Advances in Aerospace Science and Technology, 2024, 9, 61-74
https://www.scirp.org/journal/aast
ISSN Online: 2473-6724
ISSN Print: 2473-6708

A Pragmatic Template for Quadcopter Development

Iyenagbe Benjamin Ugheoke, Abdulhakeem Hassan Nurudeen, Olusola Ayodeji Abiire, Aniedi Okon Edem, Emmanuel Adedayo Towoju, Emmanuel Ogo Onche

Department of Mechanical Engineering, Faculty of Engineering, University of Abuja, Abuja, Nigeria
Email: benjamin.ugheoke@uniabuja.edu.ng

How to cite this paper: Ugheoke, I.B., Nurudeen, A.H., Abiire, O.A., Edem, A.O., Towoju, E.A. and Onche, E.O. (2024) A Pragmatic Template for Quadcopter Development. *Advances in Aerospace Science and Technology*, **9**, 61-74.
https://doi.org/10.4236/aast.2024.92005

Received: May 6, 2024
Accepted: June 17, 2024
Published: June 20, 2024

Abstract

This article presents a pragmatic quadcopter development template for parcel delivery in Nigeria. The quadcopter is equipped with a camera, parcel pouch and wireless telecommunication to capture live events and send them back to the control station for real-time delivery feedback. The study also discusses the design methodology adopted as a conceptual design approach vital to product development, it encompasses information gathering and identifying the problem, creating the solutions systematically and eventually evaluating and developing a concept for the drone and its attributes and presenting clear results for design calculations.

Keywords

Drone, Unmanned Aeriel Vehicles, Quadcopter, Drone Development, Flight

1. Introduction

Drones are also regarded as unmanned aerial vehicles (UAV) these machines are self-propelled robots, and quadcopters are four-rotor UAVs with easy controllability and simple design [1] [2]. They possess a distinct ability to manoeuvre in congested zones, and vertical take-off and landing capabilities [1] [3]. Quadcopters are equipment with some mechanisms to grasp objects and deliver them to the required destination [4]. The capability makes the quadcopter suitable for various applications and tasks such as search and rescue, delivery and other industrial applications [5]. The interest in autonomous robotic platforms in recent decades offers several advantages such as reduced costs, and flight performance improvements [6]. There are essential features to autonomous systems; these include but are not limited to efficient energy sources, structural hardware, computing hardware, sensors and actuators, and autonomous software which are generally divided into remotely piloted and autonomous vehicles [7]. This trend has led to less human supervision and more intelligence of the machines to effectively perform tasks and execute timely decision-making [7] [8] [9].

Quadcopters are part of the future drone industries with so much potential for applications, their popularity is also due to their relative cost, more torque, higher topographical advantage and more convenience [5] [10] for blades fixed on a frame with two blades having clockwise and the two having counter-clockwise rotor motions [1] [11], it is a lightweight and high thrust generating capacity motors, which increase its weight lifting capability. The copter is controlled by altering the speed of one or more rotors [2] [4], the upward and downward motion is achieved by increasing/decreasing the rotor's speed, and forward/backward, left/right movement is achieved by different control strategies by the rotor speed.

The rapid design and development of UAVs of different sizes, shapes and capabilities with improved functionalities was due to the advancement of flight control and integrated circuit (IC) technologies [9] [12]. The use of UAVs was initially for military applications [13], recently, civilian applications are on the rise with use in search and rescue, agriculture, shipping and delivery of packages, image collection and mapping, monitoring of large infrastructures and giving feedback to ensure quality decision-making [6] [8] [14]. For example, quadcopters are used in agriculture to spray pesticides, monitor livestock on the farm to improve farm security, ship and deliver parcels to required destinations, monitoring of large projects such as oil and gas, pipelines, roads, bridges, power grids and many more [6] [15] [16] [17] [18].

The Design concept for the quadcopter was based on [1], with some modifications [19] [20], the quadcopter propellers are attached to the brushless DC motors which are mounted on the ends of the frame [21]. Because of its characteristics, there's so much research on quadcopters to cater for several applications [22]. A study was conducted to design and fabricate a solar quadcopter, the design adopted the use of finite element analysis to understand the morphology of the structure of the frame upon the addition of load to the copter [3], while it highlighted the component of the copter. Some authors developed a lightweight quadcopter for transporting goods while recording flight time which increases as weight is increased [20] [23].

Despite the attributes mentioned about UAVs, implementation, testing and operating such machines has been challenging, achieving such requires effective coordination, control mechanisms, reliable communication systems, and intelligence to navigate through various terrains. As such this paper presents a pragmatic template for developing a quadcopter to perform one of the attributed tasks of UAVs for the shipping and delivery of parcels using a conceptual design approach.

2. Materials and Methods

The components used in the design consist of the frame, brushless DC motors, electronic speed controller, four propellers, video camera, sensors and flight controllers (**Table 1**) [4] [22] [23].

Table 1. Material Selection Process.

S/N	UAV Parts	Material Performance Requirement	Probable Material	Final Material Selection	Justification
1	Frame	Ductility, tensile strength, toughness, cost effective, and lightweight	Aluminium, steel, titanium, thermoplastics	Thermoplastics	Corrosion resistance, toughness, affordability, good strength, and low density
2	Motors	Efficiency, reduction in heat generation, lightweight, and low noise	Magnets of iron, copper, cobalt alloys, aluminium	Alloy with aluminium	Absorbability of heat by aluminium, lightweight
3	Propeller	Stability, spinning rate, Air density, efficiency	Wood, fiber glass, carbon-fiber, reinforced plastics	Reinforced plastics	Low cost, lightweight, high strength, flexibility, Absorbability of impacts.
4	Flight Controller	Stability, processability of commands, compatibility	Sensors such as gyroscope, accelerometer, barometric pressure (barometer), compasses (magnetometer)		
5	Battery	Rechargeability, replaceability, low cost, availability, ability to store energy for long, light weight, high discharge rate to power	Lithium polymer (Li-Po), Lithium ion (Li-ion), Lithium iron Phosphate ($LiFePO_4$)	Lithium Polymer	High energy density

3. Kinematic Structure of the Quadcopter

The kinematics structure of the quadcopter refers to the air and motion that enters for movement of the quadcopter [24]. The rotors are mounted on the far ends of the frame of the quadcopter. The rotors are controlled by the motors that drive the propellers, the flight controller controls the speed and direction of the motors which are equipped with microcontrollers that receive input from ground sensors and commands from the control centre. The camera is mounted on the copter to provide smooth shorts, while the wireless communication allows the copter to send wider footage to the control centre on the ground which can be monitored and analyzed.

3.1. Conceptual Design

This methodology was adopted in the designing of the quadcopter, which is the identification of required problems through summary, establishing functional structures, selection of appropriate working principles and unifying these problems into a working structure. It answers the following question; has the problem been sufficiently clarified, is the conceptual design needed or has known solutions permit the embodiment design, to what extent should the conceptual design be developed? [25] [26] **Figure 1** shows the steps in performing conceptual design.

3.2. Design Considerations

The design factors considered in this endeavour were based on simplicity, aesthetics, cost-effectiveness, parcel size and other engineering properties relevant to the development of a quadcopter [10] [19] [20] [25] which form part of the conceptual design process shown in **Figure 1**.

3.3. Design Calculations

Thrust calculations

The form normal to the propellers required to provide the motion to the quadcopter, the force is generated by the rotors which span at the certain angular velocity is given by the equation:

$$T = \frac{\pi * D^4 * \rho * v * \Delta v}{4} \quad (1)$$

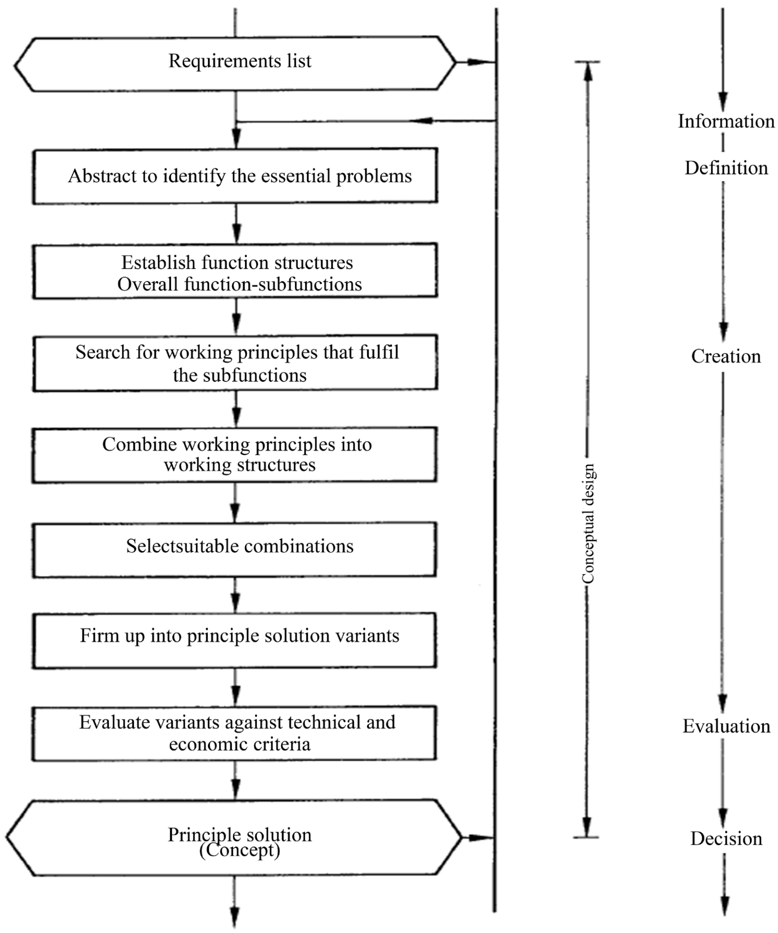


Figure 1. Steps to conducting conceptual design [25].

where: T = thrust (N), D = Propeller diameter (m), ρ = air density (kg/m^3), v = velocity of air (m/s), Δv = velocity of air accelerated by the propeller.

Total mass lifted by the quadcopter: the total mass (M) is given by the equation:

$$M = \frac{T}{a} \tag{2}$$

where:

M = total mass (kg), T = thrust, a = acceleration due to gravity = 9.81 m/s^2.

Force Analysis: the forces applied on the rod are given as thrust, centrifugal forces and the movement created by the propeller [24]

$$Fc = mRw^2 \tag{3}$$

where, Fc = centrifugal force, m = mass of the propeller (kg), R = Radius of the Propeller (m), w = angular speed = $\frac{2\pi N}{60}$.

Lift and Weight analysis: the focus is to reduce the weight by increasing the lifting capability of the flight system given by [1]:

$$W = \text{required}\frac{\text{RPM}}{\text{reference RPM}} * \text{reference weight} \tag{4}$$

Propeller Length to Weight Ratio is given by [4]:

$$y = \text{required}\frac{\text{weight}}{\text{reference weight}} * \text{reference propeller length} \tag{5}$$

$$\text{Lift}(\text{kg}) = \frac{\left(W * D^4 * N^2\right)\frac{p * 24}{cf * 29.9}}{2.2} \tag{6}$$

where cf = lift coefficient.

Duration of Flight: Duration of flight is given by [1] as

$$\text{Duration} = \text{capacity of}\frac{\text{battery}}{\text{max. current drawn by motor}} \tag{7}$$

Power required is given by,

$$\text{Power}(W) = K_p * d^4 * P * N^3 \tag{8}$$

where, K_p = propeller constant = 1.11, p = pitch of the propeller.

4. Results and Discussions

4.1. Design Calculations

Table 2. Design specification and assumptions.

S/N	Item Names	Values
1	Source of Power	Battery (1800 MAh)
2	Type of motor used	Brushless DC (BLDC)
3	Mass of the Quadcopter	1.5 Kg
4	Battery Voltage	11.1 V

Table 3. Design calculations.

Initial Data	Calculations and Sketches	Results
Weight of the quadcopter		
$M = 1.5$ kg $g = 9.81$ m/s	 From Equation 3.1b $W = mg = F_p$ $W = 1.5 \times 9.81 = F_p$ $W = 14.715\text{ N} = F_p$	Total weight of the quadcopter, $W = 14.715$N
1. Thrust of the propeller		
Number of propellers = 4 $M = 1.5$kg Number of the motors = 4	 From the Equations 3.2. and. 3.3 $\text{Thrust} = \frac{4}{1} \times m$ $\text{Thrust} = \frac{4}{1} \times 1.5$ Thrust = 6 N $\text{Thrust per motor} = \frac{m}{4} = \frac{1.5}{4} = 0.375\text{ N}$	Thrust = 6 N Thrust per motor = 0.375
1. Torque required to drive the propeller		
$R = 130\text{ mm} = 0.13\text{ m}$ $F_p = 14.715$ N	From Equation 3.9 $T = F_p \times r$ $T = 14.715 \times 0.13$ $T = 1.91$ Nm	$T = 1.91$ Nm
2. Centrifugal force required for propellers		
$M = 1.5$ kg $D = 260$ mm $N = 11000$ rpm $W = \frac{2\pi N}{60}$ $r = \frac{D}{2}$ $r = \frac{260}{2}$ $r = 130$ mm $r = 0.13$ m	From Equation 3.10 $F_c = \frac{Mv^2}{r}$ $v = wr$ $v = \frac{2\pi N}{60} * r$ $v = \frac{2 \times 3.132 \times 11000}{60} \times 0.13$ $v = \frac{8984.95}{60}$ $v = 149.7$rev/sec $F_c = \frac{Mv^2}{r}$ $F_c = \frac{1.5 \times 149.7^2}{0.13} = \frac{33637.3}{0.13}$ $F_c = 25.8748.1$ N	$v = 149.7$ rev/sec $F_c = 25.8748.1$ N

Continued

3. Power required for the propellers		
$\pi = 3.142$ $N = 11000$ RPM $T = 0.868$ Nm (as calculated above)	From the Equation 3.12 $P = \frac{2\pi TN}{60}$ $P = \frac{2 \times 3.142 \times 868.12 \times 11000}{60}$ $P = 100000\ 2.45$ W $P = 1000$ KW	$P = 1000$ KW
Quadcopter flight time		
Max motor Ampere = 4.62A	From Equation. 3.13 $\frac{1800\text{ MAh}}{1000} = 1.8\text{ Amp}$ $\therefore$ $t = \frac{\text{Batteryb Ampere} \times 60}{\text{Motor Ampere}}$ $t = \frac{1.8 \times 60}{4.62} = \frac{108}{4.62}$ $t = 23$ minutes	$t = 23$ minutes
Factor of Safety ($F.S$) for the Quadcopter		
$F.S = 1.25$	From Equation 3.8 $\sigma = \frac{\sigma_{ta}}{F.S}$ $\sigma = \frac{W}{A}$ $A = \frac{\pi d^2}{4} = \frac{3.142 \times 0.5^2}{4}$ $A = \frac{0.7854}{4} = 0.196\text{ m}^2$ $\sigma = \frac{W}{A} = \frac{14.715}{0.196}$ $\sigma = 75.1\text{ N/m}^2$ $\sigma_{ta} = \sigma \times F.S$ $\sigma_{ta} = 75.1 \times 1.25$ $\sigma_{ta} = 93\text{ N/m}^2$	$A = 0.196\text{ m}^2$ $\sigma = 75.1\text{ N/m}^2$ $\sigma_{ta} = 93\text{ N/m}^2$
Twisting moment for the propeller		
$d = 260$ mm = 0.26 m $r = 130$ mm = 0.13 m $T = 1.91$ Nm $\pi = 3.142$ $\tau = 22\text{ MN/m}^2$ $F.S = 1.25$	From Equation 3.16 $\tau = \frac{\tau_u}{F.S}$ $\tau_u = \tau \times F.S$ $\tau_u = 22 \times 10^6 \times 1.25$ $\tau_u = 27500000\text{ N/m}^2$ $\tau_u = 27\text{ MN/m}^2$ From equation 3.18b $J = \frac{\pi d^4}{32}$	$\tau_u = 27\text{ MN/m}^2$ $T_m = 76$ KNm $J = 4.5 \times 10^{-4}\text{ M}^4$

Continued

	$J = \frac{3.142 \times 0.26^4}{32}$ $J = \frac{0.0144}{32}$ $J = 4.5 \times 10^{-4}$ M^4 From Equation 3.18 $\frac{T_m}{J} = \frac{\tau}{r}$ $T_m = \frac{J\tau}{r}$ $T_m = \frac{4.5 \times 10^{-4} \times 22 \times 10^6}{0.13}$ $T_m = \frac{9900}{0.13}$ $T_m = 76153.8$ Nm $T_m = 76$ KNm	
Bending moment for the propeller		
$I = \frac{\pi d^4}{64}$ $y = \frac{d}{2}$ $d = 260$ mm = 0.26 m $r = 130$ mm = 0.13 m $y = \frac{0.26}{2}$ $y = 0.13$ m $I = 2.24 \times 10^{-4}$ m^4 $\sigma = 75.1$ N/m^2	From Equation 3.19b $I = \frac{\pi d^4}{64}$ $I = \frac{3.142 \times 0.26^4}{64}$ $I = \frac{0.0144}{64}$ $I = 2.24 \times 10^{-4}$m^4 From Equation 3.19 $\frac{B_m}{I} = \frac{\sigma}{y}$ $B_m = \frac{I\sigma}{y}$ $B_m = \frac{2.24 \times 10^{-4} \times 75.1}{0.13}$ $B_m = \frac{0.0168}{0.13}$ $B_m = 0.13$ Nm	$I = 2.24 \times 10^{-4}$m^4 $B_m = 0.13$Nm $y = 0.13$Nm
Equivalent twisting moment for the propeller		
$T_m = 76153.8$ Nm $B_m = 0.13$ Nm	From Equation 3.20 $T_e = \sqrt{T_m^2 + B_m^2}$ $T_e = \sqrt{76153.8^2 + 0.13^2}$ $T_e = \sqrt{5799401254}$ $T_e = 76153.8$ Nm $T_e = 76$ KNm	$T_e = 76153.8$ Nm $T_e = 76$ KNm
Equivalent bending moment for the propeller		

Continued

T_m = 76153.8 Nm B_m = 0.13 Nm $T_e = \sqrt{T_m^2 + B_m^2} = 76153.8\ \text{N}\cdot\text{m}$	From Equation 3.21 $M_e = \frac{1}{2}\left[B_m + \sqrt{T_m^2 + B_m^2}\right]$ $M_e = \frac{1}{2}[0.13 + 76153.8]$ $M_e = \frac{1}{2}[76153.93]$ M_e = 38077 Nm M_e = 38 KNm	M_e = 38077 Nm M_e = 38 KNm
Lift required for the Drone		
v = 2 to 9.5 m/s (speed of air from meteorological data) ρ = 1.293kg/m^3	$q = \frac{1.293 \times 344^2}{2} = \frac{153008.4}{2}$ q = 76504.2 N/m^2 $A = L \times b$ A = 0.5 × 0.5 A = 0.25 m^2 $C_L = \frac{F}{Aq}$ $q = \frac{1}{2}\rho \times v^2$ At 0˚ angle of attack C_L = 0.4096 $L = \frac{0.4096 \times 1.293 \times 344 \times 0.25}{2}$ L = 7834.03 N L = 7.834 KN	q = 76504.2 N/m^2 A = 0.25 m^2 L = 7834.03 N L = 7.834 KN
Lift required for the drone		
= $1/2\rho V^2 A C_L$ v = 2 to 9.5 m/s (from meteorological data) A = Area = $L \times B$ = 0.5 × 0.5 = 0.25m^2 C_L = 1.0 to 1.5 (for squared quadcopter depending on angle of attack, Reynolds number and other aerodynamic characteristics) ρ = 1.293kg/m^3	L = 1/2 × 1.293 × 9.5^2 × 0.25 × 1.5 $L = \frac{43.76}{2}$ L = 21.88 N	L = 21.88 N
Drag required for the Drone		
$D = 1/2\rho V^2 A C_D$ ρ=1.293kg/m^3 V = 2 to 9.5 m/2 (from meteorological data) A = area = $L \times B$ = 0.5 × 0.5 = 0.25 m^2 C_D = coefficient of Drag = 1.05 (for squared quadcopter depending on size, surface roughness and flow conditions)	D = 1/2 × 1.293 × 9.5^2 × 0.25 × 1.05 $D = \frac{30.63}{2}$ D = 15.32 N	D = 15.32 N

Continued

Thrust generated by the rotors		
$T = [(\eta W)^2 \times 2\pi R^2 \times \rho]^{1/3}$ where $\eta = 0.8$ (is taken as the efficiency) W = Propeller power = 260.94W D = 10" = 0.254m R = 0.127m ρ =1.22kg/m^3 (density of air)	$T = [(0.8 \times 260.94)^2 \times 2\pi(0.127)^2 \times 1.22]^{1/3}$ T = 17.531N	T = 17.531N
Power of the rotor		
Power required $W = K \times N^3 \times D^4 \times P \times \eta$···where K is propeller constant, it depends on the design of the propeller blade thickness, width, aerofoil profile etc. $K = 5.3 \times 10^{-15}$ N = Speed of the rotor in rpm $\eta = 0.8$ (efficiency) D = Propeller diameter in inch = 10" P = Pitch of the propeller = 4.5"	$W = 5.3 \times 10^{-15} \times 11100^3 \times 10^4 \times 4.5 \times 0.8$ W = 260.94 watts	W = 260.94 watts
Maximum current drawn at full throttle		
$I = w/v$	$I_{max} = \frac{260.94}{11.1} = 23.508$ A I_{max} = 23.508 A	I_{max} = 23.508 A
Velocity of air accelerated downward		
The velocity of air accelerated downward is given as. $V_d = (2W\eta)/T$	$V_d = (2 \times 260.94 \times 0.8)/17.531$ V_d = 23.82 m/s	V_d = 23.82 m/s
Flight of speed or Aircraft speed		
The flight speed or aircraft speed. $V_a = 1/2 \times V_d$	$V_a = 1/2 \times 23.82$ V_a = 11.91 m/s	V_a = 11.91 m/s

4.2. Discussions

The developed quadcopter presented in this study was designed to cater for cost-effectiveness, simplicity and mechanical design (See **Appendix 1**) done using Solid Works and specifications with a brief description of the quadcopter components used in the development of drones for parcel delivery and other tasks shown in **Table 2**, while **Table 3** displayed the mathematical equations used in the design and development of the quadcopter. The design was tested and proved to be effective and demonstrated stability and energy efficiency as per design calculations.

4.3. Recommendations

The following recommendations were proposed for further enhancement of the performance reliability and aesthetics.

The quadcopter should be equipped with weatherproofing to make it have multifunctional capabilities over varied weather conditions and also another design alternative should be considered to reduce the noise of the quadcopter.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tatale, O., Anekar, N., Phatak, S. and Sarkale, S. (2018) Quadcopter: Design, Construction and Testing. *International Journal for Research in Engineering Application & Management*, **4**, 1-7.

[2] Tuna, T., Ertug Ovur, S., Gokbel, E. and Kumbasar, T. (2020) Design and Development of FOLLY: A Self-Foldable and Self-Deployable Quadcopter. *Aerospace Science and Technology*, **100**, Article ID: 105807. https://doi.org/10.1016/j.ast.2020.105807

[3] Nvss, S., Esakki, B., Yang, L., Udayagiri, C. and Vepa, K.S. (2022) Design and Development of Unibody Quadcopter Structure Using Optimization and Additive Manufacturing Techniques. *Designs*, **6**, Article 8. https://doi.org/10.3390/designs6010008

[4] Paredes, J., Sharma, P., Ha, B., Lanchares, M., Atkins, E., Gaskell, P., et al. (2021) Development, Implementation, and Experimental Outdoor Evaluation of Quadcopter Controllers for Computationally Limited Embedded Systems. *Annual Reviews in Control*, **52**, 372-389. https://doi.org/10.1016/j.arcontrol.2021.06.001

[5] Komarudin, U. (2021) Drone Monitoring System to Detect Human Posture Using Deep Learning Algorithm. *Turkish Journal of Computer and Mathematics Education* (*TURCOMAT*), **12**, 1824-1833.

[6] Kangunde, V., Jamisola, R.S. and Theophilus, E.K. (2021) A Review on Drones Controlled in Real-Time. *International Journal of Dynamics and Control*, **9**, 1832-1846. https://doi.org/10.1007/s40435-020-00737-5

[7] Atyabi, A., MahmoudZadeh, S. and Nefti-Meziani, S. (2018) Current Advancements on Autonomous Mission Planning and Management Systems: An AUV and UAV Perspective. *Annual Reviews in Control*, **46**, 196-215. https://doi.org/10.1016/j.arcontrol.2018.07.002

[8] Jawhar, I., Mohamed, N., Al-Jaroodi, J., Agrawal, D.P. and Zhang, S. (2017) Communication and Networking of Uav-Based Systems: Classification and Associated Architectures. *Journal of Network and Computer Applications*, **84**, 93-108. https://doi.org/10.1016/j.jnca.2017.02.008

[9] Veres, S.M., Molnar, L., Lincoln, N.K. and Morice, C.P. (2011) Autonomous Vehicle Control Systems—A Review of Decision Making. *Proceedings of the Institution of Mechanical Engineers*, *Part I*: *Journal of Systems and Control Engineering*, **225**, 155-195. https://doi.org/10.1177/2041304110394727

[10] Tomar, P. and Krishnan, S. (2022) Development of a Drone with Spraying Mechanism for Agricultural Work. In: Sharma, R., Kannojiya, R., Garg, N. and Gautam, S.S., Eds., *Advances in Engineering Design*, Springer, Singapore, 295-308.

[11] Jeyan, J.V.M.L., Chhetri, R.T., Saithota, P., Shrestha, P. and Pasha, S.S. (2021) Design and Development of a Tri-Pro UN Manned Arial vehicle Concept for Commercial Application. *International Journal of Emerging Technologies and Innovative Research*, **8**, 2459-2473.

[12] Gunetti, P., Thompson, H. and Dodd, T. (2013) Simulation of a Soar-Based Autonomous Mission Management System for Unmanned Aircraft. *Journal of Aerospace Information Systems*, **10**, 53-70. https://doi.org/10.2514/1.53282

[13] Zeng, Y., Lyu, J. and Zhang, R. (2019) Cellular-connected UAV: Potential, Challenges, and Promising Technologies. *IEEE Wireless Communications*, **26**, 120-127. https://doi.org/10.1109/mwc.2018.1800023

[14] Ebeid, E., Skriver, M., Terkildsen, K.H., Jensen, K. and Schultz, U.P. (2018) A Survey of Open-Source UAV Flight Controllers and Flight Simulators. *Microprocessors and Microsystems*, **61**, 11-20. https://doi.org/10.1016/j.micpro.2018.05.002

[15] Rejeb, A., Abdollahi, A., Rejeb, K. and Treiblmaier, H. (2022) Drones in Agriculture: A Review and Bibliometric Analysis. *Computers and Electronics in Agriculture*, **198**, Article ID: 107017. https://doi.org/10.1016/j.compag.2022.107017

[16] Kulbacki, M., Segen, J., Kniec, W., Klempous, R., Kluwak, K., Nikodem, J., et al. (2018). Survey of Drones for Agriculture Automation from Planting to Harvest. 2018 *IEEE 22nd International Conference on Intelligent Engineering Systems* (*INES*), Las Palmas de Gran Canaria, 21-23 June 2018, 353-358. https://doi.org/10.1109/ines.2018.8523943

[17] Satterlee, L. (2016) Climate Drones: A New Tool for Oil and Gas Air Emission Monitoring. *Environmental Law Reporter News and Analysis*, **46**, Article ID: 11069.

[18] Asadzadeh, S., Oliveira, W.J.d. and Souza Filho, C.R.d. (2022) Uav-based Remote Sensing for the Petroleum Industry and Environmental Monitoring: State-of-the-Art and Perspectives. *Journal of Petroleum Science and Engineering*, **208**, Article ID: 109633. https://doi.org/10.1016/j.petrol.2021.109633

[19] Javir, A.V., Pawar, K., Dhudum, S., Patale, N. and Patil, S. (2015) Design, Analysis and Fabrication of Quadcopter. *Journal of The International Association of Advanced Technology and Science*, **16**, 1-12.

[20] Parihar, P., Bhawsar, P. and Hargod, P. (2016) Design & Development Analysis of Quadcopter. *Compusoft*, **5**, 2128-2133.

[21] Ahmed, M.F., Zafar, M.N. and Mohanta, J.C. (2020). Modeling and Analysis of Quadcopter F450 Frame. 2020 *International Conference on Contemporary Computing and Applications* (*IC3A*), Lucknow, 5-7 February 2020, 196-201. https://doi.org/10.1109/ic3a48958.2020.233296

[22] Anudeep, M., Diwakar, G. and Katukam, R. (2014) Design of a Quad Copter and Fabrication. *International Journal of Innovations in Engineering and Technology*, **4**, 59-65.

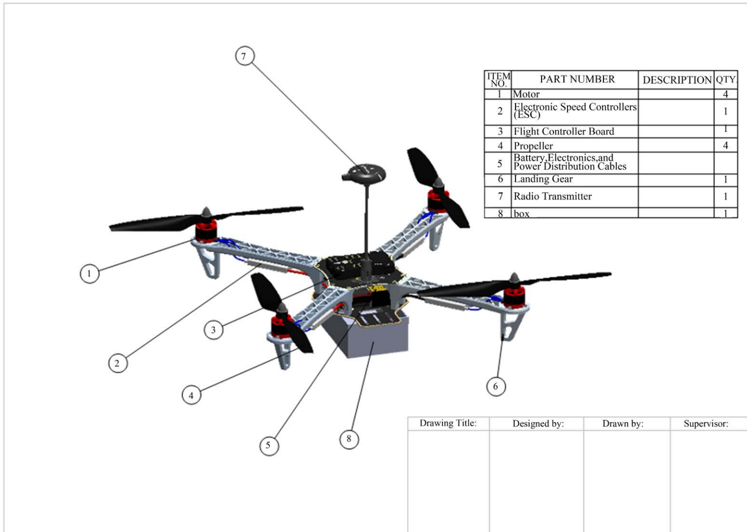
[23] Tagay, A., Omar, A. and Ali, M.H. (2021) Development of Control Algorithm for a Quadcopter. *Procedia Computer Science*, **179**, 242-251. https://doi.org/10.1016/j.procs.2021.01.003

[24] Tamilarasan, V., Gnanaseka, A.S.R., Dhanapa, B.R., John, J.J., Kandhampalayam, M.S., *et al.* (2023) Development of Surveillance Quadcopter. *Nanoworld Journal*, **9**, S62-S68. https://doi.org/10.17756/nwj.2023-s4-011

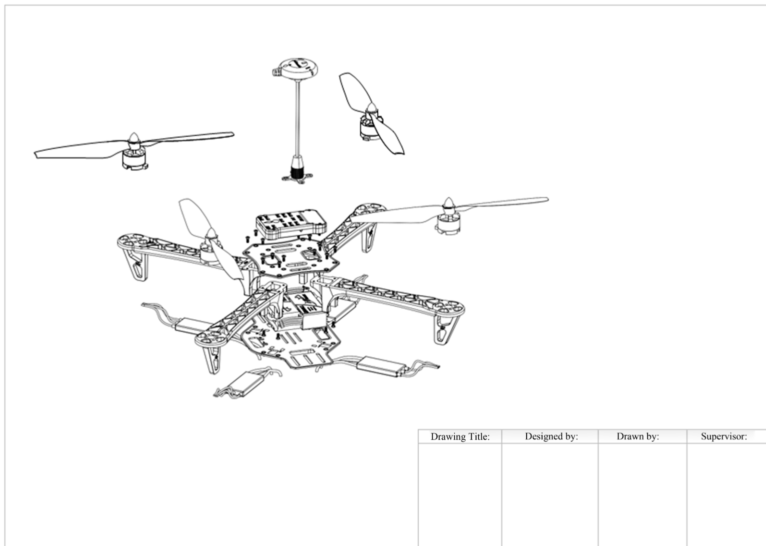
[25] Andreasen, M.M., Hansen, C.T. and Cash, P. (2015) Conceptual Design. Springer. https://doi.org/10.1007/978-3-319-19839-2

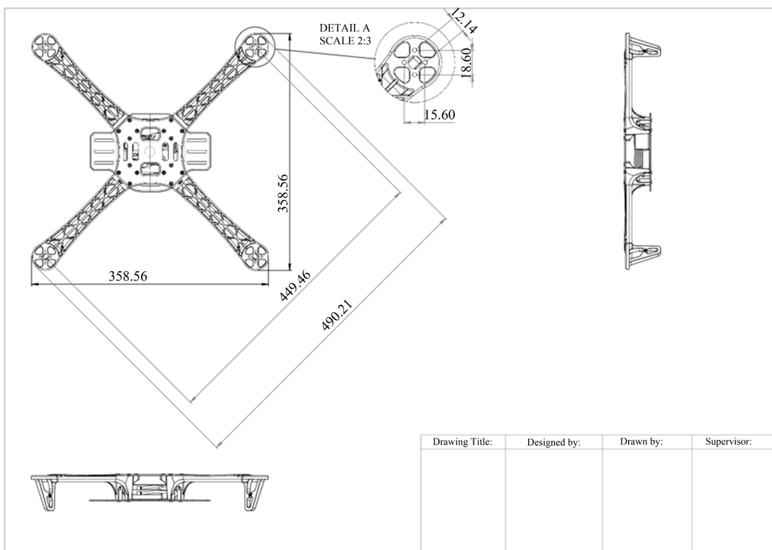
[26] Wang, L., Shen, W., Xie, H., Neelamkavil, J. and Pardasani, A. (2002) Collaborative Conceptual Design—State of the Art and Future Trends. *Computer-Aided Design*, **34**, 981-996. https://doi.org/10.1016/s0010-4485(01)00157-9

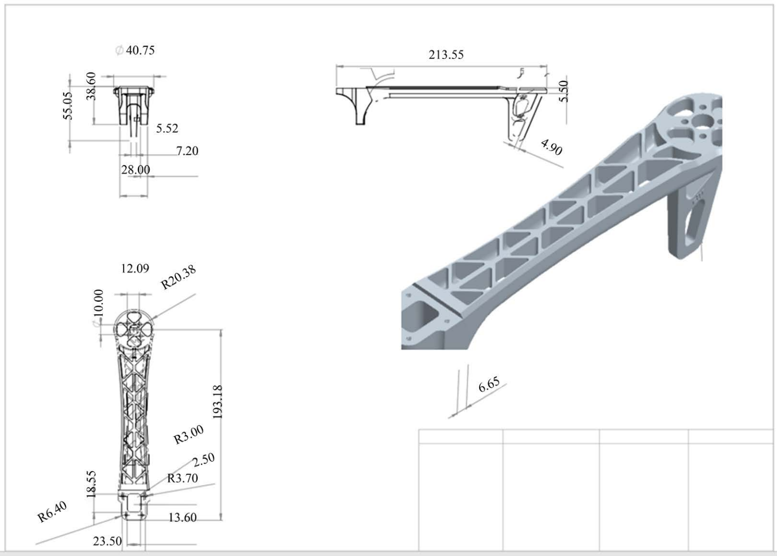
Appendix 1: Design Drawings



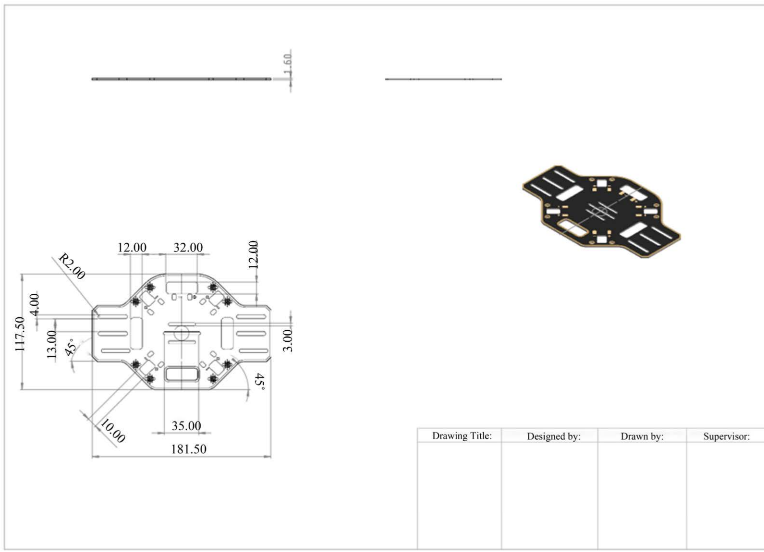
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor		4
2	Electronic Speed Controllers (ESC)		1
3	Flight Controller Board		1
4	Propeller		4
5	Battery,Electronics,and Power Distribution Cables		
6	Landing Gear		1
7	Radio Transmitter		1
8	box		1



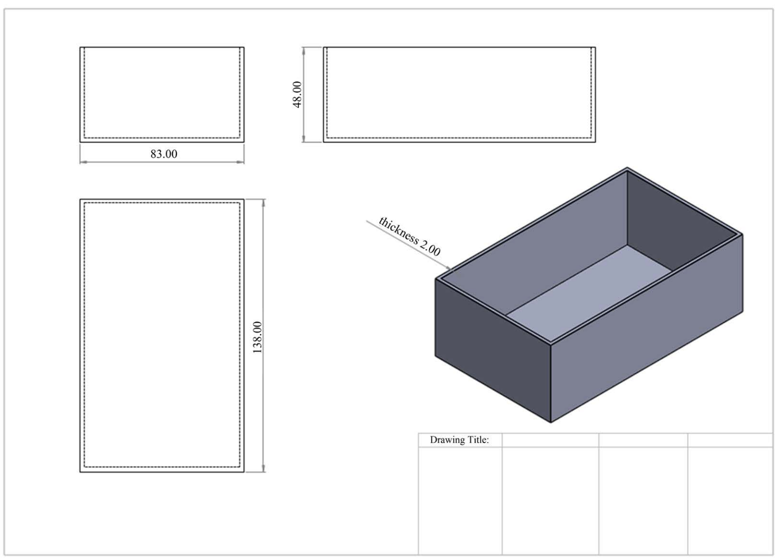




∅40.75
213.55
38.60
55.05
5.52
7.20
28.00
5.50
4.90
12.09
R20.38
10.00
193.18
R3.00
2.50
R3.70
18.55
R6.40
13.60
23.50
6.65



1.60
12.00
32.00
12.00
R2.00
4.00
117.50
13.00
45°
3.00
45°
10.00
35.00
181.50
Drawing Title:
Designed by:
Drawn by:
Supervisor:



48.00
83.00
thickness 2.00
138.00
Drawing Title: