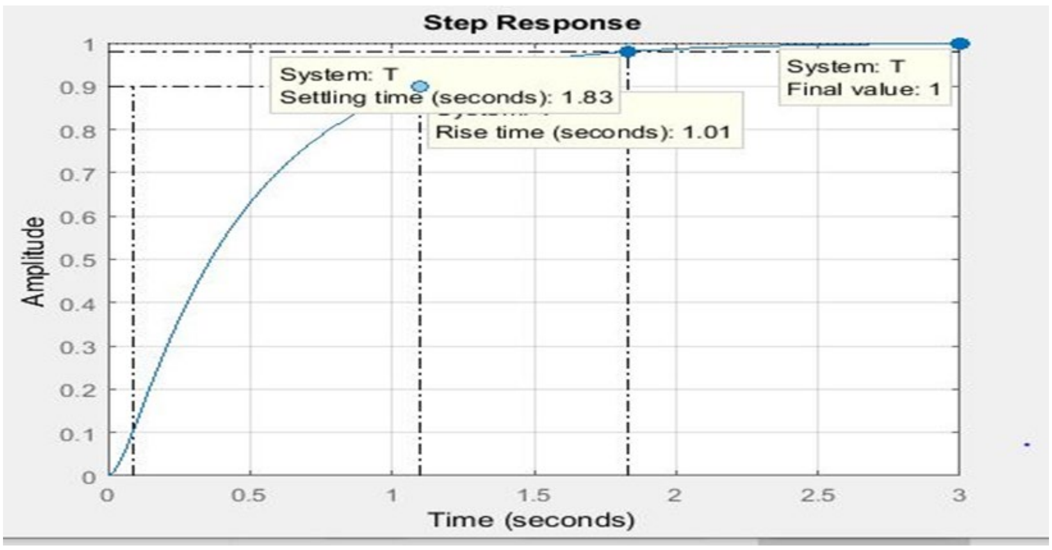


Figure 19: System Step reaction

https://doi.org/10.70118/ujet.2025.0202.18

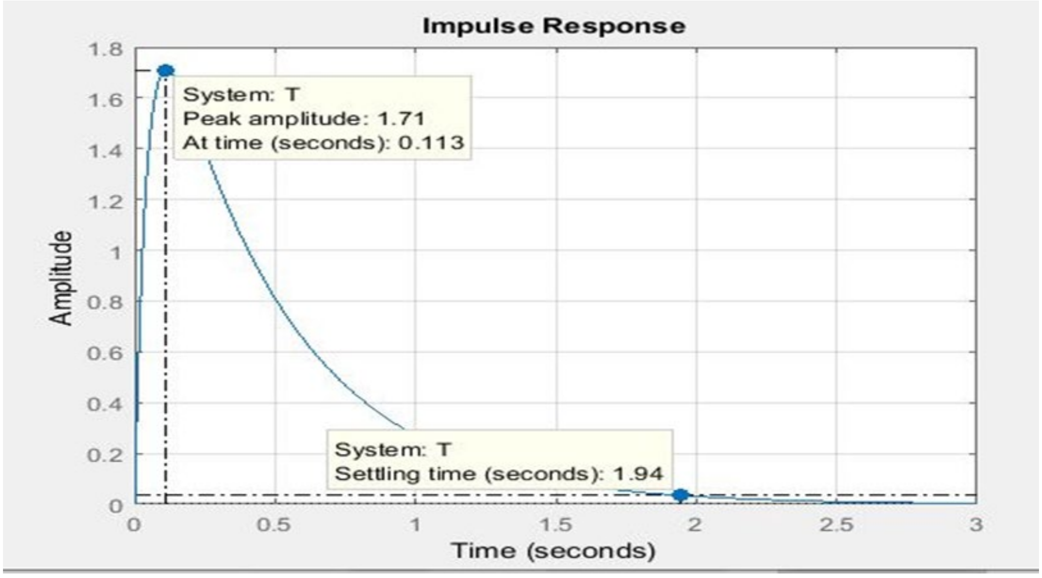


Figure 20: Impulse reaction

From the system response obtained in Figure 20, is a critically damped response as its produced a damping ratio equals to 1. The value of the system rise time at 1.01 and settling times at 1.83, indicate that the system ia relatively stable. Figure 20, shows the relationship between the amplitude and time response of the system which shows that the system peak amplitude and settling time gives a fast response. Thus, the system is stable. This result is close to the results obtained by (Chin *et al.,* 2023) and (Agrawal & Arafat, 2024).

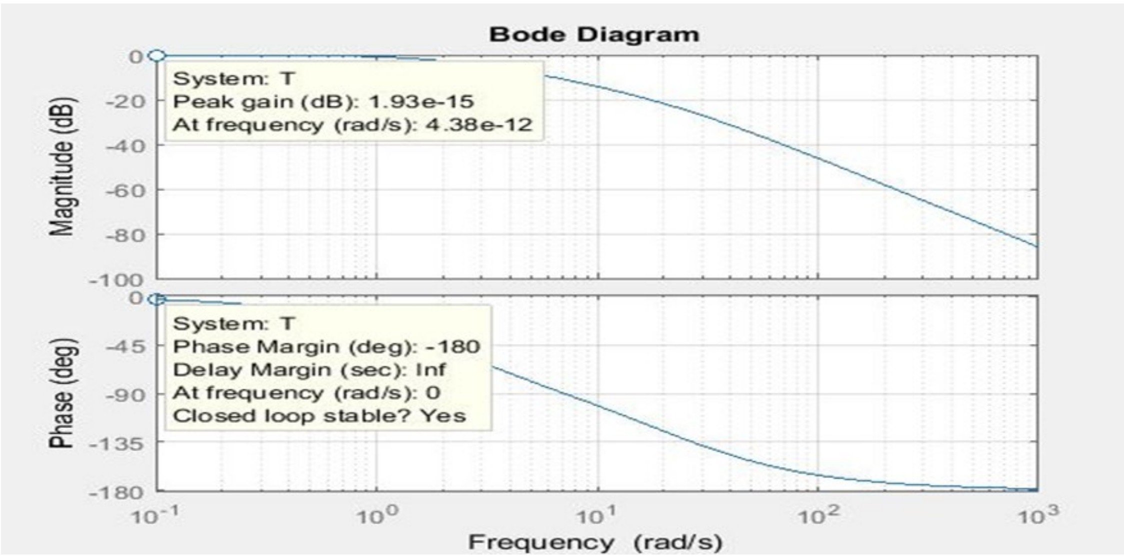


Figure 21: Bode plot

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18

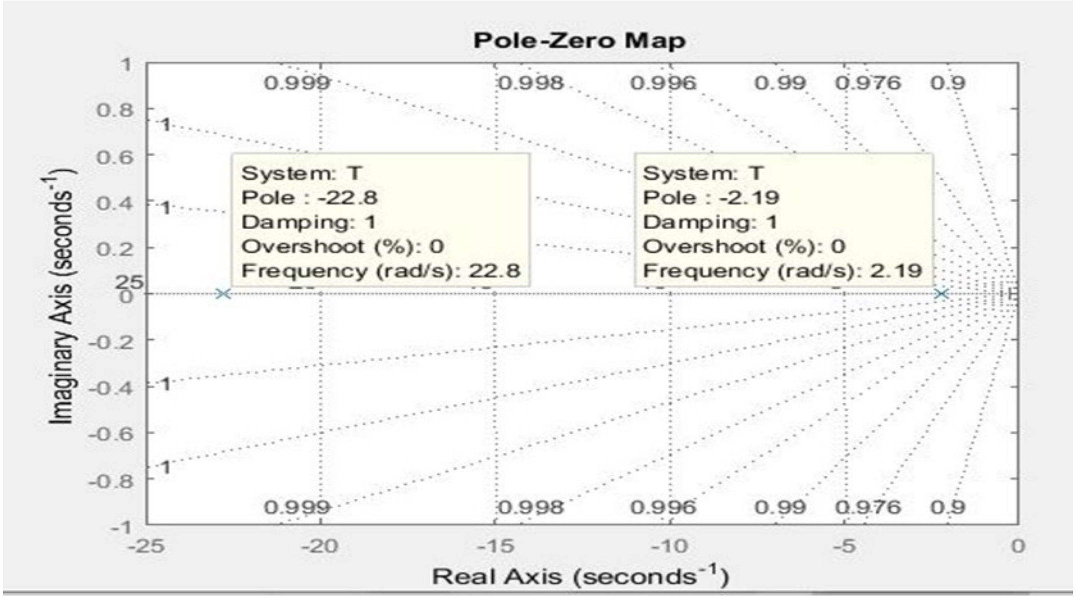


Figure 22: P-Z Map graph

The phase margin and magnitude characteristics of the system are demonstrated in Figure 21 and 22, indicating that at high frequency the system has close loop stability. When the damping ratio is equal to one, the poles-zeroes (PZ) plots in Figure 4.8 show that the system has zero overshoot on the imaginary axis, this was also reported by (Nduku *et al.,* 2023) and (Giles & Billing, 2015).

4.0 Conclusions

From a global perspective on agricultural systems, UAV mounted sprayer was considered a significant issue worthy of research. As the demand for precision agricultural systems has increased, UAVs have become useful tools in this regard. In accordance with the previously stated objectives, the hexacopter mounted sprayer design was successfully implemented based on each of the subdivided parts. Following appropriate technical considerations for selections of materials the complete system assembling was implemented for uniform spraying. The UAV spraying unit was controlled through wireless communication via a Lora module which help interact between the on-board control unit and the ground station control unit. In summary, the UAV was successfully designed to lift a 3L payload and perform uniform spraying of pesticides and fertilizers on farm sites.

References

Agrawal, J., & Arafat, M. Y. (2024). Transforming farming: A review of AI powered UAV technologies in precision agriculture. Drones. *8*(11), 664. doi:https://doi.org/10.3390/drones8110664

Anthony, D., Elbaum, S., & Lorenz, D. C. (204). On crop height estimation with UAVs. *Proceedings of the International Conference on Intelligent Robots and Systems (IROS).*

Artale, C. V., & Milazzo, G. &. (2013). Mathematical modeling of hexacopter. Applied. *Mathematical Sciences, 7*(118), 4805–4811.

Bending, J., & Bolton, A. &. (2012). Introducing a low-cost mini-UAV for thermal-and multispectral-imaging. *. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 39*, 345–349.

Cai, G., Chen, B. M., & Lee, T. H. (2010). An overview on development of miniature unmanned aerial vehicles for crop spraying. *Frontiers of Electrical and Electronic Engineering in China, 5*(1), 1-14.

Chin, R., Catal, C., & Kassahun, A. (. (2023). Plant disease detection using drones in precision agriculture. . *Precision Agriculture, 24*, 1663–1682. doi:https://doi.org/10.1007/s11119-023-10014

Devi, K., Sowmiya, N., Yasoda, K., Muthulakshmi, K., & Kishore, B. (2020). Review on application of drones for crop health monitoring and spraying pesticides and fertilizer. *. Journal of Critical Reviews, 7*(6), 667–672. doi: https://doi.org/10.31838/jcr.07.06

Gayathri, K. D. (2020). Review on application of drones for crop health monitoring and spraying pesticide and fertilizer. *Journal of Critical Reviews, 7*(6), 2394–5125.

Giles, D. K., & Billing, R. C. (2015). Deployment and performance of a UAV for crop spraying. *Chemical Engineering Transactions, 44*, 307–322.

Huang, Y., Hoffmann, W. C., Lan, Y., Fritz, B. K., & Thomas, S. J. (2014). Development of a low-volume sprayer for an unmanned helicopter. *Journal of Agricultural Science, 7*(1), 148.

Karan, K., Shawl, V. R., & Vimalkumar, R. (2020). Design and development of a drone for spraying pesticides, fertilizers and disinfectants. . *International Journal of Engineering Research & Technology, 9*(5), 2278–0181.

Koç, C. (2017). Design and development of a low-cost UAV for pesticide applications. . *Journal of Agricultural Faculty of Gaziosmanpaşa University, 3*(11), 94–103. doi:https://doi.org/10.13002/jafag4274

Mhetre, P., Deepali, S., Akshay, N., & & Harsh, V. (2020). Agricultural drone for fertilizer spraying. *International Research Journal of Modernization in Engineering Technology and Science, 2*(6), 2582–5208.

Mogihl, R. U., & Deepak, B. B. (2018). Review on application of drone systems in precision agriculture. *Proceedings of the International Conference on Robotics and Smart Manufacturing.*

Nduku, L. M., Kalumba, A. M., Chirima, G. J., Masiza, W., & De Villiers, C. (2023). Global research trends for unmanned aerial vehicle remote sensing application in wheat crop monitoring. Geomatics, 3(1), 115–136. .

Primicerio, J. D. (2012). . A flexible unmanned aerial vehicle for precision agriculture. *Precision Agriculture, 13*(4), 517–523.

Sulaiman, I., Alkali, B., Adedipe, O., Salihu, B. A., Aliyu, A. A., & Ibrahim, A. G. (2021). Structural Integrity Study for a Quadcopter Frame to Be Deployed for Pest Control. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 8*(3), 667-672.

Yanliang, Z. Q., & Wei, Z. (2017). Design and test of a six-rotor unmanned aerial vehicle (UAV) electrostatic spraying system for crop protection. . *International Journal of Agricultural and Biological Engineering, 10*(6), 68–76.

Received: 12-01-2025 / Accepted: 13-02-2025 / Published: 11-07-2025
https://doi.org/10.70118/ujet.2025.0202.18