Turbo-Multirotor Drone

By

Ignacio Aguirre Panadero

Bree Peng

Leo Yamamae

Project Proposal for ECE 445, Senior Design, Spring 2016

TA: Luke Wendt

10 March 2016

Project No. 14

Contents

1 Introduction

Drones are becoming very common today in many industries. For example Amazon is starting a project to use drones for delivery [1]. However, propellers on multirotors easily break when it comes into contact with anything hard. It tears skin when it hits flesh. Current implementations have a fairly high risk of having foreign objects caught in the propellers spin. Our project aims to make drones safer to handle. Instead of using propellers, our project will use a centrifugal fan for thrust.

1.1 Objectives

- Design a drone that flies without propellers
- Design a more robust drone than ones on the market
- Design a safer drone

1.2 Functions and Features

- Flies like a commercial drone
- Interpret sensor data and determine stability
- Safety feature that will safely bring back drone when signal is lost
- Lightweight and portable
- Balanced design for stability
- Long flight time
- State feedback control
- Long signal range
- Low power, high thrust

2 Design

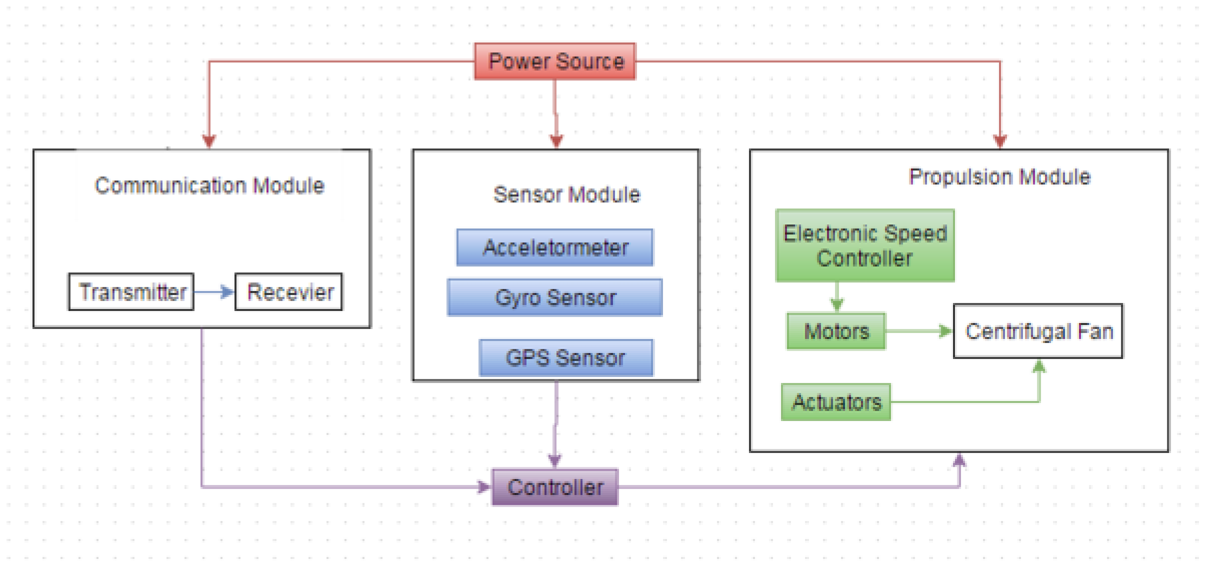

Figure 1: Block Diagram with the modules

2.1 Block Descriptions

2.1.1 Power Supply

This will properly distribute power for all components in the system diagram. Lithium Polymer Batteries will be used for the advantageous Power/Weight Ratio. Since the power supply will distribute power to the machine, the voltage and current regulators must be able to simultaneously handle the current draw of every module at maximum output. The estimated requisite battery will have to meet this demand as well, and as such a high current discharge lithium polymer battery will be selected.

2.1.2 Transmitter

The transmitter will allow the operator to control the machine at a distance by transmitting signals (Pulse Position Modulation) to the receiver on the machine. This will use the XBEE system or an alternative running on the 2.4GHz spectrum. Receiver: The receiver is the component that will receive the signals transmitted by the transmitter and send the data to the microcontroller. It will need to be able to handle a minimum of 4 separate channels of data.

2.1.3 Electronic Speed Controller

The electronic speed controllers (ESC) are the components that are calibrated to a range of PWM (Pulse Width Modulation) or PPM (Pulse Position Modulation) signals, and uses these to determine the speed at which they should be driving the motors. Each must have current-handling capabilities that include a safety factor in order to properly drive each motor on the drone without jeopardizing the integrity of the overall control system.

2.1.4 Motors

The motors are the elements that will allow the machine to move. Large brushless outrunner motors with a kV rating of greater than 2000. kV rating is the RPM generated per volt applied to the motor. Therefore, if we apply 11.1V to a 2000kV motor, the motor will be spinning at 23k RPM. Brushless motors are chosen due to less light weight, lower operating costs, lower friction, higher efficiency, and high power they provide.

2.1.5 Controller

The controller is the brain of the machine. This takes in input signals from the receiver and sensor data from the gyro sensor and the Accelerometer. Then the controller outputs PWM or PPM (Pulse Width Modulation or Pulse Position Modulation) signals to the electronic speed controllers.

2.1.6 Gyro sensor

This sensor measures the axes of tilt of the drone, which are its yaw, pitch, and roll. This data is sent to the controller in order to stabilize the drones motion. The sensor will automatically to be calibrated when turned on, though the gain response will be calibrated on a per-drone basis.

2.1.7 GPS Sensor

The GPS tracks the drones coordinates in order to aid with stabilizing its position in 3D space as well as allowing the drone to path its way to the location it was launched at in case of a signal loss or other radio signal malfunction as a failsafe.

2.1.8 Accelerometer

This sensor measures the acceleration forces upon the drone. The data from the sensor will be used along with the gyro sensor and the GPS unit to stabilize the drone.

2.1.9 Actuator

The actuator is the component that is used to angle the centrifugal fans in order to yaw the drone. This is most-likely be a brushless or coreless servo motor due to its power to weight ratio requisites.

2.1.10 Centrifugal Fan

The centrifugal fan is the key component in the project. The centrifugal fan give the project its uniqueness. This and the use of the servo creates an alternative propulsion method for drones of this size. The centrifugal fan is similar to an automotive intake compressor found in cars equipped with turbines or belt-driven compressors. It has a circular hole on its large face which takes in air and then a spinning circular blade compresses the air and pushes it out the nozzle on the side of the round housing.

2.2 Dynamics and Sketch

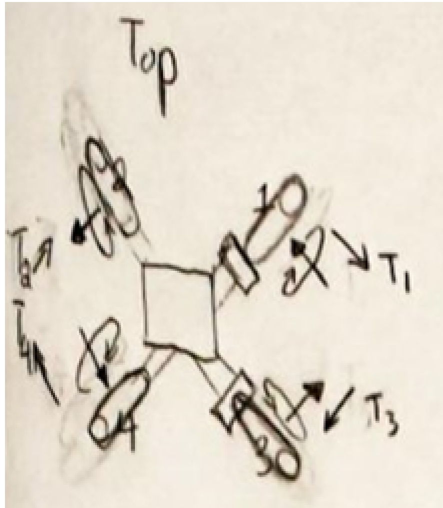

Figure 2: Top view

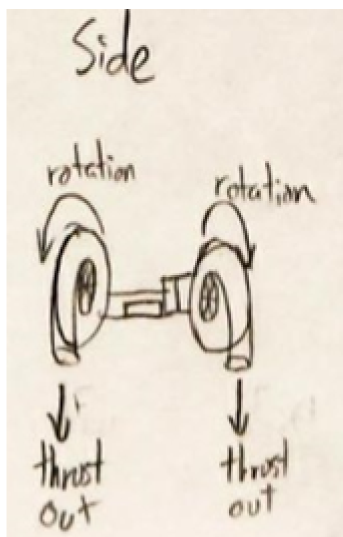

Figure 3: Side view

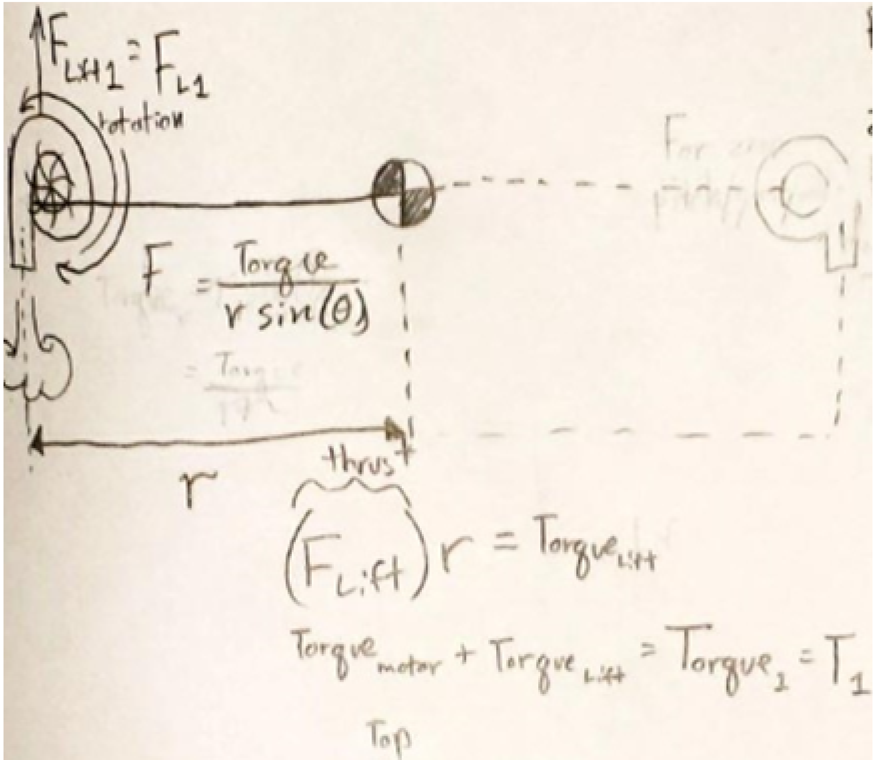

Figure 4: Torque Produced by a force

Force and Torque from Motor

$$T_{lift} = F_{lift} * R \tag{1}$$

$$T_1 = T_{lift} + T_{motor} \tag{2}$$

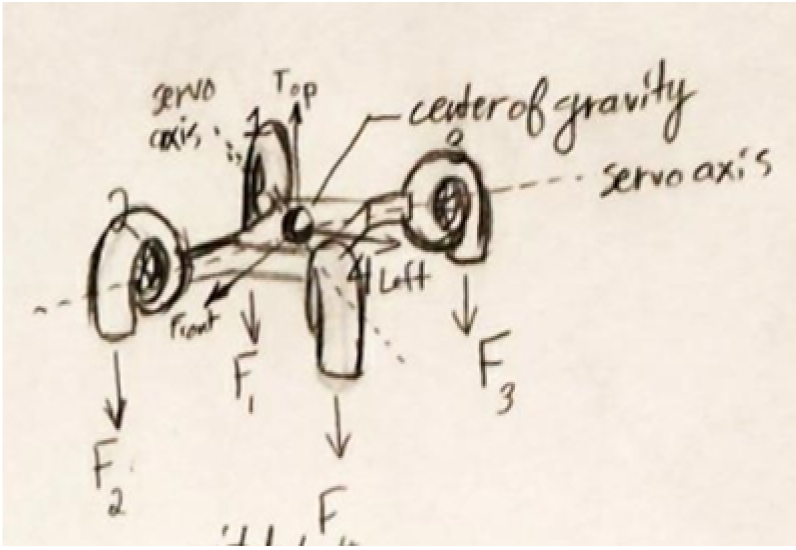

Figure 5: Isometric View: Pitch and Roll

Zero pitch, roll, and yaw:

$$T_1 = T_4 \tag{3}$$

$$T_2 = T_3 \tag{4}$$

$$F_{l1} + F_{l2} + F_{l3} + F_{l4} - mg = ma \tag{5}$$

Pitch Forward:

$$T_1 + T_3 > T_2 + T_4 \tag{6}$$

Pitch Rearward:

$$T_1 + T_3 < T_2 + T_4 \tag{7}$$

Roll Left:

$$T_1 + T_2 > T_3 + T_4 \tag{8}$$

Roll Right:

$$T_1 + T_2 < T_3 + T_4 \tag{9}$$

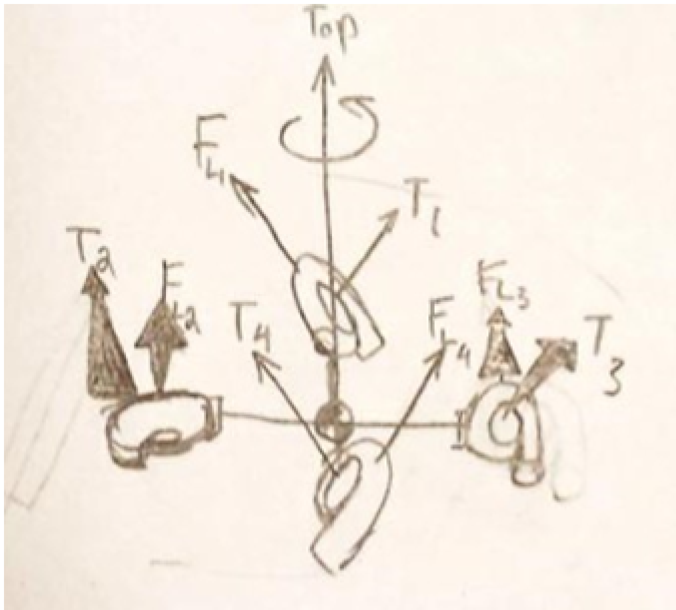

Figure 6: Isometric View: Yaw

Level: Yaw Right/Left

$$T_1 + T_1 + T_3 + T_4 \neq 0 \tag{10}$$

$$T_1 = T_2 = T_3 = T_4 \tag{11}$$

$$F_{lift} = F cos\theta \tag{12}$$

(Where θ is the angle between F and the vertical axis)

To maintain height

$$4F_{lift} = mg \tag{13}$$

3 Cost and Schedule

3.1 Labor

Table 1: Labor Cost

Name	Hourly Rate	Time invested (hr)	Total = Hourly Rate x 2.5 X Time Invested
Leo	$20	250	$12,500
Bree	$20	250	$12,500
Ignacio	$20	250	$12,500
Total		750	$37,500

3.2 Parts

Table 2: Parts Costs

Part	Manufacturer	Model	Quantity	Cost/unit ($)
Brushless Motor	NTM	NTM Prop Drive 28-36	4	30
Battery	Turnigy	nano-tech 3S	1	20
Microcontroller	Arudino	Due	1	45
Gyro + Accelerometer	Adafruit	Breakout Board	1	25
Transceiver	Spektrum	Dx6i/AR600	1	120
Actuator	HXT	12kg Metal Gear Servo	4	12
ESC	Hobby King	Hobby King 50A ESC	4	20
Chassis Frame	Hobby King	Color	1	15
Total				$ 573

3.3 Schedule

Table 3: Schedule

Week	Task	Responsibility
9-Feb	1. Finalize Proposal 2. Study dynamics of drone 3. Prepare mock design review	1. Leo and Bree 2. Bree and Ignacio 3. Everybody
15-Feb	2. CAD Centrifugal fan 3. Design ESC 4. Prepare design review	2. Ignacio and Leo 3. Everybody 4. Everybody
22-Feb	3. Purchase microcontroller 4. Purchase sensors and test 5. Purchases motors and test 6. Purchase centrifugal fan materials and prototype 7. Finalize Design Review	3. Leo 4. Bree 5. Ignacio 6. Leo 7. Everybody
29-Feb	4. Assemble Control Mechanism 5. Reiterate centrifugal design 6. Assembly prototype propulsion mechanism 7. Assemble acutuation and Chassis	4. Leo 5. Leo 6. Ignacio 7. Bree
7-Mar	5. Prepare mock demo 6. Finalize PCB Design 7. Run more tests on control 8. polish centrifugal fan design	5. Everybody 6. Everybody 7. Leo 8. Leo
14-Mar	6. Finalize mock demo 7. Polish drone design 8. Run final test on drone capability 9. Prepare individual progress report	6. Everybody 7. Bree and Ignacio 8. Leo 9. Everybody
4-Apr	7. Fix any remaining issues 8. Prepare presentation 9. Prepare demonstration	7. Leo 8. Bree 9. Ignacio

Continued on next page

Table 3 – continued from previous page

Week	Task	Responsibility
11-Apr	**8. Prepare Final paper** **9. Finalize presentation** **10. Finalize demonstration**	**8. Everybody** **9. Bree** **10. Ignacio**
2-May	**9. Finalize Final paper** **10. Lab checkout**	**9. Everybody** **10. Leo**

4 Tolerance Analysis

4.1 Centrifugal Fan Performance Tolerances

For this project, the one engineering sub-system that most affects the performance of the project is a piece of the propulsion module. The unique method of propulsion sets this project apart from the other projects and is therefore a key component. For the success of this sub-system, the combination of the centrifugal fans must be able to produce double the weight of the drone. This means that each individual centrifugal fan must be able to produce 500g max thrust when supplied with 12.6+/-0.25V. The thrust total of double the weight or 2kg is important for the purposes of providing upward lift, and as an operating safety margin in the case of reduced power. The method to test this tolerance is to have a voltage supply at 12.85V and connect it to our centrifugal fan module. Using the thrust measuring apparatus, we can able to measure the thrust from the centrifugal fan module supplied with this voltage. Repeating the measurement with the voltage source reduced to 12.35V. If the output of each fan at all tests measures at least 500g of thrust, we can verify that the sub-system is meets the tolerances.

4.2 Electronic Speed Controller Tolerances

The Electronic speed controller as this is the component that determines the RPM of the motor that is spinning the centrifugal fan. This means that the ESC must be able to handle at least 50+/-2.5A. If the ESC cannot handle the current draw of the motors, the electronics are very likely to overheat causing a loss of power best and at worst, cause a fire. To test this, we will connect the ESC to a motor which draws 52.5A and monitor the ESC for failure or overheat over 10 minutes. Then we will repeat the test with 49.5A and confirm if the device operates as intended. If it passes both tests, we can conclude that the crucial subsystem is up to tolerance.

5 Ethical / Legal Considerations

5.1 IEEE Code of Ethics Considerations

Since this drone will be airborne, this will involve the first code of the IEEE Code of Ethics where we must consider the decisions that we make which will involve the safety, health, and welfare of the public [2]. This is because even if the drone is safer than those that uses propellers, it may still fall from the sky and cause injury or property damage, cause injury or property damage from flight motions, catch fire if overheated, or catch fire if the battery is punctured. This is a concern that regarding the clause 9 in the IEEE code of ethics to avoid injuring others, their property, reputation, or employment by false or malicious action. Because since the drone will be capable of carrying and delivering a payload, we must deter its usage for malicious intent through its specifications.

5.2 Legal Obligations

A legal consideration that we must consider is the FAA regulations on Model Aircraft Operations. The FAA recently released the guidelines on flying for hobby or recreation, which restricts recreational model flight to below 400 feet, away from other people or stadiums, et cetera. The regulation that most applies to this drone states that one may not fly within 5 miles of an airport without clearance from the airport and control tower before flying [3]. This applies to our drone because the University of Illinois at Urbana-Champaign is within the 5-mile radius of the University of Illinois Urbana-Champaign Willard Airport. This means that before any testing is being done on the drone, we must contact the control tower at the Willard Airport for clearance. In addition, the University of Illinois has also placed regulations and restrictions on drone use on campus.

6 References

1. **Amazon.com, "Amazon Price Air",2016.[Online]. Available: http://www.amazon.com/b?node=803772O 03-Feb-2016].**

2. **Ieee.org,"IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/ 8.html. [Accessed: 05- Feb- 2016].**

3. **Faa.gov,"Model Aircraft Operations",2016.[Online]. Available: https://www.faa.gov/uas/model aircraft /. [Accessed: 05- Feb- 2016].**

Appendix A Requirement and Verification Table

Table 4: System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Power Supply (a) Capable of handling 620A burst oputput (b) Supply 12.6V ± 0.25V when fully charged (c) Supply 117A± 0.25 A when fully charged	**1. Power Supply** (a) Record amperage and heat telemetry from all outputs when running all systems at 100% with standard current probes. Repeat 10 times and check that heat of system does not rise above 55 degrees Celsius. (b) Measure voltage difference across power source using a Digital multimeter placed in parallel with the power supply. voltage should read 12.6V ± 0.25V (c) Measure current difference across power source and maximum load using a Digital multimeter placed in series with the power source and load that would draw 117A. The current should read 117A ± 0.25A while maintaining the first tests temperature goals.	
2. Transceiver (a) Capable range of 5+/-0.25 miles	**2. Transceiver** (a) Turn on transmitter from a distance of 5 miles and attempt to fly and hover drone. Repeat for 5.25 and 4.75 miles	

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
3. Microcontroller (a) Capable of receiving 6 signals from the transmitter using a receiver (b) Capble of outputting PWM signals to the ESC	3. Microcontroller (a) Use function $PulseIn()$ from the Arduino library to determine if the microcontroller can read signals from the transmitter using the receiver (b) Hook up PWM outputs to oscilloscope and test if output signal looks right, and then connect this signal to an ESC/motor to check that it correctly modulates the motors speed.	
4. Gyro Sensor (a) Consume less than 3.6V $\pm$ 0.25V (b) Consume less than 7mA $\pm$ 0.25mA (c) Ranges $\pm$ 500° $\pm$ 5°per second	4. Gyro Sensor (a) Place sensor in series with a test voltage source and use a Digital Multimeter to measure the voltage drop across sensor. It should be less than 3.6V $\pm$ 0.25V. (b) Place sensor in in series with a test voltage source and use a Digital Multimeter to measure the current across sensor. It should be less than 7mA $\pm$ 0.25mA. (c) Hook up sensor to a microcontroller and spin the assembly on a test rig at 500 degrees per second and see if the microcontroller outputs the correct data $\pm$ 5 degrees/second.	

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
5. Accelerometer **(a) Consumes at most 3.6V± 0.25V** **(b) Consumes at more 600μ±0.25μA** **(c) Ranges ± 6g of force**	**5. Accelerometer** **(a) Place sensor in series with a test voltage source and use a Digital Multimeter to measure the voltage drop across sensor. It should be less than 3.6V ± 0.25V** **(b) Place sensor in in series with a test voltage source and use a Digital Multimeter to measure the current across sensor. It should be less than 600 μA ± 25μA.** **(c) Hook up sensor to a microcontroller and spin the assembly on the test rig to the speed required to simulate 1g of acceleration at the accelerometer ± 0.1 m/s^2**	
6. GPS **(a) Must be accurate in the x, y, z direction by 10 cm +/− 5 cm** **(b) Must consume less than 3.3V ± 0.3V** **(c) Must draw less that 44mA ± 4mA**	**6. GPS** **(a) Place gps outside and measure its location in cm. Then check the measurements to the readings.** **(b) Place GPS in series with a voltage source and use a Digital Multimeter to measure the voltage drop across it. It must be less than 3.3 V ± 0.3 V.** **(c) Place GPS in series with a voltage source and use a Digital Multimeter to measure the current across the GPS. It should be less than 44 mA ± 4 mA.**	

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
7. Actuator (a) It must be able to rotate 180 degrees with a precision of ± 0.05°. (b) It must consume less than 6.0V ± 0.25V	**7. Actuator** (a) Give the servo the signal for its zero degree position, measure with precision angle measurement tool, then feed the servo the signal for its 90° position. Measure position again with the same tool. find the difference in angle and compare with the theoretical 90°. Repeat 10 times with +90° position and -90° positions and average results to confirm servo meets tolerance requirements. (b) Hook up the servo to a voltage source and use a Digital Multimeter to determine the voltage drop across the servo.	
8. Centrifugal Fans (a) Must generate a thrust of 500g ± 5g in conjunction with its motor running at 100% power. (b) Must weigh less than 100g ± 5g (c) Each of the centrifugal fans must weigh within ± 5 grams of each other	**8. Centrifugal Fan** (a) Attach motors to centrifugal compressors and determine thrust by measuring force (in Newtons) of each individual compressor-motor pair on a stationary force sensor pad with the compressor thrusting itself against the pad. (b) Weigh module on a scale to determine mass meets requirements (c) Compare mass measurements between each module	

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
9. Electronic Speed Controller (a) Capable of driving a motor with at least 50± 2.5A (b) Must consume less than 0.5V ± 0.1V	9. Electronic Speed Controller (a) Attach motor with a draw current of 50 Amps and spin up motor for at least 10 minutes without stalling or rising above 93C. (b) Place ESC with one of the selected motors connected in series with test voltage source and use a Digital Multimeter to measure the voltage drop across ESC as it runs the motor at full power. It must be less than 0.5 V ±0.1 V	
10. Motors (a) Capable of providing 500g of lift overall in junction with centrifugal fan (b) Must draw less than 50A ± 2.5A	10. Motors (a) Attach motors to centrifugal compressors and determine thrust by measuring force (in Newtons) of each individual compressor-motor pair on a stationary force sensor pad with the compressor thrusting itself against the pad. (b) Place Motor in series with a test voltage source and measure the current across the motor. It must be less than 50A ± 2.5A	
11. Chassis Frame (a) Capable of withstanding a fall of 1m ± 0.1m (b) Must weigh less than 1kg ±0.25kg	11. Chassis Frame (a) Drop drone from 1.1m and repeat at 0.9m (b) Weigh drone on a scale. It must weigh less than 1kg±0.25kg	