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Development and Performance Evaluation of a Quadcopter

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ABSTRACT
The aim of this project is to develop and evaluate a prototype remotely controlled quadcopter with a battery of 850mAh using locally sourced material. The quadcopter was tested and a flight time of 100secs with extra payload of about 40g was achieved. In achieving this, a frame which is the major body of this project is designed and fabricated putting into consideration the weight, strength, and flexibility of the frame and landing skid that can accommodate shock generated while landing the aircraft. MATLAB software was used for few simulations of the Roll, Pitch and Yaw of the flight controller. The developed quadcopter was tested and it met the performance requirements it was designed for.The main problem in quadcopter is the balancing and stability system. Most of quadcopter will be unbalance and loose stability in case there are direct disturbance on it such as wind. In this project design, a stable design with light-weighted frame but high strength to weight ratio was designed and constructed.Material selection for this drone (project) was thoroughly be analyzed to achieve a more stable system.
Keywords: Prototype, quadcopter, performance, locally, designed, constructed, aircraft, develop, fabricated, drone, MATLAB.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAV) are unmanned flying aircrafts, commonly known as drone, multicopters or multirotors. They are different from the commercial aircrafts and jets in way that it does not have onboard pilot. Generally, the pilot in a UAV controls the motion from the ground through a transmitter to take care of the stability and trajectory motion of the drone. Applications are often focused on the military areas, cinematography, surveillance, inspection of transmission lines and power distribution; low cost filming and panoramic picturing for the movie industry, sport events, crop and herd monitoring, among others. There are different types of copters ranging from dualcopter, tricopter, quadcopter, hexacopter and octacopter. With regards to this project, quadcopter is the essential one.

The quadcopter is a popular drone because of its unique properties.The major advantage of the quadcopter is its ability to hover, and its Vertical Take Off and Landing (VTOL) capabilities. This allows the quadcopter to be operated in nearly any environment.

A conventional helicopter with one main rotor and one tail rotor possesses many of the same properties as quadcopter. However, the quadcopter has no moving parts except for the rotating motors and propellers, while the conventional helicopter requires a complex hub to make it possible to rotate the motor axis to induce a translating motion. The quadcopter is also less prone to vibrations and it is more flexible when it comes to the placement of the center of gravity. Due to smaller size of rotors, they can be more easily covered, making it safer to fly indoors.

The typical quadcopter design has no moving parts except for the propellers. The motors and their propellers are mounted to the frame and the only way to induce a lateral motion is to tilt the entire frame. Unlike a conventional helicopter, the quadcopter does not have a tail rotor to control the yaw motion. The quadcopter has four motors where two spins clockwise and two spins counterclockwise. If the pair of clockwise motors are spinning at a different rate than the pair of counterclockwise motors, it will create a moment about the yaw axis.

II. MATERIALS AND METHOD

Equipment and Materials

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The material selection is a fundamental requirement of drone fabrication because it determines the weight of components to be mounted on the drone and the motors and propellers. Below are the more common materials found in multi-rotors. Ideally the frame should be rigid with as minimal vibration transmission as possible and should be strong enough to carry the weight of the components mounted on it.

BAMBOO

Bamboo is a material with high compressive strength and low weight, which is one of the major requirements for drone frame consideration. Its main component is silici acid, which gives the shoot its durability and hardness. The tissues composition of guadua is 40%fiber, 51% parenchyma and 9% conductive tissue, which explains its astonishing strength and flexibility. It is locally sourced and requires less fabrication processes and cost which makes it inexpensive. Fabricating drone frame from bamboo requires existing local technology, it doesn't demand high-tech such as 3D printing and PCB frames. With proper treatment, bamboo can provide a service life of up to 50years. Easy to cut, handle, repair, reposition and maintain, without the need for sophisticated tools or equipment. Another advantage of bamboo is non-polluting and does not have crusts or parts that can be considered waste.

The following were the equipment required for the drone fabrication: Drone frames, Brush motors, propellers, propeller guard, control system {receivers and the transmitters}, 850mAh Lion battery, landing skid, camera.

III. PROCEDURE FOR DRONE ARM AND LANDING SKID PREPARATION

The drone arm and landing skid was made up ofbamboo due to its strength to weight ratio which can carry the motors and weight of the drone respectively. Below are the processes to get them fabricated.

Harvesting: The woody grass known as bamboo can grow just about anywhere. Depending on what species of bamboo is trying to sprout, it can grow only in sub-tropic areas.

Processing: The freshly harvested bamboo was cut into smaller pieces to be treated to prevent it from being affected by insect. After cutting into smaller pieces, a solution of boric acid was prepared as specified by a laboratory specialist, then the bamboo was dipped into it.

Dimensioning: The drone arm was dimensioned to 60mm X 10mm X 8mm with the aid of hacksaw. And also, the landing skid was dimensioned to 70mm X 10mm X 8mm and 20mm X 10mm X 8mm because the landing skid uses a U-configuration.

In designing the frame, the arms should be strong because when the drone falls, they are first to get damaged. The failure of the arms not preventing vibrations could lead to the damage of inner electronic components due to repeated vibrations. Brush motors are required for drone to fly. They are controlled by a gear system, and in turn, responsible for the rotation of propellers, thus enabling the drone to take off.The control used include the receivers and the transmitters. They are indispensable for assembling process. The signal distance varies depending on the design.The purpose of a control board was to stabilize the copter during flight. To do this, input from the gyroscopes (roll, pitch and yaw) were sent to the microcontroller.The battery was the source for powering the drone. A Lithium Polymer battery was used for this purpose. In frame design, the weight of the battery and a compartment where it was mounted was taken into consideration. The higher the voltage of the battery, the longer the flight time.Choosing a battery is highly dependent on the purpose for which the drone is made.The camera which was used to record videos and took pictures was placed in a position that was well protected but also exposed so that the camera would not get damaged if the drone should crash land.

Process in assembling a Drone

Step 1: Assembling the frame
Step 2: Mounting the power distribution board
Step 3: Mounting the motors
Step 4: Connecting the motors to the distribution board
Step 5: The first test
Step 6: Mounting the FPV camera
Step 7: Connecting the FPV camera
Step 8: Testing the FPV camera
Step 9: Mounting and powering the receiver
Step 10: Connecting the flight controller
Step 11: Completing the build
Step 12: Software configuration
Step 13: Final test

IV. RESULTS AND DISCUSSION

P GAIN

The P Gain (which stands for Proportional Gain) parameter basically controlled how the quadcopter prioritized pilot input versus input from the flight controller's onboard sensors.

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A high value of the P Gain parameter means that the readings from the sensors will be very important. A low value of the P Gain means that pilot input will be very important. When the P Gain was set too high, it was noticed that the quadcopter keeps oscillating or kind of twitching in the air. This effect was caused by the flight controller's frantic attempts to correct even the tiniest sensor discrepancies. When the P Gain was set too low, the craft was sluggish and slow to react to changes in orientation on control input. It was difficult to keep the quadcopter airborne when the P Gain was too low since the quadcopter was expectingthe pilot, to do most of the work needed to keep the craft stable, and unfortunately, our brains and our thumbs were just not quick enough to make the rapid adjustments needed to keep the craft in the air.

TUNING P GAIN

Starting with the values suggested by hobbyist online, the quadcopter was inputted with
PI editor setting for aileron and elevator values of
P gain: 50; P limit: 100; I gain: 30; I limit: 30. Also, a rudder value of P gain: 60; P limit: 50; I gain: 30; I limit: 10
It was discovered, by flight test experiment that the P gain setting was too high in which the SOSAJU Skyquad 1 undergo instability in which the quadcopter tends to drift to one side by pitching moment and oscillation of the quadcopter in flight is observed.
Therefore, from the understanding of the effect of P and I gain, the P gain for aileron and elevator was adjusted until the quadcopter get stabled at the values set in the table below.
Therefore, from the understanding of the effect of P and I gain, the P gain for aileron and elevator was adjusted until the quadcopter get stabled at the values set in the table below.

	Roll/Pitch	Yaw	Auto-level
P gain	15	70	40
P limit	0	20	70
I gain	80	5	Acc trim-pitch-20
I limit 20 10			

Table 4.1 Stable values for the PI setting on KK2.1 flight controller.

With this value, the quadcopter responded well to pilot control and self-level control.

I GAIN

The I Gain (which stands for Integral Gain) controlled how quickly the quadcopter responded to changes in angular orientation.In flight test, the quadcopter was being flown and then controlled to move upward (VTOL). In this process, the quadcopter was tilted forward. This forward tilt directs some of the quadcopter's lift backwards instead of all the lift being directed downwards, which makes the quadcopter move forward. When I released the stick, the quadcopter was returned to a level position. Neither the tilting forward nor the returning to a level position happened instantly though. It obviously took a little time for the quadcopter to actually move. The I Gain basically controlled how aggressively the quadcopter attempts to achieve the designated tilt. When the I Gain value was too low, the quadcopter was sluggish and slow to respond to control input. When the I Gain was too high, the quadcopter oscillated in the air as it fights to keep a perfect position.

TUNING I GAIN

It was noticed during the first flight test that the quadcopter did not stop and stabilize after moving the sticks and returning them to center. To

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counter this defect, I gain was increased by values of five until a quicker response time was obtained. At this point of tuning, it gets to a point where the quadcopter returned to a level position quickly and did not wander around in the air. The I Gain value was also useful when flying in a windy condition where it was more important for the quadcopter to correct its angular position and not get moved around by the wind or gust.

When the VTOL undergoes a strong perturbation, it may not be able to recover on its own the hover situation. (Creed, 2013). Also, the robustness of the obtained closed loop system has not been studied. The failure of an actuator, for example, is likely to deteriorate seriously the dynamic properties.

Plate 4.1 Fabricated drone

QUADROTOR MOTOR MODEL

The angular speed ω of each rotor is estimated to produce a vertical force and moment according to (Powers C, 2010).

$$F_i = k_F \omega^2 \quad (4.1)$$

$$M_i = k_M \omega^2 \quad (4.2)$$

Previous research has shown this representation can be improved by considering well documented theories for helicopter thrust.

D.C MOTOR AND PROPELLER SELECTION ANALYSIS

In Table 4.2 The multicopter motor was compared to other motors indicating the ideal and max rpm using the given motor rpm/v.Theoretically, the battery discharge rates specification given by the manufacturer was used to calculate the flight time at 50% discharge rate and at 100% discharge rate. Table 4.2 shows the result computed using Microsoft excel worksheet.

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S/N	Motor	Kv (rpm/v)	Max (rpm)	Ideal (rpm)
1	L2215J-900 Brush Motor (200W)	900	9990	2498
2	MT135 multi-copter motor 935kv	935	10379	2595
3	ADH300L Brush Outrunner 1100kv	1100	12210	3053
4	AX2308N 1100kv Brush Micro motor	1100	12210	3053
5	FC 28-22 Brush Outrunner 1200kv	1200	13320	3330
6	3020 Brush Outrunner Motor1200kv	1200	13320	3330
7	L2210C-1200 Brush Motor(150W)	1200	13320	3330

Table 4.2 D.C motor selection

From Table 4.2, it was clear that the APC slow flier prop 10×4.7 propeller was the best match to the given set of motors while considering the frame dimensions also. To be more specific, the 10×4.7 propeller has an ideal rpm that would support hovering for the given estimated mass of the aircraft; this is shown incalculation in equation 4.5 and the ideal rpm of the propeller closely matches the ideal rpm of the motors listed in the appendix. Table 4.3 shows the weight of the frame.

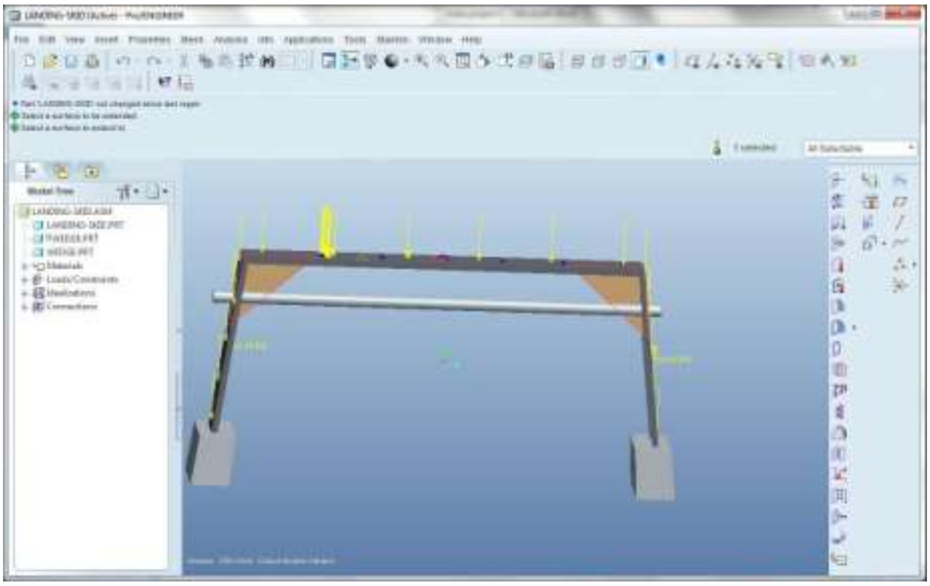

Figure 4.1 Mass properties Analysis on the landing Skid

This result shows the point at which the load is acted and a prescribed point of failure which occur majorly at the point of contact of the bolt to the frame.

JAVA FOIL ANALYSIS ON THE PROPELLER AIRFOIL

Using Javafoil to do analysis on the propeller airfoil the following were obtained.

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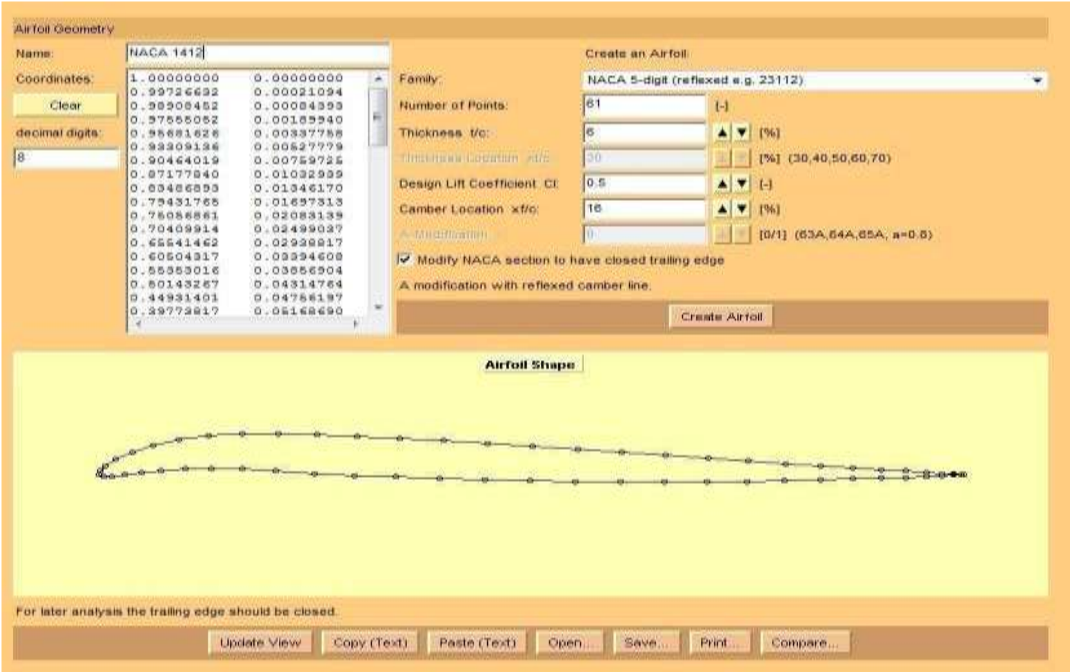

Figure 4.2 Airfoil Geometry

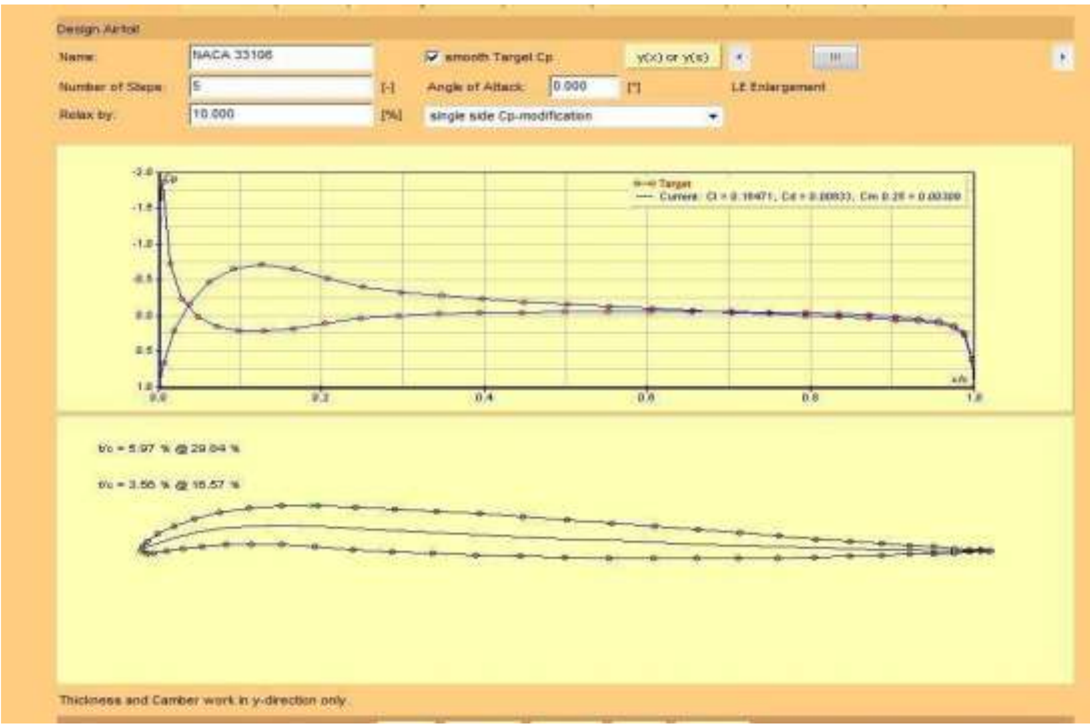

Figure 4.3 Airfoil design using Javafoil

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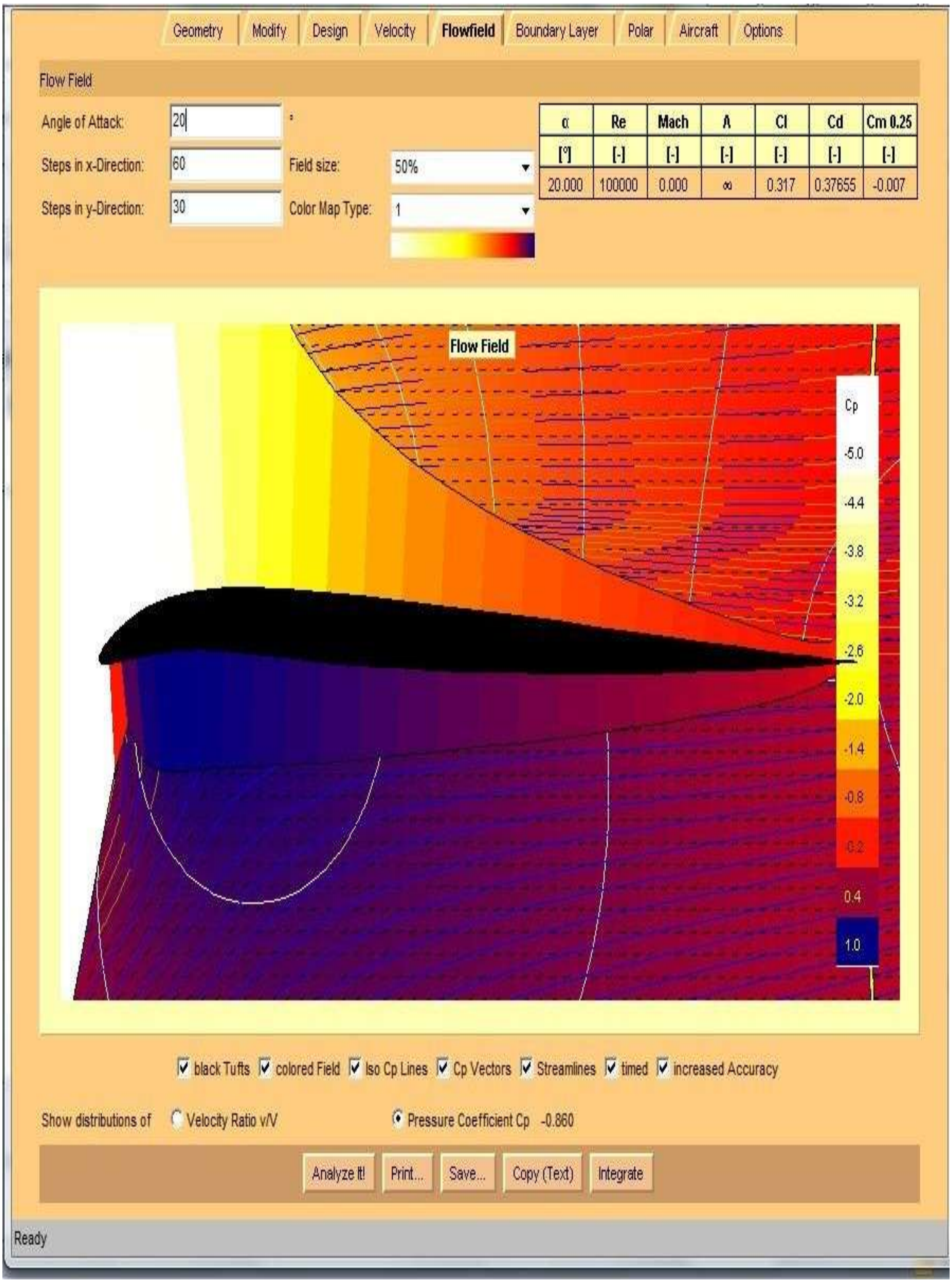

Figure 4.4 Airfoil flow Field showing the boundary layer and lift distribution on the airfoil

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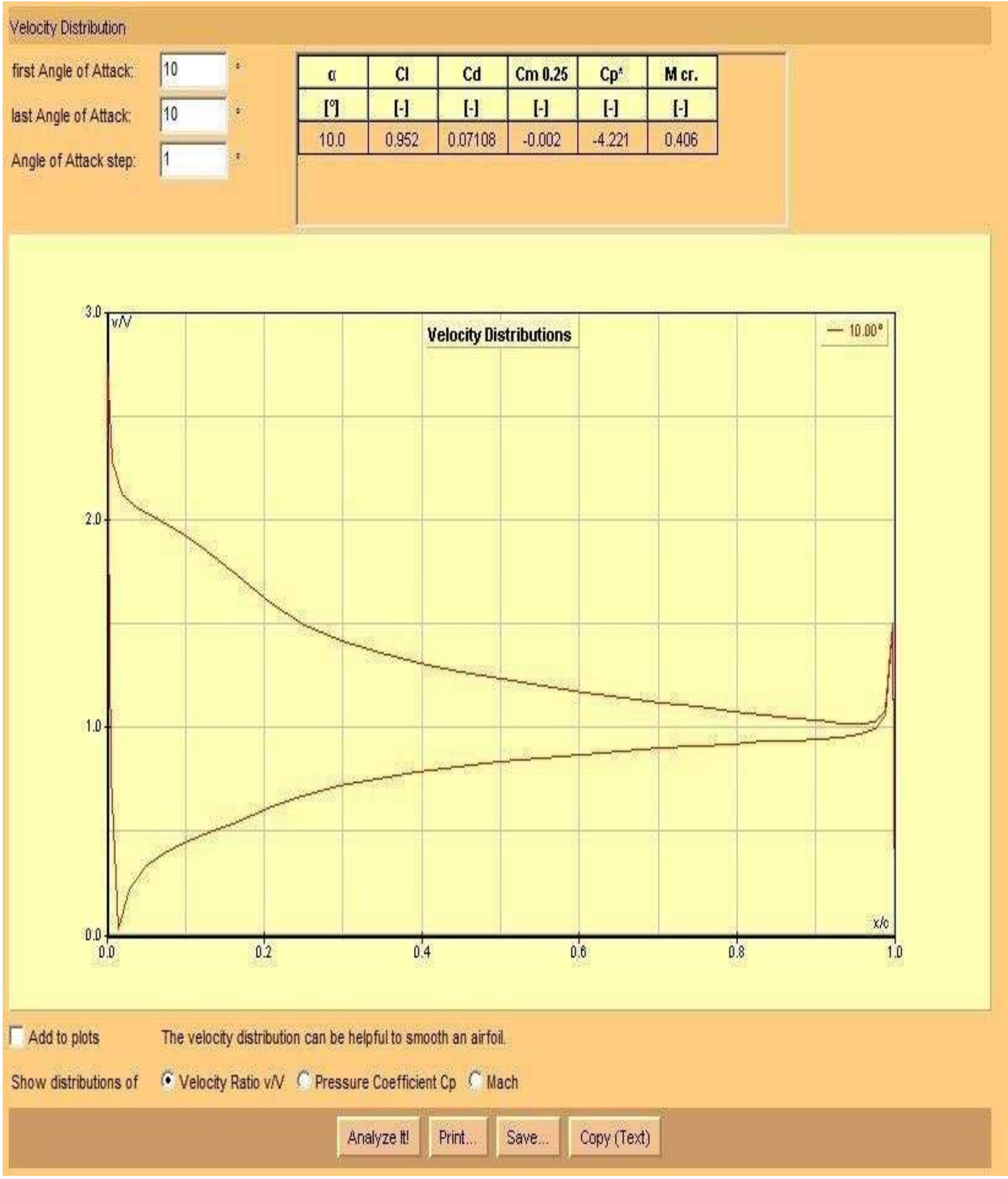

Figure 4.5 Airfoil velocity distribution

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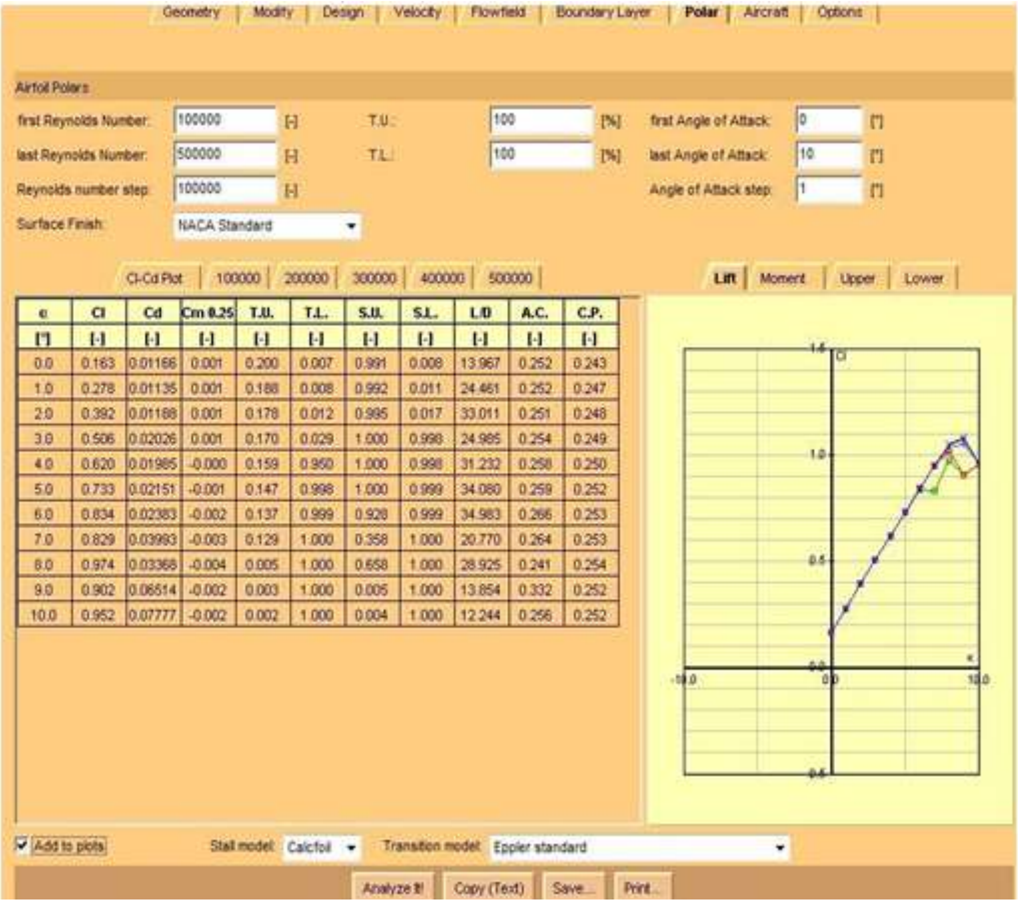

α	Cl	Cd	Cm 0.25	T.U.	T.L.	S.U.	S.L.	L/D	A.C.	C.P.
[°]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.0	0.163	0.01166	0.001	0.200	0.007	0.991	0.008	13.967	0.252	0.243
1.0	0.278	0.01135	0.001	0.188	0.008	0.992	0.011	24.461	0.252	0.247
2.0	0.392	0.01188	0.001	0.178	0.012	0.985	0.017	33.011	0.251	0.248
3.0	0.506	0.02026	0.001	0.170	0.029	1.000	0.998	24.985	0.254	0.249
4.0	0.620	0.01985	-0.000	0.159	0.950	1.000	0.998	31.232	0.258	0.250
5.0	0.733	0.02151	-0.001	0.147	0.998	1.000	0.999	34.080	0.259	0.252
6.0	0.834	0.02383	-0.002	0.137	0.999	0.928	0.999	34.983	0.266	0.253
7.0	0.829	0.03993	-0.003	0.129	1.000	0.358	1.000	20.770	0.264	0.253
8.0	0.974	0.03368	-0.004	0.005	1.000	0.658	1.000	28.925	0.241	0.254
9.0	0.902	0.06514	-0.002	0.003	1.000	0.005	1.000	13.854	0.332	0.252
10.0	0.952	0.07777	-0.002	0.002	1.000	0.004	1.000	12.244	0.256	0.252

Figure 4.6 NACA 1412 airfoil polar and lift graph

Application of Momentum and Pressure Integrals

Application of Momentum and Pressure Integrals Integration along circular path with R = 50.0 x-y system. the data are derived from Javafoil software.

Momentum + pressure = total (4.3)

| Fx | = | -0.2067 | + | -0.2067 | = | -0.4134 |
| Fy | = | 0.5679 | + | 0.5679 | = | 1.1359 |

Aerodynamic system (α = 20.0º)
| Cl | = 2.4175
| Cd | = 0.0000

For comparison: Integration over surface panels of coefficients of lift “Cl” and drag “Cd”
| Cl | = 2.4331
| Cd | = 0.0492

From the analysis obtained from the software, it indicated that the propeller was good enough to generate lift capable of lifting the quadcopter.

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FLIGHT TIME

Table 4.3: Flight time rate with respect to Battery discharge rate

Battery Discharge rates		
Capacity [mAh]	Flight Time 100% Discharge Rate [min]	Flight Time 50% Discharge Rate [min]
1000	1.5	3
1200	1.8	3.6
1400	2.1	4.2
1600	2.4	4.8
1800	2.7	5.4
2000	3	6
2200	3.3	6.6
2400	3.6	7.2
2600	3.9	7.8

FRAME EVALUATION

The frame was the basic part of the quadcopter that holds the other components in place. The structural properties of the frame determined the stability of the quadcopter. The fundamental parts of the frame are: center plate, drone arms and the landing skid.

Center Plate: The center plate contributed to the aerodynamic efficiency of the quadcopter, the weight, structural balance and stability has vital roles in making for healthy Pitch, Roll and Yaw.

Drone Arms: The length and shape of a drones' arms can significantly affect its flight characteristics. Without changing the size of propeller, having the propellers closer to the Center of the frame means that the quadcopter was able to quickly respond to commands, which increased the drone agility, but also makes it less stable. Having the propellers further from the center of the frame makes the quadcopter more stable and less agile. The propeller had to complete more revolutions to change the crafts orientation by X number of degrees then it would if the arms were shorter. This sacrifice of agility is given to smoothness of flight.

The quadcopter takes the "x configuration" to further maximize its opportunities over a "+ configured" quadcopter.

- Physics: The drone will feel different to the operator even with the same motors and software settings. In more detail, when you do the calculations for controlling a quadrotor, the distance away from the axis of rotation determines the torque generated by the motors. This means you can get about 41% more rotational acceleration from an "x" than a "+".
- Visibility of Yaw: A "+" will have one marked front arm. An "x" will have two. I think it was easier to establish front arc with two front lights/marks, rather than one. Due to the frame shape and accessories, frequently the operator could only see two of the four arms on a quadrotor. If you have one uniquely colored arm and can only see two arms, that leaves an ambiguity as to which direction the vehicle was facing. This was personal preference, but recovering situational awareness during flight was a very safety critical process.
- Camera Arc Clearance: An "x" could have a camera pointed forward without obstruction from the frame more easily than a "+".

Landing Skid: The taxiing of any aircraft at all is basically hinged on the Landing Skid (Landing Gear). The Landing Skid served as the reactional force against the Total upward force. The additional weight brings balance and stability during steady travel.

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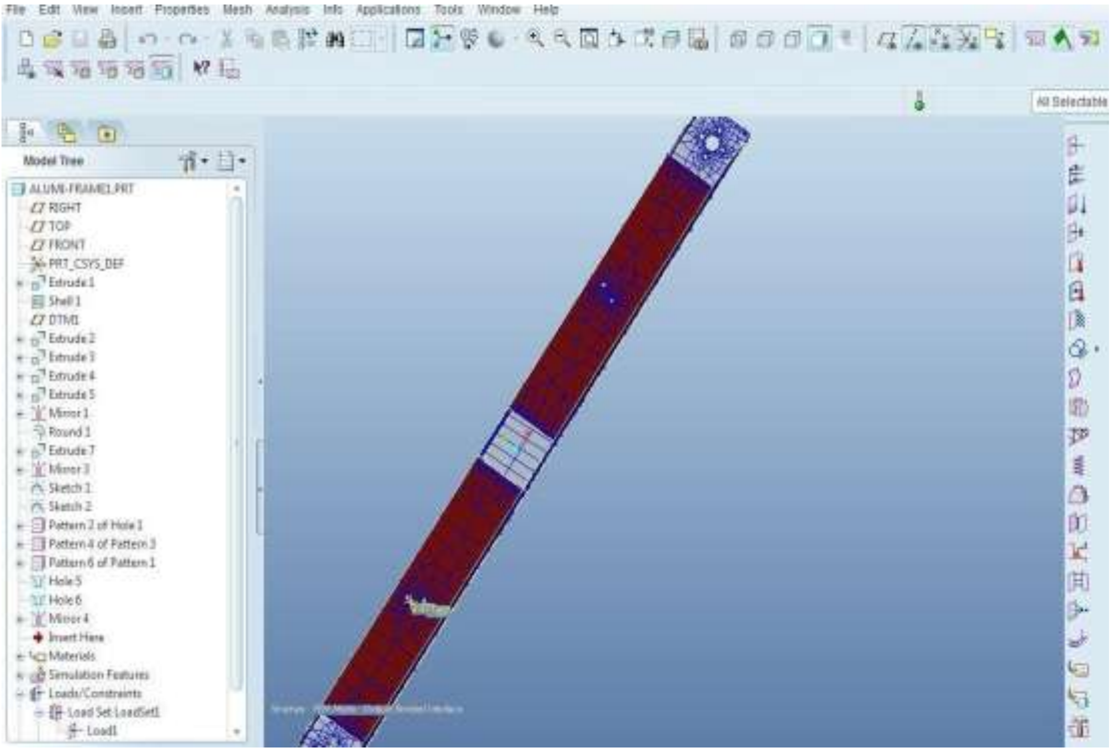

Plate 4.2 Frame Mesh analysis of FEA on Pro E

Component	Weight (g)	Quantity	Total Quantity
Drone Arm	4	4	16
Center Plate	15	1	15
Landing Skid rod	3	6	18
Total			49

Table 4.3: Weight of Frame

FRAME SELECTION

Total Thrust = 2(AUW) (4.4)

AUW = All Upward Weight (Weight of frame + weight of battery + weight of circuit + weight of arms) (4.5)

Weight of frame = 2 x 16g = 32g
Weight of battery = 60g
Weight of arms = 4 x 4g = 16g
AUW = (32 + 60 + 25 + 16)g
AUW = 133g.
Total Thrust = 2(133)g
Total Thrust = 266g.

For a 935Kv battery

Rpm = 935 x 7.4
= 6919rpm
= 115.32rps.

Work-Energy Theorem

$1/2mv^2 = F \times S$ (4.6)

$V = (2Hg)^{1/2}$ (4.7)

H = Height travelled by the quadcopter (20m)

$V = (2 \times 20 \times 9.81)^{1/2}$

V = 18.79m/s.

= ½ x 0.185 x 18.79
= 32.7J.

F x S = 32.7J.
F = 32.7/20
F = 1.64N.

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BATTERY SELECTION

Total motor current = Number of motors x motor current (4.8)

= 4 motors x 400mAmps

= 1.6 Amps.

Hence we have selected the 850mAh, 7.4v, li-po battery.

WEIGHT ANALYSIS

The overall estimated weight was 165g but after material selection and components assembly the overall weight output was 280g, which was a far cry from the estimated quadcopter weight. The obscene weight difference in weight made affected the aerodynamics of the VTOL in that the motors could not gathered enough thrust to lift the VTOL.

S/N	COMPONENTS	QUANTITY	Total Weight (g)
1	Frame	2	23
2	Battery	1	80
3	Motors	4	16
4	Propellers	4	6
5	Landing Skid	1	9.5
6	Power Distribution Board	1	17.5
`7	Connectors		3
8	Camera and gimbal	1	10
	Total		165

Table 4.4: Weight Analysis

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

The Vertical Take Off and Landing aircraft, quadcopter can now take off and reach a steady state at height, but occasionally small corrections are still needed to keep the quadcopter in one spot. Better settings of controller, for example with using another method for finding the controller actions or use a better control method it may help for a better stabilization. SOSAJU Skysquad 1 has the ability to fly for at least 100seconds and carry a payload of about 40g. Also, the design and construction of a lightweight, yet sturdy quadrotor that could take crashes with less damage with the help of customable suitable landing gears was achieved with frame load of 165g including skid. Also, the wind effect, therefore it is needed to be included this is defective into the overall stabilization. Analysis and selection of suitable material was undergone using Pro Engineer Computer Aided Design software and basic conceptual reasoning and weight determination for the design and development of the quadcopter i.e. power supply, motor, and FCB power rating, which also includes bending moment, torsional moment analysis of the forces acting on the quadcopter frame and determination of power plant to provide optimum thrust for the quadcopter i.e. the electric motors.

Recommendations

To enable telemetry, a mobile phone with camera can be used for the quadcopter aerial imaging by sending video signal to a ground station. This is a cheap method of feeding visual information to the ground station although it firmly depends on the strength of wireless service in the environment, weight of the device and functionality of the device in use.

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