UHABS-5 Mission Preliminary Design Review

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Executive Summary [RP]

The University of Hawaii Advanced BalloonSat #5 (UHABS-5) is the first BalloonSat project at UH to be done as an ME 481 senior design project as opposed to as a ME 419 Astronautics project. This year, instead of having three months to complete the project, the team will have one full academic year (both fall and spring semesters) to fully design, build, test, and launch a fully functional BalloonSat. The UHABS-5 team consists of 12 mechanical engineering students and 1 electrical engineering student. Although the team is large and have been given a longer time period than usual, expectations are higher, as the UHABS-5 should not only launch into the atmosphere, but also incorporate an autonomous recovery system that will propel itself through the ocean to a recovery site upon landing, as well as location beacons such as lights and alarms in case it does not land in a body of water. This report reiterates the tasks, objectives, and requirements for UH-ABS 5 as well as in-depth design review for each component of the system.

The UH ME 481 team will successfully develop the UHABS-5 which will be capable of carrying payloads to a near-space environment and return to safely to Earth for intact recovery. If it lands on the ocean, the BalloonSat will autonomously propel itself to a designated target for recovery. To be considered successful, the BalloonSat should ultimately be able to carry a 12-pound maximum payload, consisting of multiple modules that weigh no more than 6-pounds each, into a near-space environment with an altitude nearing 60,000 feet. While doing this, it should also be collecting atmospheric data while flight testing the Comprehensive Open-architecture Solution for Mission Operations System (COSMOS) software, which is used in the Hawaii Space Flight Laboratory (HSFL) here at the University of Hawaii. Furthermore, upon landing in the ocean, the BalloonSat will be programmed to autonomously propel itself to a designated recovery site while maintaining full functionality. This will remove environmental concerns of losing large pieces of styrofoam in the ocean, prevent losing expensive hardware, and prevent losing collected data if the modules were lost. Upon retrieval, the BalloonSat and all of its hardware should remain mostly intact.

UHABS-5 will be broken down into three subsystems in order to satisfy the objectives and success criteria: ground station, balloon and command and control (C&C) module, and payload and propulsion (P&P) module. The ground station is responsible for monitoring the real-time data from the BalloonSat (such as state of health and location) and sending commands. The balloon and C&C module contains all of the hardware and sensors for the data, such as Data Acquisition software (DAQ), thermocouples, SD memory card for storage. Parachutes and tethers will be used to slow the descent and cameras to capture images and video. This module should be as lightweight as possible since it will be towed to the recovery site by the propulsion module. The payload and propulsion module will consist of the autonomous recovery system. The recovery system should function similarly to an autonomous boat.

To improve upon previous BalloonSat missions, UHABS-5 will use leftover material from past missions to thoroughly research and test methods in order to find ones that are best suited for a successful mission. Recycling the materials and resources from past projects that work the best for the mission will allow for better allocation of funds. Having a lower-cost BalloonSat will give more flexibility for testing more prototypes and purchasing more materials. The achievements and errors of previous projects can also help improve methods of UHABS-5.

Each subsystem has come up with several ideas on the best way to accomplish the objectives of UHABS-5, analyzing each iteration on various criteria to ensure it is the optimal choice. The C&C module will be in the shape of a capsule, to limit drag, maximize the internal volume, and allow for best placement of cameras, tethers and parachute attachments. The outer shell will be made of styrofoam since it is light, well-insulated, and low-cost. The central processing unit for both the C&C and P&P module will be a Teensy 3.2, since it is lighter, lower cost, and more powerful than an Arduino, with the same capabilities. The P&P module will incorporate a rounded, double-hull catamaran design with two propellers made of ABS plastic. This allows to ease through the ocean currents, and provides enough space for necessary components such as the antenna, solar panels and electronics. The selected motors and propellers should maximize its capabilities to ensure it is able to navigate properly to the recovery site. The ground station will utilize a turnstile antenna because it can be manually orientated and adjusted to follow the BalloonSat, and has a higher general gain value at low-cost, and has a better selection of products.

So far, $2000 has been granted for UHABS-5 from the University of Hawaii at Manoa Mechanical Engineering department. The current design places the budget slightly over this amount, but the group has applied for more resources and are awaiting approval. If these do not go through, the remainder will be fundraised or the budget will be adjusted further to fit within the amount of funds that are available.

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Acronyms and Abbreviations

COSMOS	Comprehensive Open-Architecture Solution for Mission Operations Systems
FAA	Federal Aviation and Administration
FCC	Federal Communication Commission
C&C	Command and Control
P&P	Payload and Propulsion
BalloonSat	Balloon Satellite Project
UHABS	UH Advanced Balloon Satellite
CPU	Central Processing Unit
IMU	Inertial Measurement Unit
PM	Project Manager
SI	System Integrator
FA	Financial Adviser
WBS	Work Breakdown Structure
HSFL	Hawaii Space Flight Laboratory
RPM	Rotations Per Minute
AC	Alternating Current
DC	Direct Current

1 Introduction [RP, JKY, JT]

Balloon satellites (BalloonSat), are modules that use a helium-filled weather balloon to launch payloads into the stratosphere. These balloons are designed to reach altitudes of up to 100,000 feet in order to simulate space-like conditions. These balloons are often used to conduct research and collect atmospheric data. The payload that they carry consist of hardware and cameras. The hardware is necessary to relay and assess data before, during, and after the launch. The type of telemetry data include the balloon's location, temperature, and state of health. The onboard cameras record video and photo footage during the launch. After reaching a certain altitude, the balloon bursts, or is released by ground or onboard command and begins descending back to earth. Once it lands, teams are able to recover the module, retrieve its stored data, and analyze its condition post-mission.

Balloon satellites are commonly used to research atmospheric conditions. For example, due to the high concentration of hurricanes in the Atlantic Ocean, the forecasters have been launching weather balloons to track their locations, since they are able to capture data from the atmosphere at a generally low cost [1]. An autonomous recovery, especially in Hawaii where it would most likely land in the ocean, would help with the environmental concerns that come with losing hazardous materials in the ocean. It would also prevent the loss of expensive hardware and recorded data from the satellite. If the recovery system works, it would be beneficial not only for UHABS-5, but other BalloonSat missions and future recovery methods of various spacecraft and satellites.

UHABS-5 is fortunate enough to have four UHABS missions preceding it. These four missions will heavily aid in the design process for UHABS-5. Having access to most of the previous missions' resources will ensure that the team will be able to analyze and research their methods and errors. This will allow us to figure out which aspects of previous missions were most difficult to accomplish, which systems did not work, and, if any missions were unsuccessful, what the causes were. Having previous projects with similar objectives allows for making improvements to old methods to ensure that UHABS-5 is complete and successful in fulfilling all of its requirements and objectives.

The ME 419 Theia 1 MACworks` launched in Spring 2009, successfully lifted a balloon satellite payload into the atmosphere to about 45,000 feet. The module collected various pictures and videos of high altitude. Theia 1 was a special mission because it was the first one to be launched and recovered at UHM. It used a 7 megapixel digital camera with 1 gigabyte memory cards [2]. UHABS-2 MoonReika was the ME 419 class project of Spring 2014. The capabilities of MoonReika was not tested due to the lack of time that the team faced. Because of this, UHABS-2 focused more on the design and structure of their system in hopes to give the next mission a head start. The design they chose followed a saucer shape for stability, due to wind deflection on their choice of geometry. Their mission was to design a BalloonSat that would be more stable during flight [3]. UHABS-3 was the ME 419 class project of Spring 2015. Their objective was to test the autonomous water recovery. This team incorporated an Ocean Mode to their balloon satellite design. Because time was not used wisely, they did not meet their objectives in time and had many issues with their hardware and software. However, they succeeded in providing a valuable lesson for future UHABS projects [4]. UHABS-4 Clementine launched in Spring 2017 during ME 419. They incorporated an Unmanned Aircraft System (UAS) within their balloon satellite, which would fly their payload back to base. Although they never had a chance to test their UAS system due to technical issues at the last minute, it gave future projects an idea that could be improved. This project did launch successfully, but tracking data was lost and it was not able to be recovered [5].

Balloon satellites are generally low-cost, quick deploying satellites that collect data and perform other miscellaneous tasks in the stratosphere. However, the balloon satellite's descent back to ground level is highly dependent on variables outside of the user's control, making it difficult for the system to land in a particular area. This problem is magnified when a balloon satellite is launched in close proximity to a large body of water (i.e. Pacific Ocean) where the system will become damaged or completely lost if submerged in said body of water. Therefore, there is a need for a balloon satellite that can not only survive a descent from high altitude, but also autonomously propel itself to a recovery site in a marine environment.

With a solution to a recoverable balloon satellite system, a larger array of experiments and data collection can be conducted in the stratosphere where information is unable to be transmitted to a ground station and must be stored and recovered on board the balloon-sat. The capacity to perform more experiments and test different theories aboard the balloon-sat will eventually lead to breakthroughs in technology and space travel. These breakthroughs have a significant impact on society, as they are prevalent in typical everyday lives (i.e. communications, transportation, logistics, etc.).

Current balloon satellite systems that fail to be recovered can have detrimental effects on the environment. The most common material used on balloon satellite payloads is Styrofoam, as it is both durable and provides insulation for the electronics inside. According to Science Learning Hub [6], Styrofoam is not considered "eco-friendly", with a Styrofoam cup having a lifespan of 500+ years (to biodegrade). A recoverable balloon-satellite system will eliminate the amount of pollution left behind from non-recoverable balloon-satellite system without compromising the structural integrity and insulation provided from using Styrofoam in the system framing.

Other universities have attempted autonomous recovery of satellites, such as Embry-Riddle Aeronautical University, which attempted a UAS drone recovery, but could not get it to deploy from the satellite and return to the user [7]. Full-scale autonomous boats have been built and researched, but on a much larger scale than UHABS-5's propulsion module. With further research and testing, UHABS-5 will hopefully succeed in autonomous recovery because it would largely assist in allowing for other experimentation such as ocean surveying.

2 Technical Overview

2.1 Objectives and Requirements [KBC]

The UH ME 481 team will successfully develop the UH Advanced BalloonSat System mission #5 (UHABS-5) which will be capable of carrying payloads to a near-space environment and return to safely to Earth for intact recovery. If it lands on the ocean, the BalloonSat will autonomously propel itself to a designated target for recovery.

In order to complete the mission stated above Zeppelin set the primary objectives and their success criteria listed in Table 2.1.

Table 2.1: List of primary objectives and their success criteria

Primary Objectives		
Object ID	**Description**	**Success Criteria**
1	To develop a reliable, high-altitude BalloonSat system capable of carrying small payloads in a near-space environment	Balloon and modules reach desired altitude and modules released at appropriate altitude
2	To develop a recovery system for UHABS-5 that will enable the BalloonSat to safely land on land or ocean with means to enhance its recovery.	Parachute deployed when appropriate to ensure that the C&C and P&P module are able to land safely. The C&C and P&P module are highly visible and have label to indicate who to return devices to
3	To develop a recovery system that in the event of an ocean landing shall autonomously propel itself to a designated destination for recovery.	P&P module designed for ocean conditions and tested in ocean conditions
4	To use and test HSFL technologies including communication system and COSMOS for flight and ground software.	C&C, P&P, and Ground Station are able to integrate COSMOS when in use and P&P and C&C module are able to accommodate HSFL technologies

Zeppelin set the secondary objectives and their success criteria, listed in Table 2.2, in order to produce

Table 2.2: *List of secondary objectives and their success criteria*

Secondary Objectives		
Object ID	**Description**	**Success Criteria**
S.1	To teach the members of the team how to successfully plan and implement an aerospace engineering project.	Meeting all requirements set forth by the team for the system
S.2	To obtain spectacular images for PR purposes.	Capturing still images during the mission
S.3	To collect atmospheric and state of health data during the mission and transmit it to the UHABS ground station and store it onboard for later recovery	Successfully reporting telemetry data in real time that is able to be monitored by the ground station

The UHABS-5 mission must adhere to the constraints listed in Table 2.3. A majority of the constraints are set to follow FAA regulations to allow the team the ability to launch once a launch date and site are selected.

Table 2.3: *List of constraints set for UHABS-5*

7. Constraints	
7.1	Time
7.1.1	UHABS-5 design shall be complete by December
7.1.2	UHABS-5 shall be built, tested, launched, and recovered by May
7.2	FAA & FCC Regulations

The team set the following system requirements for all subsystems to work towards to complete the primary and secondary requirements.

Table 2.4: *System requirements for all subsystems*

1. Mission		
1.1	UHABS-5 shall consist of a parachute, command and control (C&C) module, a payload and propulsion (P&P) module and any necessary ancillary equipment and structure.	Mandatory
1.2	Team shall design the UHABS-5 system, procure required parts and materials, design and build modules, integrate and test the system, launch and operated the system, recover the system if possible, and analyze and report the data from the mission.	Mandatory
1.3	Instrumentation for the module shall be accommodated in the UHABS-5	Mandatory
1.4	UHABS-5 shall select a launch site appropriate for the level execution of the UHABS-5 launch sequence	Mandatory
5. Testing		
5.1	Generally, testing shall be required to prove UHABS-5 can meet the functional, environmental, and operational requirements	Mandatory
5.2	A test run on a secluded area of the ocean shall be required to prove the ability of UHABS-5 to move in and reach a designated target	Mandatory
5.3	Testing shall be required to prove the ability of UHABS-5 to release the parachute when it approached the surface	Mandatory
6. Project Management		
6.1	A Project Management Plan (PMP) shall be produced in time for the Critical Design Review (CDR). The PMP shall contain the Work Breakdown Structure (WBS), schedule and other project information as required by the Customer	Mandatory
6.2	A Configuration Management Plan shall be implemented	Mandatory
6.3	Weight, power, and cost budgets shall be produced and updated when necessary	Mandatory

2.2 Conceptual Design [RP, DA]

The Balloon Satellite system is broken into three trades, C&C Module, P&P module, and Ground Station. The design for each trade was conceptualized with the goal to effectively meet each trade's purpose.

The purpose for the C&C module is to do data collection up to near space elevations through the use of various sensors collecting data such as location, pressure and temperature and transmitting that information to ground control. To meet the C&C's purpose, a few designs were considered, a styrofoam cube structured module, a styrofoam catamaran structured module, and a styrofoam capsule structured module. After reviewing each design, it was determined that the cube design generated too much drag that would hinder the propulsion trade, and the catamaran capsule design ran a high risk of landing improperly; therefore, the capsule design was selected because it had the lowest drag, and lowest risk of landing improperly in the wrong orientation. Furthermore, styrofoam material was chosen for sensor protection and insulation.

The purpose for the P&P module is to provide an autonomous recovery system that will propel the payload (SD card) to a designated area for extraction once the balloon satellite descends and lands in the ocean. Similarly to the C&C design, the P&P trade also had a few design options to meet its purpose and each were reviewed and the most optimal design was chosen. The motor had three options, an alternating current (AC) motor, brushed direct current (DC) motor and a brushless DC motor. The motor needed to be durable and be able to provide enough torque, rotations per minute (rpm) and power to overcome ocean conditions. From the options, the brushless DC motor was the most optimal because it provides more rpm and lasts longer than the brushed DC motor and is more efficient than the AC motor. Therefore, the brushless DC motor was selected because it best fulfilled the motor design needs. The battery to support the motor must be able to handle the motor's power input and output, and the propulsion system must provide practical and effective steering. The battery options were either a nickel-metal hydride or a lithium polymer battery, and both were able to support the motor, however, the lithium polymer had the advantage of lighter weight and higher capacity that made it the clear choice for the motor power supply design. The propulsion options were either a rudder or dual propeller blades. The rudder seemed to have a higher chance of failure since it involved providing electrical power and controls for steering the rudder, whereas dual propellers can steer the boat by simply slowing or turning off of one of the motors for the propeller. The dual propeller was selected since it was the most practical steering design.

The purpose of the ground station is to monitor and record data collected from the C&C and P&P in real time and be able to execute commands. The ground station is designed to have a computer processor capable of keeping up with the constant intake of data, a reliable antenna that can pick up the data collected, and a computer compatible with COSMOS software, the operating program for the balloon satellite. The design choices for the antenna were a turnstile antenna or a panel antenna. Ultimately, the antenna that can best follow the trajectory of the balloon satellite and has a higher gain value would the best antenna that follows the design intent, and comparatively between the two antennas, the turnstile antenna met those conditions best, therefore, a turnstile antenna will be utilized. As for a computer, a Windows laptop with a linux operating system was chosen for portability and compatibility with COSMOS.

In the proposal, much of the design had not been confirmed and only possibilities were discussed. During this period, the objectives were still being clarified for each subsystem and members were still trying to determine what was necessary to accomplish these objectives. Since then, each subsystem team has thought of detailed designs about the structure, avionics and electronics, and materials of their module as well as solidified design objectives and requirements at the top level and subsystem level.

The proposal discussed which avionics may be needed, and a general overview of how the system was going to work. The balloon and C&C module would contain all of the avionics sensors such as ones to measure temperature, altitude, pressure, and location, as well as incorporate transceivers to receive commands from the ground station and communicate all of the data real-time. The P&P module would consist of the autonomous recovery system and the cameras as well as transceivers to also transmit its location data and video footage to the ground station. These two modules were to be tethered together and the propulsion module would tow both of them back for recovery.

However, since then, it has been determined that because of the high possibility of strong ocean current, that towing both modules may be very difficult. Because of this, it was decided to have all of the data measured from the C&C stored wirelessly on an SD memory card on the propulsion module. The tether holding the modules together would have the ability to be severed at the command of the ground station. These two things were decided on in case towing both modules proved too difficult or was not working.

Since, now, each subsystem has decided on specific objectives and requirements, the avionics, electronics, and structural design have been finalized. The C&C module, instead of just a cube, will be in the shape of a capsule, to allow for simpler attachment of parachutes, tethers and cameras and to reduce drag in the water. The avionics being utilized are thermocouples to measure temperature (internal and external), a GPS for location monitoring, an IMU (inertial measurement unit) which calculates position, altitude, and velocity, and a pressure monitor. All of these selected avionics should be compatible with the chosen CPU, which was determined to be a Teensy 3.2. The selected camera, should have its own wi-fi capabilities to enable live video streaming to the ground station. The P&P module will incorporate a double-hull catamaran design with two propellers. This structure provides enough space for electronics and reduces fluid drag. The electronics selected will also be a Teensy 3.2 and GPS, and will also contain the SD memory card. More detail on each subsystem’s designs and reasoning will be discussed later in the report.

Each component of the system has undergone analysis to determine which design was best suited to accomplish the objectives. Several design iterations were done to ensure that most of the concerns stemming from each subsystem were addressed, and tried to lower the risk level.

2.3 Baseline Design

2.3.1 Top Level Design [RP]

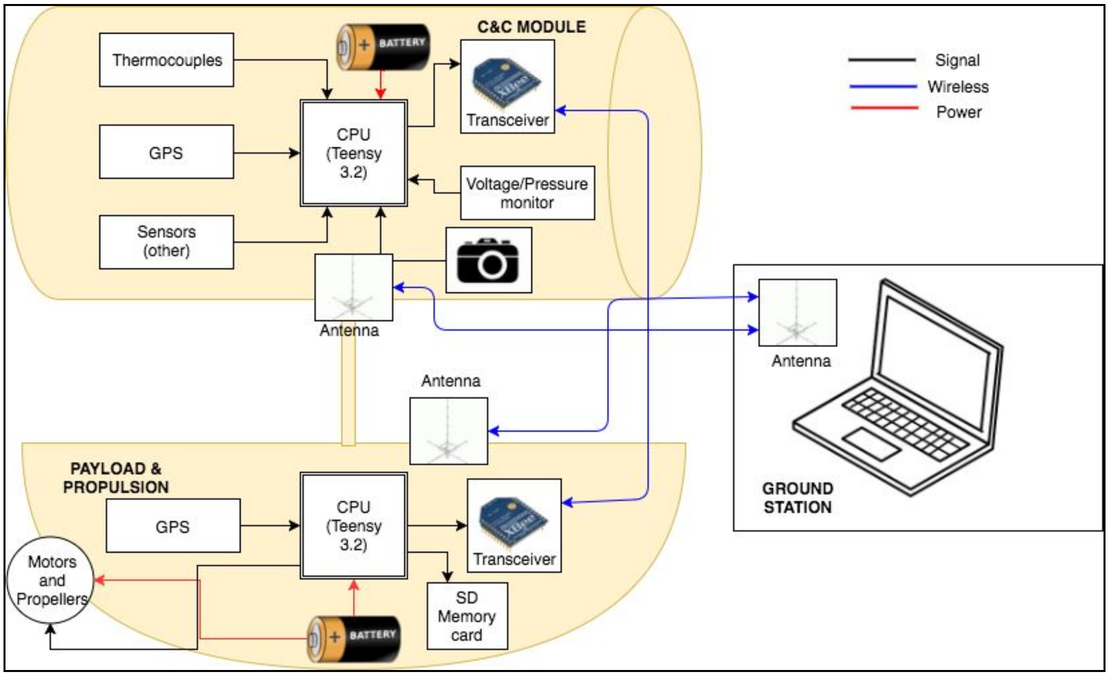


Figure 2.1: *System Architecture for overall system.*

The system architecture displays a general mapping of signals passing through each component of the system. The transceivers and antennas play a crucial role in the mission, as they are responsible for the wireless transmission of data between each module and the ground station. Each sensor (GPS, thermocouples, IMU, pressure monitor) sends the respective data to the CPU (Teensy 3.2), which sends all of it to the transceiver and antenna. The transceivers wirelessly transmit data across modules, whereas the antenna transmit data from each module to the ground station.

The selected design should meet all objectives and requirements set forth by the team. These objectives and requirements should enable UHABS-5 to have a successful mission. A successful mission entails successful launch, with data being transmitted to the ground station, and successful recovery of the payload. Prior to launch, each module will be insulated, pressurized, and waterproofed. On the day of launch, the balloon will be inflated to lift the payload into the stratosphere. During this lift, video will be being recorded from the C&C module, and all of the sensors will be collecting necessary data throughout the launch. This launch should show significant temperature, pressure, and altitude changes. The transceivers in the C&C module will be communicating this data to the ground station back at sea level, while also wirelessly storing its readings onto the P&P module's SD memory card. Once the balloon bursts at a certain altitude, or once the ground station releases the modules from the balloon, it will begin its descent back to sea level. During this time, data will still be being monitored by the ground station and collected by the C&C module. A parachute will release, slowing the descent of the modules until landing.

Once it has landed, the ground station will send the location of the pickup site to the P&P module and it will begin to travel there. Location beacons (a light and alarm) will also go off upon landing, and the onboard GPS should enable location tracking. If the C&C module proves too hard to be towed, the tether will be severed so just the P&P module can be recovered. Simple operational diagrams can be found in the appendix. Each specific part of the system and its function in meeting the objectives are mapped out in figure 2.2.

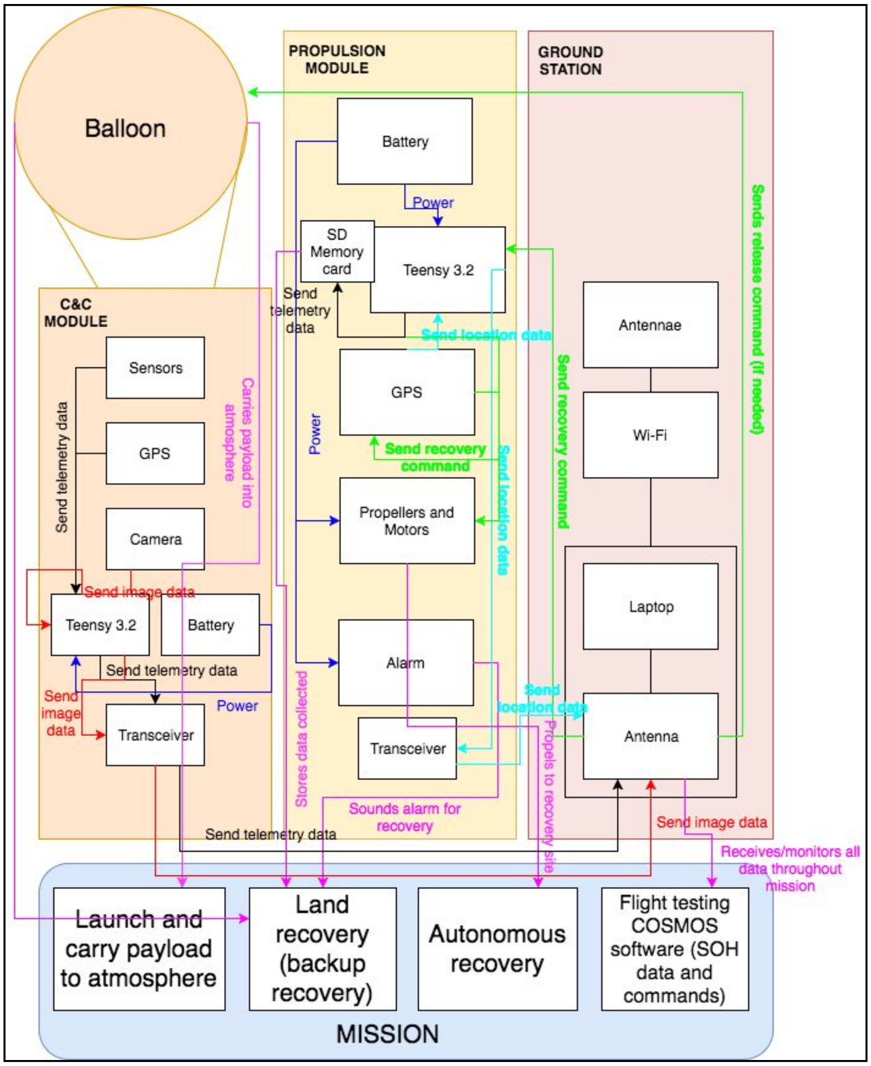


Figure 2.2: *Functional Flow Block Diagram for overall system*

Table 2.5 shows the total Mass and Volume budgets for the C&C module and the P&P module. More detailed mass and volume budgets can be found in the subsystem level technical overview.

Table 2.5: Mass and Volume of each module.

Type	**Description**	**Volume (in^3)**	**Mass (lbs)**
Total Allowable			12

C&C Module	Totals for the C&C Module, more detailed chart in the subsystem budgets	275.16	1.67
P&P Module	Totals for the P&P Module, more detailed chart in the subsystem budgets	15.281	4.1455
Total		290.441	5.8155
Remaining		-	6.1845

Table 2.6 shows the total Power budgets for the C&C module and the P&P module. These budgets are optimized because the modules need to be operational during the . More detailed power budgets can be found in the subsystem level technical overview.

Table 2.6: Power Budget for each module correlating current draw and battery capacity for an estimated operating time.

Component	**Description**	**Current Draw [A]**	**Estimated Operating Time**
C&C Module	The total current drawn from all components within the C&C module and the estimated operating time	1.46 A	6.85 hours
P&P Module	The total current drawn from all components within the P&P module and the estimated operating time	8.56 A	1.028 hours

Each system will need to complete their own subsystem-level testing before being tested together. Each subsystem should make sure that their module can withstand the temperature changes, pressure changes, and water landing, as well as making sure the sensors are measuring data accurately. They should also have done drop and impact tests to mirror the landing. After this step, both the C&C and P&P modules should test readings with the ground station. Doing this will be difficult without actually doing a test launch, however, with proper procedures, the distance that will be experienced during the mission can attempt to be mirrored closely. Before testing the range capabilities, each module will ensure the readings from the sensors and the GPS are being correctly transmitted to the ground station. Once that is confirmed, then the range capabilities can be tested. To do this, there must be a clear path between the ground station and the modules and it cannot be obstructed by mountains. Locations will be selected carefully in attempt to closely mirror the range on the launch day. Once both modules have done this, the P&P module will test their autonomous recovery. This can be done by planting the module somewhere in the ocean and sending it location data onshore. The distances it will travel will be varied, and it will be tested in various currents to further test its capabilities to withstand the ocean. The next step will be to test both modules with the ground station, the system as a whole. This step will be the same as the last, where the ranges are varied to ensure all data is being properly transmitted to the ground station. In addition to that, the data measured on the C&C module should be storing wirelessly to the SD memory card onboard the P&P module. Once all of this has been completed, if the budget allows, a test launch can be done, though this is a large risk in case any modules are damaged or lost.

2.3.2 Subsystems

2.3.2.1 Balloon and C&C

2.3.2.1.1 System Architecture showing highlighted subsystem [EV]

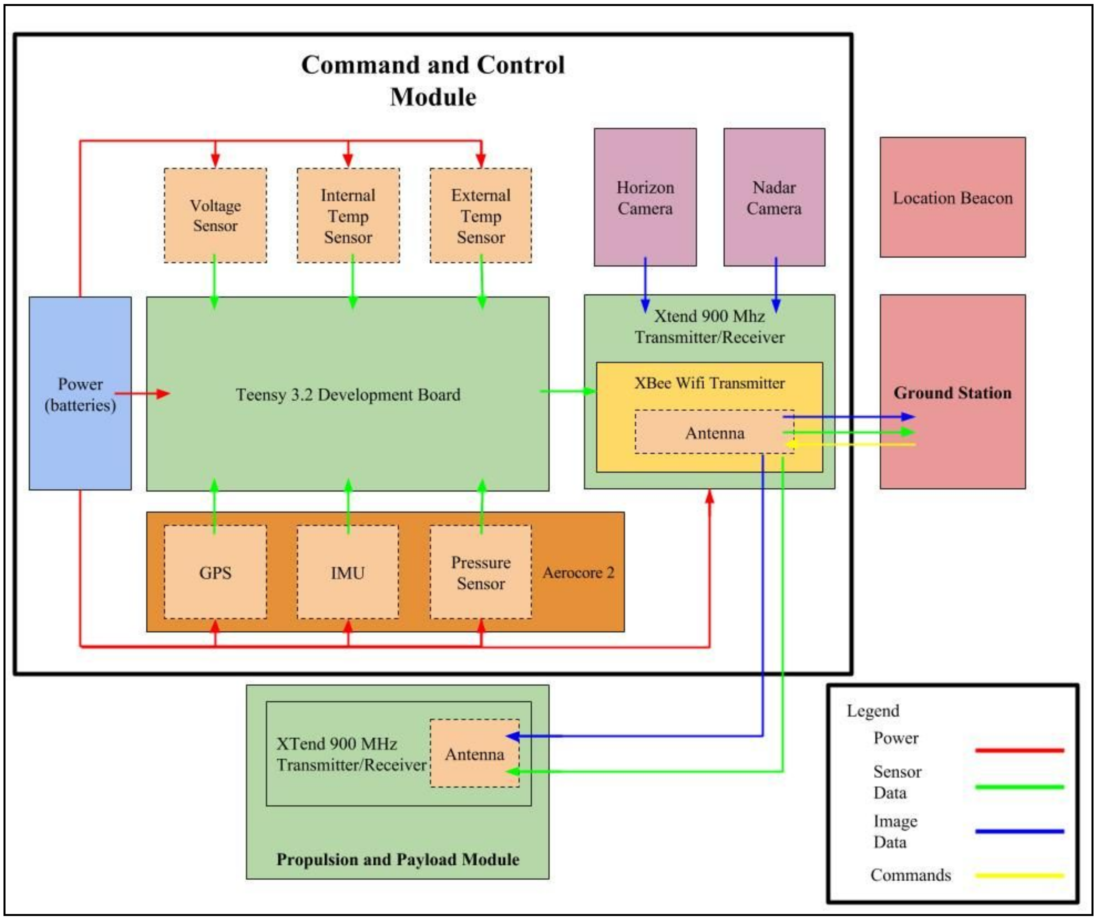


Figure 2.3: *System Architecture of the C&C Module.*

2.3.2.1.2 Subsystem Team Roles & Responsibilities [YT]

Yun Feng Tan is the Balloon and C&C Module team lead and is responsible for working on the structure of the C&C Module. This includes the design and material selection for the Balloon and C&C Module.

Manny Valdez is a member of the Balloon and C&C Module team and is responsible for the Avionics portion of the C&C Module. This includes the equipment needed to maintain constant connection with the ground station.

James Yang is a member of the Balloon and C&C Module team and is responsible for installing the payload cameras of the C&C Module. This includes the camera for the still photo and the camera which maintains a constant recording in the nater position.

2.3.2.1.3 Top Level Requirements & Constraints for Subsystem [YT, EV, JKY]

2.1. The Balloon and C&C module shall reach an altitude of up to 100,000 feet.

2.2 The C&C module shall have constant communication with Ground Control for data transmission.

2.3. The C&C module hall capture still photos and live video feed.

2.4. The C&C module shall receive a command from Ground Station or be released autonomously when data is sufficient and the balloon has not burst.

2.5. The C&C module shall deploy a parachute after separation with the balloon and reach a landing speed of up to 15 ft/s.

2.3.2.1.4 Subsystem Derived Requirements [YT, EV, JKY]

Upon ascending to high altitudes, the C&C module and onboard devices (2.1.1) shall withstand the temperature change (up to ~ -59 °C), and pressure change (to ~1 kPa). (2.2.1)There shall be sufficient battery power to cover the needs of avionics and payload cameras throughout the flight. (2.2.2) The onboard radio shall have enough range to stay connected to the ground stations (downlink telemetry data and live stream video) until balloon the bursts. Upon landing, (2.5.1) the C&C module shall be waterproof in case of landing in water. (2.5.2) The avionics and payload shall survive the shock from impact at 15 ft/s, and the C&C module shell shall remain structurally sound and waterproof.

2.3.2.1.5 Major Trades [EV, JKY, YT]

Few design concepts were discussed in the subsystem's second team meeting to have a concept of functionality, aerodynamics, and lightweight. The first design focused on the functionality aspect of design is to have a module that will fulfill the ascent, descent, and communication requirements. A cube styrofoam structure would easily attach the balloon and parachute, as well as house the avionics. However, the issue with this design is that there would be high amount of drag for the P&P to tow. The second design focused on the aerodynamics, where a speedboat or catamaran design typically have low drag. However, if it lands on the top side, there would be a high drag force and be difficult to tow. For the most recent and optimal design, the subteam decided on a capsule design. A capsule is highly aerodynamic, structurally sound to survive high impact, resistively low in drag, and spatially sufficient. The center section and lower end cap provide ease of arrangement for the avionics. When the module lands in ocean, it's shape would not be compromised due to its geometry and high moment force on its longitudinal axis. The dome cap of the module provides low drag resistance in the water and air.

Table 2.7*: DMM for the overall design of the Command and Control Module.*

DESIGN			**Cube**			**Catamaran**			**Capsule**		
Objective	**Weight**	**Parameter**	**Magnitude**	**Score**	**Value**	**Magnitude**	**Score**	**Value**	**Magnitude**	**Score**	**Value**
Structural Integrity	0.35	Emperical	Excellent	10	3.5	Good	5	1.75	Excellent	10	3.5
Drag	0.45	1/Coeff.	0.87	1	0.45	4.76	10	4.5	3.39	8	3.6
Space	0.20	cubic in.	256	10	2.0	196	7	1.4	256	8	1.6
Overall	**1.0**				**5.95**			**7.65**			**8.7**

Upon termination of the flight whether by balloon bursting or commanded release, the parachute will deploy upon separation. The parachute will be hung inbetween the balloon and the C&C module, in the closed state. This method prevents additional failures that could occur with a commanded deployment. To avoid the burst balloon shreds entangling the parachute, the plan is the release the module and deploy the parachute before reaching estimated bursting altitude. For the parachute after calculation (in Analysis), it is decided between the Rocketman 9ft Payload Recovery Parachute and a 115in diameter circular parachute fabricated out of nylon. Due to the lack of knowledge of parachute, and the excellent track record of Rocketman parachutes, making them an excellent choice.

For the microcontroller that will process sensor and image data. It was determined between an Arduino Uno and a Teensy 3.2. In the C&C module, there are a total of 6 sensors and a wifi extender that needs to be connected to the microcontroller. The wifi extender need to communicate with the cameras as well. Since the Arduino can only utilize one sensor, the Teensy 3.2 would be the best choice for the C&C's microcontroller as it can connect multiple sensors and the wifi extender.

The transmission component of the C&C is highly important as it is the device that will transmit the data to the ground station. Two transceivers were compared while considering range, power consumption, and cost. The Aerocomm transceiver was the first choice with a range of 4 miles, high-medium power consumption, and relatively low cost. The Xtend 900MHz transceiver is the second option and has a larger range of 40 miles, medium power consumption, and a high cost. The Xtend 900 MHz transceiver is the best option as it is more practical to use for the large range, since the balloon satellite is expected to travel further than 4 miles.

For the numerous amount of sensors gathering information of the C&C module SOH, it is necessary to compare components for each sensor to determine which would function best. The One Wire Ambient Temperature Sensor is the best option as it is easy to solder onto the Teensy and the sensor can adhere to any surface. The voltage detector is the better option than the breakout board since it will not need wiring and is at a low cost of $0.10. The AeroCore 2 is the best option for the GPS since it also can collect pressure and IMU data, all in one unit. This makes the use of compiling components easier and lowers the risk of failure when compared to using two.

Table 2.8: *DMM of all sensors needed for the C&C module.*

SENSORS			**Temperature**			**Voltage**			**GPS / IMU / Pressure**		
			One Wire Ambient Temp Sensor; SparkFun Digital Temperature Sensor Breakout			**Voltage Detector; AttoPilot Voltage/ Current Sense Breakout**			**AeroCore 2; SparkFun Venus GPS + Weather Shield**		
Objective	**Weight**	**Parameter**	**Magnitude**	**Score**	**Value**	**Magnitude**	**Score**	**Value**	**Magnitude**	**Score**	**Value**
Energy Consumption	0.30	Volts	3.0; 3.3	8; 8	2.4; 2.4	1.5; 3.3	10; 8	3.0; 2.4	16; 6.6	4; 7	1.2; 2.1

Ease of Use	0.35	Emperical	Great; Great	8; 7	2.8; 2.45	Excellent; Good	10; 8	3.5; 2.8	Excellent; Okay	10; 3	3.5; 1.05
Cost	0.35	$ USD	1.95; 4.95	10; 7	3.5; 2.45	0.10; 19.95	10; 1	3.5 0.35	149.00; 79.90	6; 8	2.1; 2.4
Overall	1.0				**8.7**; 7.25			**10.0**; 5.55			**6.8;** **5.55**
Final Choice			**One Wire Ambient Temp Sensor**			**Voltage Detector**			**Aerocore 2**		

The cameras compared were the GoPro Hero 5 and the Yuntab action camera. Both cameras perform the same functions, except resolution which is not necessary. The Yuntab action camera was chosen for it's price since it is lower and provides the necessary functions needed.

The Command and Control module is an important data gathering device for the BalloonSat team, however it may be a burden for the Payload and Propulsion module to take home. This comes down to two difficult decisions, to keep the C&C module or to detach the C&C module. Keeping the C&C module requires more work on the P&P module, since they will have to maneuver through ocean obstacles and drag behind an object nearly half their size. Detaching the C&C module also has its drawbacks, for example, the loss of expensive equipment. It comes down to whether or not the P&P module can handle the amount of drag the C&C module produces. A command will be implemented giving the option of detachment if the load becomes too much for the P&P module to bear.

2.3.2.1.6 Requirements and Implementation [JKY]

Table 2.9: *Side by side of the C&C requirements and implementation.*

Requirements	Implementation
Shall reach an altitude of up to 100,000 feet	Balloon of calculated size filled estimated amount of helium
Shall maintain real time communication with ground station	Onboard transceiver used at the same frequency of the ground station
Shall capture still photos and live video	GoPro or approved-equal will be installed on the side of the C&C Module and in the position facing downwards
Shall have the ability to release the balloon on command	COSMOS software will be relaying commands to the transceiver for the action of detaching the balloon
Shall deploy a parachute to reach a landing speed of up to 15 ft/s	A parachute with a release mechanism will be attached to one side of the C&C Module in preparation for deployment.

2.3.2.1.7 Functional Flow Block Diagram with External Interfaces [EV]

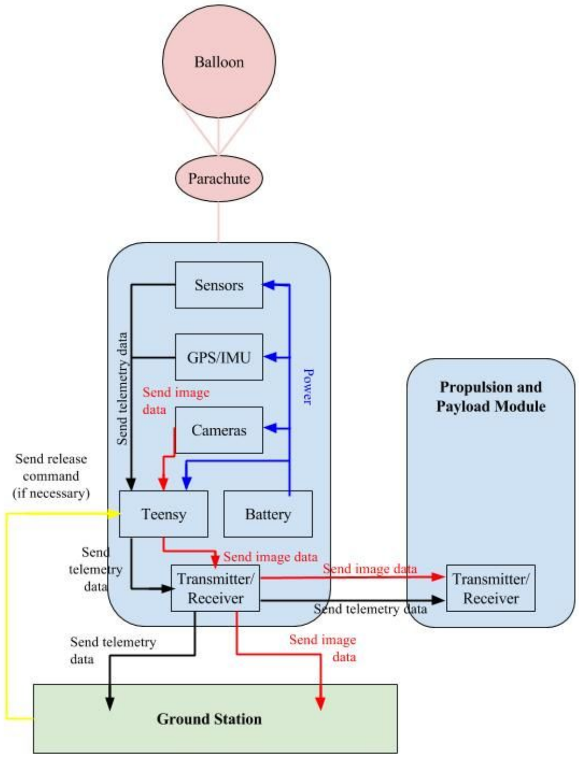


Figure 2.4: *Functional Flow Block Diagram for the Command and Control module.*

2.3.2.1.8 Mass & Volume Budgets [EV]

Table 2.10: *Mass and volume budget totals. The total volume may be subject to change.*

Type	**Description**	**Volume (in^3)**	**Mass (lbs)**
Total Allowable			6.0
Insulation	`Styrofoam	256.0	0.46
Power Supply	10,000 mAh Li-Ion	7.45	0.40
Avionics	Teensy 3.2 Development Board, XTend 900 MHz Transceiver, XBee Wifi Transceiver, AeroCore 2, sensors	4.03	0.16
Cameras	Yuntab Action Cameras	3.26	0.34
Misc. (+30%)	Adhesives, wires, spacing, beacon	4.42	0.31
Total		19.16	1.67
Remaining		n/a	4.33

2.3.2.1.9 Power Budget [EV]

Table 2.11:*Power Budget total. 6.85 hours of module power life is expected.*

Component	**Current Draw [A]**	**Power [V]**
Battery Pack	10,000 mAh	5.0
Teensy 3.2 Development Board	0.045 (max)	1.71 - 3.60
XTend 900MHz Transceiver	0.810 @ 30 dBm	2.8 - 5.0
XBee Wifi Module	0.104 @ 3.3 V	2.1 - 3.6
AeroCore 2 (GPS, Pressure, IMU)	0.500 @ 3.3 V	3.1 - 16.0
Temperature Sensors	0.0010	1.5
Voltage Sensor	0.0005	1.5
Cameras	0.200 (x2)	8~9 [9V battery] (x2)
Total Current Draw (excluding cameras)	1.46 A	
Estimated Operating Time	6.85 hours (6 hours 51 Minutes)	

Estimated operating time calculations: Time = Capacity / Current Draw → 6.85 hours = 10.00 Ah / 1.46 A

2.3.2.1.10 Description (including schematics, list of components, etc.) [EV]

Once the optimal design was decided among the subsystem members, it was presented to the rest of the project team during team meeting #3 as an update in progress and subjected to peer review. After feedback has been taken to consideration, a sketch was made to illustrate the layout of components in the module and overall internal and external design. Figure 2.3 shows the shape and geometry of the module and detailed subsections.

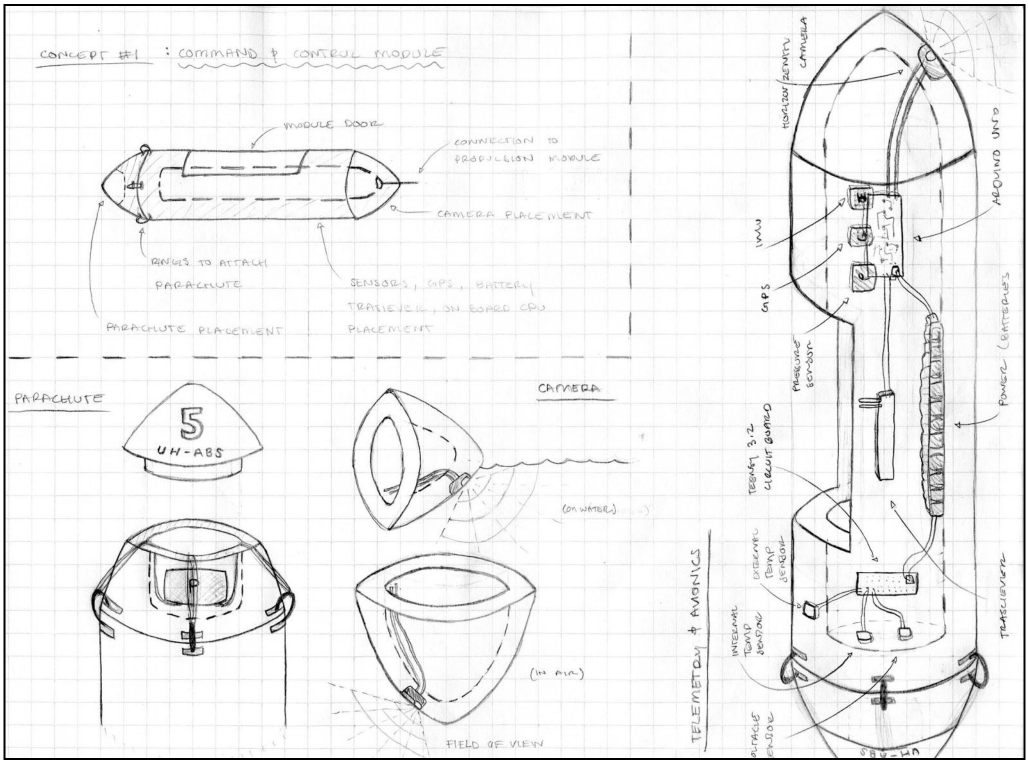


Figure 2.5: *First concept design for the C&C Module with locations of the components and hardware.*

There are 4 steel rings hooked through the module where thick plastic reinforcements are placed so the module does not detach from the parachute due to high amount of lift. The midsection and bottom dome store the avionics, which include: a 10,000mAh battery, a Teensy 3.2 development board, an XTend 9000 MHz transceiver, and XBee Wifi module, an AeroCore 2, an external and internal temperature sensor, and a voltage sensor. The temperature and voltage sensor, and Aerocore 2 are connected to the Teensy. The image and telemetry data is sent to the Ground Station through the XTend for real time data collection. The same data is also transmitted through the XBee to be sent to the P&P module for backup. The external temperature sensor would require waterproofing for maintaining a dry interior. All the components will be connected to and powered by the battery pack. The midsection is sealed with a door that will be waterproofed once the avionics are active and ready to be launched.

The material used for the C&C module is styrofoam, since it provides a great insulation while having a low mass. Styrofoam is also buoyant and when shaped with round faces, most of the structure would not be submerged in water. For adhesives, silicon is the best option as it is waterproof and easy to apply. Foil lining will be used inside to reduce interior heat loss.

2.3.2.1.11 Results of Analyses [YT, JKY]

After studying the available inventory and simulations of the projected landing sites, the 600g Latex weather balloon from High Altitude Science is a viable choice as there is one readily available, with the ability to carry the BalloonSat to the desired altitude of ~65,000 ft. 65,000 ft. was chosen because useful telemetry data can be collected and still-images of the horizon can be captured at the altitude. The equations for determining the balloon choice starts with the size of the balloon, payload weight, and positive lift. By adding the total of these three variables and dividing by 27.82, it gives the amount of helium needed to perform the way it was estimated. The altitude is predicted with a comparison of the balloon's initial volume. The lower the volume, the higher the balloon will go before it will burst. Using the equations for optimal balloon size provided by the High Altitude Science website, the performance of the selected balloon carrying 12lbs of weight will burst at the estimated altitude of 167290 ft. With 20lbs of positive lift, the balloon will require ~522 cu. ft. of helium, and have an ascending rate of ~29.3 ft/s. Based on that calculation, the flight time till reaching 65,000ft will be ~36.93 minutes.

For the descent portion of flight, a parachute with the diameter of 115 in was calculated to be a reasonable choice. This is because a 115 in parachute will slow the payload down to 15 ft/s, assuming the payload is at the maximum of 12 lbs. The calculation for the size of parachute is based on the wind resistance force equation

$$F_D = \tfrac{1}{2}\rho C_d A v^2 \tag{1}$$

where F_D is the drag force, ρ is the density of air, C_d is the drag coefficient, v is the velocity through air, and A is the area of parachute. With $F_D = F_G = mass * gravity$, by plugging in all the variables, the resulting area for a circular parachute is determined to be 115 in.

2.3.2.1.12 Testing Plan [JKY, KC]

Each individual part of the Balloon and C&C module will require testing before the final product. This is to ensure the individual sections can work together as a whole. Testing will be done during and after the fabrication phase. The structure of the balloon, avionics, and payload will all be tested using different methods.

When the outer shell of the module is completed, various tests will be conducted on the hull to ensure it meets all requirements. Of these requirements, the ability to remain watertight and thermally insulated are the areas of concern. To test if the module will remain watertight in a body of water, a large container will be filled to sufficiently cover the module. The module will then be submerged for a 12 hour period. At the end of this period the module will be inspected for any penetrations of water. Insulation will be tested in a similar fashion where a thermometer will be placed within the module before it is sealed. The module will be placed within a freezer and the interior temperature will be recorded. The duration of the experiment will last 3 hours at which point the module will be taken out of the freezer and the internal temperature will be recorded and compared to the lower limit of the operating temperature of the internal components. To ensure the module survives the initial impact onto water, it will be dropped at a sufficient height to emulate the descent velocity of the BalloonSat once the parachute is engaged, the module will be visually and tactilely inspected to ensure the module has not been damaged.

Each individual sensor will be tested to ensure proper function and accurate readings. For exterior/atmospheric temperatures, a thermocouple will be used for data collection. To test the thermocouple, it will be used to measure the surface temperature of dry ice (-75.8 °C) to replicate the freezing temperature at high altitude (-59°C at 90,000ft).

The payload consists of two cameras, one for still-image and one for live video. Functionality of each camera will be tested as well as the image quality. To test the quality of the video and images, different settings for aperture, exposures, and shutter speeds will be evaluated to determine the best setting for pictures/video in flight.

2.3.2.1.13 Subsystem Schedule using WBS and Gantt Chart [JKY]

In the time period of prototyping from September 25th to December 3rd the Balloon and C&C subteam will determine and formulate: the designated structure of the C&C Module, size of latex balloon, size of parachute, wiring of sensors, and amount of helium required for positive lift. Although most of these topics are already determined, they are subject to change if unidentified issues arise.

2.3.2.1.14 Remaining Issues and Concerns [JKY, YT]

The structure and weight of the C&C Module is a recurring issue that deals with the aerodynamics in a fluid. The design must have least resistance for the P&P to tow. Having more resistance requires more energy, which is vital when also dealing with the resistance of currents.

In order to take a good still image, the right camera and proper positioning is paramount. To take a still photo with a leveled horizon, the camera has to be securely fixed and properly balanced in the module. Unlike the onboard avionics, the lens of the camera is not insulated or protected by the foam shell; resulting in the camera to be placed in a way that is waterproof and shockproof to survive the impact and landing in water.

Insulation is another key issue for this project due to the fact that most electronical equipment will fail in low temperature. If the walls of styrofoam walls are thinner than optimal, the inside temperature will start to decrease significantly. The heat generated by the onboard avionics need to be determined in order to decide on the thickness of the walls as well as the need for additional heat supply.

2.3.2.2 Payload and Propulsion

2.3.2.2.1 System Architecture showing highlighted subsystem [CN]

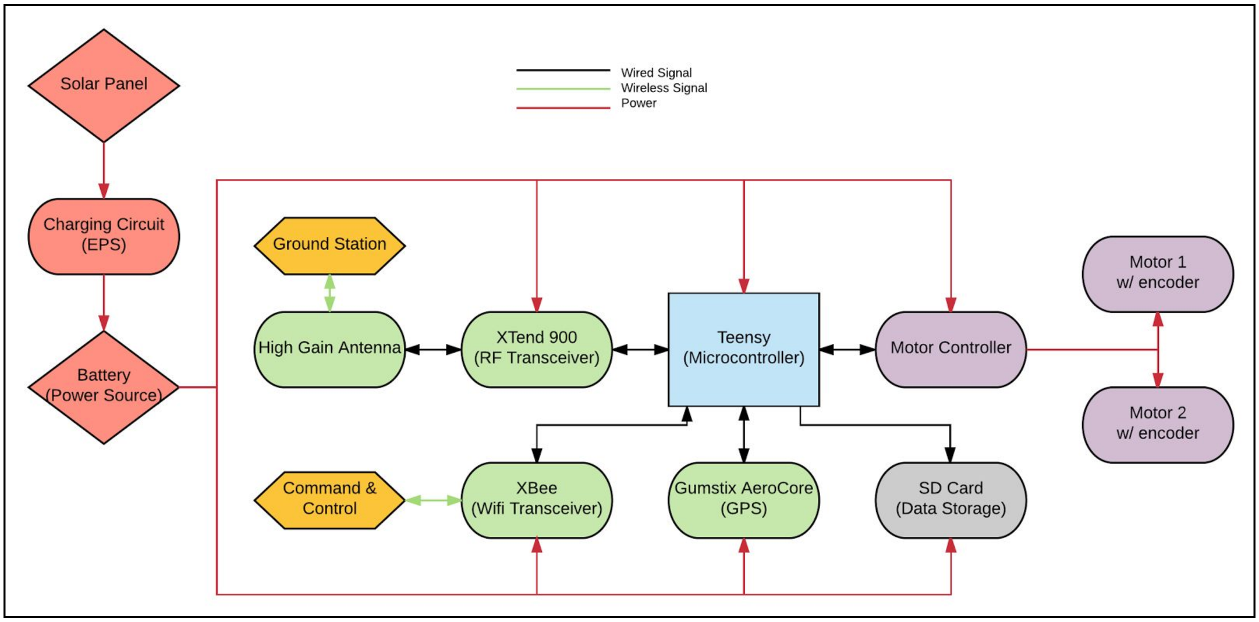


Figure 2.6: *System Architecture of the P&P Module*

2.3.2.2.2 Subsystem Team Roles & Responsibilities [KC]

Kahekili Clark is the Payload and Propulsion team leader responsible for the programming and navigation systems within the propulsion module.

Andrew Bui is a team member responsible for the design and assembly of the motor system within the propulsion module and assisting with the design of the body.

Likeke Aipa is a team member responsible for the design and assembly of the body of the propulsion module.

Cyrus Noveloso is a team member responsible for the electrical design of the propulsion module.

2.3.2.2.3 Top Level Requirements & Constraints for Subsystem [KC]

3.1 Shall initiate the autonomous propulsion system after landing and transverse to a predetermined location, where it shall standby for retrieval.

3.2 Shall possess the means to periodically communicate its position to the ground station.

3.3 Shall have an audible location beacon capable of producing an audible signal through 100 yards of scrub.

3.4 Internal temperature shall be regulated to the operating limits of its internal components at all times.

2.3.2.2.4 Subsystem Derived Requirements [KC]

(3.1.1) The propulsion module shall be sufficiently powered to prevail over oceanic wind and waves during the navigation. (3.1.2) The propulsion module shall be watertight to protect internal components from corrosive and electrical damage. (3.1.3) The propulsion module shall initiate automatically after descending to an altitude of zero meters. (3.3.1) The audible beacon shall be waterproof and remain operative for a minimum of 24 hours.

2.3.2.2.5 Major Trades [JT]

The payload and propulsion subsystem is an expansive system in itself. Responsible for navigating the open seas along with unpredictable currents and high velocity winds, the P&P module must provide adequate thrust to overcome outside factors, tow the C&C module, and autonomously pilot itself to a predetermined location. To achieve the system objectives and requirements, an array of components will be needed. The most crucial components being: the hull, hull material, and motor(s). For each component, an optimum design will be chosen after comparing to a criteria based on characteristics that define the component.

2.3.2.2.5.1 Hull Design [LA]

Table 2.12: *Dmm for Hull design*

Design	Speed	Usable Volume	Impact distribution	Buoyancy	Total Rating	Rating %
Catamaran	4	5	3	4	16	80%
Deep V Hull	5	2	3	5	15	75%
Flat Bottom	2	3	3	4	12	60%

where , 1 = poor and 5 = excellent

The current catamaran design provides advantages in that it provides a more stable base for the hull. However, since the catamaran design incorporates a rounded bottom, this makes the hull less stable and the hull will tend to roll when it is faced with waves. The deep v hull bottom is superior to the catamaran design in this aspect of stability from oncoming waves. By utilizing a deep v bottom the hull will have more support when submerged in the water. Thus the deep v hull will be more stable, and will not tend to roll when faced with waves. Another design to consider is the bottom faced hull design. The bottom faced hull design is more suited for areas of water that are less volatile and more stable. Thus, the bottom faced hull design is not a good option for stability in the open ocean because of the possibility of the hull facing incoming waves. The bottom faced hull design can reach higher speeds however this would not factor into a feasible hull design due to the loss in control of the propulsion module. The design of the hull should also take into account the protection of the motor from any water damage. If the motors are exposed to any water damage this will cause the failure of the propellers which will cause the propulsion module to fail. For the catamaran hull design both motors will be encased within the hull, thus ensuring the motors to be safe from any water damage. The catamaran hull design itself will be submerged under water up to the solar panels which will be above water. The propellers will also be submerged under water thus it is vital that the motors and batteries powering the motors have sufficient protection from the water.

Risks of the catamaran design is that it will depend on two propellers instead of one to operate the propulsion module. This is a huge risk factor to consider because it is a moderate possibility that one of the motors will fail which is connected to the propeller. If one of the motors fails then the propulsion module will just go around in a circular motion. To prevent the propulsion module from becoming ineffective due to a blown motor/propeller, a backup plan is to consider putting a third motor/propeller into the catamaran design of the hull.With a backup motor/propeller incorporated into the catamaran design of the hull if one of the motors fails, then the backup motor will still allow the propulsion module to continue its route towards being recovered.

Another implementation into the catamaran design is to consider the addition of a rudder. Without a rudder, it would be very challenging to direct the hull in the direction required. The rudder can be designed to minimize drag in the water and add further stability to the hull. Additionally to include even more support on the bottom of the hull a keel(fin-like shape) can be added to the submerged portion of the hull design. Disadvantages of having a keel on the bottom of the hull is that if it is not designed in an aerodynamic way it can slow down the propulsion module.

With regards to the solar panels on the surface of the hull, the P&P team must take into account how to protect the circuits of the solar panel. Ideas to protect the solar panels from water damage can include a thin plastic casing used to encase the solar panels. In addition to the plastic casing for the solar panels a plastic cage can be built over the panels to secure the stability of the solar panels. When the propulsion module encounters waves in the ocean this can cause the hull to rock back and forth, thus creating a risk of the solar panels from falling into the ocean.

In consideration of the size of the propulsion module the overall design of the hull will have to be able to have the necessary internal space to contain all of the wires, circuits, and other circuitries to allow the propulsion module to function properly. Therefore, when considering all potential designs for the hull a common pitfall will be, a design that does not have the proper amount of room for everything that it supposed to be put onto the propulsion module. Thus the catamaran design can be somewhat insufficient for the purpose of providing ample space for the rest of the module. However, this problem can easily be solved by created the casing for the submerged part of the hull design to be slightly bigger than the wirings that are used. The problem with the deep v hull design in terms of usable volume is whether or not the propulsion module would utilize a double or single propeller. If two propellers were to be used in the design of the deep v hull then its characteristics would be extremely similar to the catamaran. However, the difference between the deep v hull and catamaran design would be that it would lose some control of the hull with the deep v hull design. This would not be the case however with a single propeller because then the module would only have to use a single motor, less wires, and thus less space would have to be used. The flat bottom hull design would also give quite a usable volume in terms of space availability. However again the question would be whether to use two propellers or one propeller in the design. Regardless of the use of propellers despite the flat bottom hull design having ample space, this advantage does not compensate for the lack of speed that could be achieved with the flat bottom design.

Another issue that comes to light in the design of the hull is where would the antennae for the propulsion module go. For the propulsion module to have communication with the ground station and other modules an antennae would have to be utilized to perform this operation. It must also take into account the possibility of the antennae being knocked off by the waves in the ocean, or from the initial impact from the water. The location of the antennae could not be in any of the hull parts that will be submerged with water, this is because the antennae would fail if it is allowed to take on any water damage. One solution to this problem is to encase the antennae in a plastic casing which would shield the antennae from any water, while allowing the antennae to still broadcast a viable signal. This would allow the location of the antennae to be in an area of the hull where it could be potentially submerged in the water. Another solution is to have the antennae in a location above the water, where it can be restricted by wires, or a merging substance that will cause the antennae to be static. The location of the antennae will eventually depend on the location which gives us the greatest connection to the other modules, while at the same time providing a stable area in which the antennae will not get in the way of the other components of the propulsion module.

The number of antennae would also have to be considered whether one antennae would be a great solution for one of the risks that entails with having an antennae. The risk of having the antennae on the propulsion module is that if for some reason the antennae on the Command and Control Module fails, then the propulsion module will also fail because it will have no feasible way of establishing communication with the ground station. However, if there is a backup antennae then this gives the propulsion module with more room for error because if the first antennae fails, then the backup antennae can still compete the required function.

2.3.2.2.5.2 Hull Material Design [LA]

Table 2.13: *DMM for the hull material of the propulsion module.*

Hull Material	*Impact resistance*	*Manufacturability*	*Thermal resistivity*	*Density*	*Water proof*	*Cost*	*Total Rating*	*% Rating*
ABS	*5*	*5*	*2*	*4*	*4*	*5*	*25*	*83%*
Aluminum	*5*	*4*	*3*	*4*	*4*	*4*	*24*	*80%*
Nylon	*2*	*4*	*4*	*3*	*3*	*2*	*18*	*60%*

where , 1 = poor and 5 = excellent

The DMM for the hull material indicates that ABS should be chosen as the material of choice. ABS offers a flexible material allowing for optimal shaping of the hull for the propulsion module. Compared to Aluminum, and Nylon, ABS gives superior impact resistance and at a lower cost. ABS provides the most reasonable choice for the hull material of the propulsion module. However a disadvantage to using ABS is that it is somewhat sensitive to thermal conductivity. ABS can be prone to melting if it is subjected to a too high heat source.

Aluminum was one of the material considered for the hull because of its lower tensile strength (which provides a strength to weight ratio that is comparable to steel), its long service life, and its flexibility. One of the advantages of having an aluminum hull is the reaction between aluminum and oxygen because the aluminum on the surface of the hull would form an aluminum oxide coating that would act as a barrier that can prevent the metal from corroding and any protective paint would be applied only portions of the hull to be submerged. Aluminum is also well known for its lightweight properties, this is important because the hull of the propulsion module should not take up too much of the weight budget because the other entities such as, the motors, batteries, propellers, solar panels, and wirings would also have to be taken into account of the mass budget. If aluminum were to be used as a hull material than to protect against corrosion the hull of the propulsion module could be coated with solvents, extenders and binders. These three items are different paint solution which are extremely effective in preventing against corrosion. Thus, if any metal is to be considered for the hull material then the prevention of corrosion in an effective manner is something that will need to be addressed.

Nylon was also considered for the selection of a hull material. Nylon is an extremely cost effective option because it cheap compared to ABS or aluminum. Since nylon is a cheaper option one must be careful to consider what type of nylon is being used. The pitfall from using nylon is that it can sometimes be considered a very weak material to use in the long run. Thus nylon can be prone to water damage and the effects of corrosion. Thus, it can be beneficial to look at the different combinations of nylon with other materials which help increase the protection of the nylon against the effects of water damage.

Another material that could be selected for the hull is a plastic called polyethylene. The reason for the use of a material such as polyethylene is because it provides a very strong resistance against impact. This is very desirable because when the propulsion module lands in the water, the hull of the propulsion module will have to be able withstand the force of the impact with the ocean. If the hull cannot withstand this initial impact, then the propulsion module will have no chance of success because the module will be destroyed from the moment it lands in the ocean. Therefore the advantage of using polyethylene is that it will provide a sturdy material for the hull which is a necessary component of the design of the hull.

2.3.2.2.5.3 Propulsion Mechanism [AB]

For the motor design, there are three main choices for electric motors: an AC motor, brushed DC motor, or brushless DC motor. The other main components within the system include propellers, ESC (electronic speed controller) or computer, and power source, most often a battery, which are all compatible with each type of motor.

Table 2.14: *DMM for motor selection*

Motor Selection	Efficiency	Starting Mechanism	Power Output	Total Rating	% Rating
AC	4	1	4	9	60%
Brushed DC	4	5	3	12	80%
Brushless DC	4	5	5	14	93%

Where 1=poor and 5=excellent

For an AC motor design, a small AC motor that runs at single phase 60 Hz would be the most ideal one to use because the motor will only be used to propel the module and since the two-phase and three-phase motors are generally used for more complex machinery that have different modes of use. AC motors typically need a high input voltage ranging from 100-230 V but produce a much greater torque on the shaft than conventional DC motors thus maintaining a higher speed [rpm]. One motor consideration is the Groschopp AC10080FC which is a single phase 60 Hz motor which has a 0.6345 HP capacity and 3030 RPM. Another disadvantage of an AC motor system is that most motors require a starter mechanism.

Using a DC motor would be more ideal for a such a vessel due to the direct current that will be received from the battery. Choosing a brushed DC motor was somewhat difficult in which there are not many made specifically for boats or use in the water. One motor consideration is the Buyers M3300 12V DC motor. The power input is 12V which could be powered easily by a 12V battery bought in stores with a torque of 199 in*lb at 300 amps with overall of 1.6 horsepower and 92% efficiency. While very convenient, the weight is very high compared to the other motors, not waterproof, and is overall very unideal for the propulsion module.

Brushless motors are the most commonly used motors in the electric boat industry. Because of its fixed coil and rotating magnets, the motor acts very much like a synchronous AC motor which means high efficiency and less electro-magnetic interference. Compared to brushed motors, the brushless will run faster and longer if they had the same wattage and load. One motor consideration is the Neu 1509 series model 1Y; with a max power of 1450W, 90% max efficiency, 60,000 max rpm, and 3600 rpm/V. The motor is also lightweight, coming in at 0.63 lbs which is very ideal considering the weight constraints of the FAA.

One possible issue that may arise is the overheating of the motors. Since the amount of heat generated is currently unaccounted for, the use of fans or heat sinks may have to be considered if the mass budget allows for more components.

Another consideration for the motor design is the choice of battery. The batteries in question are between conventional NiMH (Nickel-Metal Hydride) batteries or state of the art LiPo (Lithium Polymer) cells. LiPo batteries are much lighter weight, have higher discharge rates, and offer higher capacities, allowing them to hold more power. Some of the drawbacks with LiPo batteries are that they have a shorter lifespan and are chemically sensitive. Due to the high capacity and discharge rate, the LiPo cells at 4500 mAh*min with a 30C rating are the more ideal choice for the propulsion module.

Table 2.15: *DMM for propeller selection*

Propeller	Diameter [in.]	Pitch [in.]	Pitch/Diameter Ratio
X432	1.26	1.68	1.33
X435	1.38	2.07	1.5

X438	1.5	2.1	1.4

Source: [*http://www.prestwich.ndirect.co.uk/octurapropellers.htm*](http://www.prestwich.ndirect.co.uk/octurapropellers.htm)

One last consideration for the propulsion module is the choice of propeller. The factors that determine the choice are the diameter and the pitch length; which is the distance the propeller travels with one full revolution. Since there is not a defined volume budget, a propeller with diameters between 1.2 and 1.5 inches shall be considered. With Octura propellers, they offer the X432 blade: with 1.26 inch diameter and 1.68 inch pitch, X435 blade: with 1.38 inch diameter and 2.07 inch pitch, and X438: with 1.5 inch diameter and 2.1 inch pitch. Comparing the pitch to diameter ratios, the X435 is the greatest at 1.5, so that would be the most ideal choice.

2.3.2.2.5.4 Steering Design [KL]

Another important component selection would be deciding on design and parts used in navigating the propulsion module. Two proposed designs to select from for steering the propulsion system would be the steered-by-rudder or steered-by-propeller design. The steered-by-rudder design would be the typical rudder steering system seen on many boats where a fin-like rudder is placed at the rear end of the hull in which steering is produced by the redirection of the flow of the water depending which way the rudder turns. On the other hand, the steered-by-propeller design would simply be using the two propellers on each side of the catamaran. To turn to hull, it will increase or decrease its propeller speed on one side or simultaneously (e.g. to turn right, left propeller increases and right propeller decreases).

To decide which steering system would be best suited for the mission, three criteria were selected; structural integrity, weight and its reliability. Starting with structural integrity, this would be the biggest concern in the design. Due to the nature of the mission, the propulsion system will be descending from the sky and onto the water and because of this matter the structural integrity will favor the propeller steering simply due to the fact that the rudder poses a risk of breaking upon landing onto the ocean. Also, since the catamaran design would already be implementing two propellers, there would be no additional fabrication needed by using the propeller steering as opposed to rudder design.This addition fabrication into the haul could lead to potential failure and having water enter the module from where the rudder is mounted. This favors the propeller steering in terms of structural integrity. The next aspect is the reliability. When compared between the two, propeller steering has the advantage over the rudder. This is due the the probability of having an additional moving mechanics of the rudder can lead to the possibility of it getting stuck or malfunctioning. The rudder design would also consume additional energy to power the rudders to turn, whereas turning with the propeller can be done as simple as by stopping the motor on one end. The last aspect is weight, due to the weight constraint, having an addition mechanism for a rudder will increase the weight of the system where every ounce counts. Whereas using the propeller steering will have zero effects on the weight of the system below on Table 2.16 shows the decision making matrix used to decide the winning design of the propeller steering.

Table 2.16: *DMM for the steering design between Rudder and Propeller*

Design	Structural Integrity	Reliability	Weight	Total	% Rating
Rudder Steering	3	3	3	9	60%
Propeller Steering	4	4	5	13	87%
where, 1= poor and 5 = excellent					

However when choosing the propeller design, there is an inherent risk of having electronic failure. There is a medium risk involved in where one of the motors will fail to operate. This has happened before to UHABS-3 in which one of the the paddlewheel had failed which resulted the system to only go in circles. In order to mitigate the risk of the propellers from failing for UHABS-5, a recessed design into the hull will be used for the placement of the propeller. The propellers would be placed into the hull allowing the hull to protect it from impact. Another concern would be water entering into the haul causing the propellers to seize. A waterproof marine epoxy would be used to help mitigate such risks.

2.3.2.2.5.5 Navigation System [KC]

A navigation program with a simple set of tasks is planned for the propulsion module. The program will be responsible for initiating the module upon landing, continuously orienting the module towards the designated location, traveling forwards in the correct direction, and powering down to conserve power to charge or to wait on standby. This program is intended to be loaded into the teensy microcontroller where it will collect coordinate data from the GPS and battery-life from the EPS. Additionally, the program will send command signals to the motors to modulate their thrust. The propulsion module needs to navigate from the place it lands to a designated location, an area not prone to rough seas or high traffic on the coast of Oahu. Before it can traverse it will need to orientate to the necessary direction. Orienting the module will be achieved with a thrust differential between the two propellers, originating as a command signal from the teensy. The GPS has an onboard 3-axis magnetometer which can be used to determine the current direction the module is facing with respect to north. Ideally, the module would simply rotate using differential thrust until the current direction of the module was the same as the necessary direction to travel towards the destination point. At a battery level that must be determined, the teensy much cease the navigation program to conserve energy until the PV module can charge it back to an acceptable level, then it can resume navigating. The module will be programed to initiate after the accelerometer stops detecting the module is descending and cease to navigate when it is within 50 feet of the GPS coordinates of the designated location.

2.3.2.2.5.6 Avionics [CN]

The P&P Module will be controlled by a Teensy 3.2, which was chosen over the more popular Arduino because it is almost quadruple the speed at 72 mHz. Also, all 33 of its digital pins have the interrupt functionality compared to the Arduino’s six, which is crucial for utilizing multiple sensors or read functions at the same time. The Teensy will be used to control a motor controller, long range radio frequency transceiver, short range Wi-Fi transceiver, GPS module (includes GPS, accelerometer, barometer, magnetometer) and will write to a microSD card.

A high current motor controller in combination with quadrature encoders will be used to control two motors, which are responsible to the mobility of the BalloonSat in the water. The motor controller can individually control the speed of each motor using pulse-width modulation, while the encoders can track the rotations and control the duration of the motor. These forms of control are important for guiding the BalloonSat back to the recovery site despite ocean currents and wind that can displace its path.

The BalloonSat will utilize an XTend 900 combined with a high gain antenna for long range radio frequency communications between the Ground Station and an XBee for short range communication between the C&C Module. The Ground Station will still be able to send and receive information to and from the BalloonSat should the transceiver in the C&C Module fail. The XBee will communicate wirelessly to the C&C Module so all of the data collected from the sensors in the C&C Module can be stored in a microSD card in the P&P Module.

The Gumstix AeroCore 2 board is capable of GPS, accelerometer, barometer, and magnetometer readings and is cheaper than the cost of all of the components separately. The GPS will provide the position of the BalloonSat, the accelerometer will provide the time when it has landed in the water, the magnetometer will provide orientation with respect to north, and the barometer will provide pressure data in excess to the pressure data collected from the C&C module.

All of this including the motors will be powered by four 11.1 V 2200mAh lithium polymer batteries in parallel, providing a total capacity of 8800mAh and run time of approximately 1.028 hours excluding temperature corrections. An 11.1 battery was chosen because it offered a balance between voltage and capacity.

2.3.2.2.6 Requirements and Implementation [LA]

Table 2.17: *Side by side of the P&P requirements and implementation.*

Requirements	Implementation
Shall initiate the autonomous propulsion system after landing and traverse to a predetermined location, where it shall standby for retrieval.	The propulsion module will be ready to activate propellers to return to land
Shall possess the means to periodically communicate its position to the ground station.	The communication between propulsion module and ground station will be activated.
Shall have an audible location beacon capable of producing an audible signal through 100 yards of scrub.	A working signal will be emitting from propulsion module.
Internal temperature shall be regulated to the operating limits of its internal components at all times	There will be a temperature gauge providing real time temperature readings

2.3.2.2.7 Functional Flow Block Diagram with External Interfaces [RP]

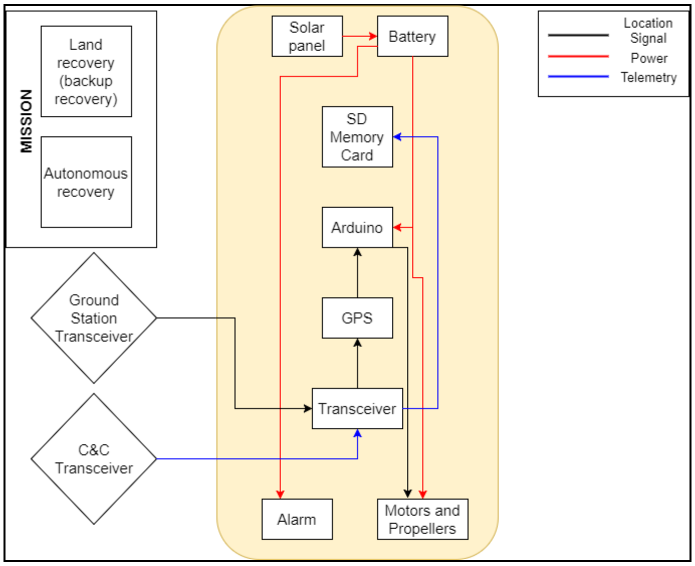


Figure 2.7: *Functional Flow Block Diagram of the P&P Module*

2.3.2.2.8 Mass & Volume Budgets [CN]

Table 2.18: *Initial mass and volume budget totals*

Type	**Description**	**Volume [in^3]**	**Mass [lbs]**
Total Allowable		No limit	6.0
Structure	Hull and Insulation	198.507	3.01
Power Supply	LiPo cell 11.1 V 2200mAh (6.702 oz) x4 Solar cells	5.997 TBD	1.6755 TBD
Motor	Model 1509 1Y (7.48 oz) x2	5.234	0.935
Avionics	Microcontroller (0.17oz), motor controller (0.87oz), GPS (1.305oz), RF transceiver (0.64oz), Wi-Fi transceiver (0.123 oz), SD card breakout board (0.1 oz),	4.05	0.2005
Misc. (+__%)	Wires	TBD	TBD
Total		213.788	5.821
Remaining			0.179

2.3.2.2.9 Power Budget [CN]

Table 2.19: *Power budget totals*

Component	**Quantity Needed**	**Current Draw (each) [A]**	**Voltage (each) [V]**
Neu 1509 1Y (Motor)	2	3.5 @ 10 V	17 (max)

Teensy 3.2 (Microcontroller)	1	0.045 (max)	1.71-3.60
VNH2SP30 (Motor Controller)	1	0.06 mA (max)	5.5-16.0
AeroCore 2 (GPS)	1	0.500 @ 3.3 V	3.1-16.0
XTend 900 (RF Transceiver)	1	0.810 @ 30 dBm	2.8-5.0
XBee (Wi-Fi Transceiver)	1	0.104 @ 3.3 V	2.1-3.6
Sparkfun SD Card Breakout Board	1	0.100 @ 3.3 V	3.3
Tenergy LiPo Battery (Power)	4 in parallel	2200mAh each → 8800mAh	11.1
Solar Cells (Power)	TBD	TBD	TBD
Total Current Draw	8.56 A		
Estimated Operating Time	1.028 hours		

Estimated operating time calculations:
Time = Capacity / Current Draw → 1.03 hours = 8.80 Ah / 8.56 A

2.3.2.2.10 Description (including schematics, list of components, etc.) [LA]

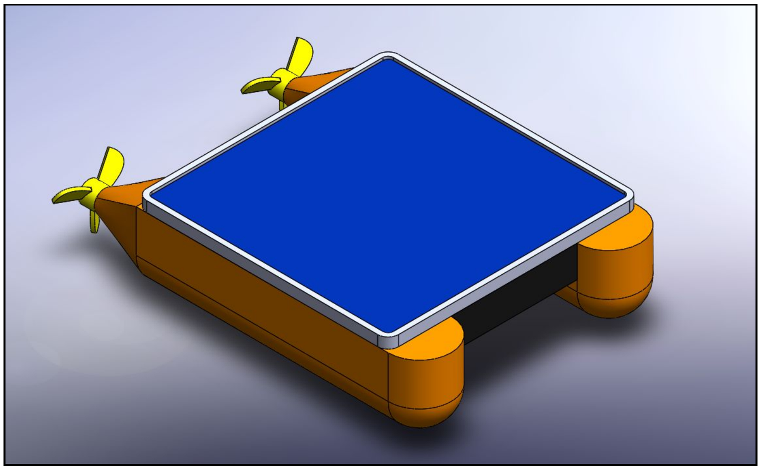


Figure 2.8: *Catamaran hull design featuring two propellers and a solar panel*

The current catamaran design features a twin propeller system with a solar panel on the top of the hull. Additionally the bottom of each attachment to the propeller has a rounded bottom. The propellers are connected to motors which will be powered by batteries connected to the motors used.

A solar panel system is to be incorporated to power the electric motors, allowing the propulsion module to use the available energy from the sun. Concerns for this current design would be the need for a deep v hull bottom. This is because a rounded bottom does not add much stability to the hull, thus making the propulsion module subject to the ocean waves. With a deep v hull bottom the module would have more support from the ocean waves and thus less likely to capsize (fall over in the water) in the ocean. Additionally, the design would need to incorporate an antennae of some capacity because communication must be made with the other modules of the BalloonSat.

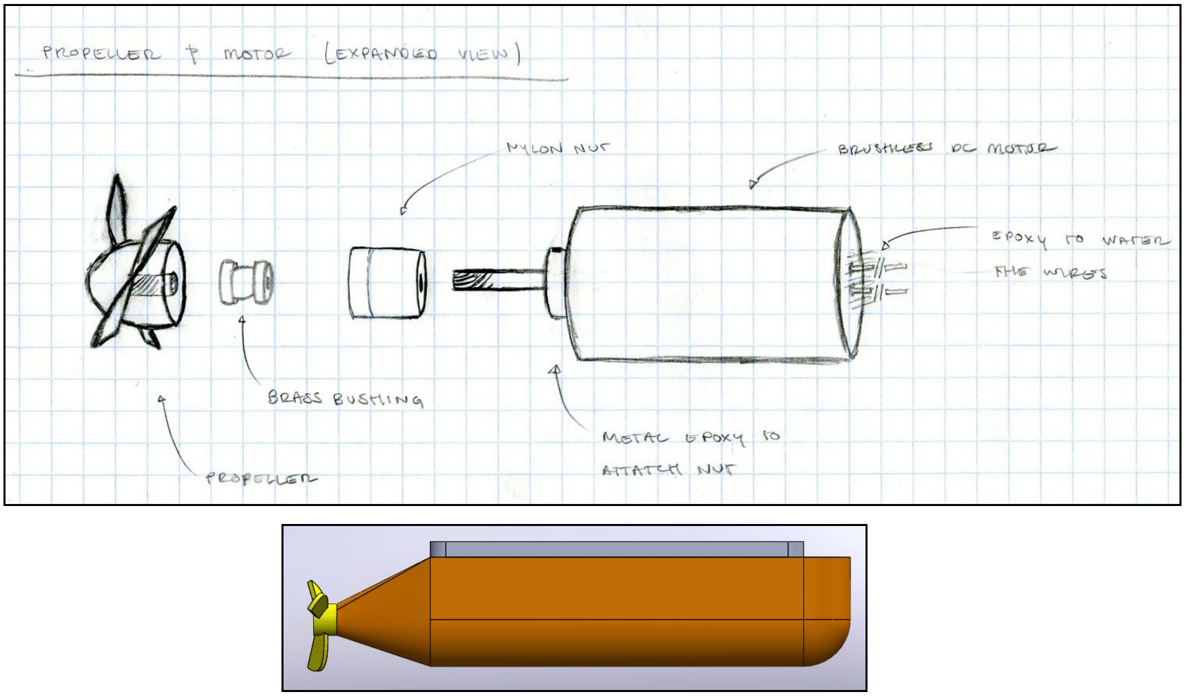


Figure 2.9: *Exploded side view of the propeller*

An exploded view of the propeller, is shown in the Figure above. The propeller would most likely have to use a brushed DC motor which can then be attached to the propeller with a nylock nut and brass brushing. The wires shown in the figures can connect to a battery source, which will power the propellers. The battery source will be further powered throughout the return of the propulsion module through the use of the solar panels. In case one of the motors fails, implementing a backup motor and battery can used as a contingency plan. If one of the motors would fail on the current catamaran design, the module would essentially operate in a circle shape motion, thus failing to make any progress.

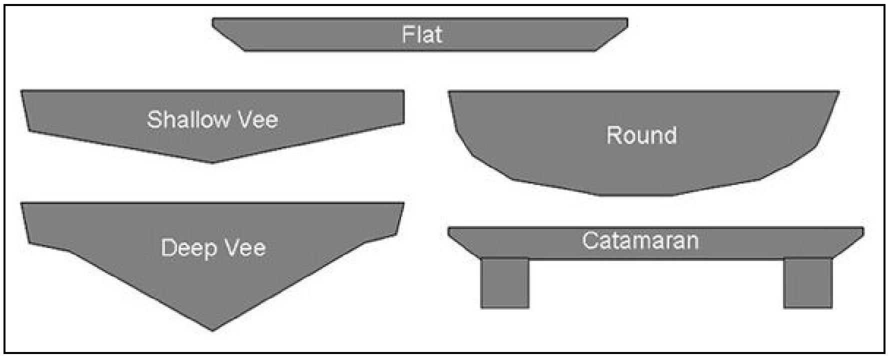


Figure 2.10: *Comparison of the different hull shapes*

Source: https://www.sciencebuddies.org/Files/3310/5/Aero_img057.jpg

This figure shows the differences between the various hull designs. The ideal hull bottom would probably be a combination of the catamaran and deep v hull bottom. A traditional deep v hull bottom would only utilize a single propeller, while the catamaran design utilizes a twin propeller system. An updated catamaran design with deep v bottoms provides the best support from ocean waves, and can easily be incorporated with the current design of the catamaran hull.

An antennae is also attached on top of the solar panels for the catamaran design with deep v bottom. However, more analysis will have to go into figuring out where to put the antennae. The antennae will have to be placed in a spot in which it is safe from any water damage, and can operate at a functional level to communicate with the other modules.

The hull designs can implement a keel(fin-like) and a rudder to help add more support to the hull. A decision must also be made to use a single or double propeller system. The risk of using a single propeller system is that if the motor/propeller fails, the module would have to have a backup motor to ensure the propulsion module will be able to execute its given task.

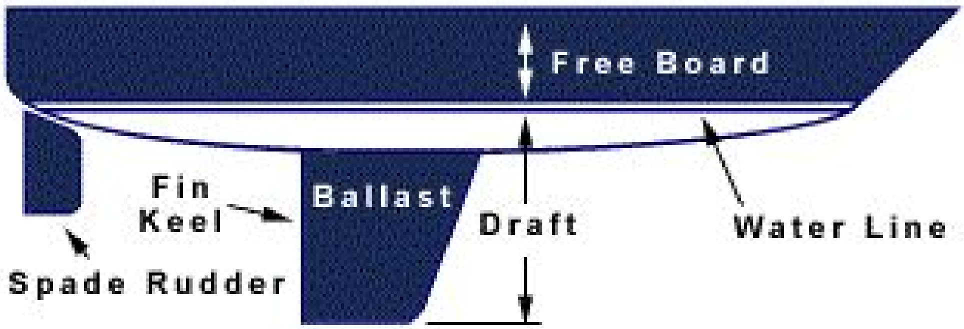


Figure 2.11: *Idea of a Fin Keel with a rudder on a hull*

Source: http://www.spinnaker-sailing.com/lessons/keelboat2/fin_keel.gif

The use of rudder steering with the catamaran hull design is shown in a side view in the Figure above. The rudder stick will be attached to a handle which can be used to move the rudder from left to right, thus allowing for a more stable control over the rudder. The rudder follows a simple design and should not create too much of problem with space usage of the overall hull design. However, if the hull is dependent on a single rudder, then this runs the risk of placing too much emphasis on one part of the propulsion module. For the idea of a rudder to be viable there would have to be a backup rudder in place to ensure that if the first rudder fails, then there will be the necessary backup for steering.

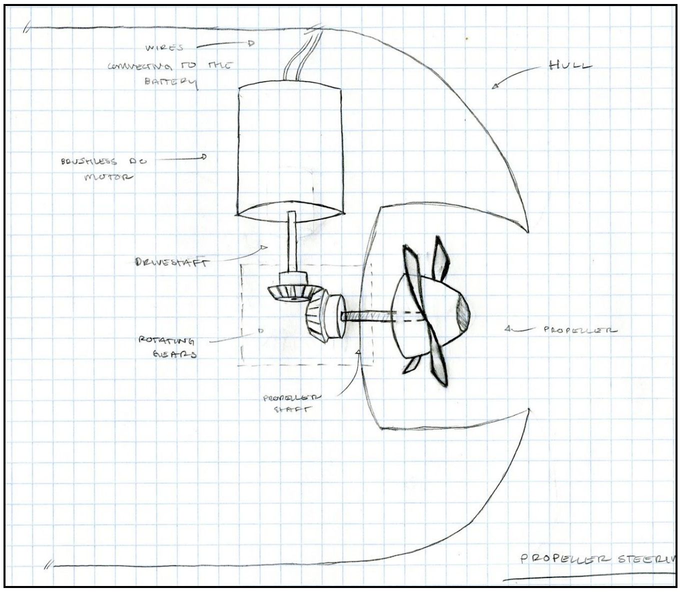


Figure 2.12: *Visual of the idea of propeller steering*

This figure shows the design of propeller steering to be used with the catamaran hull design. The idea of using propeller steering can be advantageous because this allows the propulsion module to not solely depend on a single rudder to steer the module. However, this means that a propeller shaft will have to be included into the design of the propeller, and a drive shaft will have to be constructed to power the propeller. The two propeller steering system allows for more control over the module, and thus can potentially increase the speed that the propulsion module can reach. This is because the steering of the module will come from two places, than only one.

2.3.2.2.11 Results of Analyses (Performance, etc)[KC]

Calculations for the drag force were made using SolidWorks. Using the flow simulation function, the drag force was estimated to be 3.4 lbf on each hull in water. The total expected drag force would then be 6.9 lbf on the total catamaran hull. This will give us an idea of what output force will be necessary for the propellers during testing. The parameters of the test used a projected oncoming flow velocity of 2.57 m/s in the negative z direction, the flow equation was used to model this drag. The flow velocity was determined under the assumption that the catamaran was experiencing head current at 4 knots while traveling at 1 knot.

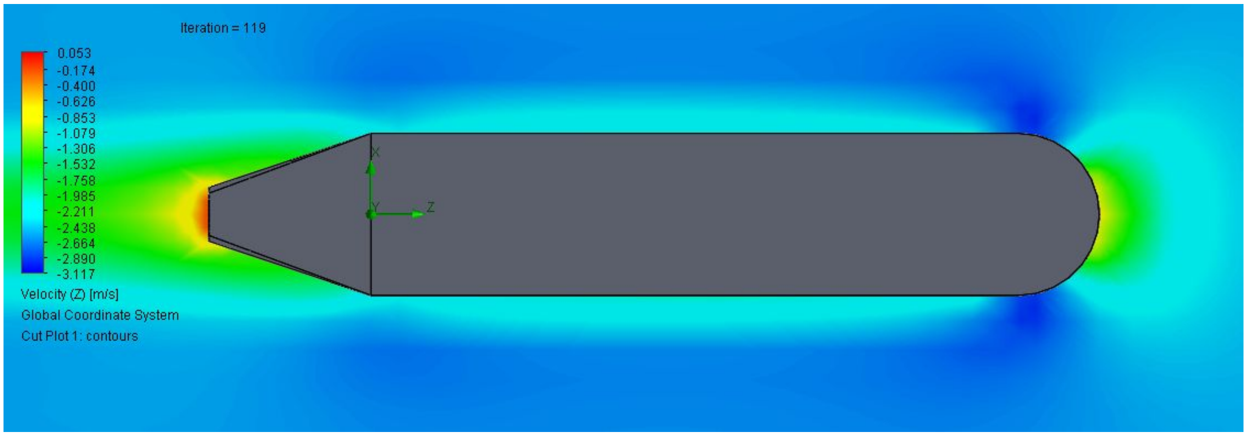


Figure 2.13: *Flow profile around single hull of the catamaran*

2.3.2.2.12 Testing Plan [KC]

For the testing of structural integrity and waterproofing, the same tests will be performed as the C&C module.

When the propulsion system is operational, a preliminary test will be conducted on the force output of the motors to ensure the system can provide an acceptable lelevel of thrust to navigate. The motor will be shielded from water and placed within a container where it will run at the expected average operational capacity. The resulting force output will be measured with a weight scale. After the hull and the propulsion system are operational, the navigational systems can be tested. First, small scale maneuvers will be programmed into the module and executed within a controlled environment such as traveling forward, turning left and right, turning 180 degrees, stopping, and combinations of the former maneuvers. If these can be successfully executed the module will be taken out to open ocean and point A to point B navigations can be tested.

2.3.2.2.13 Subsystem Schedule using WBS and Gantt Chart [JKY]

In the time period of prototyping from September 25th to December 3rd the P&P team will decide the propulsion device shape, navigational tools, battery recovery, and application of solar panel.

2.3.2.2.14 Remaining Issues and Concerns [KC, JKY]

The difficulty in powering the P&P Module increases due to the constraints in weight given by the FAA. Because the project is limited in weight, this also limits the amount of energy that can be used. Also considering ocean conditions, the propulsion module could potentially be unable to overcome the currents resistance.

In addition to overcoming the strength of currents and waves, obstacles could also hinder navigation software. These obstacles include, but are not limited to, marine life, rock formations, and naval vessels.

The heat generated by electric motors could also pose to be an issue. Each electrical device can only withstand a certain limit of temperature, whether it may be hot or cold. If the motors are constantly running, the heat build up within the module could surpass the acceptable limit of these devices if the propulsion module is statically insulated too much.

Another issue with electronics is damage from water. Water has the ability to cause the internal hardware to short, to avoid this the module must remain watertight for the duration of the mission. In addition to considering this issue, pressure adjustments will also have to be done to prevent implosion during the high altitude flight. This contradicts the implementation of a watertight hull, so pressure equalizing device that inhibits the flow of water will be necessary.

There is a difficulty surrounding the recovery area the module must reach, the module could be intercepted by a third party and taken without UHABS-5 team permission. This problem would be magnified if the accuracy of the navigation system was substantial enough for the module to land miles away from the designated location.

2.3.2.3 Ground Station

2.3.2.3.1 Subsystem Team Roles & Responsibilities [JAY]

Ground Station Team Leader/COSMOS lead programmer - Jace Yamaguchi

As the ground station lead, Jace will oversee all tasks relating to the ground station. He will make sure that his team members are on schedule. In addition to being the subsystem lead, He will be in charge of adequate mastery of COSMOS and making sure that anyone on the team that needs to know how to use it knows how it works.

Hardware Management - Ka Chon Liu

Ka Chon will be responsible for the hardware related to the ground station. This includes keeping track of the antenna, the laptop, and the backup external power source. He will also communicate with the C&C and P&P subsystem teams to make sure that a connection can be established with the transceivers on both modules.

Site Facilitator - Jake Torigoe

Jake will be in charge of launch site selection. This includes communication with City and County if UHABS-5 is launching off from a park or beach site. It also includes communication with the FAA to make sure that all laws are followed in regards to a high altitude balloon launch.

2.3.2.3.2 Top Level Requirements & Constraints for Subsystem [KL]

(4.6.1) Shall provide two-way communication with the C&C Module during the entire mission from pre-launch activation through system shut off and retrieval.

(4.6.2) Shall use COSMOS Operations to monitor and report UHABS-5 State-of-Health (SOH) during the mission and command emergency release of balloon if needed.

(4.6.3) Shall receive, process, and display all SOH telemetry and atmospheric data received from the UHABS-5 in near real-time.

(4.6.4) Shall receive a live feed from a down facing camera while the satellite ascends.

(2.6.1) Shall command an emergency balloon release in the case of unfavorable situations.

(2.6.2) Shall receive the location of the propulsion system during recovery.

2.3.2.3.3 Subsystem Derived Requirements [KL]

The first derived requirement from requirements (4.6.1),(4.6.2),(4.6.3) and (2.6.1) would be establishing a stable two-way communication connection with a range of 100,000 feet between Ground Station and C&C Module. This range was selected based on the maximum desired altitude traveled by the BalloonSat (60,000 ft.) and the possibility of the BalloonSat deviating its descend trajectory and drifts further out towards the ocean. By setting it as 100,000 feet, it provides a range far beyond the desired altitude and will also provide decent buffer range should the the BalloonSat move away from the island.

The second derived requirement from requirements (4.6.3) and (2.6.1) is to have the sensors and release mechanisms to continue to function despite the dramatic change in temperature. This temperature could be as low as -59 °C should the BalloonSat reach its maximum altitude of 100,000 feet.

The third derived requirement from requirement (4.6.4), is to have a live feed camera that would be capable of transmitting a minimum of 144p video quality back to ground station. A faster transmission of data can be accomplished by setting 144p as the minimum video quality. Based on testing and data transfer rate, a high quality could later on be implemented.

The fourth derived requirement from requirement (2.6.2), is to construct a GPS with an additional backup GPS to locate the propulsion system during its recovery phase. This provides additional security in locating the module throughout its journey.

2.3.2.3.4 Major Trades [JT]

The most crucial component for a high altitude orientated ground station is the antenna. Based on the objectives and requirements designated for the ground station subsystem and overall objectives, three factors have been derived to evaluate different antenna designs. Those factors are: configuration, gain, and frequency. An antenna has an optimal configuration if its orientation has minimal gain loss when positioned vertically (towards the balloonsat). This standard eliminates antenna designs that emphasize horizontal radio waves or spread their intensity too thin by emitting radio waves in all directions (i.e. isotropic antennas). The second factor considered when choosing an antenna design is the gain. Gain values for specific antenna designs can be obtained from the specifications/data sheets for the particular product. Gain indicates the antenna’s ability to focus radio frequency energy in a particular direction or pattern. The higher the gain value, the more reliable and efficient the antenna is in maintaining a connection and transferring data with the satellite. The final factor for determining antenna design is the frequency. Frequency determines compatibility with different transceivers and receivers (i.e. 2.4 GHz transceiver is compatible with 2.4 GHz antenna, but is not compatible with 900 MHz transceiver). In this case, 900 MHz transceivers and microcontrollers will be used on board the C&C module, therefore the antenna will need to operate within the 900 MHz range.

Based on these factors, antenna design concepts have been narrowed down to two different models: turnstile antenna (see Figure:??) and panel antenna (see Figure:??). These designs have proven to be the most competent in ground-to-satellite communications and have been used in previous high-altitude balloon missions. Both designs will be compared against each other, using the three factors as criteria, in order to determine the design best suited for this specific project.

Figure 2.14: *Turnstile Antenna Design*

Figure 2.15: *Panel Antenna Design*

The turnstile antenna design consists of crossed-dipole antennas and, when orientated in axial mode (as seen in Figure 2.14), produces circularly polarized radio waves along its axis. In terms of configuration, this design is optimized for satellite ground stations as its compatibility with circularly polarized antennas commonly used aboard satellites ensure a steady connection regardless of orientation. Gain values vary with model and price range, with higher gain turnstile antennas (~16dBi) in the sub $100 price range. There are also an assortment of turnstile antennas that run in the 900 MHz frequency range, making the design easily obtainable and compatible with the chosen microcontrollers and circuit boards.

The panel antenna design is a type of directional antenna, just like the turnstile antenna. However, this antenna consists of a metal plate which, unlike the turnstile antenna, sends a wider beam and therefore covers a larger area. This configuration compensates for the balloonsat drifting away in the lateral direction and proves to have excellent coverage. Consequently, the panel antenna's design and broad range leaves the gain factor lacking. Majority of panel antennas have a gain value ranging from 8 dBi to 14 dBi and have a starting retail price of about $150. Higher gain antennas are drastically more expensive or are configured with a different frequency (i.e. 2.4 GHz). 900 MHz panel antennas have a limited market and therefore are harder to obtain.

Overall, the best antenna design for the case of ground-satellite communications would be the turnstile antenna. Although the panel antenna has a broader lateral range, the turnstile design can be manually orientated and adjusted to follow the general direction the balloonsat drifts. The turnstile antenna outclasses the panel design in every other category, having a higher general gain value for cheaper, and a better selection of products within the 900 MHz frequency range.

Table 2.20: *DMM for Ground Station Antenna Design.*

Design	**Configuration**	**Gain**	**Frequency**	**Total Rating**	**% Rating**

Turnstile	4	4	4	12	80%
Panel	5	2	3	10	63%
Where, 1=poor, and 5=excellent					

2.3.2.3.5 Requirements and Implementation [JT]

Table 2.21: *Side by side of the C&C requirements and implementation.*

Requirements	Implementation
Shall provide two-way communication with the C&C Module during the entire mission from pre-launch activation through system shut off and retrieval	Transceiver and antenna with appropriate frequency will allow for constant contact with C&C module through each phase of mission
Shall use COSMOS Operations to monitor and report UHABS-5 SOH during the mission and command emergency release of the balloon if needed.	COSMOS software programmed and setup to run on compatible laptop
Shall receive, process, and display all SOH telemetry and atmospheric data received from the UHABS-5 in near real-time	Transceiver and antenna will download data from C&C module and uploaded to COSMOS software running on laptop to be processed and displayed
Shall receive a live feed from a down facing camera while the satellite ascends	Compatible transceiver and antenna setup used to download live video feed from C&C module
Shall command an emergency balloon release in the case of unfavorable situations	COSMOS software programmed to send a signal via transceiver-antenna to balloon module for release of balloon
Shall receive the location of the propulsion system during recovery	Transceiver-antenna setup to download coordinates from GPS aboard C&C module

2.3.2.3.6 Functional Flow Block Diagram with External Interfaces [JAY]

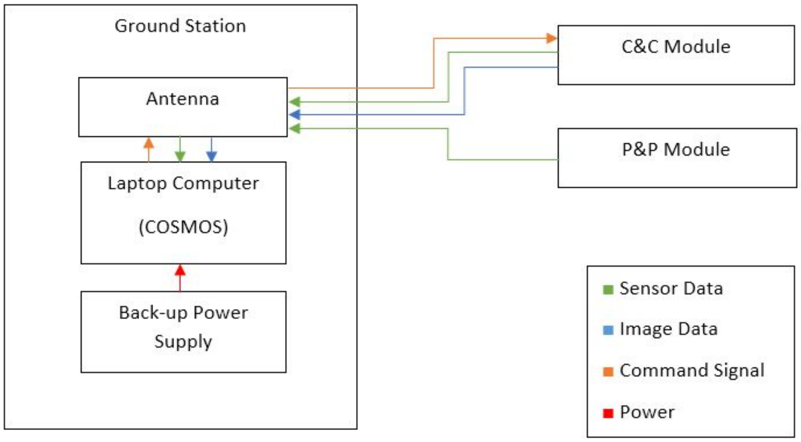


Figure 2.16: *FFBD of the Ground Station*

2.3.2.3.7 Description (including schematics, list of components, etc.) [JAY]

The ground station will comprise of laptop computer with a back-up power supply and an antenna (see Figure 2.16). The antenna should allow long range communication between the C&C module and the laptop during the flight and receive telemetry data from the P&P module during the recovery phase. The back-up power supply will extend the battery life of the laptop during operation.

COSMOS will be implemented in the ground station to communicate with each of the modules. The C&C will be treated as a spacecraft node and P&P will be treated as a submersible node. The nodes use agents to communicate accessed by the GUI (general user interface) tools from the ground station. The ground station will receive sensor data and image data from the C&C module during the flight and will have the ability to command a manual release of the balloon and a manual release of the parachute in the case that the automated system does not work. The ground station will also receive GPS location of the P&P module during the recovery phase.

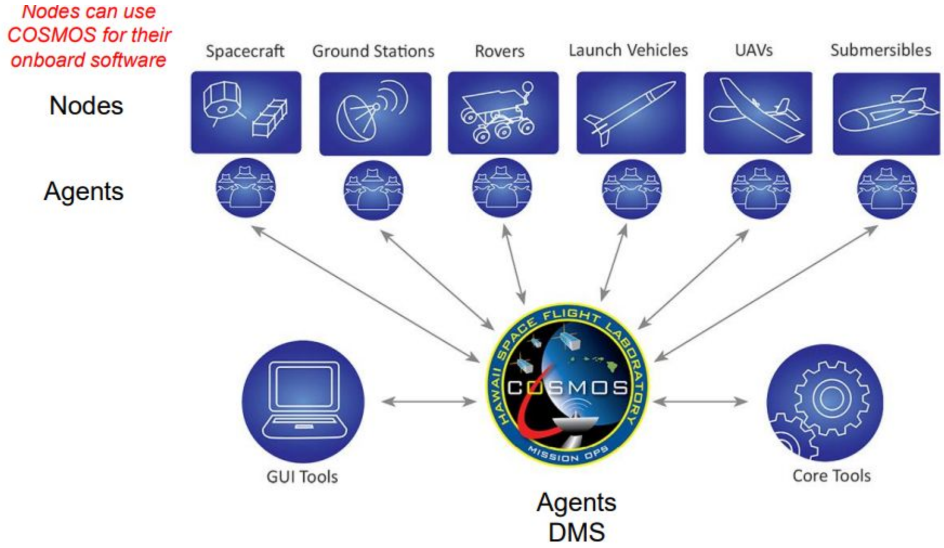


Figure 2.17: *COSMOS System Architecture*

2.3.2.3.8 Site Selection [JAY]

The launch site will be off of a public beach and contact with City and County will be established to ensure that Team Zeppelin is legally operating the launch. Preliminary contact with the FAA will be established at this time as well. 48 hours prior to launch date, contact will be established with the FAA to update the record and ensure the launch is following all protocols. 24 hours prior to launch date, a final inventory will be taken at this time and all materials will be collected at POST 536. Weather forecast and the Allen Franklin Jordan Balloon Prediction tool from the National Oceanic and Atmospheric Administration (NOAA) will be used to select an optimal site to launch from. Morning of launch day, a final weather check will be done and the FAA will be contacted 2 hours prior to launch for clearance.

2.3.2.3.9 Testing Plan [JAY]

Testing will be done during and after the fabrication phase. The antenna will be tested over varied distances over the ground. An ideal setup to test communication with the C&C module would be in an open area with little to no obstructions. The test will be successful if a connection can be established and data can be transmitted to and from the ground station to the C&C. The antenna will also be tested when the P&P module is tested in the water to make sure it receives the GPS data during the recovery phase.

2.3.2.3.10 Subsystem Schedule using WBS and Gantt Chart [JAY]

In the time period of prototyping from September 25th to December 3rd the ground station team will decide which antenna should be used for communication with both the C&C and P&P modules. Basic training for COSMOS will be learned during this time through a workshop and through supplemental tutorials from HSFL mentors if needed. A basic connection between the antennae and onboard transceiver will be established during this time. Contact with FAA and City and County regarding site selection will be done week 1 of 2018 for basic information and a final date and location will be chosen week 11.

2.3.2.3.11 Remaining Issues and Concerns [JT]

The remaining factors that pose as a concern for the ground station subsystem pertain to the COSMOS software and the reliability of the transceiver/receiver setup. These issues are to best be resolved as soon as possible because of how crucial these aspects are to meeting the subsystem requirements and more importantly, the primary mission objectives.

COSMOS operation software presents a concern in the ground station system because of the inadequate knowledge UHABS-5 currently possesses in programming. The COSMOS software utilizes an “open-architecture” in an Linux coding environment, a coding environment that is still foreign to group members. However, a COSMOS workshop that will teach the fundamentals of the COSMOS software will be open to group members in the near future and is expected to give us all the necessary tools and knowledge to program in the designated environment. In the meantime, group members are making an effort to familiarize themselves with the Linux environment and coding in anticipation for the COSMOS workshop.

The final concern involving the ground station pertains to the reliability of the selected transceiver and receivers. Majority of electronics such as circuit boards, transceivers, receivers, and antennas are fragile. Components may break in the field or in the shipping process and set back testing. Although logistics errors are out of the team’s control, user errors can be prevented by handling all components with care and properly storing them.

3 Management and Cost Overview [KBC, DA]

In order to ensure the completion of mission UHABS-5 and the effective utilization of all members of Zeppelin, the team shall follow the team organization in Figure 3.1. The structure shows that the PM, SI, and FA are responsible for the system and management level tasks, other members of the team are responsible for tasks specific to their assigned subsystem. Each subsystem team member's specific duties are detailed within the subsystem's specific sections in the technical overview.

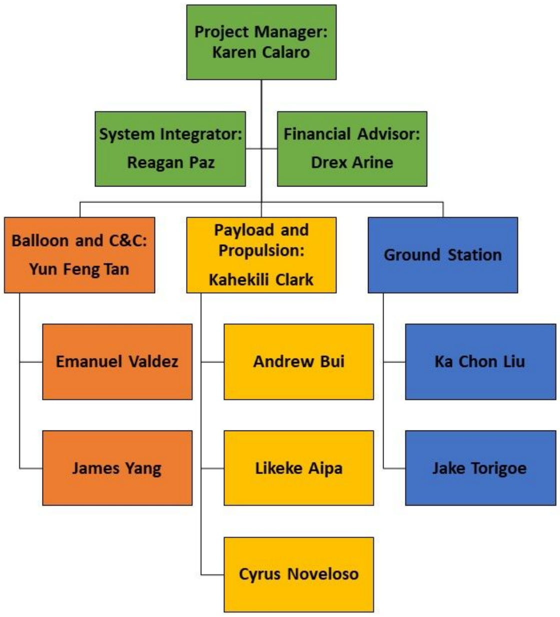


Figure 3.1: *Structured team organization for UHABS-5*

The WBS diagram in Figure 3.2 shows how the work is distributed among the subsystems. The Administrative will focus solely on the academic items, planning, budgeting and funding. The system integration will make sure that all three subsystems design are coordinated with each other and are all compatible. System testing and all concerning design changes will be logged for this role. Lastly, the remaining subsystems will be in charge of their respective components as shown below.

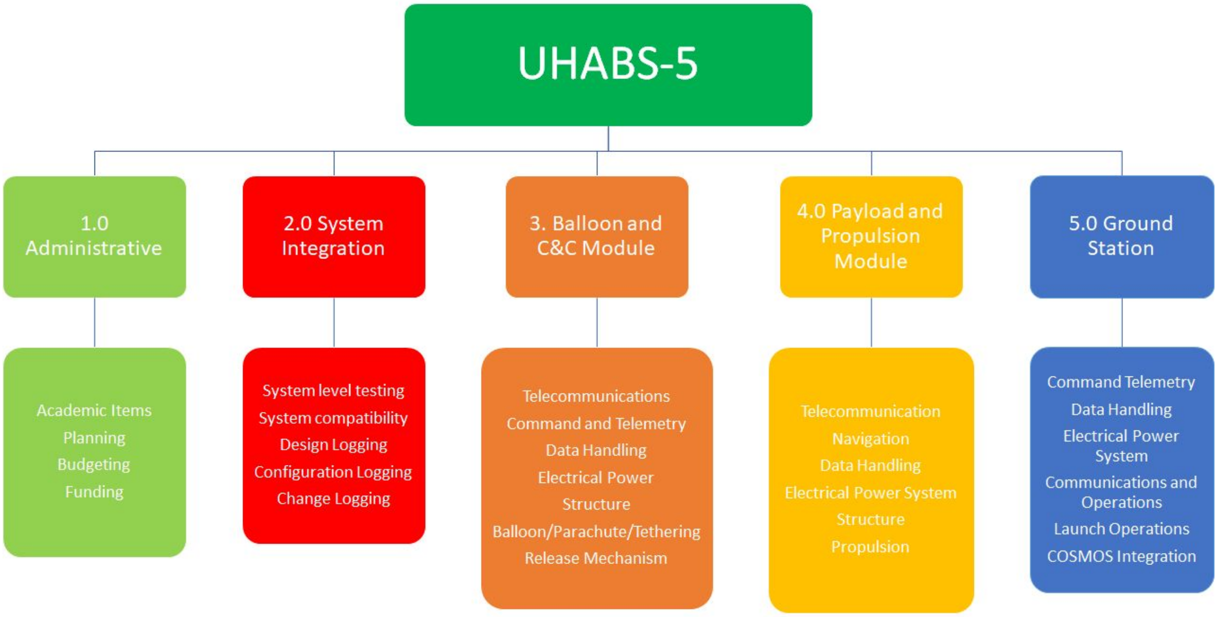
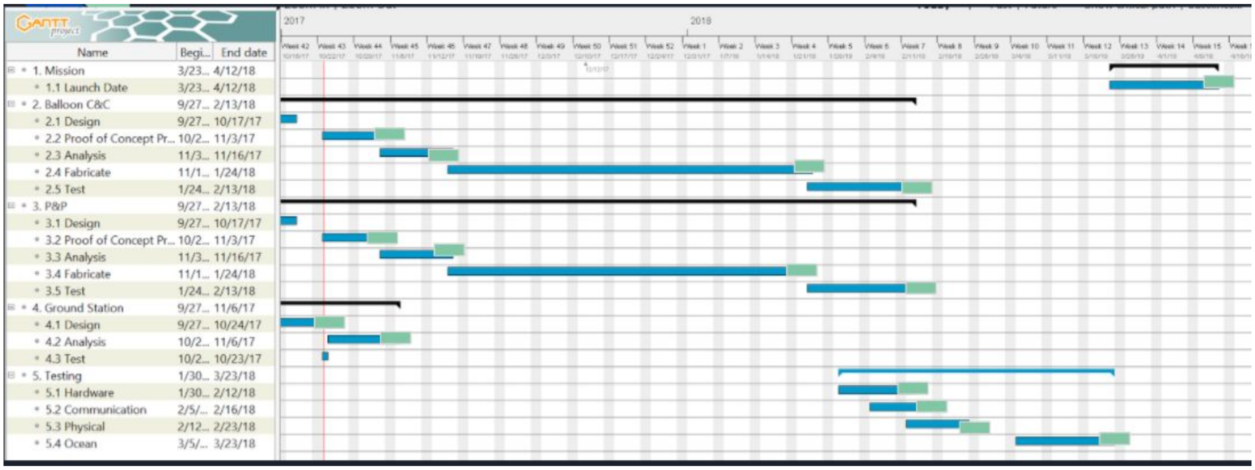


Figure 3.2: *WBS for each subteam*

The Gantt Chart in Figure 3.3 shows the projected schedule for the UHABS-5 mission along with the processes of milestone achievements. This includes the design process for each subsystem starting from the first concepts to testing and the developing the final product.



Name	Begi...	End date
1. Mission	3/23...	4/12/18
1.1 Launch Date	3/23...	4/12/18
2. Balloon C&C	9/27...	2/13/18
2.1 Design	9/27...	10/17/17
2.2 Proof of Concept Pr...	10/2...	11/3/17
2.3 Analysis	11/3...	11/16/17
2.4 Fabricate	11/1...	1/24/18
2.5 Test	1/24...	2/13/18
3. P&P	9/27...	2/13/18
3.1 Design	9/27...	10/17/17
3.2 Proof of Concept Pr...	10/2...	11/3/17
3.3 Analysis	11/3...	11/16/17
3.4 Fabricate	11/1...	1/24/18
3.5 Test	1/24...	2/13/18
4. Ground Station	9/27...	11/6/17
4.1 Design	9/27...	10/24/17
4.2 Analysis	10/2...	11/6/17
4.3 Test	10/2...	10/23/17
5. Testing	1/30...	3/23/18
5.1 Hardware	1/30...	2/12/18
5.2 Communication	2/5/...	2/16/18
5.3 Physical	2/12...	2/23/18
5.4 Ocean	3/5/...	3/23/18

Figure 3.3: *Gantt chart of the proposed schedule for the academic year*

Team Zeppelin currently has an inventory of the remaining hardware from the previous UHABS missions. Zeppelin will utilize the hardware currently on hand for prototyping UHABS-5, however the hardware on will not be used on the final product unless it is the most current version of the hardware and the team is planning to obtain as many parts on island as possible so that there is minimal lead time or shipping required. The team plans to have all components ordered by the end of December and receive them no later than the beginning of February. Appendix A-2 contains a list of the needed components, their status, and where the team plans to obtain the components.

During the design of the UHABS-5 several risks were identified. Table 3.1 shows the risk identification, the level of risk based on the risk matrix in appendix A-1, and the mitigation for the risk.

Table 3.1: *List of risk identification and mitigation*

Risk Identification	Level	Risk Mitigation (blue = proactive, red = reactive)
Balloon doesn't burst upon desired altitude	Low	- obtain balloon that will burst at correct altitude - integrate autonomous release when at desired altitude - integrate manual release from ground station when above the desired altitude
BalloonSat interfering with air traffic	Low	- research sites and find optimal site per FAA regulations
BalloonSat modules, C&C and P&P, falling on a person	Medium	-select remote site to reduce the probability of people within the range calculated for C&C and P&P landing
Batteries catching on fire	High	-optimize hardware configurations -apply measures to prevent interaction with water and survive impact

		-obtain a better battery
C&C Module unable to detach from P&P when needed	Medium	-analyze tether material for best holding modules together until release -add mechanism for release
COSMOS module being implemented not ready in time	Medium	-designate members to learn COSMOS and be able to show working operations before launch
Insufficient funding to complete project	Medium	-Apply for multiple funding sources -Set up fundraisers -Make adjustments to scope to allow for a cheaper balloonsat
Insufficient Power for P&P module to navigate to designated location	High	-optimize design to reduce drag -select higher performing motors -optimize design of propellers -move less critical components to C&C
Losing a propeller during flight or recovery	High	-integrate additional steering mechanism to propulsion module
Majority of team members in Zeppelin have little experience with programming and hardware	Medium	-Recruit EE students to help with the project and teach other members the basics -have designated members go through tutorials to master software and hardware -Utilize EE students and engineering faculty expertise to help solve problems
Majority of team members in Zeppelin have never worked with satellites before	Medium	-recruit people who have worked on satellites before -Arrange assistance from mentors who have participated in UHABS in the past -Build complete models with past iterations before prototyping and designing -Change scope of mission to allow for cheaper less complex satellite
Operations will not be ready to support the mission	High	-have buffers in scheduling -make sure test are done several weeks in advance and practice operations
P&P Module Heavier Than Budgeted	Medium	-optimize design -use lighter more expensive materials
P&P Module lands outside of the range for communication with ground station	Medium	-do analysis for launch day conditions to ensure landing with in range -add a kill switch in case of loss of communication

The design freeze for Zeppelin will be 11/27/2017, after this date no major changes to the design are allowed. Before this date all subsystems need to submit their final design to the SI.

The design entails the overall modules and their configuration during the launch sequence. Any changes that the subsystems need to make to the design after the design freeze need to be approved by the project manager, systems integrator, and the financial adviser. In order to have any changes approved the subsystem team must provide a detailed budget to show how the change will affect the set budget, a detailed schedule to show how the change will affect any major deadlines, and any analysis and testing to justify the change. Approval for any changes will only be given if the implementation of the change does not cause a deficit in the allotted budget, does not delay the completion of the overall project, and justification shows that the change will be beneficial to the overall mission.

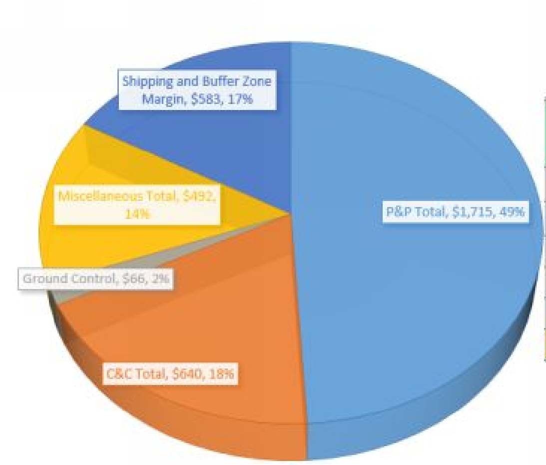
Zeppelin will need to create and keep track of the documents on table 3.2. The table includes a the title each document, the team members assigned to each document, and the deliverable for each document. All documents listed are important for the completion of the UHABS-5 mission.

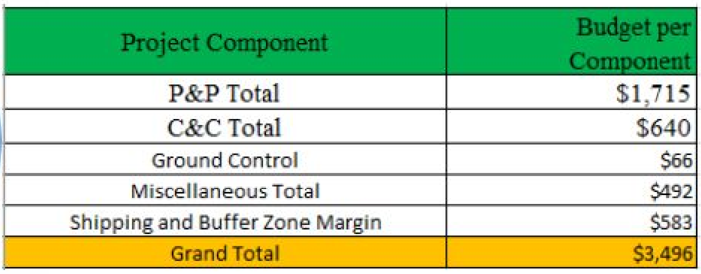
Table 3.2: *List of assigned document and their roles*

Document Name	Assigned	Deliverables
BC&C Mass and Volume Budget	James Yang	Mass Budget for the C&C module to ensure the module is optimized and stays within the FAA Mass Constraints
BC&C Power Budget	Manny Valdez	Power budget for the C&C module to ensure that the module has the power required to function for the duration of intended operation
Budget	Drex Arine	An itemized list of parts needed for the completion of the project, the budget is needed to ensure the team has the funds to acquire all needed items and filter out any excessive unneeded items
Design Change Log	Reagan Paz	Document for any changes made after the design freeze, this is needed in order to show the customer the source of any discrepancies with the design presented during the CDR and the final product, it will include all justifications for the design changes
Documentation List	Karen Calaro	List of all documents being monitored that are critical to the completion of the mission
Funding Sources and Awards	Drex Arine	List of sources of funding to consider and status of any awards and requests for funding
Gantt Chart	Karen Calaro	Tool to track the completion of tasks and provide a visual aid to keep team members on task
Mission Requirements Document	Karen Calaro Reagan Paz Drex Arine Kahekili Clark Jace Yamaguchi Yun Feng Tan	Document where the mission, objectives, requirements, and constraints related to the mission are located
P&P Mass and Volume Budget	Kahekili Clark	Mass Budget for the P&P module to ensure the module is

		optimized and stays within the FAA Mass Constraints
P&P Power Budget	Andrew Bui Cyrus Noveloso	Power budget for the P&P module to ensure that the module has the power required to function during the flight and recovery phases
Team Calendar	Karen Calaro	Google calendar that will remind team members of major milestones, academic deadlines, team deadlines, team meetings and test dates
WBS Dictionary	Karen Calaro	Document with details more details for the tasks on the WBS
Website	Reagan Paz	Tool for generating interest for the UHABS-5 and providing information for those interested

Zeppelin still has some remaining concerns after the trade study done leading up to the the preliminary design of the UHABS-5. Some of the concerns include the ability of the propulsion design to overcome the drag forces acting upon it based on where it lands during the launch sequence. The P&P module needs to do further trade study, analysis, and testing in order to solidify the design. Another concern within the P&P module is its ability to provide power to all critical components for the recovery phase because of the current estimated operational time due to the current drawn from components. The sub team needs to do further analysis on the time to charge, the time to navigate to the designated location based on certain conditions, and analysis of the electrical components within the system. The C&C module has concerns about the release mechanism in the case of conditions preventing the P&P from towing the C&C. Both modules have concerns with the possibility of the battery catching fire, so both systems need to do further studies on preventative measures. Within the ground station the main concern is the ability to implement COSMOS into the system operations as well as being able to communicate with the C&C and P&P modules at the appropriate range. Overall there are concerns with the skill set needed to complete UHABS-5 since the skill set needed in not only mechanical engineering, it includes knowledge in hardware, software,and communications.





Project Component	Budget per Component
P&P Total	$1,715
C&C Total	$640
Ground Control	$66
Miscellaneous Total	$492
Shipping and Buffer Zone Margin	$583
Grand Total	$3,496

The financial budget for UHABS-5 was derived from the costs for the collective items listed in the mass and volume budget for each trade, C&C P&P and Ground Control. This was done to ensure that all items to be utilized by each trade were accounted for. In addition, miscellaneous items such as helium and construction material were considered in the estimate. Shipping and unforeseen project costs was factored into the budget by taking a 20% percentage margin of the summed cost. After reviewing these considerations, the grand total budget needed to complete this project was estimated to be $2674. From the overall budget breakdown pie chart, the P&P module has the highest budget because of the high cost items such as the motors, motor batteries and propellers. Considering the rough conditions that the P&P module will have to endure, a propulsion system with high efficiency and power is needed and that directly increases costs. C&C and ground station has the lowest budget because sensors have a reasonable price range and most of the ground station equipment is already acquired. For a more detailed breakout of the budget please refer to the appendix.

To support the projected budget for fabrication and launch of UHABS-5, the team's financial adviser registered the UHABS-5 team as an official RIO organization for funding opportunities for the current UHABS-5 team, and for future iterations of UHABS projects. Different sources for funding were investigated. The sources considered were UROP, SAPFB, and ASUH. The team submitted applications and necessary documents for SAPFB and UROP. Table 3.3 contains information about the amounts requested and the status of the requests. During the spring semester Zeppelin plans to apply for ASUH research funding for this project, and SAPFB funding for the following iteration of UHABS.

Table 3.3: *List of funding sources and status.*

Funding Resources Applied	Funding Amount Requested	Funding Status	Funding Received
UH Mechanical Engineering Department	$2000	Approved	$2000
UROP	$2000	Still under program's review	Tentative
SAPFB	$500	Still under program's review	Tentative

4 Conclusion [JKY, KBC]

The mission of UHABS-5 is to successfully develop a BalloonSat which will be capable of carrying payloads to a near-space environment and return to safely to Earth for intact recovery. If it lands on the ocean, the BalloonSat will autonomously propel itself to a designated target for recovery. In order to accomplish the mission Zeppelin was divided into three major subsystems, each system focusing on a critical component of UHABS-5.

The Balloon and C&C subteam focuses on designed each component needed during flight and data collection of the environment. During the design phase the Balloon and C&C

subsystem focused on design the optimal shape for the system and the electrical components to perform the necessary tasks. The current design for the C&C module needs further analysis and testing to prove that it can be towed by the P&P module during the recovery phase. The hardware selected for the C&C module is based off of the selections and recommendations of previous UHABS iteration and need to be further tested to make sure the hardware selected is compatible with the design.

The Ground Station Operations subteam has to be able to retrieve data and document all aerial information, it also has to be able to send commands to the P&P and C&C module in case the autonomous features are not executing correctly. The current design for the ground station needs further testing of the selected antennas and radios to ensure they can function to the required range for a successful mission. The ground station also needs to become more familiar with COSMOS to be integrate it into operations. The subsystem team will also need to prepare operations for the launch date which is to be determined.

The Payload subteam focus is on the structure of the self-navigating device to deliver the UHABS-5 back to the team. The current design needs further trade study and testing to provide the most feasible method of propulsion for the recovery phase. The current design needs to undergo flow analysis and needs to be tested for proof of concept.

The current design for the modules in UHABS-5 have an estimated budget of $2674. This budget includes prices for the components within the C&C Module, Payload and Propulsion Module, and Ground Station as well as structural material, helium, and shipping costs for item that cannot be obtained on the island. The total cost is also subjected to a ±20% budget margin and is expected to have a smaller margin as a more accurate analysis is done detailed and critical design phase. Various funding sources were investigated to have the appropriate amount of funding to prototype and fabricate UHABS-5 the funding the team is attempting to obtain is greater than the projected budget to provide a safety net in the case that Zeppelin runs into unexpected issues and requires replacement parts. To cut prices down, Zeppelin will go through extensive testing before the launch date to prepare all module and make sure they can survive the various conditions during operations.

Many balloon satellite teams are done in the mainland United States, providing easier retrieval to their balloon satellites. However, in Hawaii the chance of the balloon landing in water is almost certain thus showing the importance of the need of a successful retrieval device. Learning from the problems from previous UHABS iterations, Zeppelin hopes to successfully develop a BalloonSat that is able to successfully expand on the current ideas and provide insight on fabricating a high-altitude data documenting device that is able to autonomously propel itself to a designated location after landing.

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Appendices

A-1: List of Requirements

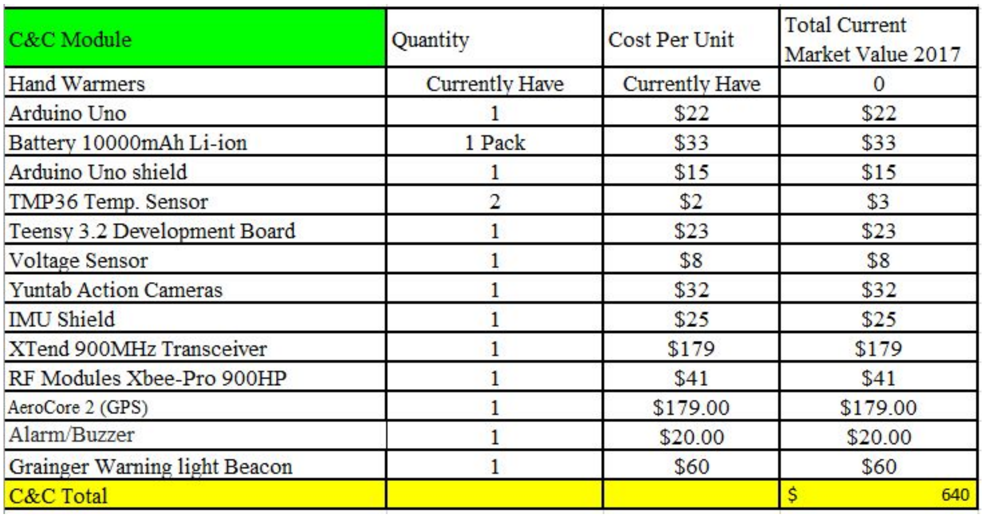
Requirements		
Object ID	**Description**	
1. Mission		
1.1	UHABS-5 shall consist of a parachute, command and control (C&C) module, a payload and propulsion (P&P) module and any necessary ancillary equipment and structure.	Mandatory
1.1.2	UHABS-5 the balloon and C&C module and the P&P module shall be separated modules	Mandatory
1.2	Team shall design the UHABS-5 system, procure required parts and materials, design and build modules, integrate and test the system, launch and operated the system, recover the system if possible, and analyze and report the data from the mission.	Mandatory
1.3	Instrumentation for the module shall be accommodated in the UHABS-5	Mandatory
1.4	UHABS-5 shall select a launch site appropriate for the level execution of the UHABS-5 launch sequence	Mandatory
2. Balloon and C&C		
2.1	The Balloon shall carry a combine of up to 12 lbs to the desired altitude and be able to detach from the modules autonomously or by command.	Mandatory
2.2	The BCC Shall have a parachute deployable after detaching from balloon and have a landing speed of below 15ft/s.	Mandatory
2.2.1	The C&C module shall withstand 15 ft/s impact without damage to onboard electronics	Mandatory
2.3	The C&C module shall have enough power to sustain flight time and maintain communication link with ground station.	Mandatory
2.4	The C&C module shall store and downlink state of health telemetry data throughout the mission.	Mandatory
2.5	The C&C module shall have an on board downward facing camera recording video during launch and ascent.	Mandatory
3. Payload and Propulsion		
3.1	The P&P module shall initiate the autonomous propulsion system after landing and traverse to a predetermined location, where it shall standby for retrieval.	Mandatory

3.1.1	The P&P module shall be sufficiently powered to prevail over oceanic wind and waves during navigation	Mandatory
3.1.2	The P&P module shall be watertight to protect internal components from corrosive and electrical damage.	Mandatory
3.1.3	The P&P module shall initiate automatically after descending to zero meters in altitude.	Mandatory
3.2	The P&P module shall possess the means to periodically communicate its position to the ground station	Mandatory
3.3	The P&P module shall have an audible location beacon capable of producing an audible signal through 100 yards of scrub.	Mandatory
3.3.1	The audible beacon shall be waterproof and remain operative for a minimum of 24 hours	Mandatory
3.4	The P&P module internal temperature shall be regulated to the operating limits of its internal components at all times	Mandatory
4. Ground Station		
4.1	Ground station shall command an emergency balloon release in the case of unfavorable situations	Mandatory
4.2	Ground Station shall provide two-way communication with the C&C Module during the entire mission from pre-launch activation through system shut off and retrieval	Mandatory
4.3	Ground station shall receive the location of the propulsion system during recovery	Mandatory
4.4	Ground system shall use COSMOS Operations shall monitor and report UHABS-5 SOH during the mission	Mandatory
4.5	Ground station shall receive, process, and display all SOH telemetry and atmospheric data received from the UHABS-5 in near real-time	Mandatory
4.6	Ground station shall receive a live feed from a down facing camera while the satellite ascends	Mandatory
5. Testing		
5.1	Generally, testing shall be required to prove UHABS-5 can meet the functional, environmental, and operational requirements	Mandatory
5.2	A test run on a secluded area of the ocean shall be required to prove the ability of UHABS-5 to move in and reach a designated target	Mandatory
5.3	Testing shall be required to prove the ability of UHABS-5 to release the parachute when it approached the surface	Mandatory
6. Project Management		

6.1	A Project Management Plan (PMP) shall be produced in time for the Critical Design Review (CDR). The PMP shall contain the Work Breakdown Structure (WBS), schedule and other project information as required by the Customer	Mandatory
6.2	A Configuration Management Plan shall be implemented	Mandatory
6.3	Weight, power, and cost budgets shall be produced and updated when necessary	Mandatory
7. Constraints		
7.1	Time	
7.1.1	UHABS-5 design shall be complete by December	
7.1.2	UHABS-5 shall be built, tested, launched, and recovered by May	
7.2	FAA & FCC Regulations	

A-2: Budget Per Subsystem

C&C Module Itemized Budget List

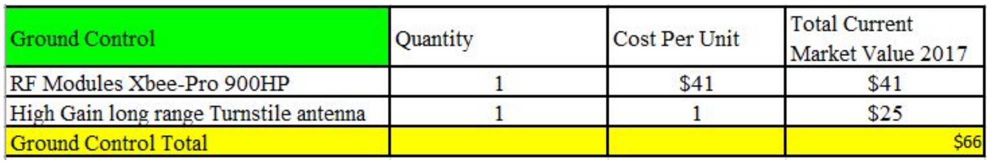


C&C Module	Quantity	Cost Per Unit	Total Current Market Value 2017
Hand Warmers	Currently Have	Currently Have	0
Arduino Uno	1	$22	$22
Battery 10000mAh Li-ion	1 Pack	$33	$33
Arduino Uno shield	1	$15	$15
TMP36 Temp. Sensor	2	$2	$3
Teensy 3.2 Development Board	1	$23	$23
Voltage Sensor	1	$8	$8
Yuntab Action Cameras	1	$32	$32
IMU Shield	1	$25	$25
XTend 900MHz Transceiver	1	$179	$179
RF Modules Xbee-Pro 900HP	1	$41	$41
AeroCore 2 (GPS)	1	$179.00	$179.00
Alarm/Buzzer	1	$20.00	$20.00
Grainger Warning light Beacon	1	$60	$60
C&C Total			$ 640

P&P Module Itemized Budget List

P&P Module	Quantity	Cost Per Unit	Total Current Market Value 2017
Large Styrofoam Cube	2	$20.00	$40.00
ABS Plastic	1 roll	Currently Have	0
Arduino Uno	Currently Have	Currently Have	$0.00
Arduino Uno shield	1	$15.00	$15.00
Teensy 3.2 (Microcontroller)	1	$23.00	$23.00
2" Construction Grade Polystyrene	Currently Have	Currently Have	0
AeroCore 2 (GPS)	1	$179.00	$179.00
Propeller Octura x435	2	$11.00	$22.00
VNH2SP30 (Motor Controller)	1	$60.00	$60.00
Neu 1509 1Y (Motor)	2	$365.00	$730.00
Floureon 2 Pack Li-Po Battery (Motor)	2 Pack	$63.00	$126.00
Castle Creations Hydra ICE 240A XL 33.6V w/Switching BEC (Motor Control)	1	$290.00	$290.00
XTend 900 (RF Transceiver)	1	$179.00	$179.00
RF Modules Xbee-Pro 900HP	1	$41.00	$41.00
Sparkfun SD Card Breakout Board	1	$10.00	$10.00
Class 10, 32GB Micro SD Card	Currently Have	Currently Have	$0.00
P&P Total			$1,715.00

Ground Control Itemized Budget List



Ground Control	Quantity	Cost Per Unit	Total Current Market Value 2017
RF Modules Xbee-Pro 900HP	1	$41	$41
High Gain long range Turnstile antenna	1	1	$25
Ground Control Total			$66

Miscellaneous Itemized Budget List

Miscellaneous	Quantity	Cost Per Unit	Total Current Market Value 2017
Parachute	1	Included	0
Helium Tank	1	1	$487
Gorilla Glue	1 Bottle	Currently Have	0
bolts/nuts/screws	Currently Have	Currently Have	0
Rubber washers and Gaskets	1 pack	$5	$5
Solder wires	Currently Have	Currently Have	0
Miscellaneous Total			$ 492

A-3: Launch Sequence Diagrams