Chapter 7: Power Analysis and Flight Time

# Mini Abstract

1-2 paragraph chapter description. Should generally go over contents, expectations, and results. Abstracts are usually the last part of something to be written out since it is a summary of the article, but we can use them here to help flesh out our ideas a bit for how to structure. Final abstract should be overhauled at the end of the chapter though, the chapter dictates the abstract, not the other way around.

Power management and analysis are crucial to understanding the achievable flight times of the drone based on the performance of the system. Power estimates are gained through individual testing of each part that is compared to the estimated power specified on each component’s datasheet. Through analyzing each component of the system and the power that will be required for each one, the flight time requirement of a greater than 30 minute normal autonomous flight time was theoretically achieved by ensuring the minimum flight time is greater than 30 minutes, fulfilling STR 1.0.0, Flight Time.

Switching and linear voltage regulators were used to achieve voltage levels required for different electrical components used. Even with power losses and replacement motors that were less power efficient than the intended motors for the same thrust, the system theoretically always results in at least a 30 minute flight time, but cannot be verified until experimental tests are done.

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# Chapter Outline

Develop the chapter outline here. Should become very detailed and broken down to paragraph level. Remember, if we invest time and effort into making a detailed outline, the actual writing will be far easier since we understand the flow and structure before we lay out the details. Before even writing a subsection, take the time to outline that subsection in the chapter outline. A lot of writing is in the layout. Remember to update this chapter in the Master Outline file so we can all keep track of the full outline of the report, its large so breaking it up this way should help everyone keep track of each other's ideas and work.

## Section 1: System Components

### Subsection 1: Control Mechanisms

* Details power required and why for each component involved with the control system

### Subsection 2: Sensors

* Details power required and why for each sensor component
  + Also mentions power required from communicating from sensors to controls

Subsection 3: Actuators

* Details power required and why for motors and servos
  + Motors will have a chart that shows power required depending on throttle, as well as ESC efficiency losses

## Section 2: Powering the System

### Subsection 1: Voltage Rails

* Shows different voltage rails and the regulators used for each, including power losses due to efficiencies
  + Also explains low-pass filter used to smoothen switching regulator voltage ripple

### Subsection 2: Battery Selection

* Will wrap up all power requirements shown before, providing a maximum and minimum milliwatt-hour requirements needed to comply with system technical requirements
  + Will explain battery selection and discharge limits for the battery

### Subsection 3: Flight Time

* Will show conclusion on how flight time can be calculated within the minimum and maximum times

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# Chapter 7

Power estimates were gained through individual testing of each part that was compared to the estimated power specified on each component’s datasheet. Through analyzing each component of the system and the power that will be required for each one, the flight time requirement of a greater than 30 minute normal autonomous flight time was theoretically achieved by ensuring the minimum flight time is greater than 30 minutes, fulfilling STR 1.0.0, Flight Time. Even with power losses and replacement motors that were less power efficient than the intended motors for the same thrust, the system theoretically always results in at least a 30 minute flight time, but cannot be verified until experimental tests are done.

## 7.1 System Components

To properly analyze the power required of the entire system, we must look at each component individually. Separating the power costs by part allows us to create a power budget that lists the amount of power needed for every part to add together for the total power required for a flight. The total power used will largely depend on the activity of the motors and servos, which amount to greater than 90% of the total system power. Most of the parts of the drone, including the sensors and internal control mechanisms, have been tested to draw a constant amount of power when the drone is in flight to simulate the constant sensor readings, data transmitting, data receiving, and control functions which are necessary for the drone to respond to user controls and to process the data it is receiving. The following data from the main power budget is divided into three categories separated by general functions. These sections include the communication mechanisms, the sensors, and the actuators. The data telemetry kit and internal pressure sensor could not be tested. However, since these parts amount to less than 1% of the total power used by the system, the estimated power values were used instead, since it will minimally affect the flight time of the drone. The power summation between every part is stated in section 7.2.2.

7.1.1 Communication Mechanisms

The communication mechanisms include the uC32 microcontroller, Raspberry Pi 3B+ microprocessor, AKK KC03 camera transmitter, a Sparkfun serial telemetry radio kit, and an FS-iA6B RC receiver on the drone. The power requirements of each of these parts were taken from their respective datasheets. These power requirements were then tested through measuring the current through an ammeter while the parts were in operation. The tests done for the control components are seen in the following system block diagrams, Figures 7.1 and 7.2. Table 7.1 describes the estimated power required for each component mentioned based on the typical power required for each part to function while in flight, as stated in their respective datasheets, and the power that was actually tested for each part individually.



Fig. 7.1. Microcontroller and Microprocessor Power Test

Microcontroller/Microprocessor Test Process:

1. Ensure Microcontroller or Microprocessor is running the code produced for their operation
2. Connect Battery to Vin of 5V Regulator
3. Connect 5V regulator Vout to an ammeter and the other end of the ammeter to the microprocessor or the microcontroller.
4. Ensure each part has a common ground
5. Wait 5 seconds for current to stabilize and record current on the ammeter



Fig. 7.2. Camera, RC, and Data Transmitter Test

Transmitters/Receiver Test Process:

1. Ensure Battery is connected to camera module with an ammeter in between and with a common ground
2. Plug in camera receiver to a USB-C port on a computer
3. Make sure camera receiver is showing output on the receiver
4. Wait 5 seconds for current to stabilize and record current on the ammeter
5. Connect any 5V source to the data transmitter and RC receiver with a common ground for both
6. Turn on the RC controller and ensure it reads the RC receiver is active
7. Record current needed for moving the joysticks on the controller
8. Connect Data receiver to a USB port on a computer
9. Ensure data is being transmitted by the data transmitter
10. Record current needed by data transmitter

Table 7.1

Estimated and Tested Power Required for Control Components in Flight

| Part Name | Nominal Voltage (V) | Estimated Current (mA) | Tested Current (mA) | Estimated Power (mW) | Tested Power (mW) |
| --- | --- | --- | --- | --- | --- |
| uC32 Microcontroller[31] | 5 | 75.5 | 60 | 378 | 300 |
| Raspberry Pi  3B+ Microprocessor[32] | 5 | 1200 | 500 | 6000 | 2500 |
| AKK KC03 Camera/Transmitter[33] | 11.1 | 340 | 312 | 3770 | 3460 |
| FS-iA6B RC Receiver[34] | 5 | 20 | 34 | 100 | 170 |
| Serial Telemetry  Radio Kit Data Transmitter[35] | 5 | 100 | N/A | 500 | N/A |
| **Total** |  |  |  | 10748 | 6930 |

The power used by the uC32 microcontroller was expected using the datasheet current required for executing code that is stored in the microcontroller. The microcontroller’s typical amperage estimate of 75mA is added to a small increase of 0.5mA of power required to maintain I2C communication protocol, as specified on its datasheet. The microcontroller was then tested to run the code required to move the servos and motors, where the current was read through an ammeter, measuring the tested value of 60mA. The current is lower than the estimated datasheet current since not all pins are being used

The Raspberry Pi 3B+ microprocessor’s estimated power requirement follows the maximum total current draw on the datasheet of 1200mA. While running the code necessary to read from sensor and control inputs, the current measured was variable between 300-500mA. Since it was unstable, the 500mA max was recorded as the tested current. The lower current is due to the processing power being used that is less than the microprocessor is capable of.

The AKK KC03 camera transmitter is connected to the camera module itself and receives the power for both to function. The provider stated the working current for the camera to be 135mA at 5V and the transmitter to work at 280mA average from 7-20V, which was assumed to be the current for a 11.1V power supply. The total current was adjusted for use at 11.1V for both, giving us a current at 340mA. This was tested by viewing the camera transmitter output on a screen with an ammeter in between the camera and our 11.1V power supply, giving us a lower current of 312mA. This difference can be attributed to the wide voltage input range of the transmitter and the vague working current stated by the provider.

The FS-iA6B RC receiver was stated to have a maximum current of 20mA at 5V by the provider. However, when tested, this part consumed 34mA at 5V, regardless of the input on the joysticks of the controller while connected. This is due to the RC controller continuously sending a signal to the receiver no matter the contents of the signal

The final control part is a Sparkfun telemetry radio kit data transmitter, which could not be tested due to the lack of data from sensors to transmit. Therefore, the transmitting current given by the provider of 100mA at 5V was kept in the power budget.

Overall, the control components only use about 64% of their estimated power, or 6.9W, due to the components not being used to their full operating capacities.

7.1.2 Sensors

A variety of sensors were implemented in the system, including an MPL311512A external pressure and temperature sensor, four HC-SR04 ultrasonic proximity detectors, an MTK 3339 GPS module, an ICM-20948 IMU orientation sensor, and an MPRL S0001 internal pressure sensor. These parts were also estimated to have a constant current requirement, which was first estimated using data from the sensors’ datasheets and then tested using an ammeter while they were on and recording data. Figure 7.3 describes a block diagram for the tests done with the sensor modules. Table 7.2 shows the results of these estimations and experiments.



Fig. 7.3. Sensors Power Test

Sensors Test Process:

1. Connect the Vin pin of the microcontroller to any 5V source with a common ground
2. Connect connect an ultrasonic sensor to the 5V source with an ammeter in the middle, with a common ground and with the trigger pin connected to pin 3 on the microcontroller, which is running the ultrasonic code
3. Record current while the ultrasonic sensor is running after 5 seconds
4. Connect the Vin of any other sensor to the 3.3V Vout pin of the microcontroller with an ammeter in the middle and with a common ground
5. Record current through the sensor after 5 seconds have passed
6. Repeat step 4-6 until no more sensors are left to test

Table 7.2

Typical Power Required for Sensors in Flight

| Part Name | Nominal Voltage (V) | Estimated Current (mA) | Tested Current (mA) | Estimated Power (mW) | Tested Power (mW) |
| --- | --- | --- | --- | --- | --- |
| MPL3115A2 External Pressure/Temperature Sensor[36] | 3.3 | 0.2 | 0.16 | 0.875 | 0.528 |
| HC-SR04 Ultrasonic Sensor[37](4 total) | 5 | 15 | 2 | 300 | 40 |
| MTK 3339 GPS Module[38] | 3.3 | 20 | 22 | 66 | 73 |
| ICM-20948 IMU Sensor[39] | 3.3 | 3 | 3 | 10 | 10 |
| MPRL S0001  Internal Pressure Sensor[40] | 3.3 | 4 | N/A | 13.2 | N/A |
| Total |  |  |  | 390 | 136 |

The MPL3115A2 external pressure sensor datasheet had a current estimate of 0.265mA at 2.5V, meaning if powered by 3.3V, it would be 0.2mA. The tested current was 0.16mA when connected to power. This difference can be due to the amount of times the sensor will be read, which was estimated at about 1 times per 2 seconds, while the datasheet says the expected current value is 1 time per second.

There are four separate HC-SR04 ultrasonic sensors, each also being used constantly throughout flight. Power for the ultrasonics is taken from its datasheet, which specifies a 15mA current at 5V. However, when one sensor was tested and returned readings, the current was only 2mA. This can be due to a 16hz rate the sensor is being used at, as the datasheet does not specify the max response rate of the sensor.

The MTK 3339 GPS module datasheet power was specified to typically be 20mA at 3.3V when a GPS signal has been acquired and is being tracked. It also had an estimated 25mA current at 3.3V when trying to acquire a signal. When tested, the current while acquiring a signal was correct at 25mA, but the tracking current was 22mA. Since the signal will be acquired within a minute, the average current was stated to be 22mA for a greater than 30 minute flight time.

The ICM-20948 IMU sensor’s activity and expected power draw were taken from the datasheet at 3mA at 3.3V. When tested, the value was exactly 3mA, as stated on the datasheet.

The internal pressure sensor was unable to be tested since the code for it had not been implemented yet, but was estimated to be 4mA from the datasheet.

The sensors in total only require about 35% of the power estimated from datasheets, or 0.136W, owing to the low refresh rate and use of each sensor comparatively with what they are capable of.

7.1.3 Actuators

The actuators, which are the motors and the servos, are different from the other components because the difference in their own power requirements are large when based on their performance and are either individually testable or stated in their datasheets. The servo power was used from its datasheet for idle, working, and stall currents and then tested to see if the stall current was reached and to verify the other current values. The motor and ESC power requirements were calculated using a simulation test with our initial motors that gives thrust per RPM when the motors were combined with the propellers. This was done since the motors amount to more than 90% of the total power usage of the system. Since replacement motors needed to be found late in the project, simulation results were not done with them. Figures 7.4 and 7.5 show the system block diagrams of the tests done for the motors and servos. Table 7.3 summarizes the findings from the simulation and tests, where the low state for the motors will be hovering at 5N total thrust from the 4 motors and the 4 servos will be idle, while the high state for the motors will be 10N total thrust and the servos will be turning without stall.



Fig. 7.4. Motor Power Test

Motor Test Procedure:

1. Tape a bottle greater than or equal to 2kg, in this case a sunny-D bottle to an electric scale
2. Tape the motor and propeller to the top of the bottle
3. Connect an ESC’s 3 wires to the motor as shown in the diagram, with Power to A, signal to B, and Ground to C
4. Connect the ESC to an 11.1V battery and ground with an ammeter in between the power supply and the ESC
5. Connect the RC receiver to a 5V source to Vin, ground it, and connect the channel 3 of the RC receiver to the ESC
6. Turn on the RC controller, the motor should now beep once and it will be ready to spin
7. Increase the throttle 1% and wait 5 minutes, then record the weight changed by the motor and the current required after 5 seconds of continuous throttle
8. Repeat step 7 until the Ammeter cannot handle the current.



Fig. 7.5. Servo Power Test

Servo Test Procedure:

1. Tape Servo to a secure place horizontally with the motor and propeller on the motor bracket connected to the servo
2. Connect the servo Vin with a 5V supply and an Ammeter in between, with the trig pin of the servo connected to channel 4 of the RC receiver
3. Connect the motor with three wires to an ESC, as described in the diagram, with Power to A, signal to B, and Ground to C
4. Connect the ESC to the 11.1V battery supply and with a common ground with the servo and all other parts
5. Connect the RC receiver to a 5V power supply and ground, with the channel 3 pin being connected to the signal pin of the ESC
6. Run the motor at full throttle(29% for the replacement motors) and turn the servo continuously
7. Observe the Ammeter and record the highest current achieved while the servo is spinning

Table 7.3

Power Required for Motors and Servos

| Part Name | Nominal Voltage (V) | Low State Current (mA) | High State Current (mA) | Low State Power (mW) | High State Power (mW) |
| --- | --- | --- | --- | --- | --- |
| SK3 2822-1275kv Motor[41](Intended) | 11.1 | 1900(Expected)  1144(Tested) | 3900(Expected)  3044(Tested) | 84,000(Expected)  51,000(Tested) | 173,000(Expected)  135,000(Tested) |
| D2822-2600kV Motor[42](Replacement) | 11.1 | 1787(Tested) | 4086(Tested) | 79,000(Tested) | 181,000 (Tested) |
| RC Sail Winch Servo[43] | 5 | 3(Expected)  1(Tested) | 350(Expected)  350(Tested) | 60(Expected)  20(Tested) | 7000(Expected)  7000(Tested) |

The servo power was taken from its own datasheet. When not in operation, the servos require power equal to the low state power consumption since they are idle and not working. This is a result of the angle detection that our servos utilize, both when they are moving and when they are stationary. When they are moving, which happens when the drone is turning or correcting itself, it will then require the high state power consumption for the duration the servo it is moving.

These values were tested for the servo, requiring 1mA instead of 3mA from the datasheet while idle. The current while the servo was turning was tested and did not exceed 350mA as stated on the datasheet, although the current read through the servo with an ammeter was unsteady. While the motor was tested with the maximum thrust of 2.5N while on the servo, the servo did not stall due to opposing torque. This would have required a current of up to 1A, but did not occur since the motor torque is about 0.9Nm, while the torque created by a 2.5N thrust 6 inches from the servo would have a torque of about 0.3Nm.

The motor power was calculated using Figure 7.6, which is a thrust simulation of our motor and propeller at different rpm values. The two thrust values that were focused on were each of the 4 motors providing 1.25N of thrust for a 5N drone to hover and 2.5N of thrust per motor to oppose maximum drag of 8N and weight of 5N combined using trigonometry, which equals about 9.3N. Since the thrust is greater than the expected max drag at our maximum drone speed, this fulfills STR 2.0.0, Drone Speed, but this cannot be verified until tested in an outdoor environment.

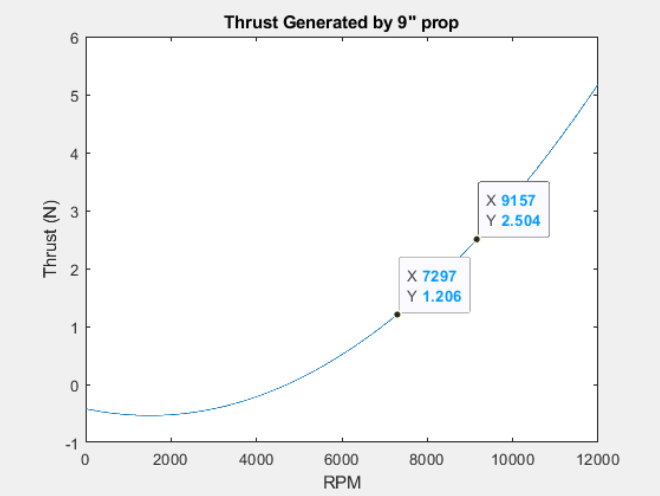


Fig. 7.6. Results of simulated propeller and motor thrust at different rpms using the intended motors.

Using equation 7.1, the power is estimated using the torque needed to turn the motors at a certain rpm. Power is equal to torque times angular velocity, which means for power, the Ω would be cubed instead of squared.

Equation 7.1[44] Power of each motor; Torque is labeled Mx

Where ⍴ is approximately 1.225, or the density of air at room temperature and at sea level. Ω is the angular velocity of the propeller that is dependent on 0-100% throttle and was simulated from 0-12000rpm, D is the diameter of the propeller or 0.2286m, and Cq is the propeller torque constant that is dependent on the wind speed flowing through the propeller. Cq ranges from 0.00184 at still winds to 0.0019 at a wind speed of 8.9ms, which is the maximum windspeed the drone should be able to fly against based on our system technical requirements. For maximum power needed, the wind speed is assumed to be max. Using this equation while varying the throttle of the propeller gives us Table 7.4 and Figure 7.7 for power required for a certain throttle by multiplying the torque by the angular velocity expected from the motor and propeller based on the results of our simulation.

Table 7.4

Power Required Per Throttle in Simulation for Intended Motor

| Throttle | Power (W)  (20mph wind) | Power (W)  (0mph wind) |
| --- | --- | --- |
| 0% | 0 | 0 |
| 10% | 0.1 | 0.1 |
| 20% | 0.7 | 0.7 |
| 30% | 2.5 | 2.2 |
| 40% | 5.7 | 5.3 |
| 50% | 11.1 | 10.4 |
| 60% | 19 | 18 |
| 70% | 29.9 | 28.5 |
| 77% | 38.9 | 38 |
| 80% | 44.4 | 42.6 |
| 90% | 63 | 60.7 |
| 100% | 86.1 | 83.2 |

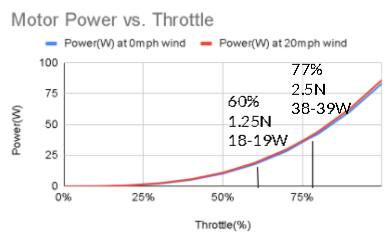


Fig. 7.7. Power required depending on throttle applied to the motors

In this chart, the limits of the motor throttle is decided by the amount of thrust required of the motor. Around 60% of this throttle is necessary to hover with 1.25N of thrust being generated by the motor and propeller. Multiplied by four, this gives us enough force to counter our 5N effective weight of the buoyant drone. This power level was chosen as the idle state power due to the drone having to hover if it is idle. 77% throttle would give us twice the amount of force, which was chosen as the limit for the max acceleration of the drone at 10N total in order to meet our system technical requirement of a drone speed of 5mph in 15mph winds, giving a max of 8N thrust as done in a drag estimation simulation. This was chosen as the maneuvering state power requirement, since the actual throttle used for maneuvering will be arbitrarily controlled by the user. Instead, the minimum and maximum power needed to hover and at max performance, respectively, are used to give a range of throttle and power that will be needed by the system. The limitations of this simplification are that the drone will not always be moving with maximum thrust, however this simplification allows us to calculate the absolute minimum and maximum flight times while an actual flight time can be found by integrating the amount of throttle used over time, as discussed later in section 7.2.3 in this chapter.

The results of testing the motors are found in Table 7.5 for the intended motors and Table 7.6 for the replacement motors. These tables show the thrust and power needed at a certain throttle level. The data is graphed in Figure 7.8 for the intended motors and Figure 7.9 for the replacement motors.

Table 7.5

Thrust and Power Needed by Intended Motors with Different Throttle Values

| Motor Throttle | Motor Thrust (g) | Motor Thrust (N) | ESC Current (A)  (at 11.34V) | ESC Power  Required (W) |
| --- | --- | --- | --- | --- |
| 0% | 0 | 0 | 0.04 | 0.4536 |
| 5% | 1 | 0.0098 | 0.055 | 0.6237 |
| 10% | 10 | 0.098 | 0.097 | 1.09998 |
| 15% | 26 | 0.2548 | 0.176 | 1.99584 |
| 20% | 43 | 0.4214 | 0.293 | 3.32262 |
| 25% | 66 | 0.6468 | 0.478 | 5.42052 |
| 30% | 94 | 0.9212 | 0.708 | 8.02872 |
| 35% | 120 | 1.176 | 1.01 | 11.4534 |
| 37% | 128 | 1.2544 | 1.12 | 12.7008 |
| 40% | 149 | 1.4602 | 1.33 | 15.0822 |
| 45% | 176 | 1.7248 | 1.69 | 19.1646 |
| 50% | 208 | 2.0384 | 2.17 | 24.6078 |
| 55% | 238 | 2.3324 | 2.67 | 30.2778 |
| 58% | 251 | 2.4598 | 2.98 | 33.7932 |
| 60% | 263 | 2.5774 | 3.16 | 35.8344 |
| 65% | 294 | 2.8812 | 3.8 | 43.092 |
| 70% | 305 | 2.989 | 4.47 | 50.6898 |
| 75% | 345 | 3.381 | 5.24 | 59.4216 |
| 80% | 371 | 3.6358 | 5.92 | 67.1328 |
| 85% | 385 | 3.773 | 6.55 | 74.277 |
| 90% | 415 | 4.067 | 7.47 | 84.7098 |
| 95% | 430 | 4.214 | 7.84 | 88.9056 |
| 100% | 452 | 4.4296 | 8.6 | 97.524 |

Table 7.6

Thrust and Power Needed by Replacement Motors with Different Throttle Values

| Motor Throttle | Motor Thrust(g) | Motor Thrust(N) | ESC Current(A)  (at 11.34V) | ESC Power  Required(W) |
| --- | --- | --- | --- | --- |
| 0% | 0 | 0 | 0.046 | 0.52164 |
| 5% | 0 | 0 | 0.046 | 0.52164 |
| 10% | 74 | 0.7252 | 0.986 | 11.18124 |
| 15% | 114 | 1.1172 | 1.61 | 18.2574 |
| 16% | 125 | 1.225 | 1.75 | 19.845 |
| 17% | 131 | 1.2838 | 1.9 | 21.546 |
| 20% | 158 | 1.5484 | 2.37 | 26.8758 |
| 25% | 215 | 2.107 | 3.23 | 36.6282 |
| 28% | 250 | 2.45 | 4 | 45.36 |
| 29% | 257 | 2.5186 | 4.25 | 48.195 |
| 30% | 266 | 2.6068 | 4.44 | 50.3496 |

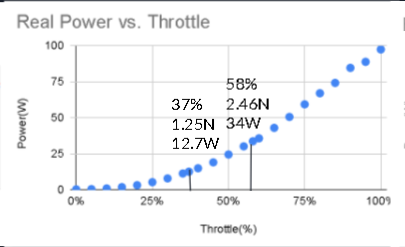


Fig. 7.8. Throttle over Power Needed as Tested with the Intended Motors.

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Fig. 7.9. Throttle over Power Needed as Tested with the Replacement Motors.

The results of the motor tests show that the intended motors are more power efficient for the same throttle. It also shows that the replacement motors are less efficient than the expected and tested values for the old motors, owing to the twice as high kV rating as the intended motors. Due to the higher kV rating, the motor will push harder to achieve a higher RPM with a certain level of voltage and when combined with the prop we have, will lose more power to heat due to the higher torque applied with the same RPM to get the same thrust as the intended motor.

The results from the tests and simulations are combined to give a power range that the motors will need in between the minimum and maximum power requirements of the motors, which is based on the thrust the motor will provide at that power up to the maximum thrust of 2.5N. This is summarized in Table 7.7.

Table 7.7

Power Ranges for Simulated, Intended and Replacement Motors

| Motor & Verification | Power Range (W) |
| --- | --- |
| Simulated Power For Intended Motors | 84.3-173 |
| Actual Power For Intended Motors | 50.8-135 |
| Actual Power for Replacement Motors | 79.3-181 |

## 7.2 Powering & Distribution

With all the components of the system decided, it is necessary to divide the power required by their nominal voltages, giving us 3.3V, 5V, and 11.1V power rails. When parts require the same voltage, they can be interconnected on one power line. For the battery selection before selecting the voltage, we have chosen a Lithium-Polymer(LiPo) battery due to its high energy density and popularity with drone usage[46]. When parts were defined by 11.1V nominal voltage, this meant they were specified for use with a three cell LiPo battery, for example, that was the max amount of cells stated to work with our motors. The voltage rails lower than this must be connected to the battery using voltage regulators to get a lower voltage. These regulators have a rated efficiency that means energy must be used to convert the voltage to a lower value and that energy is lost to heat. The total power required by the components as stated in section 7.1, added together with the heat losses in section 7.2.1 will give us the total power needed for the system to give us a 30 minute minimum flight time in order to meet the system technical requirement for a 30 minute normal autonomous flight.

7.2.1 Voltage Rails and Regulators

For the 3.3V, 5V, and 11.1V power rails, each one must be supplied by the battery. This means regulators must be used to drop down that voltage. The 11.1V nominal rail is straight from the battery, but will have heat dissipation from the 7.5ft wires that are run from the gondola to the motors themselves. The 5V rails will be achieved through a switching regulator to save power due to the high current needed and the variable voltage was allowed in each 5V part when tested, while the 3.3V rails will be gained from a linear regulator due to the very low current needed and the stable voltage needed for sensor operation. A summary of these rails and their power losses are shown in Table 7.8.

A switching regulator was chosen for the 5V rail due to the high current, which means a high power loss from heat if the regulator were linear, and because each part that is powered by 5V was specified that a variable supply voltage is allowed and it was tested that each part worked without error while powered by the regulator. Two Pololu 5V switching regulators were used, with a minimum efficiency of 85% at our battery voltage range of 9.6-12.6V.[45]. Two were used because the servos have a stall current of about 1A each and the regulator is only rated for 5A. Based on the power required for these rails, the efficiencies of the regulators were taken into account and the power loss due to heat was added onto the power required for usage of the system.

A linear regulator was used for the 3.3V power rail because of the low current required, and because our microcontroller has this function built in. Even though the 3.3V regulator is powered by the 5V microcontroller, the switching regulator that powers the 5V microcontroller will dampen the efficiency losses from dropping down from the battery voltage, while the 3.3V linear regulator will only have to drop from 5V. Due to the low current, there will be a low power loss, verifying that the 3.3V linear regulator on the uC32 microcontroller can be used.

Table 7.8

Voltage Rails and Heat Dissipation

| Rail Voltage (V) | Max Current (mA) | Max Current Allowed by Regulator (mA) | Max Heat Dissipation (mW) | Regulator Datasheet and Comments |
| --- | --- | --- | --- | --- |
| 11.1 Nominal  (12.6-9.6V) | 12906 | N/A | 471 | Heat comes from 4ft wires to  and from each motor 1.588 ohms  per 1000 feet for 14 AWG at 3.044A max |
| 5 | 1400 | 5000 | 1235 | 5V switching regulator for servos,  85% minimum efficiency[45] |
| 3.3 | 41 | 1000 | 70 | 3.3V Regulator used on  microcontroller[31] |
| 1.8 | 750 | 5000 | 662 | Same 5V Switching Regulator used for every other 5V part  85% efficient[45] |
| Total |  |  | 2600 Max |  |

7.2.2 Battery Selection

Now that we have each component’s power, we can add them all together to get the total power needed for the system, which we can use to calculate flight time. The total power of the system is shown in Table 7.19. This table shows the expected power from the intended motor simulation and datasheet power values, while also detailing the actual power from the tests conducted. However, the initial battery selection was done with the expected power and will be discussed at the end of section 7.2.2.

Table 7.9

Power Ranges for System and Each Part Category

| Part | Sensors | Control Mechanisms | Servos | Motors | Heat Loss | Total |
| --- | --- | --- | --- | --- | --- | --- |
| Expected Power(W) | .419 | 10.75 | .12-7.0 | 84.3-173  (Simulated) | .94-2.8(1275kV) | 100-194(1275kV) |
| Actual Power(W) | .136 | 6.86 | .04-7.0 | 50.8-135(1275kV)  79.3-181(2600kV) | .94-2.4(1275kV)  1.3-2.6(2600kV) | 58.8-151(1275kV)  87.3-197(2600kV) |

With the total power, our system technical requirement for flight time requires a normal autonomous flight time of 30 minutes. Due to the arbitrary nature of this requirement, which was given to us by our client, the safest way to fulfill this requirement would be to ensure the minimum flight time would have to be greater than 30 minutes. This means that the maximum power required for a 30 minute flight must be below the capacity of our battery. This power amounts to the maximum expected power of 194W times half an hour, which equals 97Wh of energy required.

Selecting a battery that is capable of 97Wh discharge starts with selecting the type of battery. We have chosen a Lithium-Polymer(LiPo), due to the high energy density, low weight, and higher safety compared to Lithium-Ion batteries[46]. For LiPo batteries, each cell has a 3.7V nominal voltage and they can range from 3V-4.2V depending on the amount of energy left in the battery. The motors chosen for the drone are able to handle up to 3 cells of a LiPo battery, giving us a maximum voltage of 12.6V, a minimum voltage of 9.6V and a nominal voltage of 11.1V. The supplier for our LiPo battery was chosen as the company of MaxAmps Batteries, due to the highly variable selection of batteries and their high safety rating despite their higher cost.

LiPo batteries are rated by milliAmp-hours(mAh), this means that it is rated for releasing that amount of current for one hour, which will cause the voltage of the battery to drain from 4.2V per cell max to 3.0V per cell minimum. However, releasing the entire capacity is very harmful to the battery if a cell falls below 3.0V and continues to discharge[47]. For this reason, research into this issue concluded that discharging the battery fully had minimal effects on the long-term lifetime of the battery compared with discharging it partially[48]. A linear depth of discharge was chosen as an approximation due to the lack of a depth of discharge curve. This led to keeping the voltage of each cell above 3.2V per cell as a safe buffer to enable the drone to find a spot to land and to conduct emergency landing procedures without going below 3V[49]. Assuming a linear depth of discharge, this will allow us to discharge 83% of the battery without going below 3.2V per cell. Another assumption for a depth of discharge was researched and concluded that about 90% of a LiPo battery can be discharged when approaching 3.2V[49], but this was not able to be tested or verified with the 83% estimation due to not being able to measure the current used over a long enough time to estimate the energy discharged from the battery and the voltage that the discharge resulted in.

Since the current being used in our system is at different voltages, it was necessary to measure the battery in milliWatt-hours(mWh) instead, which is multiplying the mAh by the nominal voltage of the battery. Therefore, with these restrictions that 83% of our battery capacity must be above the required minimum flight time power of 97,000mWh, the battery that was selected was a 3 cell, 11000mAh battery[50]. 83% of the mWh capacity of the battery is 101,750mWh, which is above the required battery capacity required. There is about 4,750 mWh of excess power because it was the smallest battery size our provider had that would meet our minimum flight time power requirement.

7.2.3 Flight Time

With our battery chosen, we can compare the battery capacity with the power required for keeping the drone in the air. This will allow us to calculate the minimum and maximum flight times. By calculating the maximum power and the minimum power required for the expected power with the intended motors, the tested power with the intended motors, and the tested power with the replacement motors, we can get the minimum and maximum flight times in Table 7.10, where the maximum energy required will be the motors always opposing maximum drag and the minimum energy required will be while the drone is only hovering.

Table 7.10

Minimum and Maximum Flight Times & Power Requirements with 101750mWh Battery

| Motors & Verification | Always Opposing Max Drag Flight Time | Hovering Only Flight Time |
| --- | --- | --- |
| (Intended)1275kV Simulated | 31.8 minutes | 66 minutes |
| (Intended)1275 kV with 20A 4 in 1 ESC | 40.2 minutes | 103.2 minutes |
| (Replacement)2600 kV with 4 single 30A ESCs | 30.6 minutes | 69.6 minutes |

A limitation of these times in Table 7.10 are assuming the drone is at maximum and minimum motor and servo performance, respectively, meaning that for the minimum time, the drone is always turning and pushing the motors to their limit while the maximum time is for the drone hovering in place. Calculating the actual flight time of a flight that is in between the minimum and maximum performance will require integrating the power needed for the throttle the motors are receiving over the time it is used. A chart that shows the equations used is displayed in Figure 7.8 for the intended motors and Figure 7.9 for the replacement motors. Integrating by the throttle used over time plus the time the servos are used over time for turning and also when they are not turning will give us the variable power to be added to the constant component power drain for the sensors and controls to give us the power required for a time and performance variable flight, and therefore its flight time if compared with our battery capacity.

## 7.3 Conclusion

Even though this system has not been fabricated completely, the individual component power tests for each part justifies that theoretically the drone can reach a 40 minute flight time at the minimal 20mph airspeed. Since the minimum flight time, verified through power draw analysis, is above 30 minutes, STR 1.0.0, Flight Time, can be met. The requirement cannot be experimentally verified until a flight test has been completed with their flight time measured above 30 minutes.

# Chapter 7 Bibliography

We do have a full bibliography that should absolutely be updated with all content here. The point of the chapter bibliography is to help keep track of citations in the chapter since the numbering may change in the full bibliography with changes and additions. This way will isolate the sources in this section so you can cite here without having to worry about it, and can use a simple find and replace on your citations to update the new numbering when we combine everything in the final report.

[31]

“PIC32 Microcontroller Brochure Datasheet by Microchip Technology,” *Digi*. [Online]. Available: https://www.digikey.com/htmldatasheets/production/1226947/0/0/1/pic32-microcontroller-brochure.html?utm\_adgroup=Integrated+Circuits&utm\_source=google&utm\_medium=cpc&utm\_campaign=Dynamic+Search\_EN\_Product&utm\_term=&utm\_content=Integrated+Circuits&gclid=Cj0KCQjw5PGFBhC2ARIsAIFIMNclkbZgYsZL4TNqLElx6Y66iKwxbTL8PUYJ-CD\_EM-rkiEYb5YGFjwaAvgxEALw\_wcB. [Accessed: 06-Jun-2021].

[32]

“Power Supply,” *Power Supply - Raspberry Pi Documentation*. [Online]. Available: https://www.raspberrypi.org/documentation/hardware/raspberrypi/power/README.md. [Accessed: 06-Jun-2021].

[33]

“AKK KC03 2.8MM 120 Degree 800TVL NTSC Switchable Camera with 40CH 600mW FPV Transmitt,” *RC Groups RSS*. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?2892758-AKK-KC03-2-8MM-120-Degree-800TVL-NTSC-Switchable-Camera-with-40CH-600mW-FPV-Transmitt. [Accessed: 06-Jun-2021].

[34]

“Flysky FS-i6 Transmitter / FS-iA6B Receiver Digital Proportional Radio System,” *Dragon Sailing North America*. [Online]. Available: https://radiosailing.net/products/flysky-fs-i6-transmitter-fs-ia6b-receiver. [Accessed: 06-Jun-2021].

[35]

“Serial Telemetry Radio Kit - 915MHz, 100mW,” *WRL-15007 - SparkFun Electronics*. [Online]. Available: https://www.sparkfun.com/products/15007. [Accessed: 06-Jun-2021].

[36]

A. Industries, “MPL3115A2 - I2C Barometric Pressure/Altitude/Temperature Sensor,” *adafruit industries blog RSS*. [Online]. Available: https://www.adafruit.com/product/1893. [Accessed: 06-Jun-2021].

[37]

“Ultrasonic Distance Sensor - HC-SR04,” *SEN-15569 - SparkFun Electronics*. [Online]. Available: https://www.sparkfun.com/products/15569. [Accessed: 06-Jun-2021].

[38]

A. Industries, “Ultimate GPS Module - 66 channel w/10 Hz updates,” *adafruit industries blog RSS*. [Online]. Available: https://www.adafruit.com/product/790. [Accessed: 06-Jun-2021].

[39]

“ICM-20948,” *DigiKey*. [Online]. Available: https://www.digikey.com/en/products/detail/tdk-invensense/ICM-20948/6623535. [Accessed: 06-Jun-2021].

[40]

“MPRLS0001,” *MPRLS0001 Honeywell Sensing and Productivity Solutions | Pressure Sensors, Transducers*. [Online]. Available: https://www.digikey.com/en/products/base-product/honeywell-sensing-and-productivity-solutions/480/MPRLS0001/454895. [Accessed: 06-Jun-2021].

[41]

“Turnigy Aerodrive SK3 2822-1275kv Brushless Outrunner Motor,” *Hobbyking*. [Online]. Available: https://hobbyking.com/en\_us/turnigy-aerodrive-sk3-2822-1275kv-brushless-outrunner-motor.html?queryID=&objectID=47269&indexName=hbk\_live\_magento\_en\_us\_products. [Accessed: 06-Jun-2021].

[42]

Banggood.com, “Flash Hobby D2822 1100KV 1450KV 1800KV 2600KV 2-3S Brushless Motor For RC Airplane,” *www.banggood.com*. [Online]. Available: https://www.banggood.com/Flash-Hobby-D2822-1100KV-1450KV-1800KV-2600KV-2-3S-Brushless-Motor-For-RC-Airplane-p-1628289.html. [Accessed: 06-Jun-2021].

[43]

“Sail Winch Servo 25T 10.63kg / 0.9sec (360deg) / 55g,” *Hobbyking*. [Online]. Available: https://hobbyking.com/en\_us/sail-winch-servo-13kg-0-7sec-360deg-55g.html. [Accessed: 06-Jun-2021].

[44]

R. W. Beard and T. W. McLain, *Small unmanned aircraft theory and practice*. Princeton, NJ: Princeton University Press, 2012.

[45]

“Pololu 5V, 5A Step-Down Voltage Regulator D24V50F5,” *Pololu Robotics & Electronics*. [Online]. Available: https://www.pololu.com/product/2851. [Accessed: 06-Jun-2021].

[46]

J. Galos, K. Pattarakunnan, A. S. Best, I. L. Kyratzis, C.-H. Wang, and A. P. Mouritz, “Energy Storage Structural Composites with Integrated Lithium‐Ion Batteries: A Review,” *Wiley Online Library*, 15-Apr-2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/admt.202001059?casa\_token=4qYDt26PI0YAAAAA%3A9QCrXJ3Hc0xuuQ3ql-sT0bae0kJfknuRlFTqXRbpW\_mq09iNIKVys1IIDBa7rcchB98vW-imUv32wDc. [Accessed: 06-Jun-2021].

[47]

“Lithium Polymer Charging/Discharging & Safety Information,” *MaxAmps.com*. [Online]. Available: https://www.maxamps.com/lipo-care.php. [Accessed: 06-Jun-2021].

[48]

S. Barcellona, M. Brenna, F. Foiadelli, M. Longo, and L. Piegari, “Analysis of Ageing Effect on Li-Polymer Batteries,” *TheScientificWorldJournal*, 2015. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4506813/. [Accessed: 06-Jun-2021].

[49]

“LiPoly Battery - When to stop draining?,” *Electrical Engineering Stack Exchange*, 01-Jan-1961. [Online]. Available: https://electronics.stackexchange.com/questions/32321/lipoly-battery-when-to-stop-draining. [Accessed: 06-Jun-2021].

[50]

“LiPo 11,000 3S 11.1v Battery Pack,” *MaxAmps.com*. [Online]. Available: https://www.maxamps.com/lipo-11000-3s-11-1v-battery-pack. [Accessed: 06-Jun-2021].