Payload Video Stabilization Apparatus: Stabilizing a Weather Balloon Payload During a Solar Eclipse

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Abstract
When flying, balloon payload experiments can be subjected to rapid acceleration and wind shear, causing the payload to spin and swing wildly. This causes videography to be of low quality and can induce motion sickness in viewers. The spinning of the payload can also cause intermittent signal loss when sending signals to or from the payload. Our team plans to create a passive and lightweight apparatus to drastically reduce spin and swing in weather balloon payloads. We will do so by attaching air scoops to the bottom corners of the payload to increase drag and the moment of inertia, making the payload less susceptible to wind forces. Air scoops have been shown to work well at low altitudes due to the thick atmosphere, but at higher altitudes, they become less effective. We will present an analysis of the data gained from the April 8th test flight to determine the effectiveness of our design.

1.0 Mission Statement
Our mission is to live stream a near-space video of the 2017 American Eclipse in August. Initial test flights have shown that the payloads on balloons are unstable and prone to excessive spin and swing. This causes nausea in viewers and intermittent signal loss.

To combat this, we have modified the design of a passive and light-weight apparatus to provide stabilization for a balloonSAT payload. This device will be referred to with its acronym, VISPA, which stands for Video Stabilization Payload Apparatus. VISPA is based on a design shown to provide stabilization against swing and rotation during the portion of the flight between ascent and burst. It is not in our design to stabilize the payload as it descends to Earth; VISPA will only be providing stabilization for the payload that it is attached to. However, VISPA’s design should be able to attach to other payloads with minor modifications to provide them with stabilization during flight.

The purpose for designing and building the VISPA is to take better photographs and videos during the balloon’s flight. Current balloon satellites do not have any built-in stabilization devices. This means that if the balloon is launched on a windy day or if the payload line is under a fair amount of swing, as well as many other unpredictable factors, then the media that the payloads capture will be of a much lower quality. It is our team’s goal to create a system that is capable of mitigating swing and rotational spin so that the photography and videography equipment onboard the payload can capture the best possible shots. We plan to test this technology during the April 8th COSGC balloon flight and use it during the eclipse launch in August of this year to better capture


the eclipse at altitude.

With two cameras and a small array of sensors onboard the payload, we intend to learn important flight details about the effectiveness of VISPA. The VISPA itself is designed to be a passive system meaning that it will work on its own without any power requirements or any other outside equipment. To determine the effectiveness of the VISPA, the payload that it is attached to will have sensors on it to provide data of the flight as well as two cameras of which the video taken will be compared to a similar payload without a VISPA.

Our plan is to use gyroscopes and accelerometers to learn exactly how well the VISPA prevented any type of swing and rotation. We will also include two GoPRO cameras, one pointing up towards the balloon and another pointing out towards the horizon. The videography of the flight is our primary concern in this experiment.

2.0 Technical Overview

To achieve better quality images and capture a crisp video that isn’t nauseating to its audience we have improved upon a design for a stabilization system. We will attempt to achieve our goal using air scoops extended on carbon fiber rods to stabilize a payload on a high-altitude balloon in the hopes of quenching the violent spin and swing. This is achieved due to the increased inertia of the payload resulting from the extended mass and the wind drag of the air scoops. At higher altitudes, the air scoops become less effective and the increased moment of inertia becomes the primary method of stabilization.

2.1 Payload Structure

The core payload box will be a cube with the lengths of each side being 15 cm containing two cameras, a heater kit, and an Arduino carrying a sensor package. In each of the four bottom corners will be 3D printed cubes of 2cm length with a 45-degree hole from one corner to another. These cubes will serve to attach the air scoop rods and keep them at the desired angle. Of the two onboard cameras one will be mounted to a top corner facing directly upwards, this camera will need to be activated prior to sealing the payload. The second camera will be mounted to a side pointing horizontally outwards, there will be a hole in the side of the payload to turn this camera on. See, Figure 1. The Payload Layout, for a visualization. The stabilization system will consist of four carbon fiber rods of diameter 4mm and length 75cm which will attach to the payload through the rod blocks in the bottom corners. At the end of each of these rods will be an air scoop made of three separate foam core circles with a diameter of 16cm arranged to form the frame of a sphere. Another carbon fiber rod will run in-between each air scoop to make the combination of rods outline a pyramid with its top at the core payload and its bottom at the scoops. See, Figure 2. The Stabilization System, for a visualization.
launch, there will be a large amount of spin and swing created as the flight string is yanked on by the quickly rising balloon. Should our design be as effective as we hope the spin and swing caused by this initial instability will be quickly mitigated, reaching stability of the payload within minutes after the balloon itself becomes stable. As the payload rises it will resist rotational forces from gusts of wind or wind shear. The payload will be most stable while at a low altitude as it will have the benefit of a thick atmosphere with which to brake against. As the atmosphere thins the stability may decrease slightly due to unstable payloads above and below ours shaking and spinning the flight string. At this point stabilization will be primarily reliant on the mass of our air scoops increasing the moment of inertia of our payload, rather than through air drag. At burst we do not intend to provide any stabilization. The payload if unhindered by others will turn upside down and likely not spin, however as it is attached to others as well as a parachute, it is more likely the payload will roll and tumble freely. Upon landing, it is possible the rods supporting the air scoops will break, though based on our drop tests described in section 3.2, we do not predict any damage to the scoops, main payload, or electrical components.

### 3.0 Testing

The concerns of this project are: mitigation of spin, the potential of entanglement of the flight string with the air scoops, the swing of the payload, the battery life of our cameras and Arduino due to cold, and the structural stability of the payload on landing.

#### 3.1 Fan Test

To test how our payload would respond to wind forces from various directions we sought out simulation chambers. We were unable to find anything approaching a wind tunnel, and the best we could find was a large fan. We attempted to simulate various wind conditions and despite the power of the fan we encountered difficulty in getting the wind to blow evenly across our entire payload. Instead, the wind was focused entirely on one or two scoops at a time, resulting in one side being pushed more than the others and causing the payload to spin. These tests found that swing was reduced, but due to our inability to apply force over the entire payload we were unable to test spin reduction.

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**Figure 2. The Stabilization System**

The rods connecting to the box will be inserted into the 45-degree angled holes in the rod blocks. The length of the rods from the outside corner of the payload to the top of the air scoop will be 59 cm.

**Figure 3. The Theory of Operation**

Minutes prior to launch we shall power on the Arduino and heater kit and start the cameras. At launch, there will be a large amount of spin and swing created as the flight string is yanked on by the quickly rising balloon. Should our design be as effective as we hope the spin and swing caused by this initial instability will be quickly mitigated, reaching stability of the payload within minutes after the balloon itself becomes stable. As the payload rises it will resist rotational forces from gusts of wind or wind shear. The payload will be most stable while at a low altitude as it will have the benefit of a thick atmosphere with which to brake against. As the atmosphere thins the stability may decrease slightly due to unstable payloads above and below ours shaking and spinning the flight string. At this point stabilization will be primarily reliant on the mass of our air scoops increasing the moment of inertia of our payload, rather than through air drag. At burst we do not intend to provide any stabilization. The payload if unhindered by others will turn upside down and likely not spin, however as it is attached to others as well as a parachute, it is more likely the payload will roll and tumble freely. Upon landing, it is possible the rods supporting the air scoops will break, though based on our drop tests described in section 3.2, we do not predict any damage to the scoops, main payload, or electrical components.

**2.2 Sensor Package**

The hardware of our payload consists simply of two cameras, one pointing upwards and another horizontally, a heater kit, and an Arduino Uno with a 9 degree of freedom sensor stick. The 9 degree of freedom sensor contains a gyroscope, accelerometer, and magnetometer and each of those tools records in the x, y, and z axes. We however will only be using the gyroscope and accelerometer in our experiment. The sensor data for the duration of the flight will be saved to a 1GB SD card.

**2.3 Theory of Operation**

The rods connecting to the box will be inserted into the 45-degree angled holes in the rod blocks. The length of the rods from the outside corner of the payload to the top of the air scoop will be 59 cm.
3.2 Drop Test
To test the structural stability of the payload upon landing the payload was dropped two stories in multiple orientations. We found that regardless of the angle of impact the carbon fiber rods did not break. There was denting of the corners of the core payload, but no further damage. All electrical components including the cameras did not suffer any damage. Through rapidly spinning the payload by its string and then repeatedly spiking it onto the ground we managed to break the carbon fiber rods. Because of these tests we feel confident that our payload will survive landing, especially considering that it will be slowed by a parachute.

3.3 Spin Test
To test rotational stability, we took the payload outdoors and spun it around by the flight string similar to an Olympic hammer throw, See Figure 4. The Spin Test. During this test the payload oriented such that the axis defined by the flight tube inside the payload pointed along the tangent of the path taken by the payload. This caused it to experience higher wind speeds that we could achieve through our fan test. In this way, we believe it was a suitable analog to a wind tunnel. The payload flew very stably, with little to no rotation along the axis of the flight string tube running from the top of the payload to the bottom. Due to a lack of better testing equipment this test gives us the most confidence in our ability to reduce the spin of the payload.

3.4 Tangle Test
To test whether the flight string would become entangled in our rods during descent we wrapped string around them in several ways and pulled to test whether it would slip off. We found that if the string were to wrap around the top of the scoop it would become stuck, but no other method of wrapping encountered any problems. To fix this issue we implemented a smooth 3D-printed cone to cover the intersection between the rod and air scoop, this removes the indentation that was causing the tangling and replaces it with a slope for the string to slide off.

3.5 Cold Test
To test the battery life of our electrical components we turned them on and ran them from inside a freezer around -30 degrees Celsius. It was found that the Arduino could run for 3 hours in these conditions, while the cameras could run for between 90 to 120 minutes. The duration of flight is typically 120 minutes or less, and so we are confident we will capture most the data, if not all of it. We have no intentions of stabilizing the payload post burst, and so where we wish to gather data here we have accepted the potential of not capturing data for this phase of the flight.

4.0 Expectations
The expectation of this project is to passively and efficiently stabilize a payload to improve the image and video quality recorded during flight. During our initial test flight in Guernsey, Wyoming a video from the payload was streamed live to YouTube and caused nausea in viewers and poor resolution of the sun and earth. We hope to fix both issues in a way that is simple and lightweight so that it can be used in future payloads, most notably the Solar Eclipse Project in August 2017.

5.0 Results
The experiment flew on April 8th and as such we are still analyzing the data recovered however, the preliminary results are as follows. When watching the payload at initial launch from the ground we could easily see that the flight string and the radio below the VISPA had much more pendulum like swinging whereas at and above our payload was very stable. Our side camera and Arduino recorded the entire

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flight from launch to landing, while our upwards facing camera died 10 minutes before burst. Our side camera recorded a pleasant video of launch with very little to no swing, and very little spin. Our top camera shows that the other payloads on our same flight string were spinning much more in relation to our payload, using the background such as clouds as a reference. We found a decrease in stability as expected once the payload reached the upper levels of the atmosphere. We will present more detailed results as well as our videos in our speech at the Colorado Space Grant Symposium.

6.0 Conclusion
Our team plans to stream a near-space video of the 2017 American Eclipse in August, in previous testing we have found that a lack of stabilization lead to nausea in viewers and intermittent signal loss. To amend this issue, we have created a light-weight stabilization system to passively stabilize the payload against spin and swing during the flight. We do not intend to provide stabilization during descent, and testing suggests that we will successfully stabilize the payload. The test flight took place on April 8th and results will be presented at the Colorado Space Grant Symposium on April 22nd.

7.0 References