Apollo 18
Project Nokia

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1.0 Overview and Mission Statement

1.1 Mission Statement

Apollo 18 plans to design, build, and launch a BalloonSat weighing less than 864 grams to reach the near-space environment, at approximately 30 kilometers above sea level with a sponsorship from the class, ASEN 1400, that is offered at the University of Colorado, Boulder. The purpose of launching this BalloonSat is to determine if reaction wheels inside of the craft can properly minimize the spin of the craft about its vertical axis, on launch and throughout its flight. This BalloonSat will also attempt determine its own location in the atmosphere based off accelerometer, gyroscope, and magnetometer sensor readings. If successful, this mission will help pave the way for future ADCS that are weight and cost efficient, while independent of GPS.

1.2 Mission Overview

Most of the BalloonSat projects launched in ASEN 1400 in the past have been at the mercy of uncontrollable spinning during flight. Apollo 18’s initial goal was to eliminate as much of this spin as possible without external control. The project also took on another aspect to make the BalloonSat contain a fully functioning ADCS system.

The ADCS system created by Apollo 18 will have two separate subsystems, the Attitude Determination System (ADS) and the Attitude Control System (ACS). According to a lecture given at the Massachusetts Institute of Technology, GPS is a sensor that is commonly used in the ADS of spacecraft near earth. Apollo 18’s mission will help alleviate future ADS from the constraints of GPS. For example, in 2004 NASA had to consider how future missions on Mars would be able to determine their location. The same article on NBC News also says “A dedicated Mars GPS system would be a boon for future robots bound for the red planet, allowing them to drive farther without having to stop and check their distance with photographic records.” Having a spacecraft that has to constantly check its position with pictorial records is not very efficient in terms of power and time. In order to avoid this inefficiency, Apollo 18 strives to develop a way for spacecraft to determine their own location without the use of GPS.

As for the ACS subsystem, Apollo 18 decided to use reaction wheels. Reaction wheels were chosen over other types of control systems after researching the benefits of reaction wheels. According to NASA reaction wheels offer a very power and space efficient way to successfully control spacecraft of various mission types. For a Balloonsat with weight, space, and power restrictions it is going to be crucial to have the smallest, lightest, and most power efficient method to stabilize the Balloonsat. Another crucial aspect is that reaction wheels do not require any propellants. Apollo 18 plans to build their own reaction wheels so that they can fabricate the reaction wheels to the desired specifications.

With the recent boom in the commercial space industry it is becoming more available for smaller satellites to launch into space. These satellites have to be as resource efficient as possible so that they can catch a ride into space without compromising the main mission. Apollo 18’s goal is to develop one way for these satellites, as well as other missions where GPS is not

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Project Nokia

preferable, to determine their attitude and control it all with very basic and inexpensive hardware.

2.0 Technical Overview

Several technical components will be required to ensure that Project Nokia successfully completes its scientific mission; these components are detailed in the following sections.

2.1 Design Overview

The framework of the BalloonSat will be constructed primarily from foam core. The experiment will be cased in a rectangular prism, 20cm by 20cm by 15cm, made of foam core panels held together with aluminum tape and hot melt adhesive. The corners will be reinforced with foam core. Two acrylic reaction wheels, 5.25 cm in diameter, will be mounted across one of the box’s diagonals and powered by a single brushless DC motor controlled by one Arduino Uno. This Arduino interprets data from a 9 Degrees of Freedom sensor that integrates an accelerometer, gyroscope, and magnetometer to determine how to move the reaction wheels. The sensor’s data will also be recorded on a microSD card and will later be used to determine the location of the BalloonSat throughout its flight. The Arduino-sensor pairing will be positioned in one of the corners of the box not occupied by a reaction wheel. This corner will also include the heater for the system. The fourth corner will hold a second Arduino Uno connected to a humidity sensor, a 3-axis accelerometer, internal and external temperature sensors, and a pressure sensor, along with a data logger and second microSD card on which to store the data. A GoPro Hero 4 Session digital camera will also be mounted against one wall in this corner. The camera will be mounted onto the wall so it can image the box’s surroundings during flight; it contains its own constant power supply and microSD card to store image data. The distribution of weight across the box is integral to the box’s stability, as keeping the center of mass of the unit close to the tether in the center will enhance performance. The entire BalloonSat box will be mounted to a flight string passing through a polymer tube through the center of the box and attached to a ball-bearing or 2 Teflon washers (See Sec. 2.5) to ensure that the BalloonSat can freely leverage the reaction wheels to rotate about the tether.

2.2 Hardware Overview

2.2.1. Command and Data Handling

The BalloonSat’s mechanisms and data-handling will be managed by two Arduino Uno processors coded in the Arduino IDE by team members. One Arduino will be programmed with logical controls to determine the motion of the reaction wheels based on gyroscopic and accelerometer data. The other Arduino will handle recording the majority of sensor data to a microSD card through an OpenLog microSD card reader; it will also be responsible for processing temperature data to determine when to turn on a heater. The payload will also include a GoPro camera which contains its own processor; its hardware and software will not be modified.

As for the sensor data that is retrieved during flight, all sensor data recorded during flight will be logged on two 2-GB microSD cards via OpenLog microSD card readers in conjunction with each Arduino. The GoPro camera will store image data on a third 4-GB microSD card that is integrated into the GoPro. The three cards will be retrieved from the BalloonSat upon recovery and used to complete the mission.
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2.2.2. Scientific Systems

The sensors contained in the BalloonSat fall roughly into two categories. The first set of sensors is analog and measures the internal and external conditions of the BalloonSat at various stages of flight. Included here are a pressure sensor and a humidity sensor which provide information about the atmospheric conditions around the BalloonSat during flight. The internal and external temperature sensors are also an important part of this group; they will be used to track the variations in temperature with altitude as the BalloonSat travels and to provide data for controlling the heater. The final analog sensor is the accelerometer, which provides data regarding changes in the balloon’s velocity. This accelerometer data will provide some noise control for the accelerometer in the 9DoF sensor below. All the analog sensors here are connected to one Arduino.

The second class of sensors is critical to the success of the mission in that they determine the motion and efficacy of the BalloonSat’s scientific mission, the reaction wheels. Included here are an accelerometer, a gyroscope, and a magnetometer which are integrated into a single digital ‘9 Degrees of Freedom’ sensor. The data from this sensor is processed in Arduino two and used to determine when to power the reaction wheels and where Project Nokia is spatially.

The last component of this project’s sensory system is the GoPro camera, which records image data of the space outside the box at various points during the flight.

Finally, Project Nokia’s scientific mission is based on two acrylic reaction wheels, each about 5 cm in diameter and hollowed around the axis of rotation. These wheels will be powered by a single brushless DC motor, and their motion will be controlled by Arduino based on inputs from the 9DoF sensor. The Arduino and reaction wheels are expected to work in tandem to negate the BalloonSat’s rotation about the vertical axis.

2.2.3. Power

Project Nokia will be powered by three 3.7-V rechargeable lithium-ion batteries that will be connected to each other in series so the required voltage and storage can be met. The rest of the power will be distributed via a parallel circuit so that a single point failure is avoided.

2.2.4. Interface

The BalloonSat will be equipped with a set of three external switches to provide easy control of both Arduinos and the heater. The project also includes 6 LED lights wired through the BalloonShield and connected to 330-ohm resistors. These LEDs will enable easy monitoring and testing of the environmental sensors on board the BalloonSat.

2.2.5. Thermal Regulation

One dissipative heater will be flown on board the BalloonSat to protect the internal hardware from damage due to low temperatures in the upper atmosphere. It will be controlled by Arduino based on inputs from the internal temperature sensor.
2.3 Testing

Extensive testing will be necessary to ensure that the BalloonSat, along with all its components, is not destroyed due to the environmental hazards of near-space. Testing will simulate specific factors of the near-space environment to ensure that the payload completes its mission successfully without critical structural failure.

2.3.1. Whip Test
The accelerations a BalloonSat undergoes upon burst can easily destroy an untested payload. The whip test will accelerate the BalloonSat’s structure to emulate burst conditions. To conduct this test, the satellite will be swung above the head of a team member, ensuring that the structure will not collapse inward during flight due to centripetal forces. This test must be completed in an area with no obstructions, and the satellite will be loaded with items similar in mass to its future components. To be considered a success, the exterior structure must remain intact after the test has been performed.

2.3.2. Drop Test
The drop test will determine if the BalloonSat will survive sudden impulses throughout the flight and landing of the BalloonSat. For this test, Project Nokia’s external frame will be filled with test masses of the same weights as its components to protect the mission hardware. A member of the team will climb to a height of approximately 10 meters from the ground and drop the test payload; if afterwards the box has broken in any way - tears, cracks, dents, rips, or internal damage - then the satellite will have failed the drop test.

2.3.3. Stair Test
Even after landing, the BalloonSat still may be damaged; high winds on the plains of eastern Colorado can blow the parachute and drag the string of satellites along the ground. The stair test will simulate such a situation, and if the BalloonSat passes, it will be able to withstand being dragged across the ground. The satellite will be filled with masses similar to its internal hardware and kicked down two flights of concrete stairs. If the structure has any pronounced internal or external damage, the BalloonSat will have failed the stair test.

2.3.4. Cooling Test
The effects of extremely low temperatures on electronics are certainly cause for concern, especially on a near-space mission reliant on batteries, which don’t function below about -20°C. The cooling test is meant to simulate the below freezing temperatures of near space in order to test the thermal systems of the BalloonSat. The test will consist of placing the BalloonSat in an insulated box with a supply of dry ice. The BalloonSat will then be powered on, the container closed, and the satellite left running for 140 minutes (about the duration of flight). After opening the box, all components of the internal hardware will be assessed; if all systems were functioning during and after the test, then the satellite has passed the test.

2.3.5 Electronics Test
The electronics test is conducted to determine the reliability of the electronics in the BalloonSat. There are two main criteria encompassed in this test for evaluating the success of the Project Nokia’s electronics. The first area is hardware reliability, characterized by how well circuitry and wiring maintains integrity under simulated stresses of the flight environment. The

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Commented [LC22]: failure
second area is software, which relies heavily upon the former area, and will be tested by means of the quality of data gathered by the OpenLog SD writer. The tests themselves will consist of repeated previous tests, such as the stair, whip, and drop tests, after Project Nokia’s structure has successfully passed them. If wires or circuitry break during these tests or the software malfunctions, Project Nokia will have failed the electronics test.

2.3.6 Vacuum Test

To function in the low pressure of the near-space environment, the BalloonSat will have to be able to handle pressures as low as 0.011 atmospheres. If the BalloonSat cannot withstand this pressure, then it will not be able to accomplish its mission. Team members will use a vacuum chamber to examine the effects of near-vacuum on Project Nokia, and if being surrounded by near-vacuum leaves the BalloonSat damaged or dysfunctional, then it will have failed the test.

2.3.7 Stabilization Test

One of the major missions of the BalloonSat in this proposal is attitude control around the vertical axis; essentially, control over the BalloonSat’s yaw. A stabilization test will seek to stress the systems that are to control this rotational motion. The BalloonSat will be hung from a rope tethered above and below, and spun about the tether by a rope, much like a toy gyroscope. The mechanisms inside the BalloonSat should then bring the project to a halt. If the internal reaction wheels do not affect the BalloonSat’s yaw significantly, then the system will have failed the test and significant redesign of the reaction wheel systems becomes necessary to prevent complete scientific mission failure.

2.3.8 Integration Test

None of these tests is indicative of the full functionality of the BalloonSat if the tests are done only in isolation. Before launch, the BalloonSat will undergo a cumulative battery of tests designed to accurately simulate the BalloonSat’s flight. To pass this test, Project Nokia must pass all previous tests in series - whip, stabilization, freeze, vacuum, drop, and stair - without its hardware, software, structure, or science subsystems malfunctioning.

2.4 Safety

During the creation, testing, and launching of Project Nokia, safety precautions will be amongst the highest priorities. When building Project Nokia, and especially when working with power tools, members of Apollo 18 will be sure to wear appropriate personal protective equipment. In addition, multiple members will be present during construction should emergencies arise. Testing will be conducted in an open area with no nearby bystanders or property that could be harmed during the test. Steps will also be taken to ensure that none of the members of Apollo 18 could be harmed in the testing process. All members will be held responsible for conducting themselves appropriately always.

2.5 Special Design Features

One of the Project Nokia’s distinctive features is the way it will be attached to its flight string. Due to the team’s mission of attitude control, independence from the rotation of the rope that supports the payload is essential to the success of the mission. So far, Apollo 18 has come up with several different mechanisms to enable free rotation about the vertical axis, specifically ball-bearings and Teflon washers. Each solution has benefits and drawbacks: the bearings have
lower friction, but are heavier, while the washers are lighter but are more prone to friction and wear. Further testing is necessary to decide which solution will be most beneficial to the mission of the BalloonSat, though the bearings appear to be better from a preliminary standpoint.

2.6 Data Retrieval

Data from the mission will store in two 2 GB microSD cards that mounted in Project Nokia throughout the duration of the flight. The data from all sensors will be stored in text files written to the microSD cards by the OpenLog SD card writers in conjunction with the Arduinos. The files will then be analyzed post-flight to examine the flight path of the BalloonSat and the performance of the reaction wheels.

2.7 Functional Block Diagram

The diagram below displays the overall layout of Project Nokia’s workings, and has been color-coded as such: Power distribution are the blue arrows, data flow are the arrows, controls are the green arrows, sensors are light blue, data storage is red, main functional components are green, functions carried out with the help of the Arduinos are purple, and the 9 DoF sensor has been indicated with a grey rectangle. The functions in purple described are as follows:

- PID feedback loop: A method of controlling an output based on a certain measured condition
- Gravity correction: Removing the effect of gravity from the accelerometer readings
- Smoothing + Kalman filter: Various methods and algorithms to reduce noise and error
- Double Integration: Integrating the acceleration twice will yield the total displacement
- Altitude compensation: Compensating for the fact that the magnetic field will vary with height

Commented [LC23]: That will be mounted
Commented [LC24]: Delete this
Commented [LC25]: conjunction
Commented [LC26]: How will the flight path be determined from the data? How will you know whether the path determined is accurate or not?
Commented [LC27]: Red arrows?
Commented [LC28]: There are a few problems with the diagram below:
1) SD card 1 and 2 should be routed through their respective Arduinos
2) Functions (in purple) do not need to be shown separately unless they are performed by specific, separate hardware.
3) Wiring everything through a single set of batteries might not be the best idea.
3.0 Management and Budgeting

3.1 Management

The team is split into seven subsystems and each system is split into primary and secondary parts. This ensures that no individual is given all the responsibility for one system. This chart is not a strict limitation of roles; all members are expected to contribute to all systems.

<table>
<thead>
<tr>
<th>Subsystem:</th>
<th>Primary:</th>
<th>Secondary:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Leaders</td>
<td>Conner Shaver &amp; Bella Colosimo</td>
<td>N/A</td>
</tr>
<tr>
<td>Software</td>
<td>Sara Reitz</td>
<td>Bella Colosimo</td>
</tr>
<tr>
<td>Science</td>
<td>Ashkan Bafli</td>
<td>Justin Miller</td>
</tr>
<tr>
<td>Structure</td>
<td>Justin Miller</td>
<td>Frasier Feight</td>
</tr>
<tr>
<td>Budget &amp; Weight</td>
<td>Nathan Hetzel</td>
<td>Ashkan Bafli</td>
</tr>
<tr>
<td>Scheduling</td>
<td>Bella Colosimo</td>
<td>Conner Shaver</td>
</tr>
<tr>
<td>Testing and Review</td>
<td>Conner Shaver</td>
<td>Nathan Hetzel</td>
</tr>
<tr>
<td>Power &amp; Electronics</td>
<td>Frasier Feight</td>
<td>Sara Reitz</td>
</tr>
</tbody>
</table>

3.2 Schedule

Team meetings are a time for the team to bring ideas together and complete tasks. Each meeting will have a goal to be completed within the allotted time period. The team will have scheduled meetings every Monday from 8:00-10:00pm. Another meeting will be planned at the beginning of each week that will fit into the team’s schedules.

<table>
<thead>
<tr>
<th>By Date:</th>
<th>Task:</th>
<th>Team Members:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/13/17</td>
<td>● Proposal due</td>
<td>All</td>
</tr>
<tr>
<td>2/16/17</td>
<td>● Authority to proceed meeting with Chris&lt;br&gt;● Order Parts</td>
<td>All</td>
</tr>
<tr>
<td>2/20/17</td>
<td>● Finish design and budget</td>
<td>Nathan, Ash, Justin, Frasier</td>
</tr>
<tr>
<td>2/21/17</td>
<td>● Begin structure construction&lt;br&gt;● Begin required sensor programming</td>
<td>Justin, Frasier, Sara, Bella</td>
</tr>
<tr>
<td>2/23/17</td>
<td>● Begin drafting PDR (due 3/2/17)&lt;br&gt;● Finish construction of box</td>
<td>All</td>
</tr>
<tr>
<td>2/27/17</td>
<td>● Begin fabrication of reaction wheels&lt;br&gt;● Structural testing (whip, drop, and stair tests)&lt;br&gt;● Vacuum test</td>
<td>All</td>
</tr>
<tr>
<td>3/6/17</td>
<td>● Finish thermal system&lt;br&gt;● Cooling test</td>
<td>All</td>
</tr>
<tr>
<td>3/7/17</td>
<td>● Incorporate reaction wheel system with motors&lt;br&gt;● Motor testing</td>
<td>All</td>
</tr>
<tr>
<td>3/13/17</td>
<td>● Finish coding involved with sensors&lt;br&gt;● Begin coding control loop for reaction wheels</td>
<td>Sara, Bella</td>
</tr>
</tbody>
</table>

Commented [LC29]: This works ok but an org chart would be better, with co-leaders at top and all other subsystems branching off of that

Commented [LC30]: There are some important things missing in the schedule, including the submission of drafts and the final version of your Design Document
3.3 Budget

An overview of what Apollo 18 plans to spend to complete the stabilization experiment.

Weight per item has been added to make sure the BalloonSat stays below the weight requirements. Any remaining budget will be reserved for replacement parts.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Weight Per Item</th>
<th>Total Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Uno + Micro SD Shield</td>
<td>2</td>
<td>25g * 2</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>GoPro Hero 4 Series</td>
<td>1</td>
<td>73g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>2 GB microSD Card</td>
<td>2</td>
<td>2g * 2</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>3-Axis Accelerometer</td>
<td>1</td>
<td>1g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Humidity Sensor</td>
<td>1</td>
<td>1g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Temperature Sensors</td>
<td>2</td>
<td>2g * 2</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Pressure Sensor</td>
<td>1</td>
<td>5g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Heating System</td>
<td>1</td>
<td>100g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Foam Core (Incl. other materials)</td>
<td>3 half sheets</td>
<td>120g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>LEDs</td>
<td>4</td>
<td>3g * 4</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>All other wiring, resistors, etc.</td>
<td>-</td>
<td>20g</td>
<td>-</td>
<td>Provided</td>
</tr>
<tr>
<td>Acrylic for Reaction Wheels</td>
<td>2</td>
<td>110g * 2</td>
<td>$15.00</td>
<td>Ebay.com</td>
</tr>
<tr>
<td>3.7V 9900mAh Batteries</td>
<td>3</td>
<td>45g * 3</td>
<td>$6.50</td>
<td>Ebay.com</td>
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<tr>
<td>Brushless DC Motor</td>
<td>1</td>
<td>68g</td>
<td>$20.00</td>
<td>Amazon.com</td>
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</table>

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### Project Nokia

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Weight</th>
<th>Price</th>
<th>Store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Ice</td>
<td>6 pounds</td>
<td>N/A</td>
<td>$18.00</td>
<td>King Soopers</td>
</tr>
<tr>
<td>9 DoF Sensor Stick</td>
<td>1</td>
<td>3g</td>
<td>$14.95</td>
<td>Sparkfun.com</td>
</tr>
<tr>
<td>Battery Holders</td>
<td>3</td>
<td>10g * 3</td>
<td>$7.00</td>
<td>Amazon.com</td>
</tr>
<tr>
<td>Ball Bearing (See Sec. 2.5)</td>
<td>1</td>
<td>11g (If used)</td>
<td>$7.09</td>
<td>Amazon.com</td>
</tr>
<tr>
<td>Teflon Washers (See Sec. 2.5)</td>
<td>2</td>
<td>4.5g *2 (If used)</td>
<td>$4.95</td>
<td>Amazon.com</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>856 g± 1 g</td>
<td><strong>$87.47 ± $6.02</strong></td>
<td></td>
</tr>
</tbody>
</table>

### 3.4 The Dream Team

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