Team 2: *Dancing With The Stars*

Written by:
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Revision Log

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B</td>
<td>Conceptual and Preliminary Design Review</td>
<td>March 7, 2017</td>
</tr>
<tr>
<td>C</td>
<td>Critical Design Review</td>
<td>April 6, 2017</td>
</tr>
<tr>
<td>D</td>
<td>Analysis and Final Report (There is a first draft and final draft)</td>
<td>April 29, 2017; May 10, 2017</td>
</tr>
</tbody>
</table>

User Notes:

This template describes the topics which should be discussed during the evolution of your project. The following sections have a Revision letter following the section description. This indicates when this section is expected to be a part of this document. If a section is required in Rev A/B, then that section should be in Rev A/B and updated in subsequent revisions. As your project becomes more defined, return to previous sections and update accordingly.

Each time when you submit your Design Document, remove any unnecessary sections or template notes. For example, if you are submitting Rev A/B, don’t include the Conclusions section. Be sure to incorporate all feedback/comments from previous graded revs and/or the proposal. Failure to address this feedback WILL adversely affect the score on your next rev.

This report is due in electronic form on the days indicated on the class syllabus. Please follow this format exactly. The final (Rev D) report length should not exceed 50 pages without prior permission from the instructor.

NOTE – Include Revision Log in your revisions.

Commented [LW3]: Delete all of this: these are guidelines for writing the design document and are not meant to be included.
# Table of Contents

1.0 Mission Description 5
   1.1 Mission Statement 5
   1.2 Mission Overview 5
   1.3 Mission Hypothesis 4

2.0 Requirements 6
   2.1 Requirement Flow Down 6

3.0 Design 7
   3.1 Concept of Operations Diagram
   3.2 Structure 8
   3.3 Functional Block Diagram 10
   3.4 Sensor Hardware 11
   3.5 Reaction Control System 12
   3.6 Thermal Control System 12
   3.7 Command and Data Handling 13

4.0 Management 14
   4.1 Organization Chart 14
   4.2 Schedule 15

5.0 Budget
   5.1 Itemized Budget and Weight 17

6.0 Testing and Safety Plans
   6.1 Testing
   6.2 Safety 25

7.0 Expected Results 25
   7.1 Thermometer data 25
   7.2 Pressure Data
   7.3 Humidity Data 27
   7.4 Accelerometer Data 28

8.0 Launch and Recovery

9.0 Results, Data Analysis, Failure Analysis (if applicable), and Conclusions

Page 4 of April 6th, 2017
Rev C
10.0 Mission Description

1.1 Mission Statement

*Dancing with the Stars* will craft a balloon satellite which stabilizes and orients itself during ascent, using an apparatus consisting of a reaction wheel, gears, and motor. This assembly will point the satellite in discrete directions at given checkpoints of every twenty thousand feet. A servomechanism attached to the GoPro will adjust the vertical angle of the camera and take photo or video of the target location.

1.2 Mission Overview

In an operation such as this, keeping individual control over one’s satellite is an arduous process. The hydrogen balloon and parachute provide no means of stability; the satellites are subjected to substantial spin and tilt. The team aspired to find a means to control the satellite, and found a method of doing so through articles from Utah State University and University of Michigan Ann Arbor. *Dancing with the Stars* will incorporate a plastic reaction wheel into Pirouette, composing of a torque wheel, motor, and gears to stabilize the satellite and control its heading. Instead of taking pictures in random directions, the team will harness the moment of the reaction wheel to direct the camera at designated locations every twenty-thousand feet. Determining the direction is the craft’s guidance system, composed of a Nine Degrees of Freedom sensor, a GPS, and a barometer. Controlling the vertical angle of the camera lens is a servomechanism reading data from the accelerometer. When the operation of the reaction wheel is combined with the swivel of the servomechanism, the result is imagery directed at specific targets, such as the city of Denver, the sun, and the Rocky Mountains. *Dancing with the Stars* aspires to control the flight into the stratosphere, and takes heavy inspiration from the stunning snapshots of the earth and other celestial bodies from NASA satellites, such as the Pioneer Missions. The opportunity to innovate a method

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for high-quality, high-atmospheric photography from a low-budget spacecraft motivates the team to tackle this challenge.

1.3 Mission Hypothesis

Provided that the reaction wheel and attitude determination and control system works as a whole, the team expects Pirouette to function as intended; the wheel will control the acceleration on the horizontal plane and the camera will point in the vertical direction assigned. The reaction wheel will possess ample power to turn the structure in any discrete direction necessary. The major concern stems from the risk involved with the moving parts on the interior of Pirouette. If the reaction wheel experiences any internal friction with the components of the satellite, the whole mission will be compromised. Additionally, if the camera is separated from its servomechanism which provides it the capacity to swivel on a vertical plane, the precise snapshots will not be acquired, undermining much of the mission. Finally, if the 9 DoF sensor experiences too much trauma thermally or via motion, the reaction wheel will not have any readings to instruct it to act- it will go inactive. Overall, the mission will be carried out as planned, provided that the flight isn’t chaotic enough to destabilize the internal structures of the satellite and cause the moving parts to become unattached or displaced.

2.0 Requirements

2.1 Requirement Flow Down

The flow down tables below show the Level Zero and Level One Requirements for the BalloonSat. Level 0 Requirements can be directly traced back to the Mission Statement and the Request for Proposal. Level 1 Requirements can be traced back to Level 0 Requirements. These requirements can are consistent with the condensed mission statement: to fly the BalloonSat approximately 30 km high, controlling the attitude of the satellite and camera at predetermined points throughout the flight.

<table>
<thead>
<tr>
<th>Level 0</th>
<th>Number</th>
<th>Requirement</th>
<th>Derived From</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
<td>The BalloonSat shall be ready for launch on April 8th, 2017.</td>
<td>2017 COSG RFP</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>The BalloonSat shall meet the specifications set forth in the 2017 COSG RFP.</td>
<td>2017 COSG RFP</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>The BalloonSat shall be able to travel up to 30 km high and maintain functionality.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>The BalloonSat shall be able to determine and control its horizontal attitude and verticality of its camera angle.</td>
<td>Mission Statement</td>
</tr>
</tbody>
</table>

Commented [LW13]: Each requirement should start with "Team Dancing with the Stars shall..."

Commented [LW14]: Specify that this is denoted by RFP

Commented [LW15]: Delete this

Commented [LW16]: Title this “Level 0 Requirements”
The BalloonSat shall record data including temperature, humidity and acceleration during the flight.

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Derived From</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>The BalloonSat shall record data including temperature, humidity and acceleration during the flight.</td>
<td>2017 COSG RFP</td>
</tr>
</tbody>
</table>

### Level 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Derived From</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The BalloonSat shall weigh no more than 864 grams</td>
<td>0.1 &amp; 0.2</td>
</tr>
<tr>
<td>1.2</td>
<td>Project Pirouette shall adorn the American flag on the outside</td>
<td>0.2</td>
</tr>
<tr>
<td>1.3</td>
<td>The internal temperature of Project Pirouette shall not go below 0°C</td>
<td>0.1 &amp; 0.3</td>
</tr>
<tr>
<td>1.4</td>
<td>Project Pirouette shall use the output from the GPS sensor while below 30,000ft to determine its position and orientation.</td>
<td>0.3</td>
</tr>
<tr>
<td>1.5</td>
<td>The BalloonSat shall determine its orientation from the 9DoF sensor, and command the wheel to point the Satellite in a certain direction</td>
<td>0.4</td>
</tr>
<tr>
<td>1.6</td>
<td><em>Pirouette</em> shall use a servo motor to rotate and control the GoPro camera at certain altitudes</td>
<td>0.4</td>
</tr>
<tr>
<td>1.7</td>
<td>Project Pirouette shall use a reaction wheel controlled by a motor to orient the BalloonSat</td>
<td>0.4</td>
</tr>
<tr>
<td>1.8</td>
<td>Project Pirouette shall be securely attached to the COSGC flight string without harming internal operations</td>
<td>0.5</td>
</tr>
<tr>
<td>1.9</td>
<td>All of the Satellite’s sensors shall remain functional and output data throughout the flight to be recorded on an SD card</td>
<td>0.3 &amp; 0.5</td>
</tr>
</tbody>
</table>

### Design

#### 3.1 Concept of Operations Diagram

*Pirouette* aims to stabilize a camera about two axes of rotation. This will be accomplished by integration of a reaction control system and a series of motion and location dependent sensors. Data from these systems will be analyzed by software before returning the BalloonSat to COSGC in fully working order.
being outputted as instructions for the control system.

3.2 Structure

The satellite bus will be an octagonal prism composed of foam core and aluminum tape. Each face of the prism will be a rectangle 10 cm long by 9 cm high. The octagonal design will provide the optimal circular area to fit a reaction wheel while still keeping the bus relatively simple in terms of construction and design. This will also allow for a relatively large area on a face to fit the camera and the anchor for the servomechanism motor.

A hole will be cut into one face in order to interface with the camera and servo motor and to allow the camera freedom to rotate. These two components and the hole will be shielded with a transparent polycarbonate half-dome. The string connecting the BalloonSat to the balloon will feed through a tube in the center of the bus. Bearings on

Commented [LW25]: This would be a good intro to your design section, but it doesn’t work well as an intro to your CONOPS because it isn’t really related to your CONOPS diagram
the top and bottom of this tube will allow freedom of rotation about the string, while bearings on the outsides of this tube will allow rotation of the reaction wheel about the tube at its center.

The structural and component design of Pirouette is detailed in Figure 3.2. An isometric view is provided by Figure 3.3.

Figure 3.2 - Top-down schematic. Units are in millimeters.
3.3 Functional Block Diagram

*Pirouette* will be composed of three main subsystems: the BalloonSat Sensor System (2.3), the Thermal Control System (2.4), and the Reaction Control System (2.5). A single lithium ion polymer battery will power all of these subsystems. While this creates a single point of failure, it is deemed necessary because the mass saved by having just one single, dense battery allows for the fabrication of a heavier (and thus more effective) reaction wheel. If the battery powering the reaction wheel fails, the attitude control purpose of the experiment is nullified, but the camera will continue to function.

*Commented [LW26]: These sections don’t exist, section 2 is your requirements section*
3.4 Sensor Hardware

Atmospheric Sensors: Each sensor shall be integrated with one of two Arduinos. The first set of sensors are prerequisite for the mission, and will be integrated with the Balloon shield. These include a 3-axis linear accelerometer, a humidity sensor, a pressure sensor, and two temperature sensors. Before flight each sensor will be tested and stimulated individually to ensure sensor functionality. All of these will be logged to an SD card for post-mission analysis.

Control Sensors: The second set of sensors will be used as inputs to the Reaction Control System (Section 2.4). 3-axis linear and angular acceleration as well as heading will be measured by a 9 Degrees of Freedom (9 DoF) sensor; a GPS will measure latitude, longitude, and altitude; and a second barometer will measure pressure to measure altitude once the GPS cuts out around 18,000 meters. A hall effect sensor integrated with the main motor will provide angular position data for the reaction wheel. All of these sensors will feed data to the second Arduino. This data will be recorded to an SD card for post-flight analysis as well as used to compute outputs for the two motors.
3.5 Reaction Control System

The RCS will consist of two major subsystems: a reaction wheel and a servo. The reaction wheel will provide torque on the axis about the string, while the servo will control angle about an axis perpendicular to the string.

The reaction wheel was designed in SolidWorks and has been milled from Delran plastic. The wheel contributes 170 grams of the satellite’s weight, so it will be able to affect the rotation of the satellite. The wheel’s rotation is driven by a motor connected with a meshed gear system. The driver gear will be connected directly to the motor’s shaft, while the driven gear will be connected directly to the reaction wheel. Both the reaction wheel and its attached gear will be connected to the central tube with a set of bearings in order to allow the best freedom of rotation. The reaction motor will have its torque controlled by the Arduino via a motor controller. This subsystem allows for a full 360 degrees of rotation.

The servo motor will function as the camera’s gimbal, allowing rotation about a second axis. This subsystem will thus allow the camera to capture any photo within 90 degrees above or below the horizon, as well as correct for tilt induced by wind shear. The servo is controlled in angular steps, so its angle is dependent on initial angle and previous inputs, all of which can be either controlled or logged such that its angle will always be known.

The data stream from control sensors (Section 2.3) will contribute to the control of the RCS. This implementation shall be detailed in the software integration section (Section 2.6). However, it is important to note in this section that the composite data will account for the calculation of position, control of rotation, and camera angle correction, which will in turn allow the RCS to aim the camera at any target within its potential field of view.

3.6 Thermal Control System

At high altitudes, temperature drops significantly. The environment at near-space altitudes includes temperatures between -50 to -70 degrees Celsius and low pressures of 20 millibars. In order to maintain functionality and efficiency of BalloonSat components, a heater will be used to prevent the internal temperature of the satellite from dropping too low. The heater is provided by Colorado Space Grant Consortium and will be turned on at launch (2.2). This is extremely important because the Lithium Polymer battery being used to power the reaction wheel drastically decreases in efficiency as temperature decreases. In order to maintain sufficient power from the battery, temperatures should be maintained near 0 degrees Celsius. There is a trade-off however, because as more power is used to keep the battery warm, less power is available to power other components of the satellite.

Commented [LW29]: This section doesn’t exist
Commented [LW30]: This section doesn’t exist
Commented [LW31]: What’s this?

In addition to the active heating component, foam insulation will be used to retain the heat generated by the heater. The LiPo battery pack is encapsulated with foam to keep it warm because the battery is the component that is most affected by cold conditions and is therefore the limiting factor. Specifically, its charge capacity decreases as temperature decreases (Figure 3.1), thus making less energy available at lower temperatures as well as significantly increasing the component’s chance of critical failure.

![Figure 3.1 - lithium ion polymer battery capacity vs voltage at varying temperatures.](http://www.ibtpower.com/Battery_packs/Li_Polymer/Lithium_polymer_tech.html)

3.7 Command and Data Handling

The primary, and most complex, component of C&DH is the RCS. The RCS command interface will be an inertial control system. 9 DoF sensor’s 3-axis angular and linear accelerometer data will be fed to a Kalman filter in order to decrease sensor noise and to calculate the satellite’s linear and angular acceleration, velocity, and position on all three axes.

The altimeter will be an integration of the barometer with the Arduino, and will calculate altitude as a function of pressure in order to tune the vertical position vector, and will itself be tuned with the GPS unit up to 18 kilometers. The GPS unit will also tune the position vector up 18 kilometers. This complete subsystem shall be referred to as the “position tracker.”

A second set of data containing position and altitude data for a series of pre-set targets, which shall be referred to as “target data,” will be pre-loaded onto the RCS Arduino. This target data will include a camera position and an angular velocity target, the result of this will be a smooth sweeping motion. The goal angular velocity is 10 degrees/sec so that a

Commented [LW32]: I’m still looking for more detail here. This is one of the most crucial parts of your mission, you really need to explain more

Commented [LW33]: Need to explain what this is

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5 [http://www.ibtpower.com/Battery_packs/Li_Polymer/Lithium_polymer_tech.html](http://www.ibtpower.com/Battery_packs/Li_Polymer/Lithium_polymer_tech.html)
complete circle will be made in approximately 36 seconds. The camera angle will be dependent on the altitude. Immediately after launch, the camera will be programmed to face directly downward until all the sensor have set up. Then, as altitude markers are reached, the PID loop will assume control to achieve target data.

The control component of the RCS will be handled by a proportional-integral-derivative (PID) control loop. This will be sent the resultant vector data from the Kalman filter, as well as angular position data from each motor, and will in turn control each motor. The servo motor will simply be sent an input for its desired angle. The reaction motor will be given a specific amount of current, either negative or positive, to turn the reaction wheel via a motor controller connected to the Arduino. First, the reaction wheel will be rotated until it is facing the correct direction; then, its angular velocity will be canceled. The wheel’s torque will be taken into account for these calculations as a function of its acceleration, which will be calculated based on its position over time. This subsystem shall be referred to as the “control loop.”

The second component of C&DH is the thermal control system. By comparison, this is much simpler: the internal temperature of the craft will be limited by a lower bound with the thermal controller. The operation and requirements of this system are detailed in Thermal Control System (2.5).

Over the course of the flight, all data will be logged to SD cards for post-flight analysis.

4.0 Management

Our team’s subsystem layout was separated by each person to best fit everyone, and their unique skills set. We have continued with having two team members per subsystem to ensure quality as well as efficiency so our satellite is complete on time and fully operational. Our larger team allows us to assign each member to two different subsystems which leads to a broader understanding of each concept being implemented into our mission. This is possible because subsystems must connect to others for the success of the mission, this means our team must communicate well to eliminate any possible errors. Mission Pirouette is a complex experiment with many moving parts, every aspect (or subsystem) must be accounted for in every other subsystem’s calculations/construction. The amount of mechanics within the satellite require constant calibration while in the testing phase, since there are multiple systems that interact it is vital that each subsystem is spoken for by at least one of its co-representatives at each team meeting.

4.1 Organization Chart

Commented [LW34]: This section doesn’t exist

Commented [LW35]: Move this title to the next page
4.2 Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Dates</th>
<th>Tasks</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/6 - 2/12</td>
<td>Select a Mission, Divide into Subsystems, Develop Proposal, Learn basic Arduino commands, HW 05 &amp; HW 06 due</td>
<td>Team will be able to describe the basic necessities of the mission, and communicate code to an Arduino</td>
</tr>
<tr>
<td>2</td>
<td>2/13 - 2/19</td>
<td>Proposal Due Monday, Order Parts, Complete Authority to Proceed Appointment with Chris (2-16/17), HW 06 DUE</td>
<td>Met with Chris and established authority to proceed. Parts have been sourced and will arrive at a later date</td>
</tr>
<tr>
<td>3</td>
<td>2/20 - 2/26</td>
<td>Initial phases of prototyping the BalloonSat, and machining the structure, Research how sensors interact with Arduino, Build heater system, HW 07 &amp; HW 08 DUE, DD Rev A/B assigned</td>
<td>Team has begun building the structural components of the BalloonSat, and understands the coding necessary for the sensors</td>
</tr>
<tr>
<td>4</td>
<td>2/27 - 3/5</td>
<td>Software Subsystem team begins Coding for on the Arduino, Science Subsystem begins machining on the Reaction Wheel, PDR</td>
<td>Standard sensors function with the Arduino and are ready for testing</td>
</tr>
</tbody>
</table>

Commented [LW36]: Inset comma after this and delete extra space
<table>
<thead>
<tr>
<th>Week</th>
<th>Dates</th>
<th>Task Description</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3/6 - 3/12</td>
<td>Finish Building Reaction Wheel and attach to motor to be controlled by the code, code debugging, DD rev A/B DUE 3/7, DD rev C assigned</td>
<td>Wheel functions and reacts based on code, Team has DD rev A/B complete and ready to turn in</td>
</tr>
<tr>
<td>6</td>
<td>3/13 - 3/19</td>
<td>Mechanical Testing: whip, stairs, and drop test, then temperature resilience test with dry ice and cooler. Mid-semester team evaluations assigned and due (3/14), Service Approvals due (3/16) PAYLOAD INSPECTION with Chris (3/16)</td>
<td>Testing results are accounted for and necessary design changes are made</td>
</tr>
<tr>
<td>7</td>
<td>3/20 - 3/26</td>
<td>In-class mission simulation test (3/23), RFF cards assigned. Finalize BalloonSat (time built in for fixing things we messed up)</td>
<td>BalloonSat will have all testing complete, final design modifications have been addressed</td>
</tr>
<tr>
<td>8</td>
<td>3/27 - 4/2</td>
<td>Team members are assigned tasks to ensure readiness for next week's launch.</td>
<td>It is Spring Break</td>
</tr>
<tr>
<td>9</td>
<td>4/3 - 4/9</td>
<td>Launch week, Launch Readiness Review Presentation (4/4), DD rev C DUE (4/6) Balloon Weigh in and Turn in (4/7)</td>
<td>BalloonSat is ready for launch, all testing is complete and code is debugged</td>
</tr>
<tr>
<td>10</td>
<td>4/10 - 4/16</td>
<td>Convert Raw data collected during flight to meaningful data, DD rev D assigned, Quick Look post-launch presentations (4/13), Work on DD rev D</td>
<td>Team will be able to describe the outcome of the flight and understands errors that were made.</td>
</tr>
<tr>
<td>11</td>
<td>4/17 - 4/23</td>
<td>Prepare for Design Expo, final presentation and rev. D, Make team video</td>
<td>Team video will be complete and ready for judging next week, steady progress made on DD rev. D</td>
</tr>
<tr>
<td>12</td>
<td>4/24- 4/30</td>
<td>Design Expo (4/29) First draft of DD rev. D due (4/29), Continue work on Final Presentation and DD rev. D</td>
<td>Team will have a display and meaningful data to display at the Design Expo</td>
</tr>
<tr>
<td>13</td>
<td>5/1-</td>
<td>ALL Data and final presentations due in</td>
<td>Team will have competed</td>
</tr>
</tbody>
</table>
5.0 Budget

5.1 Itemized Budget and Weight
The following is a detailed plan of where funds will be used. The budget is managed by Ellie Raaum and includes both items provided by Colorado Space Grant and items purchased by the team.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Quantity</th>
<th>Weight (grams)</th>
<th>Cost</th>
<th>Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Arduino Uno</td>
<td>2</td>
<td>50g</td>
<td>$25.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Space Grant Shield Kit</td>
<td>2</td>
<td>4g</td>
<td>$30.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Micro SD Card</td>
<td>2</td>
<td>34g</td>
<td>$3.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Pressure Sensor</td>
<td>1</td>
<td>2.2g</td>
<td>$10.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Temperature Sensor</td>
<td>1</td>
<td>2.8g</td>
<td>$10.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Three Access Accelerometer</td>
<td>1</td>
<td>3g</td>
<td>$10.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Heater</td>
<td>1</td>
<td>100g</td>
<td>$30.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*Half sheet Black Foam Core</td>
<td>2</td>
<td>50g</td>
<td>$45.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>*GoPro Hero4 Session</td>
<td>1</td>
<td>74g</td>
<td>$200.00</td>
<td>COSGC</td>
</tr>
<tr>
<td>**9DoF Sensor Stick</td>
<td>1</td>
<td>17g</td>
<td>$14.95</td>
<td>SparkFun</td>
</tr>
<tr>
<td>**GPS Receiver - EM-506 (48 Channel)</td>
<td>1</td>
<td>16g</td>
<td>$39.95</td>
<td>SparkFun</td>
</tr>
<tr>
<td>**Barometric Pressure Sensor</td>
<td>1</td>
<td>&gt;1g</td>
<td>$9.95</td>
<td>SparkFun</td>
</tr>
<tr>
<td><strong>Standard Gearmotor - 303 RPM (3-12V)</strong></td>
<td>1</td>
<td>116.23 g</td>
<td>$24.95</td>
<td>SparkFun</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>---</td>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Servo - Generic (Sub-Micro Size)</strong></td>
<td>1</td>
<td>9g</td>
<td>$8.95</td>
<td>SparkFun</td>
</tr>
<tr>
<td><strong>11.1V Li-Ion 2200mAh Battery Pack</strong></td>
<td>1</td>
<td>150.25 g</td>
<td>$26.99</td>
<td>Robot Shop</td>
</tr>
<tr>
<td><strong>Radial Ball Bearing, Double Sealed Bearing</strong></td>
<td>4</td>
<td>40g</td>
<td>$7.09</td>
<td>Grainger</td>
</tr>
<tr>
<td><strong>10A DC Motor Driver Arduino Shield</strong></td>
<td>1</td>
<td>25g</td>
<td>$15.75</td>
<td>Robot Shop</td>
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<tr>
<td><strong>Custom Torque Wheel</strong></td>
<td>1</td>
<td>50g</td>
<td>$40.00</td>
<td>CU Boulder ITLL</td>
</tr>
<tr>
<td><strong>Gears</strong></td>
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<td>40g</td>
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</tr>
<tr>
<td><strong>Temperature Sensor</strong></td>
<td>1</td>
<td>&gt;1g</td>
<td>$1.50</td>
<td>SparkFun</td>
</tr>
<tr>
<td><strong>Camera Cover Dome</strong></td>
<td>1</td>
<td>29g</td>
<td>$15.02</td>
<td>Amazon</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>29 items</td>
<td>950g</td>
<td>$87.27</td>
<td></td>
</tr>
</tbody>
</table>

*Provided by COSGC
**Within provided mission budget

**Contact Info**

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800-637-6050
6.0 Testing and Safety Plans

6.1 Testing

Tests will be performed to mimic the environmental conditions of near-space as well as the turbulence at burst and impact at landing. Necessary adjustments will be made based on the results of these tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Complete by Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooler Test:</td>
<td>The BalloonSat will be placed in a cooler containing dry ice for approximately 3 hours in order to test the ability of the battery and other components to function at low exterior temperatures. This will verify that the heater and insulation are functioning correctly.</td>
<td>04-05-2017</td>
</tr>
<tr>
<td>Whip Test:</td>
<td>The BalloonSat will be connected to a string and then swung in circles in the air. This will test the satellite’s ability to withstand the forces at burst and throughout descent.</td>
<td>03-13-2017</td>
</tr>
<tr>
<td>Stairs &amp; Drop Test:</td>
<td>The BalloonSat will be kicked down a flight of stairs and dropped from the ITLL bridge. Similar to the whip test, this test will measure the BalloonSat structural integrity on landing and its ability to endure impacts.</td>
<td>03-13-2017</td>
</tr>
<tr>
<td>Spin Test:</td>
<td>The BalloonSat will be hung from a tree and will try to orient itself using the code provided. This will test the functionality of the RCS hardware and software.</td>
<td>04-05-2017</td>
</tr>
</tbody>
</table>

Commented [LW40]: Nowhere near enough in this section. No camera test, no mission simulation test, no environmental sensor test, no environmental sensor calibration, no results from structural tests, and no results from cold test.

Commented [LW41]: Look at my comments in Rev A/B for this section.
6.2 Sensor Calibration

In addition to testing the resilience of the satellite, the sensors are individually tested to ensure they are functioning properly.

GPS: The GPS was tested by driving around Boulder by car and recording latitude, longitude, and altitude measurements. The results of the test were that the GPS was functioning properly. The altitude matches expected values for Boulder, CO.

*Figure 1: GPS Latitude and Longitude*
9DoF Sensor: The 9DoF Sensor was both tested and calibrated. It was tested by spinning it by hand flat on a table and observing sensor readings. It was calibrated by placing the 9DoF flat and stationary for 15 minutes and calculating the average error. This error could then be subtracted from future measurements to “zero” the sensor.

Commented [LW43]: Formatting, the next graph goes off the bottom of the page
Commented [LW44]: Fix the x-axes on the second and third graphs (it’s impossible to read anything and no labels or units)
Commented [LW45]: The x-axis of the graph doesn’t have a label or units
Indicates spin around z-axis

x,y values around 0 because BalloonSat was flat on a table

Spin direction switched

z values close to 1g due to gravity

x,y values around 0 because BalloonSat was flat on a table

Spin causes some small acceleration values in x,y,z
Stationary Test Results

Stationary Accelerometer Test

- z values should read 1g due to gravity

Stationary Gyroscope Test

- All values should have read 0 because the gyro was not spinning
Calibrated Stationary Data Results: The following graphs demonstrate that the accelerometer and gyroscope values were calibrated, as they show expected values for a stationary sensor.

Rope Spin Test Results: The BalloonSat system was tested by hanging freely on the flight string and being spun initially. The PID controlled reaction wheel then countered the spin to bring the satellite to equilibrium. The results from this test were used to further calibrate the PID loop’s sensitivity.

Commented [LW48]: Add labels and units for the x-axes
Commented [LW49]: Fix x-axis (impossible to read, no label or units)
6.3 Safety

*Dancing with the Stars* is committed to making the project safe for all team members and community members. To do so, all machining, soldering, and testing will be done with proper safety equipment—including close-toed shoes, eye protection, hair ties, and no loose clothing. Testing will be done in a considerate manner, so as not to endanger team or community members or university property. This entails clearing the area of bystanders when throwing or whirling the BalloonSat and not whirling it near windows. Another consideration is that the dry ice can damage skin. To avoid this, team members will wear appropriate gloves to protect from the cold. If a team member is uncomfortable performing any necessary tasks, they will ask an experienced individual to help them complete the task, whether it be other team members or ITLL staff.

7.0 Expected Results

There will be five sensors attached to *Pirouette* recording data. This includes two temperature sensors measuring the interior and the exterior temperature during the flight, a pressure sensor that will record the amount of pressure at different altitudes throughout the flight, a humidity sensor that will measure the percent of water particles in the air, and an accelerometer that will measure the acceleration of *Pirouette* in three dimensions.

7.1 Thermometer data

This chart shows what is expected for the thermometer data during the flight. The exterior temperature of the satellite is represented with the orange line and the interior temperature with the blue line.
7.2 Pressure Data

We expect the pressure to decrease as the altitude increases. Due to Colorado’s high altitude, we expect to have the pressure start at 84 kPa. The satellite will undergo an extreme change in pressure. There is expected to be a steady decline in pressure until a quarter of the way up there is going to be a big drop in pressure from 70 kPa all the way down to 1 kPa at burst.

Figure 7.1 - Expected Temperature data from our sensor

https://www.avs.org/AVS/files/c7/c7edae6b-95b2-438f-adfb-36de54f87b9e.pdf
7.3 Humidity Data
Humidity is hard to project due to changing weather. The humidity sensor will sense the percentage of water vapor in the air over the time of the flight. The average humidity in Denver is fifty percent. We are expecting to see the percentage drop as the satellite gains altitude, until it starts to enter some cloud cover. We are expecting to have cirrus clouds in the air around ten kilometers up, represented in Figure 7.3 with the spike in humidity around 1500 seconds and around 5250 seconds.

https://www.avs.org/AVS/files/c7/c7edaedb-95b2-438f-adfb-36dc54f87b9e.pdf
Figure 7.3 - Percent of Water in the Air vs Time

7.4 Accelerometer Data
Starting off with launch, there is going to be a lot of acceleration in both the upwards direction, represented by the orange line, and in the rotational x direction, represented by the blue line. After launch, the acceleration upward will level off and have a constant acceleration at 1 meter per second squared. The rotational acceleration will level off at zero after launch, until we run our experiment. The torque wheel will operate five times throughout the ascent before burst, causing the spikes in acceleration. The second set of large spikes for both the z and x directions are during the burst of the balloon, which will cause acceleration all over the place. Once the satellite is falling, it will level off again for both accelerations. The last set of spikes is during landing when the satellite impacts with the ground.
8.0 Launch and Recovery

Prior to flight, pictures will be taken of both the internal and external mechanisms and structures of the satellite. These will be comprehensive, giving detailed visuals of both the state of the exterior, including the camera dome, switches, LEDs, and foam core, and the interior, including the Arduinos, wiring, sensors, thermal system, and the reaction wheel system. Both the orientation and physical appearance of the components will be analyzed. On launch day, the satellite will be launched and recovered by team leader Max Audick. Once Pirouette is recovered, exact replicas of the pre-launch photos will be taken as soon as possible. These will be precise recreations of the initial selections, replicating both the angle and lighting of each respective pre-launch photo. The same camera will be used for both sets of pictures as well. A comparison of the two albums will then be conducted to assess for damage or displacements sustained during the mission. This information will be integral to post-flight failure analysis. Even minor changes to a component will be noted, scrutinized, and analyzed. To retrieve the in-flight data, the Arduinos, containing GoPro photos, videos, sensor data, and GPS readings, will be carefully removed from the satellite. Upon return to the University, they will be synced and uploaded to a computer and subsequently analyzed in Matlab. This method has already been tested numerous times by the team; they have taken data from the 9 DoF sensor, GPS, barometer, and thermometer, acquiring significant quantities of data (up to...
an hour) and later uploading the Arduino’s data to a computer.