High Altitude Balloon Operations in the Mid-Atlantic States

Michael Walker * *
University of Maryland, College Park, MD, 20742, USA

Joseph Breeden, Ji Chang, Bianca Foltan, Dale Martin,
Camden Miller, Mohamed Nassif, Sarah Onimus, Michael Owca, Luke Renegar, Blaire Weinberg †
University of Maryland, College Park, MD, 20742, USA

A high altitude balloon flight is a useful test bed for developing technologies for use in atmospheric science, spaceflight, and developing an understanding of real world applications of engineering technology. This paper will discuss the multitude of procedures, methods, and technologies have been developed in order to ensure a successful balloon flight program. These topics include: Flight path predictions using atmospheric wind models ensure the balloon and payloads do not violate restricted air space while providing a landing location; Software developed to determine lift, ascent rate, and burst altitude for use in flight path predictions, in addition to software for receiving in flight position data and sending ratio commands to payloads; Amateur radio for receiving and sending position reports though the APRS network, sending commands, and commutating on the ground; and lastly, guidelines and rules regarding payload construction to ensure a successful flight.

Nomenclature

BPP: Balloon Payload Program
Payload: Individual research payload, usually consisting of a foam box with electronics and sensors
Payload string : String of payloads tied together with paracord, typical for launches conducted by the program
Command: Command Module, communications and location tracking payload, flies on every flight
APRS: Automatic Packet Reporting System, used by Command Module
HABduino: High-Altitude Ballooning Arduino (developed by Anthony Stirk, Nevis Computers Limited)
Cell Tracker: Location tracking via the cellular telephone network
Balloonduino: Ballooning Arduino Mega (developed by Camden Miller, UMDBPP)
XBee: Digi XBee radio communications module, developed and supplied by Digi International
UMD: University of Maryland (College Park)
MdSGC: Maryland Space Grant Consortium

I. Introduction

Dedicated undergraduate research programs give students practical experience, kindle active interest in research projects, and offer a powerful development platform for smaller and more disposable innovations that, while ultimately making significant contributions to academic research, may not be as appealing to faculty and graduate researchers. When combined with high-altitude ballooning, a research team comprised of undergraduate students can develop and rapidly iterate dramatic innovations in atmospheric science and aerospace. This paper will discuss one such program, the Maryland Space Grant Consortium Balloon Payload Program (MdSGC BPP), and the multitude of procedures, methods, and technologies developed to support

*Student, UMD Aerospace Engineering, 8735 Doves Fly Way, Laurel MD, 20723 , Student
†Students, University of Maryland, College Park,MD , Students

and improve student-run high-altitude balloon flights. The topics discussed in this paper will be flight path prediction, in-flight telemetry systems, flight rules, and payload construction guidelines.

Each flight conducted by the BPP comprises a small number of individual payloads, each developed and managed by individual payload teams. Each team works together to design and build a payload for a specific research objective, and accompanies their payload to launches. Payloads are tied together via paracord, and hang beneath the balloon and parachute on a single line, with each payload spaced around a meter apart from its neighbors. After balloon inflation and launch, the program follows the balloon in vans with roof-mounted tracking antennae, in order to maintain stable radio signal and track the current location and altitude of the payload string. After the balloon bursts, and the payload string lands, the cellular tracker sends the landing location to the vans, and the payload teams recover their equipment.

I.A. Balloonduino

Balloonduino is a single microcontroller board designed in-house specifically for UMD BPP flights. It integrates several common electronic subsystems onto a single Printed Circuit Board (PCB) and shares form factor, function, and software compatibility with an Arduino Mega. This compatibility allows those already familiar with Arduino be able to use Balloonduino on their own payloads and take advantage of its standard features. So far, 11 flights have used Balloonduino.

As modular hardware, Balloonduino is designed to reliably perform standard payload functions, such as logging and wireless communication, so that development time can focus more on unique payload objectives. Some notable functions provided by Balloonduino include LiPo discharge protection with a robust and efficient power supply, a hardware interface with microSD and XBee, orientation via Inertial Measurement Unit (IMU), and various environmental sensors (pressure, temperature, and humidity). Along with a standard Arduino library, this selection of hardware allows teams using a Balloonduino to easily implement logging environmental and flight data to benefit postflight profile and atmospheric analysis. Logging power consumption and payload functions to microSD also aids postflight analysis of individual payload performance.

I.B. Command Module

The Command Module (Command) was first developed by Dru Ellsberry in 2003 as the programs first payload, and has since undergone six revisions. The current iteration, v7, was designed and developed by a previous program director, William Cooper Gilbert, who graduated from the University of Maryland in 2016.

Command acts as the central authority amid the hierarchy of payloads on each flight with the program. It provides in-flight tracking and telemetry, which allows for fast payload recovery. It consists of externally developed hardware chosen for high performance and reliability, and consists of 3 main components: an Automatic Packet Reporting System (APRS) transmitter, a cellular transmitter, and a 900 MHz radio transmitter.

Due to the importance of tracking and telemetry, it is customary for at least one of the three acting program directors to lead the Design and Operations team for Command. This team works regularly to adapt the module design to better serve the shifting goals of the program, along with maintaining and improving the capabilities of the hardware.

I.B.1. APRS Transmitter

The Balloon Payload Program uses two APRS units for redundancy, specifically High-Altitude Ballooning Arduinos (HABduinos). HABduino units are designed and built in the United Kingdom by Anthony Stirk of Nevis Computers Limited, and are currently on their fourth iteration. The primary feature of the standard form of HABduino unit purchased by the program is the integrated Radiometrix HX1 VHF Narrow Band FM 300 mW transmitter, tuned for operation in the United States on 144.39 MHz, the United States APRS frequency. Using this transmitter, the Command Module transmits GPS data from the balloon over the APRS network, to be received by the ground station in the tracking vans. This data is used for calculating various flight parameters, such as ascent speed, ground speed, and possible landing sites. The HX1 transmitter requires an external 144 MHz frequency antenna, which is attached to the unit via an SMA type connector. HABduino also contains a Ublox MAX M8Q GPS module, which is compatible with all four major positioning systems (GPS [USA], Galileo [EU], GLONASS [Russia], and BeiDou [China]) and, as a professional class device, has a maximum operating altitude of approximately 49 km. An external patch antenna is used for acquisition of satellite signals, which is connected to the HABduino module via a second SMA type connector.

I.B.2. 2G Cellular Transmitter

Another redundant tracking system, the Cell Tracker, consists of a Ublox MAX-7 series GPS and a Ublox SARAG350 cellular telephone modem mounted on an Arduino shield, and transmits data over the GSM cellular telephone network. The system continually records GPS data from the GPS receiver at 1 Hz, generating a definitive log of the balloons trajectory. While the balloon has reliable cellular telephone service (generally below 2000 meters), it sends program members text (SMS) messages with the balloons current position. This is especially useful for locating the balloon upon landing, as APRS repeater coverage tends to be rather poor below a few thousand meters.

I.B.3. 900 MHz Transmitter (LINK)

The LINK system is our primary method of transmitting and receiving communications payloads to the ground station. The system consists of a 900 MHz radio and an XBee radio module, both connected to a Balloonduino. This allows the Balloonduino to act as a relay through which program members on the ground can communicate with and receive telemetry from their payloads in the air. Software for Link was developed by Steve Lentine.

I.C. MARS

MARS, Mechanically Actuated Release System, is a payload built and designed to separate active weight from the payload during flight. The MARS system utilizes a 10mm or 30mm linear actuator as the method for release, and receives a release command from and sends confirmation to the ground via LINK. Upon receiving the command to release, the actuator pulls a pin out of a loop in the string supporting to the weight to be released and lets it fall. This system was initially designed for long-duration flights to release stored data files, such as a microSD card with payload logs, that are too large to be reliably transmitted over 900 MHz radio.

II. Preflight Operations

II.A. Launch Location Selection

II.A.1. Time of Year and Weather

Wind and weather conditions in the Mid-Atlantic generally limit balloon launch operations to between April and November. Not only is it important to have mostly clear skies and low winds on the ground for the launch, but it is also essential to have winds aloft that result in an acceptable ground track. In the winter months, the jet stream dips down over the mid-atlantic states and results in very strong westerly winds at altitudes from 9000 to 12000 meters. The balloon and payloads are entrained by this flow and can travel from western Maryland (our preferred launch location) across the state into Delaware, or north into Pennsylvania, or possibly out to sea (Figure 3). In the summer months, the jet stream tends to be further north, so we have a few months with excellent launch conditions, where the ground track may actually go south or west from western Maryland. In times like these, the balloon will occasionally ascend almost vertically, resulting in a landing site relatively closer than is usual in balloon launches.

Weather issues include ground fog in the early morning or unexpected rain showers during launch preparations. Because of humidity-sensitive electronics in the communications and tracking hardware, or in any number of other payloads, risk of precipitation is generally grounds for postponing the flight to another day. In fact, any weather prediction that includes thunderstorms or severe weather of any sort anytime during the day results in postponement partly because of possible damage to the payload string but also because payload recovery operations, which generally take well into the afternoon, are far more difficult in the rain.

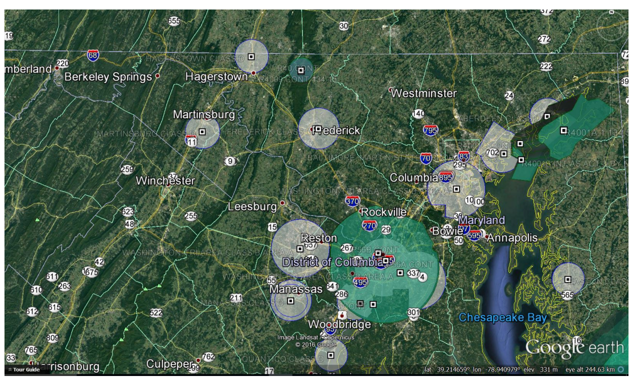
II.A.2. Restricted Airspace

The Mid-Atlantic region, particularly the area around Washington, DC, contains some of the most heavily regulated airspace in the world due to post-9/11 security concerns. In addition to a number of prohibited and restricted areas in which balloon flight is prohibited under the terms of Federal Aviation Regulation (FAR) 101.5, such as those around Camp David and Aberdeen Proving Ground, the airspace around greater Washington contains the only Flight Restricted Zone (FRZ) in the country [1][2]. The FRZ is a roughly circular area of approximately 15 nautical miles radius centered around Reagan National Airport (KDCA) in which balloon operations are prohibited [2]. These features, combined with the proliferation of controlled airports in the greater Baltimore-Washington corridor can significantly complicate finding a suitable landing site when the winds are blowing strongly from the west.

Figure 1.shows the various airspace considerations in the programs normal area of operations. Areas shaded white are controlled airspace around airports where balloon flights are prohibited within 2,000 feet of the surface. Areas shaded green are prohibited or restricted areas (including the FRZ) where balloon flights are prohibited to much higher altitudes (e.g., 18,000 ft. for the FRZ). This figure was generated using Google Earth and data from the U.K. 3-D Airspace Project/Lloyd Bailey (http://3dairspace.org.uk) and the D.C. municipal government.

In order to avoid violating any of this airspace, the program runs multiple 3-D trajectory predictions prior to each launch. Flight parameters (e.g., ascent rate, descent rate, and burst altitude) are input in order to determine an envelope of likely trajectories. These trajectories are then plotted in Google Earth in 3 dimensions and compared against the Google Earth representations of the restricted airspace. If an airspace violation seems reasonably possible, the program will move the launch site or change balloon filling parameters to alter the trajectory and avoid the violation.

Figure 1. Mid-Atlantic Restricted Airspace White and green areas indicate restricted airspace. Google Earth render using data from the U.K. 3D Airspace Project and the D.C. Municipal Government.



II.A.3. Landing Location

In addition to minimizing the possibility of flying through restricted airspace either on ascent or descent, it is also necessary to put significant effort into picking a launch location that yields an acceptable landing zone. Generally speaking, landing in open farmland or sparsely populated residential areas is ideal, and lightly forested or somewhat developed land is okay; but there are quite a few landing spots in this region that are unacceptable, for example a landing in water (Chesapeake Bay or any significant body of water like a reservoir or large river), landing in a major metropolitan area (Washington DC, Baltimore), or landing in any restricted area (Camp David, Aberdeen Proving Grounds, Dulles Airport,). When a landing is predicted for an unfavorable spot, the procedure is to either postpone the launch to another day, or to move the launch location so as to obtain a better flight trajectory and landing zone.

II.B. FAA Regulation, Preflight Notifications

II.B.1. Regulation

The release and operation of an unmanned free balloon is governed by Federal Aviation Regulation FAR Part 101. This FAR states that a balloon flight is exempt from FAA oversight if the total payload weight is less than 12 lbs, if no single box on the payload string weighs more than 6 lbs, if there are no sharp points or edges, and if the balloon can be separated from the payload string with a reasonably small force. If these conditions are met, there is technically no need to alert the FAA before a flight. However, it is the policy of the MDSGC BPP to contact the FAA and file a NOTAM (Notice to Airmen) the evening before a flight, mostly as a courtesy to keep local authorities apprised of the operation. The NOTAM will identify the launch location, the flight altitude (through Flight Level 600, i.e. above 60,000 ft above mean sea level). In addition, direction of travel, predicted landing area, and flight duration are included in the filing.

II.B.2. Contacting Area Tower

In addition to the issuance of a NOTAM, our procedures include a call to the closest airport with a control tower on the morning of the launch at least an hour before the target release time. The control tower operator generally is aware of the operation because of the NOTAM, but they will sometimes want to follow the progress with a call-back 5 minutes before release, after release, when the balloon clears through FL600, when the payloads descend back through FL600, and/or when they are back on the ground. Most of the time, there are no issues, but on occasion, a balloon flight does not follow a predicted ground track, for example if its ascent rate is much slower than predicted. In cases like these, our procedure is to call the tower and alert them of the situation, and they take the responsibility of contacting other Air Traffic Control entities that may need to be informed.

II.C. Program Regulations and Approval Process

The program currently utilizes an extensive list of safety-oriented regulations drawn from the FARs or developed from past experience. The rules and regulations used are split into three levels: Flight rules, Recommendations, and payload-specific guidelines. Flight rules are typically drawn from the FAR, such as no self-propelled devices on the balloon (i.e. a drone or small rc plane). They are also created based on any safety concerns brought up by program members at the weekly meetings. Recommendations are developed from past launches, with a focus on avoiding failures. One such recommendation is for payloads to to have an external power switch to facilitate easier launch and recovery operations. Every payload has a different mission, and to ensure safe and reliable operation, certain guidelines are developed to aid the team in development. This is usually done during the approval process, which is discussed below.

A three stage approval process is currently used for vetting payloads pre-flight. The first stage involves pitching a payload idea to the faculty advisor, and then during the weekly general meetings. This pitch is meant to let other program members know the payloads mission and allow the leader to recruit people with certain skillsets (programmers, fabricators, modelers) to help achieve their mission. The second stage involves a design review, which anyone in the program can be a part of. The team develops documentation concerning the science behind the mission, as well as proposed design solutions to collect the desired data. This information is presented to other program members in a presentation, and then an open forum is held to ask questions and provide advice. This is also when payload-specific guidelines are developed, and a test plan is introduced that the team must complete before launch. The third and final stage of the approval process requires teams to submit a launch proposal form, which validates the completion of a test plan and provides the final weight, size, and additional flight requirements. Once the proposal is submitted, the team is allowed to fly on the condition that their payload is in full operating condition by the time of the flight.

II.D. Launch Equipment

A typical balloon flight requires some basic hardware, most of which is reusable (like the command module and the parachute assembly), and some of which is not (the balloon and helium). Most of our flights carry a payload weight of approximately 12 lbs total, and we therefore use a 1600 g latex weather balloon which requires two K-size tanks of Helium (roughly 300 ft3 of Helium in each). To achieve a peak altitude somewhere between 80,000 and 100,000 ft before the balloon bursts, approximately one and a half tanks of helium are used to fill the balloon. Inflating the balloon with just enough helium to lift the payloads and have an additional 4 or 5 lbs of free lift will result in an acceptable ascent rate (roughly 1000 ft/min or 5 m/sec) and will allow the balloon to go as high as possible before bursting. Other consumables include a large number of lithium-ion batteries and significant duct tape and parachute cord for each flight.

The parachute assembly that we have used for over 50 balloon flights consists of a 8-foot diameter Rocketman parachute in bright orange and purple colors to aid recovery operations. It is made of rip-stop nylon and has held up remarkably well over many many flights, which often end in being stuck in a tree with the parachute and shrouds tangled in the branches. The 4 shrouds of the parachute are attached evenly to a 3 foot diameter hula-hoop, which spreads them apart during descent to ensure that the parachute inflates quickly. The Command and Tracking Module is located below the hula-hoop in a nylon bag attached using a removable harness system. More information is provided about the Command Module in Section III B. All of the payloads, different for most every flight, are attached to a single string that hangs below the command module.

III. Flight Operations

III.A. Setup and Launch of Balloon

Before our payloads can travel to the edge of space we must first setup and launch the balloon. We begin our setup by first laying down a large tarp that keeps the balloon from coming in contact with the ground or any other objects that could weaken or puncture it. Once the tarp has been laid down we open the balloon packaging and place it inside of the BLT, the Balloon Launch Tube (as described below) and prepare to start the filling procedure. Before we begin the filling procedure we call all of the local airports to remind them of the NOTAM that was filled and give them notice that we will be launching soon. Once that phone call has been placed, the rest of the inflation process can begin.

The first step is to lay out the parachute and payload string in flight configuration. Making final preparations of the payloads for flight should occur at this time. Inflation should occur simultaneously with these preparations. Our system has a regulator that attaches to the helium tanks and releases helium through a filling hose into the balloon. We use a set of PVC pipes as an adapter interface between the balloon and the hose to ensure that the balloon neck has a good fit around the end of the filling apparatus. Additionally, we wrap the PVC and balloon neck in duct tape for added security. For a 1600 gram balloon we usually fill the balloon with one and a half to two tanks of helium, depending on the desired amount of lift. When switching between the tanks the same procedure should be used to attach the second as the first. Care should be taken to avoid loss of helium while switching between the two tanks to avoid loss of helium.

Once the balloon is filled to the desired amount, the tether from the top of the parachute should be placed around the neck of the balloon. The neck should be folded up so that the tether sits in the fold. This should be duct taped over, zip tied on top of that, then duct taped again. If this procedure is not followed, especially the zip tie, the balloon may slip off of the parachute causing early termination of the flight.

III.B. Balloon Launch Tube (BLT)

III.B.1. Introduction to the BLT

One of the most challenging aspects of launching a weather balloon is the inflation of the balloon during the setup phase. The traditional method of balloon inflation requires a minimum of one person holding the neck of the balloon as it is filled with helium. This results in at least one, though a minimum of two is recommended, balloon handler(s) holding onto a balloon, which by the end of the inflation period has upwards of 20lbs of lift for a period of 30 to 45 minutes. As the balloon continues to inflate, holding on to the balloon becomes more difficult as any sudden gusts of wind can cause damage to the balloon through impact with either the balloon handler(s) or nearby objects. Furthermore, this method requires the balloon to be laid out on the ground at the start of the inflation process, risking contact with debris such as small pebbles that may damage or weaken the balloon, causing a premature burst. Additionally, this method of inflation is risky as it is not possible to tether the balloon to anything until after inflation is completed. This means that if the balloon handler(s) let go of the balloon before the inflation process is completed, there is a high chance of accidentally releasing an untracked balloon with no payloads on it, costing helium and time.

III.B.2. BLT Components

The Balloon Launch Tube (BLT) was created primarily with the intent of dealing with sudden wind gusts, but has also served as a way to significantly reduce the chances of balloon loss due to balloon handler error. Despite the prevalence of the difficulties surrounding a traditional inflation, there is little precedent for methods that address them. The BLT is based off of a system described in a 1989 issue of The Journal of Atmospheric and Oceanic Technology, customized to fit the specific needs of the program. It is a large, 19 ft x 34 ft, sheet of 6mil plastic sheeting made from three smaller sheeting, which are held together using a combination of tape application and sewing. One side of this plastic sheeting has two strips of soft sided Velcro attached to it. The first strip follows exactly one of the 19ft long edges, the other is offset by one foot from the other 19ft edge. When the BLT is in its tube state, those two strips are lined up next to each other so that there is a foot of plastic sheeting overlap within the tube and the sides are held together with a strip of hard hooked Velcro on top. The choice to have the soft side of the velcro on the plastic sheeting was a deliberate choice to reduce the risk of the hard velcro contacting the balloon while inflating it.

III.B.3. BLT Launch Procedures

In order to inflate using the BLT, the uninflated balloon should be roughly centered on the completely flat sheet, which is then folded over the balloon as described above. During the early inflation process it is best if the BLT is rotated slightly so that the Velcro strip is at about shoulder height. Throughout the entire inflation no fewer than four people should be assigned to holding down the BLT, one for each corner. The balloon is released from by removing the Velcro and allowing the the balloon to rise up out of the BLT, then to follow normal launch and release procedures.

III.B.4. Post-BLT Launch Procedures

Following the launch of the balloon from BLT, the balloon is slowly hoisted up by the payload string in order to reduce any possibilities of strain on the balloon and to prevent the balloon from swaying from side to side. Once the parachute reaches eye level, two very long strings attached to kite reels are fed through the metal ring located on the top of the parachute. Four people are required for this process; two holding the kite reels and two holding the other end of the strings. While the balloon is slowly released higher, the kite reel holders play out the string, removing any tension present in the string. Once the payload string is fully off of the ground, the final lift of the balloon can be measured. While the precise lift that each launch requires varies from launch depending on the predicted landing spot, the average lift that the program aims for approximately 5-6 pounds above the weight of the payload string. This launch procedure allows the launch team to measure the lift of the balloon, check the approximate time of launch, and confirm telemetry packet receiving. Once lift, time, and packets are recorded, the balloon is ready to launch. Following the release of the balloon, the people holding the free end of the string release the string, allowing the string to fall out of the metal ring. In case of possible entanglement, all kite reel holders are given a pair of scissors to cut the string. Cutting the string is not recommended as it can tangle with the payload line during flight and should only occur in the case of entanglement.

III.C. Performance Prediction Software

The useage of BLT provides a benefit to the program, however, the unorthodox method causes some additional challenges. The lift cannot be measured directly while the balloon is inside the launch tube using a spring force gauge, as is nominally done in the high altitude ballooning hobby. Even after the balloon has exited BLT, winds make measuring lift inaccurate, if not already impossible. Moreover, if the balloon if found to be underfilled, opening the balloon after integration with the payloads unnecessarily stresses the balloon neck and increases the risk of failure. As such, a method for predicting the lift of the balloon based upon atmospheric conditions and the amount of helium gas put in was developed.

The software is a Graphical User Interface (GUI) coded in MATLAB. The code requires a multitude of inputs. The launch altitude is required for calculations. Temperature, Pressure, and Dew Point are taken from measurements done on the launch site, as well as the closest airports Automated Weather Observation System (AWOS). The Balloons Temperature is taken by aiming an infrared thermometer at the surface of the balloon. Balloon pressure would also be required, but through experimentation and measurement it has been determined that assuming the pressure inside the balloon is equal to ambient pressure is justified. The mass of the entire payload is inputted, including the mass of the balloon, along with a margin that allows for on-the-pad mass increases due to last minutes fixes and fastening.

One of the most important inputs is the Helium Mass. This quantity is the biggest driver of balloon performance, as is expected. The software provides a tool that will compute the mass of helium let out by a tank based on starting pressure plus surface temperature, and ending pressure plus surface temperature of the tank. This tool uses ideal gas law and assumes the volume of the tank. Even though the program uses the same size tank, manufacturers create slightly different sizes. This is a source of error that has been attempted to be eliminated by measuring the mass of the tanks directly and recording their difference before and after filling. A mass of 10 grams of helium can affect lift by a half a pound and burst altitude by 3000 feet. Scales accurate enough to measure a usable mass difference cost thousands of dollars. A much less costly system was used, it included two Nintendo Wii Fit boards linked via bluetooth protocol to a Raspberry Pi. The Raspberry Pi would output a website page on a local IP address such that a computer could be connected by an ethernet cable and view the total mass indicated by all connected boards. These boards sensors have a high jitter, and commonly the measurements will have to be disregarded due to unsteady ground and poor footing.

Using these inputs, lift, ascent rate, the weight, and free lift or delta lift is calculated and displayed for both sets of atmospheric condition datum. Weight is a simple unit conversion from kilograms to pounds, delta lift is the difference between the weight and the lift generated by the balloon. The lift is calculated such that the mass of the helium is already accounted for, so it does not need to be included in the payload mass. Ascent rate is an iterative calculations that starts with a nominal ascent rate, calculates the drag force using a drag coefficient of a sphere at the calculated reynolds number, and then uses that speed to calculated it again. 10 iterations are all that is needed for a reasonably accurate ascent rate.

The burst altitude calculation uses both a standard atmosphere table, and a custom atmospheric table built using conditions measured on the ground. The answer is displayed as a plot of burst altitude vs. burst diameter. The industry standard for the burst condition is exceeding a diameter of the latex balloon. The provided diameters can be ambiguous or non-existent. The charts allow for the user of the software to see the ranges of achievable altitudes and give a burst prediction based suggested burst diameter and prior flight experience.

III.D. Active Tracking and Prediction of Landing Site

III.D.1. Radios

The program utilizes many different types of radios during launches. On both the main and secondary tracking vehicles, there are two monopole antennas, used for SSB voice communication and receiving APRS packets. The APRS packets are fed from the radio into a laptop running in-house APRS decoding software. This software provides position and altitude data from the packets and also calculates ascent rate, ground speed, and estimated time to landing. Patch antennas are also commonly used for a wide range of uses. The main tracking vehicle utilizes a patch antenna in order to communicate with Link, and occasionally another antenna will be used to communicate with a payload directly.

In the event that the balloon payload lands in an area that is inaccessible by road vehicles, and a final position of the payload string is not available, a different APRS tracking setup is used. Handheld Radios such as the Baofeng UV-5R are used in conjunction with a smartphone application. The radio is then tuned to the APRS frequency and its mic output connected to the microphone input of the smartphone. The APRSDroid app is then used to decode the packets and continue tracking the payload on foot.

As well as using radios in order to communicate between the balloon and the vehicles, there are two redundant systems used in order to communicate between vehicles, the first of which being the Zello app. Similar to a normal radio, Zello allows members in all vehicles to communicate with one another on a virtual radio, with no restrictions on who is using the app or worries about radio bandwidth. This works well, until tracking goes through locations with no cell service, and Zello can not work. When that occurs, the communicators switch over to using over HAM radio. At least once per semester, a trip is organized to go to a local HAM licensing exam in order to continue having members able to operate the HAM radios during launches.

III.D.2. Recovery Methods

Once the payload string has landed, the team begins recovery operations by determining whether the landing site is on public or private property. If it is on private property, as it often is, the recovery team always seek permission from the landowner before beginning said operations. After locating the house attached to the property, the program sends in a small delegation (no more that two students, sometimes accompanied by a professor) to approach the homeowner and explain the situation. The rest of the team remains in the vans, which are parked a good distance away from the house, and awaits further instructions. If the landowner isnt present, we approach neighbors and inquire after the possibility of entering the property. Once the team receive permission to do so, the team approaches the balloon and begin recovery operations. If no one is present to give permission, the team cautiously proceed onto the property and leave a few students by the house in case the owner comes back.

After getting permission to enter a property, the payload string must still be located. Sometimes it is near a road and accessible with the vans. Usually, it is farther in a property and the team needs to hike up to the location carrying all the retrieval equipment. Retrieval equipment includes materials for various possible landing sites, such as machetes for hiking through woods or a slingshot to retrieve the payload string from trees. Though the payloads have sometimes landed in corn fields or lawns, the vast majority of the time the string was snagged by a tree. The standard approach for tree recovery involves a slingshot, which is used to shoot a bean bag attached to a nylon rope at the hula hoop below the parachute or the branch it is snagged on. When successful, the bean bag and the rope are used to pull up a thicker rope. That rope is used to either shake the branches in order to dislodge the payloads, or pull up a rope saw unto the branch and use a seesaw movement to attempts to cut through the branch. If all else fails, a tree climber is contacted to return to the landing site the next day to recover the payloads.

IV. Conclusion

The Balloon Payload Program at the University of Maryland has been active for over 10 years. Throughout that time it has constantly evolved and improved, and has conducted over 60 launches. The procedures and technologies detailed here give an overview of the processes the program deems essential to a successful balloon flight program. The program continues to evolve and expand its capabilities, as innovation and development are fueled by an ever increasing influx of undergraduate student members.

V. Acknowledgments

The Balloon Payload Team at the University of Maryland College Park would like to thank the Maryland Space Grant Consortium for funding this program since its inception in 2003, through over 60 tracked balloon flights.

VI. References

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