RadioFlier-1: An individual experiments in the stratosphere via Weather Balloon

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Abstract

Experiments at extreme altitudes in the stratosphere have historically been considered out of reach for the individual experimenter or scientist. This paper will discuss the reasons why balloons are the ideal choice for such experimenters, as well as present both the design and launch of the balloon platform *RadioFlier-1*, demonstrating the feasibility of this idea. The contents of the payload and various subsystems will be discussed in detail, along with the data retrieved from its initial flight. It is the goal of this paper to show that these results can be achieved with minimal outlay of capital and manpower.

Introduction

Weather balloons are an often-overlooked method of achieving altitude. This vehicle involves no explosions, engines, airfoils or complex control surfaces, and is elegantly simple in operation. The NOAA and other meteorological organizations drive a market demanding cheap, expendable balloons, thus making them affordable. Considering these facts, balloons make an ideal vehicle for a scientist or researcher to achieve altitudes of 30 kilometers (98,000 feet) and beyond. At above 99% of the density of the earth's atmosphere, these balloons travel into conditions that are practically indistinguishable from space. It is this very reason that I chose this vehicle to carry my first atmospheric experiments for the *RadioFlier-1* launch.

RadioFlier began with the need to develop a reusable vehicle able to be loaded with various experiments, sent into the stratosphere, and recovered easily. The first "test" experiment was simple for *RadioFlier-1*—Ascend to 30 kilometers while take pictures and video along the way. This would involve a simple payload consisting of a 35mm camera and Hi-8 camcorder. I soon discovered the need for much more hardware to support even these basic experiments.

Environmental considerations

Since the temperatures plummet as one ascends away from the denser lower atmosphere, consumer electronics designed to operate at room temperature could be expected to develop

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problems. Resistances and capacitances will vary in electronics relative to temperature, so it was paramount that I keep as much heat in the package as possible. To solve this problem, I used a Styrofoam cooler wrapped in Aluminized Mylar[2]. This strategy does not address the possibility of the package overheating, which will become a problem if the package sits for extended periods of time prior to launch or before recovery on the ground. To avoid such troubles, I decided to turn on the equipment immediately before launch, and to recover the package as quickly as possible. Unfortunately (as will be discussed later) I did have some thermal overheating issues as the package landed in the Mojave Desert on a 49° C (120° F) day.

Another important consideration are the voltage levels in payloads sent up to 30 kilometers. Removing 99% of the insulation provided by the atmosphere will severely reduce the amount of voltage required to jump an arc or develop corona discharge. For this reason, I made absolutely certain that all devices sent up operated at very low voltages of 12 volts or below. The only item I needed to worry about in this respect was the viewfinder flyback in the camcorder, which developed potentials of several kilovolts. As this was not needed and could only cause trouble, it was disabled.

Telemetry and tracking

Real-time tracking of the balloon was desired, so that the 3D position (latitude, longitude, and altitude) of the balloon could be known at the ground station-- GPS[3] was an obvious choice for this requirement. Additionally, it was decided that the ground station should be able to send various commands the balloon in order to operate on-board experiments. An off-the-shelf solution is a "Packet Radio" modem commonly used by Amateur Radio Operators, and serves the purpose of a radio modem. This modem was interfaced to a standard "HT" handheld 5 watt radio feeding an eggbeater-type antenna, and a CPU board.

In addition to the GPS telemetry system, there are also three independent backup beacons that were designed into the payload specifically to aid in recovery. The first beacon utilized the main telemetry channel and transmitted a Morse-code message upon landing. This is used as the primary method of retrieval due to its high power output. Armed with the last reported position from GPS, and utilizing RDF (Radio Direction Finding) techniques on this beacon, I expected to be able to find the landing site quite easily. To handle unforeseen failures, an additional 1/3-watt beacon is also included on 144 Mhz band with it's own power supply as a backup. This would cover any failures of the main battery or main radios, and was kept completely isolated from any other systems. The third and final beacon is an audible one, designed to sound upon landing. This is necessary to find the package when in close proximity, or in deep brush.

The procedure for recovery first involves driving to the last known location reported by GPS, then using one of the two RF beacons to find the location of the box. These RF beacons can be utilized by performing a quick sweep with a directional "Yagi" antenna, which reports the maximum signal strength in the direction of the package. Following this bearing would eventually lead one to the landing site of a beeping box.

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[2] Space Blanket material commonly found at camping stores
[3] Global Positioning System run by the United States government

Antenna and Frequency Selection

The type of antenna and frequency used were selected based on various experiments carried out by the author. A mock-up telemetry package was assembled which included a transmitter, antenna, and battery, and placed on a mountain at 1.8 kilometers (6,000 feet) in altitude. Various frequencies were attempted, as well as power levels and antenna polarization. In the end, 440 Mhz was selected due to reduced antenna size, and a circular polarization was chosen to reduce signal flutter from package spin. The "Eggbeater" antenna proved to be ideal in tests for the balloon. It consists of two full-wave loops of wire, one orthogonal to the other and driven with a delay of 90 degrees phase difference. A vertically polarized, directional 8.6 db gain Yagi antenna on a mast was used on the ground. This antenna could be rotated manually to point at the balloon.

Utilizing these antennas and polarizations, the 5 watt balloon signal was able to be received and decoded by the modem at a distance of over 100 kilometers from the mountain, with any rotation of the transmitting and receiving antennas, as long as the Yagi is pointed within 30° of the balloon.

Payload

The payload is outlined in Figure 1, and consists of the telemetry system, tracking beacons, camera equipment, and CPU board. The CPU consists of a 68HC11 microcontroller evaluation board from Motorola, along with some custom I/O to interface with other devices in the payload. Primarily, the CPU is responsible for gathering data from onboard devices (temperature, GPS, etc.), packetizing these data, and sending these packets to the modem for transmittal to the ground.

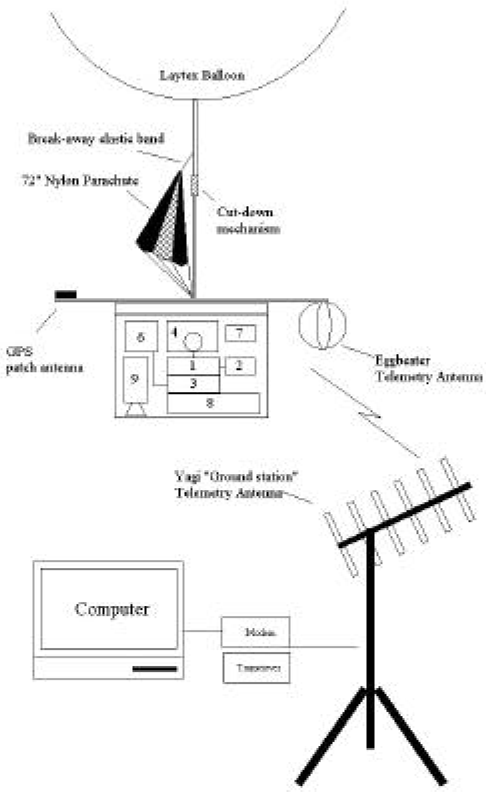
A consumer camcorder was chosen to record video during the flight, avoiding the complexity of transmitting the video from the balloon itself. For higher quality photos, a cheap 35mm camera with an electronic film advance feature and an electronic shutter was employed. This allowed easy interface to the CPU board, as the CPU could simply toggle a line high, which connected directly to the shutter switch logic in the camera.

Balloon, Tether, and Parachute

I chose to use the 1200 gram Latex sounding balloon available from Kaymont. This balloon is rated to carry 1 kilogram (2.3 lbs) to an altitude of 33.2 kilometers (108,000 feet), ascending 320 meters per minute (1050 fpm). There were other balloons offering more altitude and payload capacity, but were exponentially more expensive and heavier. This would make sense, as the atmospheric pressure drops in the same way with altitude. For this reason, I decided on this balloon as the most economical. I expected this balloon would burst well below the published 33.2 kilometer burst rating, as the payload was to be many times over the recommended 1 kilogram payload.

The connection between payload and balloon received special attention, due to the possibility of a wind-induced "spin". Package spin would not only cause potential problems with the signal flutter due to antenna spin, but would also result in poor video quality and blurring from on-board cameras. I eventually decided to use a rigid nylon tube as a tether to minimize the possibility of "windup" from package spin, along with a bearing in the center, allowing the package to spin freely. Later, the bearing was eliminated, as the tube seemed to be rigid enough to avoid this hazard.

A Nylon parachute was selected from a high-powered rocketry magazine. The manufacturer published drag coefficients on these parachutes, and 72” was the size that slowed the 4.5 kg (10 lb) package to 3.5 meters/sec (8 mph) at sea level pressure.



RadioFlier Balloon Hardware:

1. 68HC11E9 computer
2. Motorola Oncore GPS
3. 1200bps modem
4. 35mm camera
5. Audio buzzer
6. 5 watt 440 transciever
7. 144 MHZ beacon
8. Lithium battery
9. Hi-8 Camcorder

Physical Balloon Package:

- Styrofoam cooler
- 72” Nylon Parachute
- 1200 gram balloon
- Helium (5.7 meters^3)
- 5.2 kg total weight

On The Ground:

- 440 MHZ “Yagi” antenna
- 1200 bps TNC
- Pentium laptop computer
- Custom software

Figure 1 Block diagram of Balloon platform and ground station

It is important to disconnect the payload from the balloon in the event of various situations. What if the balloon were to drift towards restricted airspace, or stop ascending at 10 kilometers altitude due to a lack of lift and begin a journey that would take it hundreds of kilometers away from the ground station? These situations are handled quite nicely with the cut-down system. For RadioFlier-1, I used a small hobby rocket engine and igniter to melt through a plastic strap. If a cut-down were desired, the engine would be ignited and would melt through the plastic, releasing the balloon. Note that this method was not very effective, as will be explained later.

Ground Station

Custom software was developed under Visual Basic and ran on a Windows based laptop. This software was responsible for presenting a moving map, showing the balloon’s position and path in real-time, and logging all received packets to a database. Buttons allowed the operator to snap photographs, or issue a “cut-down” command. To assist in antenna positioning, a vector bearing to the balloon was displayed, and the antenna was manually rotated to match.

Launch Day

A launch location in Barstow, CA was chosen due to its remote location and mostly open desert surroundings. This minimized the possibility of landing in someone's backyard or on a freeway. I chose a relatively high elevation with a good vantage point of the surrounding city. This was done to maximize our vision of the balloon during its flight, and to improve the line-of-sight telemetry link. My only concern was the possibility of landing in Barstow or in restricted airspace 55 kilometers (30 miles) outside the city, but other than these obstacles it was an ideal site. The FAA[4] was notified in advance of the flight in accordance with part 101 regulations, and we were given a number to call before and during our flight.

Unlike most balloon groups, our launch team consisted of three people: Myself, my fiancé Christy, and by boss from work, J. Walt. Christy was responsible for filming and documenting the launch day's events, while J.Walt and I were to carry out the actual launch.

We laid out two blue tarps, both 3 x 3 meters, and weighted them down with rocks. One tarp was designated the "balloon and filling" tarp, and the other was for various equipment and the payload package itself.

Cotton gloves were used during the handling of the balloon, to avoid contaminating the Latex with the oils from our skin. These oils reduce the integrity and strength of the thin Latex walls, and could cause the balloon to burst prematurely.

Filling was performed from a large 8.5 cubic meter cylinder of helium, through a standard helium regulator. We filled the balloon until it was able to lift the payload and a 453 gram (1 lb) weight. This gave us 453 grams of positive lift over the package weight. We estimate the total volume used at 5.7 cubic meters.

After filling was complete, the telemetry equipment was checked. We had GPS lock, full signal strength, full batteries, and everything seemed to be working flawlessly.

At 8:00 am we let the balloon go, and watched it go up about 10 feet and come right back down. We discovered our ballast weighed less than we expected, and we had to carefully refill additional helium into the balloon. Finally, at 8:10 am the balloon lifted into the sky.

The entire trip went flawlessly. I remained on the ground, pointing my antenna toward the balloon guided by the vector reported from the laptop. Telemetry went back and forth the entire time with no lost packets. Watching the GPS data coming back from the balloon was very exciting-- Every additional kilometer of altitude felt like another success in itself. We launched a very heavy payload (5.2 kilograms) so I assumed we would not reach the altitudes described on the balloon data sheets.

When the balloon reached 40 kilometers (25 miles) away, it started coming right back to us. Finally, it veered north, and we were staring right at it when it popped at its apogee of 28.7

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[4] The Federal Aviaition Administration (FAA) monitors and controls air traffic in the United States

kilometers (94,000 feet). I watched the telemetry on my laptop as it descended. The numbers decreased rapidly from apogee down to 609 meters (2,000 feet) where it hit ground level. The impact caused the onboard computer to reboot, as we received an unexpected "Boot Successful" message. The package hit the ground so hard it rebooted; yet we were able to maintain our link from takeoff until landing.

We drove about 16 kilometers (10 miles) north and I heard a strong signal from the package's 5 watt radio—It was sending out it's Morse code ID on the telemetry channel, waiting for us to find it. We had to drive on very sandy dirt roads for quite a few miles, ending up in the middle of nowhere with absolutely no sign of civilization. We arrived within one mile of the package, yet the 5 watt tracking signal was not to be heard.

Assuming the batteries died, I got out a directional 2 meter "Yagi" antenna and did a sweep of the area. To my surprise, there it was: The faint crackle of the backup beacon. We followed that bearing to the beeping box. It became apparent that we had the backup beacon to thank for our ability to recover the payload.

We quickly discovered the reason for the telemetry radio failing-- It was in thermal shutdown because our box was acting like a solar oven, cooking the equipment inside. As a matter of fact, it was so hot that anything placed in the sun for 10 seconds would be too hot to touch. The LCD screen on my handheld radio and watch were black from the heat. I would have never guessed heat would have been this much of an issue.

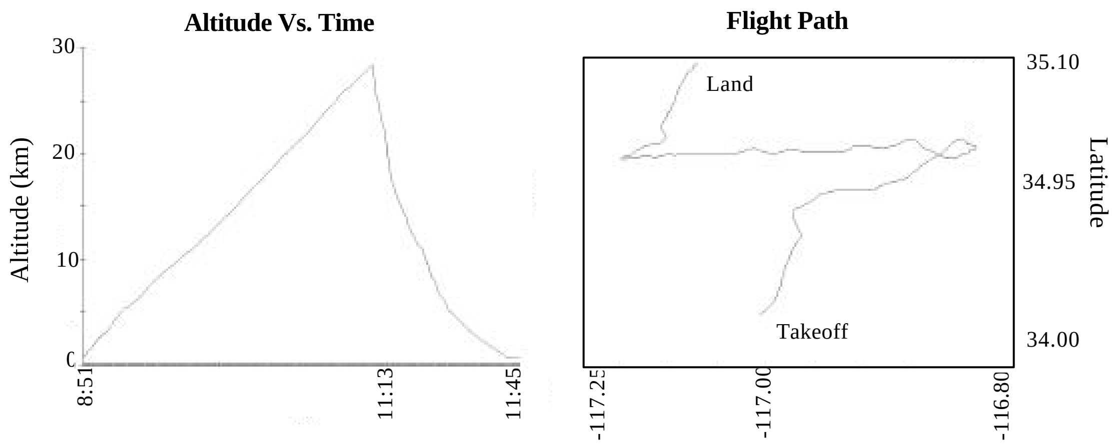

Figure 2 Balloon ascent plots

After the landing

Despite the unforgiving sun, the film turned out great. The payload couldn't have performed its mission better. Package spin was still noticeable on the video we recovered, and could be improved further. Overheating was obviously an issue on landing, and I believe it would help tremendously if the package had "break away" vents that automatically fell off upon landing. This would not be necessary for a launch on cool winter days, but would defiantly help during a hot summer in the Mojave Desert.

The cut-down mechanism didn't release the balloon from the package as commanded after burst. We later discovered the fact that rarified atmosphere didn't allow the ignition process to complete inside the mechanism, as the fuse had burned and charred the hobby engine without ignition. Additional experiments showed that the cut-down system could be simplified with a nichrome wire, which burns through a plastic zip-tie much better than our current system.

The telemetry system could be simplified if only tracking and simple I/O was required. It is no longer necessary to include a CPU board as I did—There are may packet modems now available, which include built in I/O and device control. Some of these also include ARPS[5] functionality, which can interface standard NMEA GPS devices directly to the packet modem with no custom circuits needed. One such modem is available from *Kantronics*, and is worth taking a look at.

Conclusions

I have shown that even an individual scientist or researcher can launch an experiment into the stratosphere and space-like conditions, recovering the payload fully intact with minimal outlay of capital and manpower. RadioFlier-1 directly shows this as not only achievable, but also relatively simple given the advent of miniaturized modems, transceivers, and GPS.

Figure 3 – RadioFlier launch photo, 10 meters above Barstow, CA

Figure 4 View from RadioFlier-1, 27.8 kilometers (94,000 ft) above Barstow

Related Material

Ryan, Craig "The Sport of the Scientist" The Pre-Astronauts- Manned Ballooning on the Threshold of Space 40-87

Shevell, Richard S. (1989) "Characteristics of the Standard Atmosphere" Fundamentals of Flight 422-425

Straw, R. Dean (1997) "High-Performance Yagis for 144,222, and 432 Mhz" The ARRL Handbook , 18.19-18.28

Kaymont (October 2001) "Sounding Balloons" http://www.kaymont.com/pages/sounding_frmst.html

[5] Amateur Radio Positioning System (ARPS) is a relatively new way for ham radio operators to report their position via Packet Radio modems