NASA Floating DRAGON Balloon Challenge

Team 1

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# Purpose/Background

Space exploration is expensive as it can cost NASA billions. NASA is always applying alternatives to the more well-known missions such as rockets, rovers, and the space station. Balloon missions are one of these alternatives. Balloon missions were first kicked-off over 30 years ago and are run by the Balloon Program Office (BPO) [4]. 10-15 missions are launched each year all over the world [8].

     Balloon missions are large (up to 150 meters wide) gas filled balloons that stay in the in the atmosphere at heights up to 130,000 ft [8]. This height is of interest as normal aircrafts cannot fly at these heights, but satellites cannot be this low [7]. Furthermore, these balloons can stay at these altitudes for several weeks, need shorter development time, and have flexible launch opportunities. They hold different observations tools that allow us to gain knowledge to of the earth’s atmosphere and the universe in fields such as but not limited to upper-atmosphere physics, infrared astronomy, cosmic ray physics [6].

    These balloon missions need some innovation that we plan to address through our purpose. At the very highest level, our design will contribute to the NAE grand challenge that is engineering tools for scientific discovery. To improve our understanding in science, new inventions must constantly be created, and current methods need constant innovation. Learning more about space is a category within the grand challenge. This challenge will contribute to further discovering space.

And finally, where our challenge comes in is getting information to the ground from space. The current methods of data retrieval from these balloons need innovation. They need improvements that can allow these missions to increase their effectiveness and flexibility. Effectiveness - the balloon missions need to be able to send data to the ground without sending the entire payload. Flexibility – decent of data vault needs to have control to allow drop-offs in less remote areas i.e., closer to cities. More detail on the problems with current methods will be discussed in the next section.

The balloon missions and their problems can be broken down into 3 sub-problems: air safety, data integrity, and ground safety. The height of which these payload descent from means they must go through the troposphere which is the part of the atmosphere in which regular plane fly in i.e., commercial, military, etc. [3]. Because of this we must make sure to comply with Federal Aviation Administration rules as their goal is to ensure a safe and navigable airspace [9]. People and structures must also be protected at the landing stage of the payload. Data integrity is a non-negotiable problem that must be taken into high priority to ensure government funds do not go to waste on these missions.

# Overview Diagram

## Hardware Overview Diagram

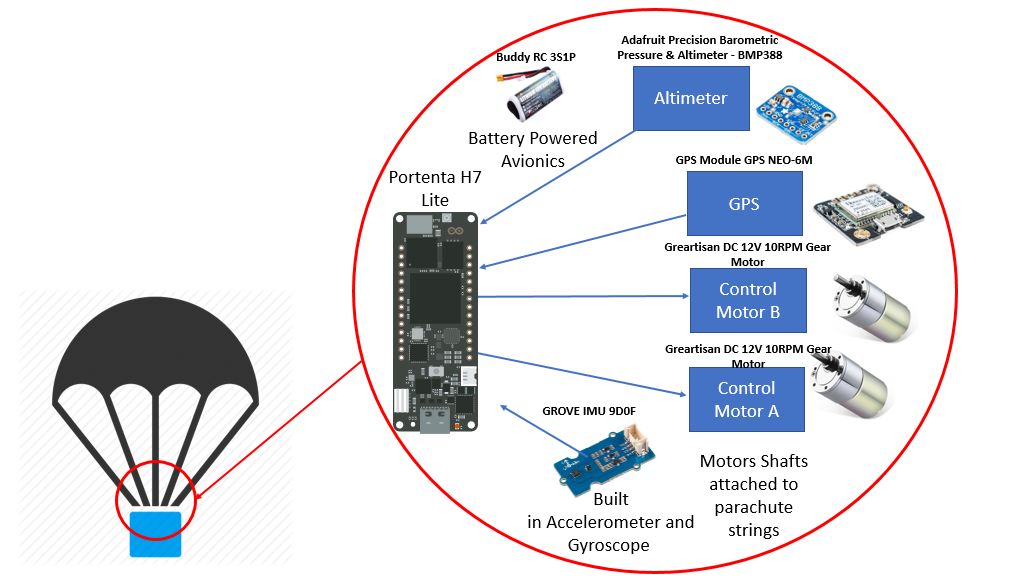
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Figure 3.1: Hardware Overview Diagram

## Software Overview Diagram

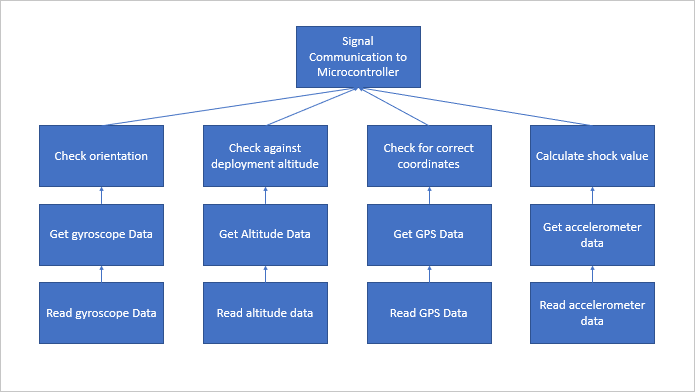
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Figure 3.2: Software Overview Diagram

# User Analysis, Product Specification

Our design and solution will be used by NASA as we are competing in their competition. They have required our design to meet their Design Guidelines, Requirement, and Constraints. The first requirement is for it to be compatible with the system and balloon NASA currently uses.

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Figure 4.1: HASP-type Balloon Overview

Currently, the entire system is composed of many parts as shown in Figure 4.1. The balloon is followed by a parachute, followed by a cable ladder, followed by the Payload which can weigh up to 3600 kg. The Payload subsection holds the gondola and instruments. Attached to it are support systems such as the telemetry, communication, and solar power systems. The gondola is where our design will attach to, specifically a HASP-type gondola. A more detailed look at the sensor system in the payload can be found in Figure 4.2

Diagram

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Figure 4.2: HASP-type Balloon Gondola Breakdown

We plan on accommodating our design to meet the balloon system by having a system that is able to safely transport a data vault to the ground. The entire data vault recovery system will consist of two parts: deployer and node. The deployer will release the node while being mounted to a HASP-type balloon gondola. Deployer will mostly be handled by one of the mechanical engineering teams. Our team, as ECE majors along with another mechanical engineering team oversee developing and designing the node that can fall safely. Although each subsystem requires their own design, the overall goal and objectives for the system are universal. In addition to the two sub-systems, we will give NASA a final report with a summary of test flight, data collected, and system performance. A folder with all the raw data will also be delivered. The process of recovering the data vault from the is illustrated in Figure 4.3:

Electronic signal tells our deployer to release the node. The signal will come from a telemetry system on the balloon. Signal will be sent from NASA’s Columbia Scientific Balloon Facility.

The node will then need to maneuver itself to the target by taking in real-time atmosphere and weather condition inputs and adjusting trajectory accordingly.

Our team will tell the facility when to send the signal based off calculation that our team will make based off sounding file and trajectory predict NASA will be giving us.

Figure 4.3: Data Recovery Flowchart

We plan on having our device to work with a GPS tracker and accelerometer to know where our device is with respect to the way point. A wind tracker will be used to measure real-time wind conditions to provide further information on how to maneuver the node. Our current anticipated method of maneuvering the node is a set of wings that will be deployed at a set height (one with atmosphere conditions deemed controllable). Lastly, a shock sensor to make sure the node hits land at a force within the constraint. Engineering analysis will be used to make these devices work together. We should consider every phase of flight from deployment to landing. We also need to pay attention to additional aspects of the design that are not on the requirements or constraints. This includes but is not limited to cost, reliable materials, operational simplicity, effective packaging, etc. The system should be able to complete this process whilst adhering to a set of requirements proposed by the NASA Floating Dragon Balloon Challenge.

The requirements from NASA are as follows.

Table 4.1: Design Competition Requirements

|  |  |
| --- | --- |
| Initial Drop Altitude Range | 33.5 to 36.5 km (110,000 to 120,000 ft) |
| Weight | Total system mass is limited to 10 kg (22 lbs) or less |
| Shock | Both the deployment subsystem and node must be able to survive a 10g shock or higher without yielding |
| Environment | Must be able to withstand temperature ranges between -70C to +65 C; -30C nominal at 36.5 km (120,000 ft) or 4 mBar to 11 mBar |
| Dimensions | The deployment subsystem must fit within 120 cm x 45 cm x 45 cm and be able to house the node subsystem until deployment |
| The Payload | 1 x data vault: Volume 12.5 mm x 75 mm x 100 mm; 1 kg (will be provided to each finalist team) |
| Deployment | Deploy when receiving a signal from the gondola. |
| Mounting | System must mount vertically to 2” Aluminum ‘L’ channel with (3) ¼-20 bolts on 100 mm (~4-inch) spacing |
| Descent time | 1.5 hours or less |
| Accuracy | Node should land within 0.25 km (820 ft) radius of the targeted coordinate |
| Communications | If using a computer or microcontroller, one physical point of communication (e.g., USB port, Ethernet port, etc.) is required on the outside of the deployment subsystem to verify operation post compatibility test. |
| Safety | Fail safe is required in the event of loss of power (to the system) |

    We must also exclude these items from our design:

Table 4.2: Forbidden Items

|  |  |  |
| --- | --- | --- |
| Thrusters | Rocket Motors | Liquid propellants |
| Rocket Engines | Compressed gases | High-voltage source ( < 50 [V] ) |
| Excessively large magnets | Batteries without UL Cert | Chutes/drag system |

# Engineering Specification

We have chosen the Arduino Nano Portenta H7 Lite as the brain of our system, and it will be paired with an IMU (Inertial Measurement Unit) 9DOF. The Arduino Nano Portenta H7 Lite consists of dual 32-bit Arm Cortex M7 and 32-bit Arm Cortex M4 cores with various peripherals and features that make this integrated circuit suitable for many applications. Some of the peripherals include Inter-Integrated Circuit (I2C), Universal Asynchronous Receiver/Transmitter (UART), Serial Peripheral Interface (SPI), and Flexible Memory Control (FMC). Some of the applications this integrated circuit is suited for are motor drive, industrial applications, and alarm systems.

 We have chosen the IMU 9DOF because it is a combination of a LCM20600 and an AK09918. The LCM20600 consists of a 3-axis gyroscope and a 3-axis accelerometer. The gyroscope will be used for measuring and maintaining the orientation of the node when descending onto the ground and an accelerometer will be used to measure the acceleration of the node and determine shock. The AK09918 consists of a 3-axis electronic compass that will be used to detect the direction our node is facing. We will also have a NEO-6M GPS module to work with the electronic compass to navigate our node to the targeted area on the ground.

            As determined beforehand, the Arduino Nano Portenta H7 Lite will be powering the other modules and working alongside them. For us to be able to configure the hardware, the first step in the process of developing any system to navigate our node to the ground safely and accurately will be to learn the Arduino software. The next step would be to learn the programming language the Arduino software requires. Once we can figure out how the software works, we will then look into each piece of hardware by looking through their datasheets. To begin with the configuration of the Inertial Measurement Unit, we will have to configure the I2C module on our Arduino to establish communication between the two devices after connecting them together. To configure the GPS module on our Arduino, we will connect it to the Arduino and then establish serial communication with the module. With the Arduino community and vast amount of resources we will also be able to seek help online configuring each component.

    To navigate our node we will need motors to control how far to retract and release our parachute. The motors we are choosing to use are the Greartisan DC Gear Motor. These motors have a max speed of about 120 rotations per minute and a max voltage of 12 volts will operate these motors. To operate these motors, we will connect a motor driver to the Arduino which will then have to be configured to operate the direction of the spin of each motor and the speed at which each motor spins.

# Test Plan

Our terminal objectives mostly focus on the response we want from our hardware and software overview diagram. We start by reading the sensor data from our altimeter, accelerometer, GPS, and gyroscope data. From there all the data is sent to our software application and Arduino to calculate a system response. Based on our system response, we will rotate the shafts using motors to control the parachute. Then we will need to create an algorithm to generate an ideal trajectory for the flight. We then can control the paraglider using the predetermined ideal trajectory and land the node safely and accurately.

Diagram

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Figure 6.1: Goal Analysis and Terminal Objective

To ensure that we have accomplished each goal effectively, we must run tests. Testing the sensor input is as simple as saving timestamped readings of the sensor data to the microcontroller’s memory to be extracted later for analysis. The actual test will be different for each sensor. For example, to test the altimeter, the node needs to be placed at different known heights. The values being examined for the altimeter can be found in Table 6.1:

Table 6.1: Altimeter Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Time between Data Reads | Every 50ms | 20 ms |
| Difference in Altitude compared to Reference | +- 0.5 meters | +- 1 meter |

To test the gyroscope, the node needs to be recorded as it is rotated so that we know if the controller is recording the tilts correctly. The values being examined for the gyroscope can be found in Table 7.2:

Table 6.2: Gyroscope Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Time between Data Reads | Every 50ms | 20 ms |
| Difference in Orientation compared to Reference | +- 5 degrees | +- 15 degrees |

To test the accelerometer, a student can be recorded running a predetermined distance with the node and use the data from the recording to compare with the reading from the accelerometer. The values being examined for the accelerometer can be found in Table 6.3:

Table 6.3: Accelerometer Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Time between Data Reads | Every 50ms | 20 ms |
| Difference in Acceleration Compared to Measurement | +- 1 | +- 2 |

And to test the GPS, a student can walk to various locations and record the GPS coordinates from Google Maps and compare these coordinates with the coordinates given by the GPS module. The values being examined for the GPS can be found in Table 6.4:

Table 6.4: GPS Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Time between Data Reads | Every 50ms | 20 ms |
| Difference in Coordinates compared to Reference | +- 10 meters | +- 10 meters |

The mechanical engineering team will determine what voltage is necessary to operate the DC motors but we will ensure that our microcontroller reliably delivers the appropriate voltage to the DC motor. The values being examined for the GPS can be found in Table 6.5:

Table 6.5: DC Motor Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Update Output Voltage | Every 50 milliseconds | 20 milliseconds |
| Difference in Shaft Position Compared to Reference | +- 0.5 degrees | +- 2 degrees |
| Time to Release Parachute | 10 seconds | 20 seconds |

Once this is all verified, we can determine if the system response we calculated is correct or not by physically dropping the node in its final state from a 40 m height. However, before we do that we will want to ensure that our software is properly validated.

Using MATLAB’s Aerospace Toolbox, our team will generate various simulations of our node subsystem in its various stages under different conditions in order to search for edge cases that we have not thought about. These simulations will take into account the trajectory of the balloon in which the node subsystem will be dropped as well as the wind profile of the environment. This simulation should measure the final result of the system and the events leading up to it. These values should be relatively similar to the constraints placed on us by NASA’s competition guidelines. The values being examined for the system response can be found in Table 6.6:

Table 6.6: System Response Parameter Targets

|  |  |  |
| --- | --- | --- |
| Parameters | Target Value | Tolerance |
| Accuracy | Within 0.3 km diameter | Within 0.5 kilometer diameter |
| Descent time | Less than 30 mins | 1.5 hours max |
| Simulation Scenario Success | 95% confidence or higher | No less than 85% confidence |

Solutions to the following edges cases may need to be designed in the future:

* The node subsystem is orientated up-side down such that the parachute’s top points to the ground, becoming useless
* A sudden impulse of wind pushes the node far off course
* The node loses its ability to sense the environment

Additionally, if it is still not possible to do a physical test our team will attempt to simulate the control system on a smaller scale that is independent of the mechanical design. For example, we will build a robot car that will follow a pre-determined path to a waypoint. By building a robot car, we would be able to replicate all of the tests listed above without taking on the risk of dropping the node subsystem from the sky.

# Summary/Conclusions

This semester was a sound starting point for our senior design project, with one of our biggest accomplishments being having our initial design for the control system already planned out. As demonstrated in our hardware and software diagrams, we have all the components chosen for our design and the foundation of how our software will communicate and function with these components. This puts us at a stronger start going into the 2nd semester as we will order all the parts over winter break and focus on testing an early prototype of the subsystem at the beginning of the spring semester.

Another accomplishment the team is proud of is the increased communication with the mechanical engineering teams we are working with. We have been able to prepare a control system that can assimilate well with the physical design the mechanical engineering teams are working on because of the communication between our three teams. We know which parts we need that work well with the design they have planned, and we provide feedback on what parts will make the control system function the best. This is the most important accomplishment of the semester, as without the increase in communication, the entire project would have fallen apart. As most professionals know, the biggest contributor to a project going well is the communication between teammates.

Not all accomplishments start off as positive. One of those accomplishments is our team using the feedback from both the NASA preliminary report and the 2nd duo presentation for senior design to improve the overall design of our project. The most important feedback from the NASA preliminary report directed at the ECE team is considering that even if we design and test at a smaller scale, we still need to consider outside variables such as wind conditions at different parts of the atmosphere, varying pressures, and the temperatures. Our components need to be chosen and designed with these conditions considered. In our 2nd duo presentation, Dr. Contreras mentioned we should look into having a stronger microcontroller. By stronger, he meant not only the communication speed between our microcontroller and parts, but the ability to handle varying weather conditions. That’s why with the feedback given, we changed our current microcontroller to a more robust version. This is an accomplishment in the eyes of the team, as we improved our initial design to a superior design that can handle more of the obstacles we may experience in testing.

To follow up on this, hazards and risks that must be taken into account and considered before the actual design implementation. For instance, one of the main hazards of our balloon gondola design is that the node must be dropped down to the ground. This can pose a potential risk to people, pets, and any structure on the ground. Without the proper controls and systems in place, there is a significant possibility that the node could damage art structures or harm a human being when dropped from a high altitude. This hazard also poses the risk of compromising the data collected from the device. If the delivery system fails and the node is not able to be delivered safely, then on top of posing a risk to people and structures on the ground, the data itself could be lost, costing a lot of capital to replace and recover the data. Additionally, since the balloon gondola is going to be suspended in the air so there is a chance of it coming into contact with other airborne objects such as planes, helicopters, birds, or even humans who could be skydiving in an area close to the gondola. In the case of the helicopter or plane, the balloon could get in the way of the windshield, get stuck in the turbines or rotor blades, and potentially inhibit the pilot’s view or the machine's functionality. In the case of birds or humans, there is the risk of damage to the balloon and damage to the birds and humans since getting trapped in the balloon could inhibit flight and parachute mechanisms. Another potential hazard is poor weather conditions, which could cause the device to malfunction or compromise the data, leading to some of the other risks discussed previously. These are some of the main hazards and risks of field implementations, but there are also some developmental risks that may be important to consider. For instance, developing the node itself may require circuitry and connection to a power source which always poses the risk of electrocution, which is why safety procedures are crucial.

As with any project in development, there are risks involved for individuals and organizations investing in the technology in hopes that it will be effective in the field and pay off the original investments. There are a number of things that could impact the stakeholder risk and reduce the project's scalability. For instance, one of the risks to consider is supply chain delays. If there are delays with the project materials or there aren’t enough supplies to continue the project, then this could impact its return on investment if necessary data is not collected on time. Other risks include price escalations or loss of funding which could also slow the development of the project if there is not enough capital to order parts, purchase labor, and test the machinery. Furthermore, labor availability could be an issue if there is not enough expertise to fully complete the project, resulting in wasted since this risks the project being delayed or stopped before the design is fully developed. Tying into the previous section on project risks, if any of those risks occur it could pose a risk for stakeholders. If there are safety violations or anything of that nature, it is possible that funding could be halted for the project, government limitations could greatly slow down development, or the project may have to be scrapped overall based on the severity of the incident. Taking this into consideration is very important to avoid any complications with the project down the line.

Consequently, we can conclude that most of the hazards and risks are acceptable since the overall probability of occurrence is low, and we are able to mitigate these occurrences by careful design, planning, and implementation. There are various ways to reduce the risks we discussed in the previous sections. For the risk of the node harming people or structures on the ground, having a reliable set of system controls in place would reduce the risk of the nodes going to an undesired location. We can also implement the device in rural locations to reduce coming into contact with others and make the node lightweight and harmless in case it does. There is also the risk of the data being compromised which can be reduced by making the node storage durable and able to withstand harsh conditions and impacts. For the risk of the balloon coming into contact with other airborne objects or animals, planning the field implementation in areas away from air traffic and making the balloon “animal-safe” will reduce this risk. The weather condition risk can be navigated by having the balloon only tested during appropriate weather to reduce the chance of damage to the device or a malfunction. During the development of the electrical components of the project, the risk of electrocution can be reduced by working with lower voltages when possible and making sure the individuals are qualified for the work and having safety equipment at all times. For some of the stakeholder risks, there are a number of actions to take in order to reduce their impact and probability. For instance, while supply chain delays are relatively uncontrollable, the general trends can be tracked and the effects can be mitigated by ordering parts ahead of time and preparing for any potential shortages. Similarly, price escalations of loss of funding can be unpredictable, but making plans ahead of time to acquire and allocate capital can be useful when unexpected funding issues occur. To reduce the chance of a labor shortage, it is a good idea to meticulously plan the design beforehand so implementation and testing are easier, and hire individuals on contracts to increase the chance of the work coming to fruition. Consequently, it is not feasible to completely eradicate risk from a project, but taking different precautions and meticulously planning can reduce our risk to a level that we are comfortable with.

# Significance

These missions are very important to our understanding of space. Sarah Roth, chief of technologist of the BPO, says “Scientific balloons clear the way for groundbreaking science. The data they collect contribute to our understanding of Earth, the solar system, and the universe,” [5]. The information they collect is important. It is difficult to see the connection on how space exploration can benefit us as a society. However, information collected by these balloon helps us understand the conditions of the atmosphere therefore helps us understand how the sun rays impact us. Satellites, which are crucial for cell phone and other communication, are improved. It helps us take on climate change [1]. A Venus balloon mission gathered data on Venus’s atmosphere to learn about climate change here on Earth. The planets have “similar densities, chemical compositions and gravities” which makes it ideal to study [2]. Some of the missions are astrobiology missions which study potential life off Earth. The Grinspoon & Bullock 2007 mission found “presence of an unknown ultraviolet (UV) absorber, which was speculated to be emblematic of biological activity” [6].

This project is also important because it provides a new and efficient outlet to collecting data on earth science research and investigations. It helps us to test out various detectors and instruments related to radio applications as well as meteorology, atmospheric, and climate research. While different rocket launched satellite missions are used for similar results, the cost of a flight balloon can be one hundred times cheaper than a rocket launched mission. With this drastic difference in cost, it is far more economically sound to deploy balloons for research instead, and with an increased number of balloons, data collection and processing can be expedited significantly. Another factor to consider is that balloon missions run on helium, unlike rocket launched missions which makes them a much more environmentally sustainable option. Some rocket missions can consume over 11,000 lbs of fuel per second, which releases heat trapping gasses and further contributes to global warming. By utilizing balloons more, we can greatly reduce our negative effects on the environment while still collecting data efficiently.

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Figure 8.1: Historical Costs of Rocket Launched Missions

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# Appendix

## Appendix B

**Graphical user interface

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Figure 10.B.1: DC-Servo Motor & Pully Control System using a Microcontroller

To power all these devices we need a strong enough battery. We calculated the power consumption of our devices needed. We know that 5 components need to be powered for a max of 1.5 hours, which is the max descent time constraint. We know how we are attempting to connect our components and find our device power consumptions

Table 10.B.1: Power Consumption from Avionic Components

|  |  |  |
| --- | --- | --- |
| **Part** | **Operating Voltage [V]** | **Running Current [mA] (Max)** |
| **Microcontroller** | **3.3** | **8** |
| **Servo Motor** | **12** | **330** |
| **Altimeter** | **3.3** | **0.7** |
| **IMU** | **5** | **N/A** |
| **GPS** | **3.6** | **67** |

The Aerial Descent Mechanical Engineering Team respecified the node subsystem to only include 2 DC Servo Motors for the paraglider control. They determined that using four motors in our design will create redundant control as well as add unnecessary complications to the design.

|  |  |  |
| --- | --- | --- |
| Necessary Battery Life to power 2 DC Servo Motors |  | (10.B.1) |

    The equation above shows the reduction in motors which will lead to up to 990 [mAh] of battery life savings. We are still waiting on the Aerial Design team to calculate the torque necessary to control the DC Servo Motors. This is necessary to accurately create a simulation.The mechanical engineering team will also work on thermally insulating the avionics in the Aerial Descent Vehicle so that it remains within the proper operating conditions.