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Design and Development of Aluminum Frame Unmanned Aerial Vehicle Hexacopter Configuration to Support Heavy Payload

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ABSTRACT

Previous research has proven that the use of Unmanned Aerial Vehicles (UAVs) can increase the efficiency of human work. However, the design of the usefulness of UAV is considered to be limited. This limitation, for example, is that the UAV's lifting capacity is only capable of lifting 3-5 kilograms of load on average. In addition, the main material of the UAV frame also uses carbon fiber produced by build-up factories abroad, this makes the UAV design less economical. Furthermore, this study discusses the development of the UAV's lifting capacity of 25 kilograms to be able to lift the pesticide liquid load and considers the economic value. The hexacopter type multicopter UAV design was chosen in this study, equipped with 6 main propulsion rotors capable of carrying out its main task of lifting heavy loads, compared to the multicopter type of fewer than 6 rotors. The design is carried out by calculating the lifting force and analyzing the strength structure of the frame material with the help of AutoDesk Inventor software. The final result of the study was that the aluminum-based heavy-lift hexacopter drone was able to support heavy loads, as evidenced by structural analysis simulations resulting in a safety factor value of 1.67 ul, equipped with a 120KV rotor, 23x88 inch propeller, and 6S lipo battery 16,000 mAh, with a total weight of the frame 15kg drone flying for 19 minutes, with an additional 10kg of load the drone can fly for 6 minutes. This research can be developed by adding a nozzle or griper so that it can lift the pesticide spraying tank on a large enough agricultural land.

Keywords: *UAV, hexacopter, heavy-lift, multifungtion drone*

INTRODUCTION

UAV (Unmanned Aerial Vehicle) is a flying robot technology that can be controlled wirelessly using a remote control or run automatically with the help of sensors such as GPS navigation and lock position that has been determined using a computer [1], this technology is becoming popular and widely used as a topic of research [2] [3]. In the last two decades, robotic technology has continued to develop and the deployment of both commercial and private UAVs has revolutionized many ecosystems [4], several researchers have developed flying robot technology [5]. Not only the defense department, including the automation industry sector and universities began to study, research and develop these technologies [6].

Flying robots or UAV (Unmanned Aerial Vehicle) are categorized into two types or forms, namely fixed-wing and multi-rotary. Fixed-wings UAV is a type of winged aircraft [7]. To be able to fly required aileron wings on both sides of the tip. In addition, in order for the aircraft to be maneuverable, rudder wings and elevators are needed. Meanwhile, the multi-rotary UAV (multi-copter) is an aircraft powered by a rotor with propellers on each arm as a thrust to be able to fly or hover [8].

UAV technology, especially the multi-copter type, is an important part of every human's daily life to make work easier [9]. Interest in using multi-copter UAVs, also known as drones in various applications, has grown significantly in recent years [10]. The reason is related to technological advancements that continue to develop, especially the emergence of fast microprocessors, which support intelligent autonomous control of multiple systems [11]. The type of multi-copter is distinguished by the number of rotors used, generally thirdcopter (3 propellers), quadcopter (4 propellers), hexacopter (6 propellers), and octocopter (8 propellers).

Drones have become a basic tool in tasks where humans have limited skills that prevent superlative time optimization [12]. The usefulness of drones is widely used to assist human work [13], [14] has proven by his research drones as unmanned aerial vehicles for parcel delivery and fast food, the results show that the peak hourly traffic density of express package and fast food delivery drones will exceed the current global commercial air traffic of 10,000 per day is more than six times for just one potential metropolis.

Then what was done by [15] in his research UAV quadcopter model was used for mapping land parcels, showing the results that this type of UAV was able to accelerate the PTSL program with an accuracy level of 96%, a plot of 1000 hectares of land could be done in less than 5 days, but this is quite expensive.

While in previous research conducted on a hexacopter-type multicopter UAV to carry out the task as an automatic pesticide sprayer on agricultural land, this research provided convenience for farmers in spraying pesticides in addition to avoiding direct contact of human skin with pesticide liquid that caused irritation, equipped with 6 980KV rotors [16]. The drone design is also capable of carrying 2.5 liters of pesticide liquid, able to fly for 1 minute 45 seconds and spraying pesticide liquid automatically at an altitude of less than 320 cm.

The difference between the quadcopter and hexacopter type multi-copter lies in the ability to lift loads due to the addition of rotors, the more rotors used will cause its own problems when the drone is given a fairly heavy load which makes it difficult to control [17]. The lifting power of this UAV is purely obtained from the rotation of the rotor and its movement is obtained from the torque of each rotor [18]. Because its main task is to lift heavier loads, the main choice for the design is a hexacopter or octocopter type multicopter, therefore to be able to design a multicopter drone that is able to lift more loads, this study chose a hexacopter type multicopter, even though the multicopter type octocopter has 8 the rotor will produce a greater lifting power than the hexacopter type, but the design of the octocopter type multicopter will make the price high and uneconomical or become more expensive due to the use of more motors.

The focus of this research is to design and build a multi-purpose drone using a heavy-lift hexacopter configuration with more lifting power, as the main task is to carry heavier loads, an appropriate design is needed in selecting the multicopter configuration to be used. In multicopter drone designs [19], [20] and [21] using the raw material for the manufacturing frame made of PVC or carbon fiber composite, the difficulty of getting these raw materials at the local shop where this research was carried out caused its own problems in this study, it is necessary a replacement material for the drone frame which has characteristics similar to the manufacturer's material which is able to withstand heavy loads, has economic value and is easy to obtain.

METHODS

The research method used in the development of the Hexacopter configuration UAV to be able to lift heavy loads is the Research and Development or R&D research method, the method is a research model that aims to develop an existing product for research to analyze the level of need and then develop it to produce a more efficient and tested products [22].

In this research, there are several stages that will be carried out. The first stage is identification of potential and problems, the second stage is needs analysis, the third stage is product design design, the fourth stage is the manufacture or realization of products that have been previously designed and the last stage is product testing. Identification of potential and problems in previous research is used to find out various problems and design an existing product and then develop it so as to produce a more efficient product.

Then proceed with conducting a needs analysis. The requirements analysis is derived from the analysis of the performance of the developed system related to the requirements of the system development components. The design is done by designing a hexacopter drone frame in 2D using the CoreDraw software and 3D using the SketchUp Pro software. The next design is realized at the design stage. Finally, to determine the effectiveness of the system used, the system is tested. Figure 1 shows the stages of research carried out for the development of drones to be able to lift loads above 3 kilograms.

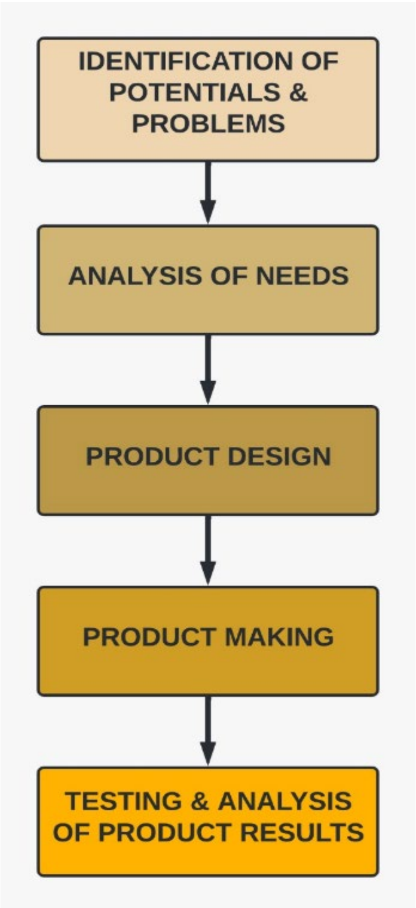

Figure 1. Fowchart of Research Development

The purpose of this research is to produce a product where the existing product belongs to [21] [23] for the latest innovation to design a pesticide spraying hexacopter drone used on automatic agricultural land. The results of testing and analysis of the drone can fly for 1 minute 45 seconds with a total weight of the drone being lifted 3 kilograms. Then the product is researched and developed to be perfected, so that it can increase the work effectiveness of a drone in lifting heavier loads. The product is a hexacopter-type multicopter drone to be able to lift a liquid load of 10 kilograms.

RESULT AND DISCUSSION

The design of the heavy-lift hexacopter drone begins with drawing a 2D sketch to determine the size and angle of work to be worked on later. The dimensions of the heavy-lift hexacopter drone are designed to have an arm length of 550mm for a motor to motor distance of 1404mm, while the main base is 350mm in diameter, the angle between the arm and the other arm is 60˚, and the diameter of the propeller or propeller is 584mm as shown in Figure 2.

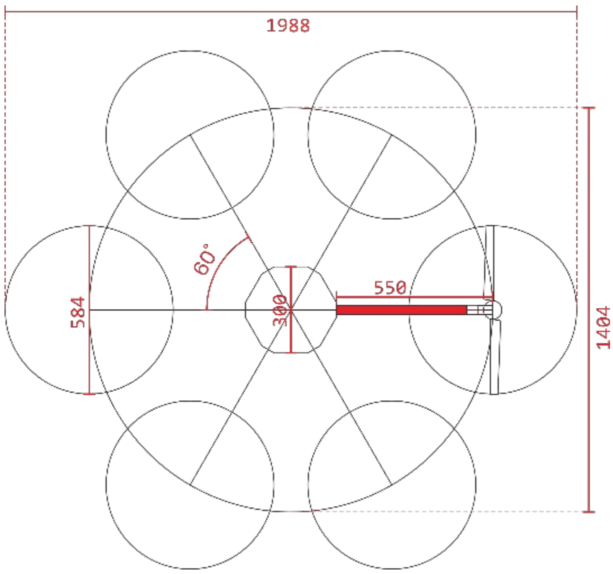

Figure 2. Sketch 2D drone dimension size

Furthermore, modeling in 3D using the help of sketchup pro software to be able to project a hexacopter drone into 3D modeling can be seen in Figure 3 below :

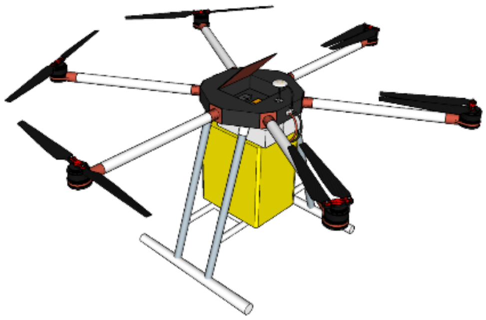

Figure 3. Design 3D Drone ISO view

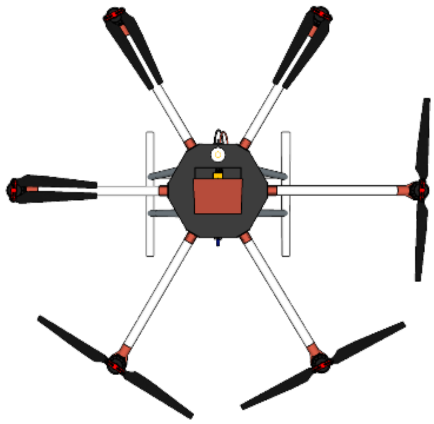

Figure 4. Design 3D drone top view

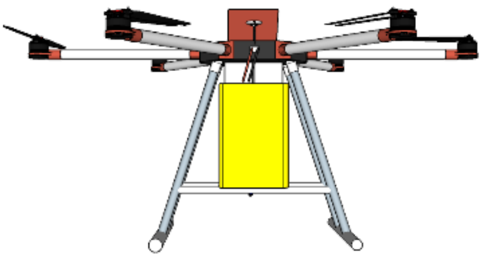

Figure 5. Design 3D drone side view

The frame on the heavylift hexacopter drone arm is made of stainless steel T-6061, strong, has lightweight characteristics, and is inexpensive. After the drone frame is drawn and assembled into a complete arm shape, the first step in analyzing the structure on this hexacopter arm is to import or enter the design of the object diagram arm that was created earlier into the AutoDesk Inventor software.

Figure 6. ARM Design on Inventor

Then determine the fix point of the support restraint in the form of a nut-bolt-ring and the distributed force comes from the motor-propeller pair then determine the point of force experienced on the workpiece, in this simulation the point is at the end of the pipe frame (motor mount) given the magnitude of the thrust force of 116.699 Newtons. This figure (thrust force 12 Kg) is obtained from the brushless motor specs that have been selected, the loading table (remote force).

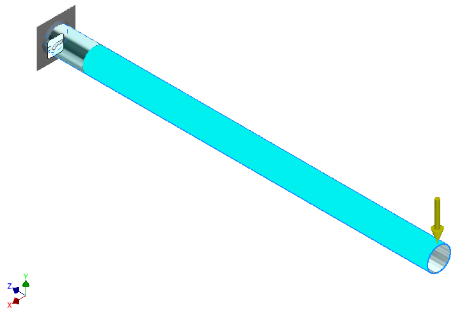

Figure 7. Force point

Then it is simulated so as to produce data in the form of von mises stress and total displacement as shown in Figure 4.11 and Figure 4.12 as follows.

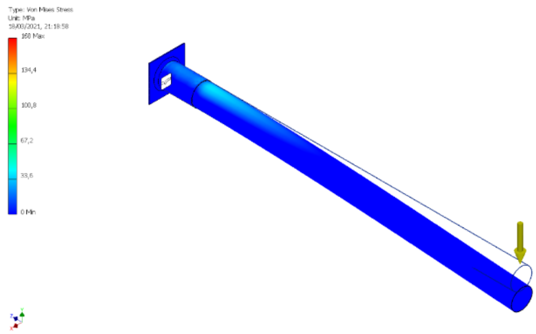

Figure 8. Von mises stress

The calculation results between the equivalent stress and strain used in the von misses stress tool design. As in Figure 9 the results can be seen with the orientation of the colors and numbers listed with the maximum stress occurring 168 Mpa and the minimum stress being 0 Mpa.

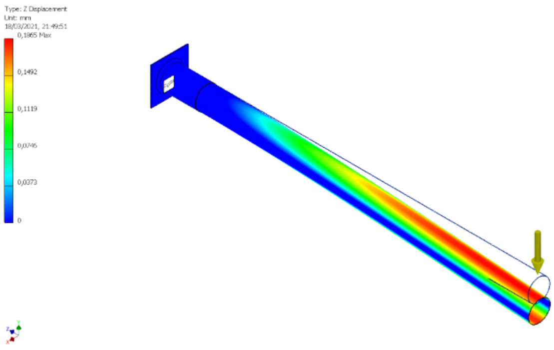

Figure 9. Displacement total

The result of the static structure analysis of deformation or displacement is the total result of the formation in the modeling. The simulation shows that the largest total formation is at the end of the arm (motor mounting) 0.186521 mm and the smallest total formation is at the support plate frame, which is 0 mm. illustrated in Figure 9.

Factory safety or safety factor is one of the most important parameter values to determine whether the design construction made is feasible or not. Safety Factory is a comparison between the permissible voltage and the actual voltage that occurs. Construction materials are declared safe if the safety value is above 1.5 ul [21][24][25].

$$FS = \frac{Yield\ Strength}{Von\ Mises\ voltages} \quad (1)$$

$$FS = \frac{275\ Mpa}{168\ Mpa} = 1.697\ ul \quad (2)$$

The results of the simulation of the design comparison of the permissible voltage with the actual stress obtained a minimum result of 1,697 ul, above the standard of 1.5, so it can be concluded that the design of the drone arm using 2mm thick aluminum material is suitable or aluminum material can withstand the load and the safety factor is good. Shown the results of the analysis in Figure 10 below.

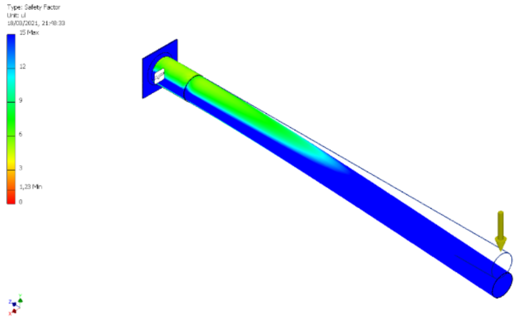

Figure 10. Safety factor

Determination of lifting power on the rotor is the most important thing in this design, where the rotor is the main component of the drone to be able to lift loads, especially in its main task as lifting heavy loads of 10 kilograms. The selection of electronic components such as flight control, esc, rotor, battery, receiver, power distributor is also considered so as not to increase the weight of the drone later.

In this design using flight control Naza M V2, revicer X8R, lipo battery with a voltage of 24 volt 12S with a capacity of 16,000 mAh and a water tank with a capacity of 10 kilograms of liquid. From these components, a table of the total weight of the drone is obtained.

Table 1. Material requirement

No.	Component	Weight (g)
1.	Flight Control	80.5
2.	Battery	3980
3.	Power Distributor	116.4
4.	GPS	52.6
5.	Receiver	8.5
6.	Tank	400
7.	ESC	1209
8.	Propeller	746
9.	Rotor	4865
10	Drone Frame	3500

By knowing the total weight of the drone is 15.0 36.7 grams, the thrust for each motor is determined as follows:

$$Thrust = \frac{payload\ x\ 2}{number\ of\ rotor} \quad (3)$$

$$FS = \frac{15.036}{6} = 5.012\ gram \quad (4)$$

Based on the above calculation, each motor must produce a thrust of 5,012.23 grams with the assumption that all motors have the same thrust. The motor and the type of propeller used in this research are HobbyWings Xrotor X6 120KV and Propeller with a diameter of 584mm or 23inch.

By looking at the datasheet on the HoobyWings Xrotor X6 120KV motor user manual, the maximum thrust (maximum thrust) is 11,900 kilograms and the recommended load is 3 to 5 kilograms per axis, from the calculation of the weight and load lifted by the drone if the frame is heavy. of 15,036.7 grams plus the load carried by 10,000 grams, the total drone is 25,036.700 grams, from the total calculation of the overall load, the motor is able to lift the load and the drone can hover or fly.

In holding the realization of the design, the results of the heavylift hexacopter drone design are as follows:

Figure 11. drone design results

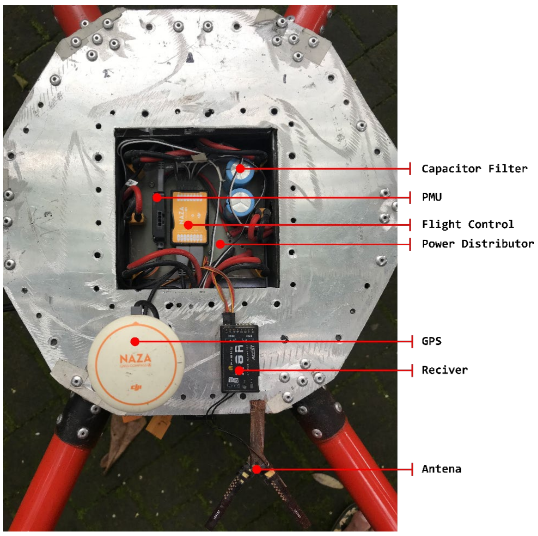

Figure 12. component layout

The heavylift hexacopter drone was then tested and obtained the results of the ability of each rotor to lift a load of 1 to 10 kilograms per one trial, the connectivity of the remote control range was also tested in this study to obtain how far the remote control communication with the receiver on the drone is, the following is a test table remote control connectivity distance.

Table 2. Connectivity Distance

No.	POINT	DISTANCE (M)	CONDITION
1	A	220	Take-Off
2	B	390	Take-Off
3	C	535	Take-Off
4	D	645	Take-Off
5	E	748	Can't Take-Off

The drone's flight distance that can be controlled by remote control is the widest around 650 to 700 square meters with tree and building barriers. The results of this test are influenced by the object of the transmitter signal barrier in the area, the fewer obstacles experienced by the transmitter, the wider the range that can be controlled by the remote control. The position point and status of the remote control signal can be seen in Figure 13.

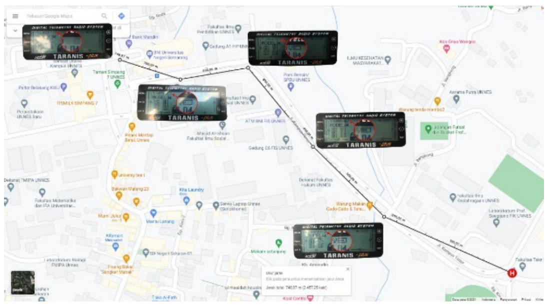

Figure 13. Mapping distance remote control

Furthermore, testing the drone travel time without carrying a water tank load. The flight time test was carried out to determine the level of battery endurance or travel time when flying without a load or with a varied load, equipped with a Lipo battery type Tattu 12S 24Volt with a capacity of 16,000 mAh, the longest flight time produced was 19 minutes with a remaining battery of 8% , if on average the drone can fly without carrying a load for 18 minutes. Here's a test table for the drone's travel time when it's not carrying a load.

Table 3. No Load test

Test	Heavy (kg)	Remaining Battery	Long Fly
1	15	16%	18:22
2	15	18%	17:51
3	15	15%	18:18
4	15	22%	17:05
5	15	8%	19:09

Then in testing the hexacopter drone's load-bearing capacity by loading liquid water on the tank, starting with filling the tank capacity of 1 kilogram then each sequence adding 1 liter/1 kilogram of liquid water until it reaches the full capacity of the water tank of 10 kilograms / 10 liters, the following table of results testing the duration of flying drones with varied loads.

Table 4. Load test

Test	Heavy (kg)	Remaining Battery	Long Fly
1	16	15%	16:21
2	17	16%	15:09
3	18	15%	13:94
4	19	15%	12:85
5	20	14%	11:74
6	21	16%	10:61
7	22	17%	9:49
8	23	15%	8:37
9	24	15%	7:25
10	25	79%	2:13
11	26	-	FAIL

Figure 14. Drone charged 1 kilogram

Figure 15. Drone charged 5 kilograms

Figure 16. Drone charged 10 kilograms

With the addition of a varied load starting from 1 kilogram/liter the drone can fly for 16 minutes 21 seconds, at the peak of the loading of 9 kilograms/liter the drone is able to fly for 7 minutes 25 seconds. However, when the dorne hexacopter was charged with a tank filled with 10 liters of water, the drone was only able to fly for 2 minutes 13 seconds due to a system failure that caused the rotor to catch fire and burn. The length of time a drone can fly depends on the capacity it carries, the greater the load capacity it carries, the shorter the drone's flying time.

CONCLUSION

Based on the results of testing and analysis on the design of a multipurpose drone using a heavy-lift hexacopter configuration with an overloaded lift that the researchers have done, it can be concluded that: (1) The heavy-lift hexacopter modeling has been successfully modeled in real and complete with dimensions of size 1988 mm X 1988 mm X 550 mm with a total weight of the frame without a load of 15,036 grams; (2) Starting from the calculation of the total weight of the drone, the lift produced by each motor to be able to fly is 5 kilograms/pair, the specifications of the motor to be used must match or exceed the previous calculation, the Hobbywings X6 Pro 120KV, ESC 80A, and 23x88 brand motor inch was chosen in this design, which is written on the datasheet the motor is capable of lifting 3 to 5 kilograms per rotor; (3) The replacement material for the frame is the 6061-T6 aluminum type where the material is no less strong than PVC or carbon fiber and is very easy to find in local stores at a cheaper price, as evidenced by the results of the analysis of the strength structure of the drone are made of aluminum 6061-T6 at the time. given a pressure of 116.6 newtons (12 Kg) produces maximum stress of 168 MPa and at the end of the drone arm experiences a displacement of 0.186521 mm, the material is following the standard safety factor of 1.67 ul; (4) The heavy-lift hexacopter drone designed by the researcher can fly (hover) with an overall total load of 25 kilograms and can fly stable, equipped with a lipo battery of 16,000 mAh, the drone designed by the researcher can fly for 18 minutes without a load, while carrying a load a maximum of 9 kilograms of drones can fly for 7 minutes 22 seconds with a remaining battery of 15% of capacity, the ability of the travel time produced by the drone depends on how heavy the load is and also the remaining percentage of the battery is discharged.

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