Construction and Testing of a Quadcopter

A senior project presented to the Aerospace Engineering Department

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by

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This project looks at the construction and testing of a quadcopter capable of carrying a 500 gram payload for approximately 11 minutes. The results of the testing proved that it would be capable of completing its mission and tested a variety of other functions.

I. Nomenclature

C = Capacity
L = Load in grams
t = time
V = Voltage

II. Design Requirements

The payload for the system defines many of the requirements necessary to design and select parts. For this system the payload is a 500g weight that will be suspended below the UAS during flight. Once the payload is determined the overall size of the system can be determined. The frame can be selected and purchased or built that will be capable of carrying and distributing any loads caused by the payload while supporting the motors and other systems.

There are multiple options for control, many RF remotes are capable of sending the necessary signals to drive a set of four motors from the receiver that is mounted on the UAS, however this does not provide any built in stability to the system. By adding an off the shelf control system or developing one using accelerometers and magnetometers the system can stabilize itself during flight; this is critical in a multi-rotor vehicle.

Total weight of the non-propulsive systems drives the size of the motors and propellers necessary to lift and fly the system. Using information from the propulsion system a battery can be selected that will provide the proper discharge rate for the motors at full throttle. The total power the battery must be capable of supplying the system for sustained flight can also be determined.

III. Part Selection

To reduce the weight of the system a carbon fiber frame, the Turnigy Talon quadcopter frame, was selected that provided the necessary size and strength to carry the payload. It provides motor mounts and convenient wire management. Since the system is not designed for major acrobatic maneuvers the chances of the system crashing and thus breaking are significantly reduced allowing for the lighter carbon fiber frame instead of a traditional aluminum which provides better impact resistance.

An ArduPilotMega 2.5 was selected as the control board for the system. It includes an electronic barometer provides pressure readings to accurately calculate altitude. This combines with the onboard accelerometer and magnetometer to provide an accurate heading, altitude, and speed which the board uses to adjust the motors speeds to obtain stability. The board also allows for the signal to be read off of it using a usb connection this is vital for the analysis of the controller.

Table 1 shows the weight of all the non-propulsive components of the UAS, based on this table of weights motors and propellers were selected to provide the necessary thrust, these parts and there weights are also listed in the table. Based on the total weight of the system, a minimum thrust for stable flight can be determined. This led to the selection of the Turnigy 2836/9 motor which with an 10 inch propeller at full speed provides 850g of thrust, this value was provided from the manufacturer. After selecting the motor and propeller, the 25Amp Turnigy ESC was selected to properly manage the signals going into the motor. It was important to select an ESC with a high enough amp rating that it would be able to handle any surges in the system if the motor required more power to do a specific operation.

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Selection of a battery is the next step in the process, and is most influenced by the discharge rate required by the system and the flight time desired. These two characteristics define the requirements for the selection of the battery. Using equation 1 flight time can be

calculated based on an estimated system efficiency and an estimated load of the system as a whole during flight. The load is calculated using a relationship between necessary thrust and amps used by the motor.

$$t = \frac{C}{Load} \tag{1}$$

Where t is in hours, C is the capacity of the battery in mAh, and Load is the estimated power load of the motors. By backing out the energy storage in the battery in mAh and selecting a discharge rate that meets the maximum rate the system may require a battery can be selected. A 5600 mAh 60C LiPoly battery meets the requirements necessary for a steady level flight time. Although this battery is heavier than many smaller less energy dense batteries, it allows for a much longer flight time even with its added weight.

Part		Weight (g)
Frame	Talon V2.0	280
Flight board	Ardupilot	17
Battery	Turnigy Nano 5600mAh	442
Motors	Turnigy 2836/9	70
E. Speed Controller	Turnigy Plush 25amp	22
Rotors	Maxx 10x4.5	70

Table 1: Part List

IV. Assembly

The first step in the assembly process is to do a complete test of each individual component. Power can be provided by the selected LiPo battery, or a DC power supply can be set up to provide power to the system. A power supply provides many advantages over the battery since it can provide a constant stream of power without requiring large recharge times but it does require wiring and must stay on the ground do to its weight. Each individual motor was tested in combination with an ESC, during the testing the ESC was connected directly to the wireless receiver's throttle signal allowing the motor to be spun up using the radio controller. Connecting the ESC and motor at this stage was completed by alligator clips to ensure that a defective part can easily be swapped out for a good one. All of the parts were functioning properly after the test which allowed the assembly process to continue. Setting the motors direction of rotation is done by switching two of the signal wires from the ESC to the motor. Determining which connections cause counter-clockwise rotation and clockwise rotation is a key aspect in the assembly phase; the motors must be mounted in such a way that the rotation of the propellers is opposite the one next to it. Once this was determined the connections were soldered and heat shrink was applied to ensure that he connections were strong and would not come undone during flight. After being soldered each component was tested again to ensure a strong connection was made.

Testing the control system is a vital part of the assembly process, ensuring that when the system is fully assembled it will work properly. The APM 2.5 connects through a usb connection, which is able to power the control board, is capable of links to a computer to program the board with the proper software. Mission planner is an open source program which allows a user to view the RC controllers input to the system, setting the proper ranges and calibrating the inputs to the controller. The software also uploads the proper software for the UAS's configuration, which is user selected. Through the mission planner the APM's built in accelerometer and magnetometer can be calibrated for first flight. While testing the RC transmitters signal for each input the APM is able to set the maximum and minimum input levels for control, this allows for more precise operation during flight. Once the testing of the motors and control system was complete a complete test of the system was performed. A range test was performed after the system was assembled ensuring that the quadcopter would receive a signal from a distance.

V. Testing

To provide a safe testing environment and to reduce the risk of damaging the quadcopter during flight a test bed that restricted the motion of the quadcopter to vertical flight was constructed. Using PVC and metal guide wires a box approximately 5'x 4'x5' was constructed, the sketch can be seen in Figure 1, and the frame of the quadcopter was modified so it could be attached to the guide wires. By doing this it allows the testing of the quadcopter to be completed safely within a building and allows for the environment during testing to be controlled.

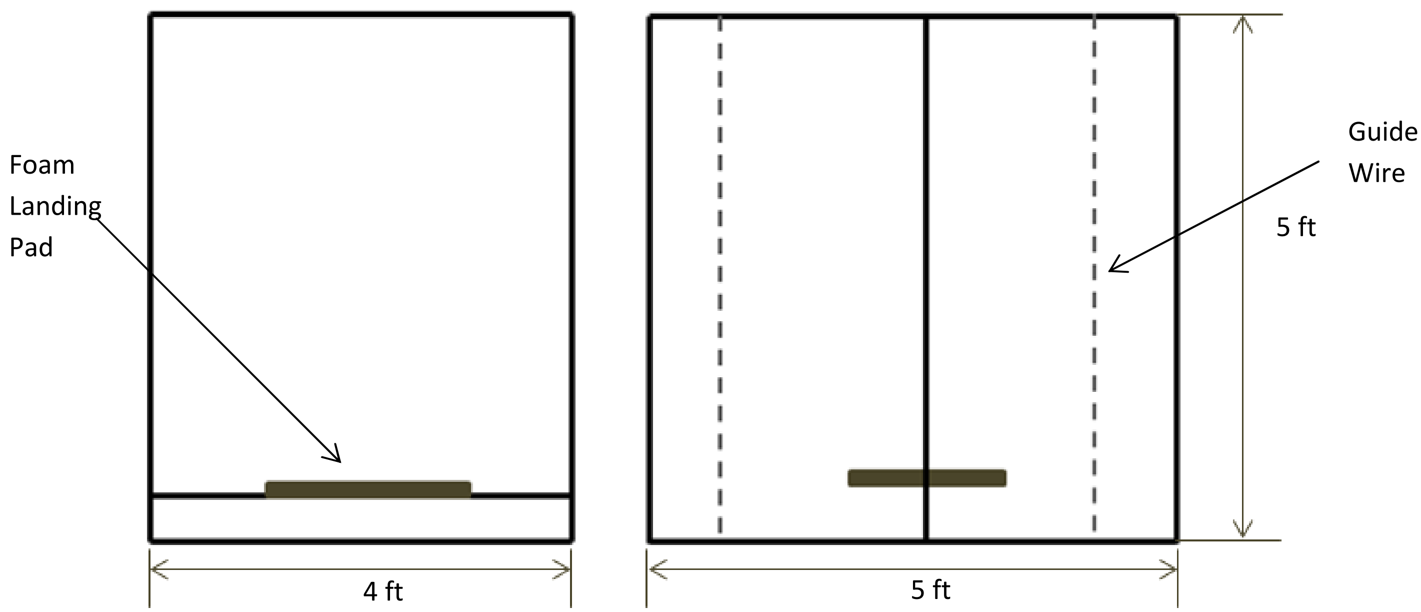

Figure 1: Vertical Constraint

Two testing methods were used to determine the flight time of the quadcopter with multiple loads. The first was a fixed test, the quadcopter was securely attached to the framed and a coiled wire was attached between the battery and the power distribution. When coiling the wire it was folded in half before being spun to prevent any magnetic interference from being created during the test. The coil was previously attached to a circuit with a known resistance and a fixed voltage was applied, by doing this the ratio of current to the voltage drop measured across the wire could be determined. With this information the power consumed by any circuit can be determined. Table 2 shows the results from this test. Using equation 2 the duration of the flight can be determined. Equation 2 uses the ratio determined by the test on the known circuit.

$$t = \frac{Battery\ Capacity}{\left(\frac{V}{Voltage\ Ratio}\right)} \quad (2)$$

Where the battery capacity is the measured in mili amps, and V is the voltage drop measured across the wire.

Throttle	Measured voltage (mV)	Voltage Ratio (mV/A)	Amps	Duration (hrs)	Duration (min)	Fixed Test (min)
Ambient	3.9	9.765	0.40	14.02	841.29	NA
Minimum to turn prop	38	9.765	3.89	1.44	86.34	NA
One-half	160	9.765	16.39	0.34	20.51	19.58
Full	420	9.765	43.01	0.13	7.81	7.9

Table 2: Fixed Throttle Duration Test

To confirm these time estimates, the quadcopter was run at half throttle and full throttle while fixed to the frame until the battery was fully drained. The results were within 5% of the estimated duration confirming that the test was an accurate measurement of the flight duration.

The next test was actual flight time with loads ranging from 0 grams to 480 grams. AA batteries were used as the load, the batteries weigh 24 grams each and are easy to attach over the entire vehicle to distribute the load. The tests were conducted in both the constrained space and freely outdoors. The results of the constrained test are shown in Table 3. These results were verified by flying the quadcopter unconstrained with a weight of 96 grams and 480 grams to check performance differences at the two extremes and to determine the effects of the quadcopter being constrained during testing. During the test the quadcopter was flown at approximately five feet off the ground and the control board was set to stabilize flight.

Load (grams)	Duration (min)
0	17.85
96	14.87
192	13.33
288	12.80
384	11.96
480	11.45

Table 3: Fixed Vertical Flight Test Results

A plot of this information provides a relationship between the load and the flight time and can be seen in Figure 2. From this figure a linear relationship can be found between the load and the duration of flight which is shown in Equation 3.

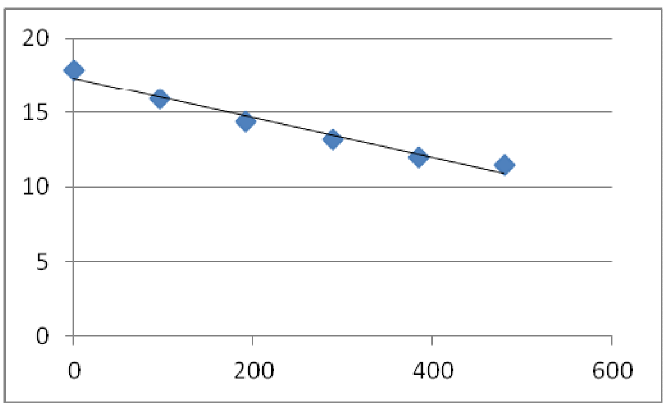

Figure 2: Results of Vertically Constrained Test

$$t = 0.0134(L) + 17.314 \qquad (3)$$

Where t is the duration of flight and L is the load in grams.

A maximum speed test was also conducted, to do this the quadcopter was taken out to a large field and flown at max throttle straight up and then brought back down to the ground. The APM 2.5 recorded flight data which could then be viewed using the mission planner application. During the flight test the quadcopter reached a max speed of 39 mph with no load.

The final test conducted was an unbalanced load test, to conduct the test a load was placed under an individual motor. This test was conducted to determine the effects of an unbalanced load on the duration of flight the quadcopter could achieve. The results of this test are shown in Table 4.

Load (grams)	Duration (min)
96	13.47
192	12.15
288	11.65

Table 4: Unbalanced Load Results

The test was only done with three weight increments, this is because at the 288 gram load the quadcopter began behaving abnormally during flight and the risk of damage at a higher weight was deemed too great. The quadcopter was able, until the 288 gram load, to easily adjust its power between the motors to achieve level flight.

VI. Conclusion

The results of the testing of the quadcopter clearly showed that it would be capable of completing a mission with a 500 gram payload. During the testing however strains caused by the vertical constraining system caused cracks to form in the motor mounts, these cracks eventually led to one of the motors coming unattached during a test due to vibration. The issue can be easily fixed by replacing the motor mount, and changing the vertical constraint system to rely on another attachment point which will transfer the stress more evenly between the structure of the quadcopter and the vertical constraint system. Testing on the quadcopter proved that the vertical constraint system with some modification would easily allow for a fixed safe testing environment for the quadcopter with a variety of payloads.