

Launch Procedures for Offshore Flights

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The Linn-Benton Community College Space Exploration Team held two successful offshore high-altitude balloon launches from the deck of the research vessel Pacific Storm. The payload filmed the umbra casted by the total eclipse as it passed across the Oregon coastline on August 21, 2017. Assigning roles and having a set procedure made the launch process operate more efficiently. Approximately ten onshore launches were conducted to rehearse procedures in preparation for the launch. During these launches, members became more familiar with their roles and the roles of others on the team to prepare for any and all situations that may occur. Completing an offshore flight differs from a standard onshore launch given that the sea produces various weather conditions such as: sizeable waves, increased chance of precipitation, higher wind speed, and the possibility of limited visibility. Seasickness, internet accessibility, and offshore communication are among other factors. A sudden change in wind direction caused a tear in the latex of the balloon which caused the payload to not achieve the desired altitude. The launch did not achieve 28,000 meters, however the team learned from its successes and failures, and anticipate that the next launch will be successful.

Nomenclature

(SI Units)

d_{air}	=	density of air
d_{He}	=	density of helium
Cd	=	drag coefficient
FPS	=	frames per second
g	=	acceleration of gravity
mA□h	=	milliamp hour
m_b	=	mass of the balloon
m_p	=	mass of the payload
t	=	time
V	=	volts
V_b	=	volume of the balloon
v_f	=	velocity of balloon

I. Introduction

During the summer of 2016, five students from Linn-Benton Community College, or LBCC, went to Bozeman, Montana to build equipment to film the eclipse that occurred on August 21, 2017. The week long workshop was put together by Angela Des Jardins of Montana Space Grant Consortium. The equipment was originally developed by Montana State University graduate students as a basis for payloads for the student teams who attended the workshop. Upon the LBCC Space Exploration Team's return, the team began discussing various locations to launch their high altitude balloon, or HAB. After holding several meetings, the team narrowed down two possible launch sites; Madras, Oregon or on an Oregon State University research vessel. The team learned several months later that a ship had been secured by their mentor Parker Swanson for the upcoming eclipse. Procedures that the team developed for ground flights, now had to adapt to the offshore flight to come. A question arose amongst the team, "What does it take to launch a HAB from a ship?"

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1. *Student Researcher, Engineering, AIAA Student Member*
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II. Payload

A. Cutdown System

The original balloon payload design featured a cutdown system that was entirely designed by Montana State University, or MSU, students. The device was affectionately called the ‘Occam’s Razor Termination System’ developed by Micaela Moreni and Dylan Trafford of MSU [1]. The completed system consisted of: a cutting wheel and DC motor, a 3D printed housing, foam housing, a Xbee antenna, an OCCAMS board, a lithium battery, and battery housing. The purpose of the cutdown was to give students a way to terminate a flight rather than wait for the balloon to burst. It was expected of all the teams involved in the Eclipse Ballooning Project to use this system.

B. Anti-Spin Device

The original housing of the cutdown box only allowed one string to go through it, the string that would be cut to detach the payload and parachute from the balloon. The payload would then be spinning on a single axis with no control. To reduce the spin of the payload camera and serve as a way to prevent helium from escaping the balloon, the team developed a 3D printed part dubbed the Anti-Spin Device. This was achieved by increasing the number of strings connecting the balloon to the payload from one to four strings. The new housing, which consisted of a six by ten by twenty centimeter plastic, latching tupperware, allowed storage of the cutdown system and the team’s Automatic Package Retrieval System, or APRS, tracking device.

B. Iridium

With so many balloons flying during the eclipse, the Federal Aviation Administration, or FAA, required all balloons flying as a part of the Eclipse Ballooning Project to have an Iridium tracking system. This allowed the FAA to have knowledge of the balloon’s coordinates so as to avoid contact with aircraft while flying at high altitudes. These are not commonly found on high altitude balloon payloads, and they were provided by Montana Space Grant Consortium, to track the team’s payload during the eclipse. The Iridium system in the payload sends a data packet containing its coordinates to an Iridium satellite. The satellite uploads the coordinates to a map and allows users to track the payload path over the internet.

C. Antenna Packet Reporting System

The antenna packet reporting system, or APRS, is a radio tracking system that the team used in the event that the Iridium tracking system failed or became inefficient. Dipole antennas were used for optimal packet broadcasting to find the location of the payload via a HAM radio. The APRS was contained in the aforementioned latched tupperware that also contained the cutdown system of the payload.

III. Final Payload Design

As the months progressed, the team came to the conclusion that some of the equipment aboard their payload was not going to fulfill its original mission of live streaming video. It was the middle of July of 2017 when the team decided to move in a new payload direction after performing a line of sight long distance radio test that was unsuccessful. With little under a month until launch, the new design was to perform two simple main tasks: prevent water from breaching and storing twenty-four frame per second high definition video. The main body of the payload was a two gallon food grade bucket purchased from a local hardware store.

A. Cameras

To store the high-definition video, a GoPro® Hero4 Black edition video camera was chosen. Not only is it compact and light enough for the job, but the lens is capable of capturing a 170 degree field of view. The GoPro® was attached on the bottom of the payload and encased in an aluminum housing with a magenta fifty-two millimeter lense to filter hazing caused at high altitudes. The system featured two external batteries that would ensure that enough power was supplied to sustain stored video throughout a three hour flight, one being an official GoPro® Bacpac battery that connected directly to the back of the camera and another being an Anker® 26800 mA·h lithium ion battery. Capturing high definition video depletes memory fairly quickly, so the team chose to store the film on a 128gb microSD card with enough headroom to guarantee a successfully stored video. As a failsafe, and for

additional footage, a Raspberry Pi 160 degree wide angle camera was installed facing horizontally off the side of the payload. The Raspberry pi camera was connected to a Raspberry Pi 3 via a sixty-one centimeter cable.

B. Waterproofing

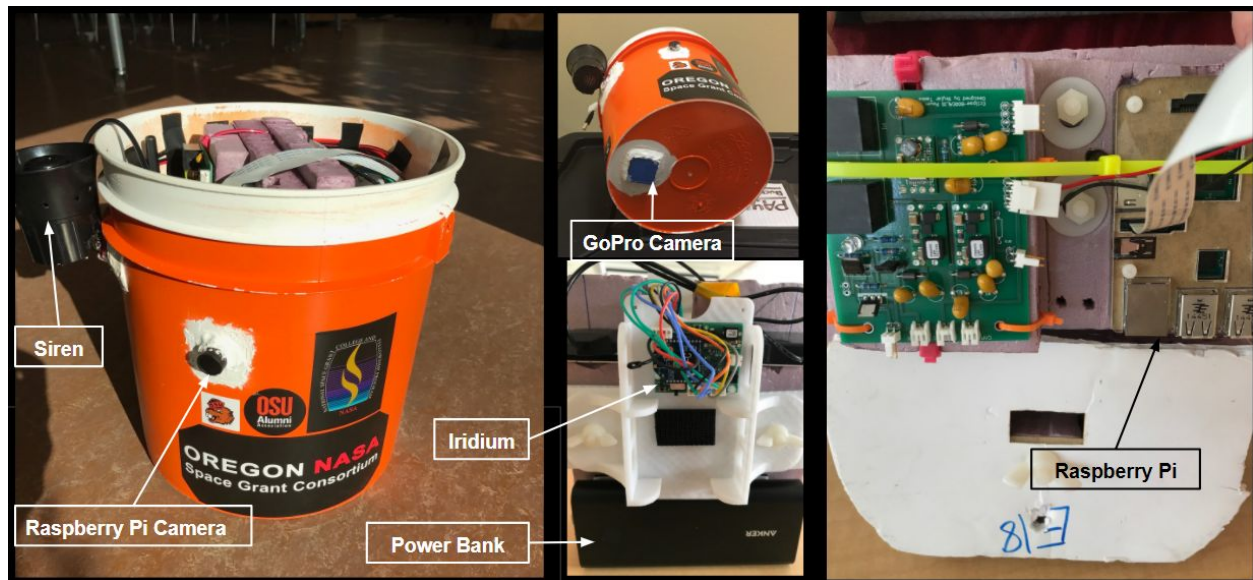
To protect the inner electronics within the payload from water damage, Dynaflex 230, and Recreational Vehicle Mastic sealant were applied around exterior breaching points. Both are common materials that can be found at a local hardware store that are great for waterproofing. As a last step of water damage prevention, Kapton tape was applied along the brim of the payload before launch.

C. Breathability

Due to varying altitudes as the payload ascends and descends and necessary waterproofing required for an ocean touchdown, one very important feature of the payload is breathability. If the payload is sealed tight and placed under extreme air pressure changes, the chances of rupturing increases. But if left unsealed for pressure changes, water is likely to breach the payload upon landing in the ocean. Water can damage the electronics in the payload, so the design needs to allow air in and out but not liquid. The team bored a one centimeter hole on top of the payload seal and super glued a 5 centimeter by 5 centimeter piece of patented Gore Tex material, which is commonly found within raincoats for lightweight, all weather applications.

D. Visibility and Sound

Determining the payloads location after touchdown in the ocean is vital. To ensure retrieval two additional components were added, visibility and sound. The payload was painted a bright, traffic cone orange and a twelve volt 120db six tone waterproof car alarm was added to the exterior. The siren system was supplied power through the 26800 mA \cdot h Anker \textregistered lithium ion battery via five volts USB, and stepped up through a twelve converter. To activate, the team would hold the lock button on a designated car key fob with a range of approximately three hundred meters.



IV. Lift Calculations

The team was originally provided the URL for a HAB calculation site to predict how much helium to fill the balloon with, but the students saw this as a chance to apply physics and programming skills learned in the classroom for the project. With the help of an Oregon State University assistant professor, Dr. Bryony DuPont, the final algorithm (Figure 1) was programmed using Matlab [2] to produce a 3D graph (Figure 2) that compares the mass of the payload and the amount of helium in the balloon to the horizontal asymptote of the velocity. The forces calculated and applied to the balloon include buoyancy, drag, lift, and gravity. The graph in Figure 2 was used

before the collective agreement to limit the amount of helium in the balloon to a single full standard tank of helium. This algorithm was tested on several flights and proved to be more reliable when compared to the HABhub calculation site. When using the HABhub calculations, the amount of helium that filled the balloon was not enough to lift the payload off the ground. After this was discovered, weight was removed to allow the balloon to take off.

Only the program created by the students was used after this failed launch. With the limit of one tank determined two months before the launch, the team used the program to determine what mass the payload must be for the lift velocity to equal between four and five meters per second. The resulting range of payload masses came to be 3 kilograms to 4.3 kilograms. As long as the team stayed within this range of mass when constructing the payload, they will reach the desired altitude of 28,000 meters.

$$A = \frac{V_b \times d_{air} \times g}{m_b + (V_b \times d_{He}) + m_p}$$

$$B = \frac{d_{air} \times Cd \times \left(V_b \times \frac{3}{4\pi}\right)^{\frac{2}{3}} \times \pi}{2 \times m_b + (V_b \times d_{He}) + m_p}$$

$$C = A - g$$

$$v_f = \sqrt{C/B} \times \tanh\left(\sqrt{\frac{C}{B}} \times B \times t\right)$$

Figure 1

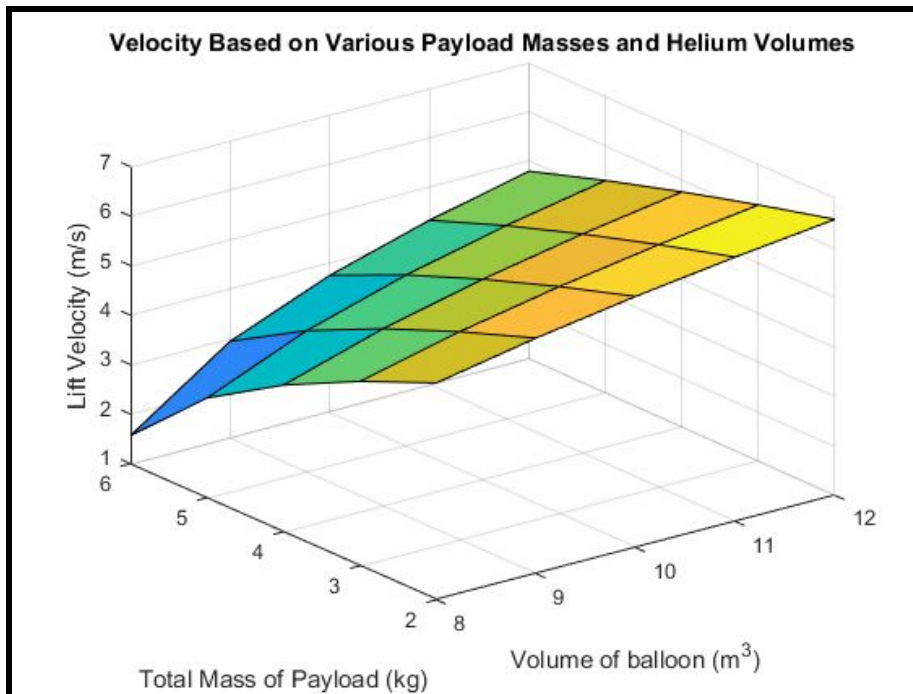


Figure 2

V. Onshore Flight Procedures

Flights were typically scheduled several weeks in advance. Modifications and additions to the payload and design were made during this time in preparation for the flight. Three days before the launch, predictions would be made with a HABhub flight predictor to determine the approximate path of the balloon. In many instances, a strong wind in the stratosphere would blow the HAB over the Cascade Mountains of Central Oregon and preparations would be made for an early cutdown to avoid a retrieval of the payload in a densely forested area. Weather would also be monitored over the coming weeks to comply with FAA regulations of launching with less than 50% cloud cover.

On the day of the launch, testing would be done on the cameras and tracking systems to check that the systems were recording video and coordinates respectively. The payload would be weighed to determine the amount of helium required for the amount of lift that would get the payload at a lift velocity average of five meters per second. These calculations would allow the team to plan for how many helium tanks to take out into the field. Several weather prediction sites such as the National Weather Service and the Weather Channel would be monitored if there was concern present with the amount of cloud cover. This would ultimately determine whether or not the team would be launching a HAB that day.

Once it was determined that the team could launch in accordance to FAA regulations, the team would start transferring all the necessary equipment to the launch site, which was typically an open area on the North side of the Linn-Benton Community College campus. All the equipment, such as the balloon, zip ties, helium, and tool kit, were then accounted for and assembly of the payload with the rigging would be done in the field. There was a coordinated Launch Master for every launch and he would keep track of time so that the balloon would be launched at the same time as was filed for the Notice to Airmen or NOTAM before launch. The fill process of the balloon would begin at the Launch Master's command.

A regulator fill valve and hose would be attached to the helium tank. A PVC pipe was placed within the neck of the balloon to ensure that the hose obtained a snug fit and prevented helium from leaking during the filling process. Students who handled the balloon would wear latex or cotton gloves to prevent exposure of oil to the latex of the balloon. A tether would be attached from the balloon to the dolly holding the helium tank to prevent the balloon from flying away during the fill. Launches would typically require two tanks to acquire the necessary amount of helium for the launch. Students would surround the balloon and keep it from moving by stabilizing it with their hands. When the balloon was filled, the anti-spin device would be inserted into the neck of the balloon, with an attached payload, and would be zip tied and duct taped to ensure the payload did not detach from the balloon before the cutdown signal was sent. The tether would be cut and the balloon released. The team would immediately begin tracking using the APRS and the Iridium tracking system for payload retrieval.

VI. Offshore Flight Procedures

Launching from the R/V Pacific Storm created more of a challenge for the team compared to the previous launches from their community college. Weather is more extreme in the Pacific Ocean as natural barriers for wind are absent and there is an increased chance of precipitation from the water. The payload was made easier to locate in the open ocean with the addition of the siren and bright paintjob. It was also made waterproof to prevent damage to the hardware and to prevent sea life from being harmed by the small components within.

The team performed calculations to decrease the number of helium tanks from two to one as switching tanks during the fill process in the ocean would be extremely difficult with waves rocking the boat. The volume of a full helium tank used by the team is seven cubic meters. It was determined using the team's created algorithms (Figure 1) that if the tank were emptied, the balloon would reach between 4.5 m/s and 5 m/s lift velocity if the payload mass stayed between 2 and 2.5 kg. The payload mass was kept within this range so the team did not have to perform accurate measures of helium on the boat and simply emptied an entire tank of helium into the balloon.

Seasickness was also an important factor as more than half of the team had never been on a boat before and did not know how they would react once in the ocean. Many methods of seasickness prevention were discussed prior to boarding the ship such as motion sickness pills, patches, and ginger candy.

VII. Offshore Launch History

A. Flight One: August 14, 2017

The first flight aboard the R/V Pacific Storm was a test to practice as many procedures on the ship as possible without launching the eclipse payload. The plan for the flight was to fill the balloon with helium, but keep it tethered to the balloon. While the balloon was filling, two students would work integrating the rigging through the payload and cutdown box. The payload was not attached to the balloon, but was merely assembled to experience the challenge of working with rigging on a rocking ship.

It was discovered when the team arrived at the Port of Newport, Oregon that the R/V Pacific Storm did not have internet accessibility at sea and the only way to track using the Iridium tracking device was to call a teammate who would stay onshore in Corvallis, Oregon. The APRS would be the only way to track the payload directly from the ship on the day of the eclipse.

Once the ship left port, progressively more and more team members became seasick. By the time the ship was 16 kilometers out at sea, more than half the team was affected by motion sickness. The members who were not affected, stepped up in their roles and alternate roles to complete the fill and assembly processes. Many members with leadership roles were giving commands as they were combatting nausea and dizziness.

After the procedures were complete, a hole was pierced in the balloon to gently release the helium. The strong winds caused the balloon to tear away after the balloon was pierced and it landed in the ocean. The crew of the R/V Pacific Storm was able to fish the latex balloon out of the water to prevent the contribution of ocean debris. The launch was labeled a success despite the number of sick team members and the ship made its way back to port after 2 hours at sea.

B. Flight Two: Eclipse August 20-22, 2017

On Sunday August 20 at 1900 hours, approximately 15 hours before the total solar eclipse, the Linn-Benton Community College Space Exploration Team loaded all the necessary equipment for the launch aboard the R/V Pacific Storm. Before leaving port, the team reviewed predicted sea and weather conditions to prepare for their launch window on Monday, August 21st at 0830 hours. The predicted conditions did not look promising for the team. Four to six meter high ocean swells, and six to eight meter per second winds almost docked the project entirely. Launching a high altitude balloon in those conditions is an almost impossible task. However, after some discussion, the team came to conclusion that too much work had been put into the project over the past year to cancel the trip out to sea based on possible weather conditions.

After performing a review of weather predictions one last time before leaving port, the team noticed a small window of opportunity to launch within. The location was approximately eighty-eight kilometers west of Depoe Bay, Oregon, and appeared to guarantee less than fifty percent cloud cover as required by the FAA for launch a HAB.

1. Troubleshooting

On the night of August 20, the team began performing payload equipment checks to ensure all equipment was in proper working order. After testing the Raspberry Pi 3 and the Raspberry Pi wide angle camera, the team discovered that they were unable to Secure Shell, or SSH, into the Raspberry Pi 3. In addition, the team was unable to check if the camera was storing video via a red flashing light that was covered by Dynaflex 230. A decision was made to remove the ribbon cable and connect the Raspberry Pi 3 to a back up camera. The team observed that the red light indicating that the Raspberry Pi was capturing video was flashing. However, because they were unable to SSH into the Raspberry Pi 3, there was still no guarantee that the camera was storing video. There was no back up for Raspberry Pi 3 aboard the ship, so the team reassembled the payload in hopes that their back up camera would perform.

2. Seasickness

In preparation for being out at sea for approximately twenty-four hours, the team purchased medicated patches to prevent seasickness. Throughout the night leading up to the eclipse on August 21, roughly two-thirds of the team became ill due to the rocking motion of the vessel and obtained little to no sleep the night before the launch due to there being fourteen team members and six reporters on a ship with eight beds provided for passengers. Many slept on the floor using life vests for pillows and others slept in chairs in the ship's designated lab space. Those on

the team who were felt well enough throughout the night, traveled through the boat to help the people who were need of assistance and felt ill.

3. Eclipse Launch

In the morning at 0700 hours, 3.25 hours before the eclipse, the team began preparing for the launch scheduled at 0830 hours. The team arrived at destination chosen based off of the predicted weather conditions that showed signs of a chance of less cloud cover than the surrounding areas. However, at that the time of arrival, visibility still remained with more than fifty percent cloud cover, above the required limit of the FAA. Many of those that were sick throughout the night were still suffering, roughly half of the team. Those that were still functional and cognitively aware, gathered the strength to push through the setup process. Team members quickly gathered themselves and began organizing the team into their designated roles. The payload, rigging, and computer science teams began running through a final check of equipment in the science quarters of the vessel, while the lift precision team reviewed their calculations and began preparing the launch site area on the outside main deck. The tank was unchained from the side of the vessel and secured firmly to a latching point in preparation for filling the HAB. All systems checked passed their inspections and were given the notice to move forward with the launch.

At 0800 hours, the team collected upon the main deck of the vessel and passed out cotton gloves to wear in preparation for handling the HAB during the filling process. The balloon was removed from its packaging and strung out across a line of team members protected hands. This was to prevent the HAB from touching the main deck of the vessel and becoming damaged. At this time the team noticed a clearing in the cloud coverage that began to form, and the launch was given the okay to progress. The filling hose was attached to the regulator valve on the helium tank, and inserted into the neck of the balloon. A cotton bed sheet along with balloon handlers on all sides of the balloon were used to secure the HAB during the fill process. At this time the winds were approximately eight meters per second with six meter high swells, making handling the 2000 g HAB extremely difficult. While those on deck the were struggling to secure the HAB, the payload team applied RV Mastic and Kapton tape to the brim before arming the GoPro® to record.

At 0845 hours, the clouds opened a large port of blue sky and the payload was attached to the HAB below the cutdown box. The team meanwhile concluded with filling and was ready to launch. In order for the payload to clear the boat during release, the signal was given to the captain to angle the Pacific Storm perpendicular to the wind. At 0850 hours the boat moved into position and the balloon began to twist violently from the change in wind direction. When the payload was successfully launched from the Pacific Storm, the team noticed that the lift velocity was not as high as it was for ground flights. The balloon ascended slowly into the air than was normal.

Tracking of the balloon began as the team waited for the eclipse to begin. The balloon stopped rising as it began reaching four km in altitude. APRS showed the balloon beginning to descend as the coordinate packets came to a halt after crossing beyond the horizon line. The team attempted to call a member onshore to get coordinates via the Iridium tracking system, however the satellite phone could only be used in emergencies during the eclipse. At the time, there was no way to pinpoint the exact location of the payload. The team made the decision after many hours were spent searching to return to dock. The payload was not recovered.

VIII. Conclusion

The payload, as of October of 2017, has not been recovered but the team is hopeful of it washing to shore one day and discovering what footage was captured during the eclipse. The team learned many lessons during the offshore launches and now know how to improve upon them in the future. The team is optimistic about another eclipse occurring in 2020 that will be travelling across Chile. The team will be taking this opportunity to revise their offshore launch procedures so that damage to the balloon via strong ocean winds is minimized. An additional form of tracking will be utilized for payload retrieval in the case of APRS failure. The team has not finished researching and developing flight procedures for launching in the ocean.

IX. Acknowledgments

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