The Montana Space Grant Consortium Ballooning Program Handbook

http://www.spacegrant.montana.edu/BOREALIS

13 June 2004

Abstract: This document serves as a primer for the BOREALIS project, containing all the information required to build, launch, track, and recover the basic BOREALIS near-space system.

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SECTION I: Introduction

The purpose of the BOREALIS (Balloon Outreach, Research, Exploration, and Landscape Imaging System) Program of the Montana Space Grant Consortium (MSGC) is to provide students across Montana the opportunity to ***Design—Build—Fly*** science and engineering experiments in a near-space environment. BOREALIS was begun only in early 2001, so the program is still quite new and growing and evolving with each flight.

In Montana the consortium's Lead Institution, Montana State University, is the home of the BOREALIS program. The ballooning "infrastructure" and the majority of faculty and students involved in the program are at MSU. We have a core team of about 3 faculty, and roughly 10-15 students involved at present. Our Space Grant Workforce Development project has, in the last year, provided funds for eight MSGC affiliate campuses to set up student/faculty teams building payloads to fly on the BOREALIS platform. These payloads are being flown in the spring through fall of 2003.

Figure 1: Balloon fill at sunrise.

In addition to the MSGC Director (Hiscock) and Associate Director (Klumpar), for whom this can be claimed to be part of their "work", one staff member, Sean Kirn, our Flight Director and payload czar, receives salary for BOREALIS. Students can receive hourly pay (through undergraduate research involvement, funded by MSGC) and/or academic credits for involvement. Many faculty and students participate simply for the excitement and fun of the program.

At present, we do not have a formal course offering connected to the ballooning program, though we hope to further explore that possibility in the future. We have had an electrical engineering senior design project centered on the balloon system, and anticipate additional involvement in the future with engineering design courses, as well as senior project/thesis research in science areas such as physics.

Our program has, from the beginning, been closely coordinated with MSGC's CubeSat program, which is run by the MSU Space Science and Engineering Laboratory. Many of the students working on the CubeSat are active in the ballooning program and vice versa.

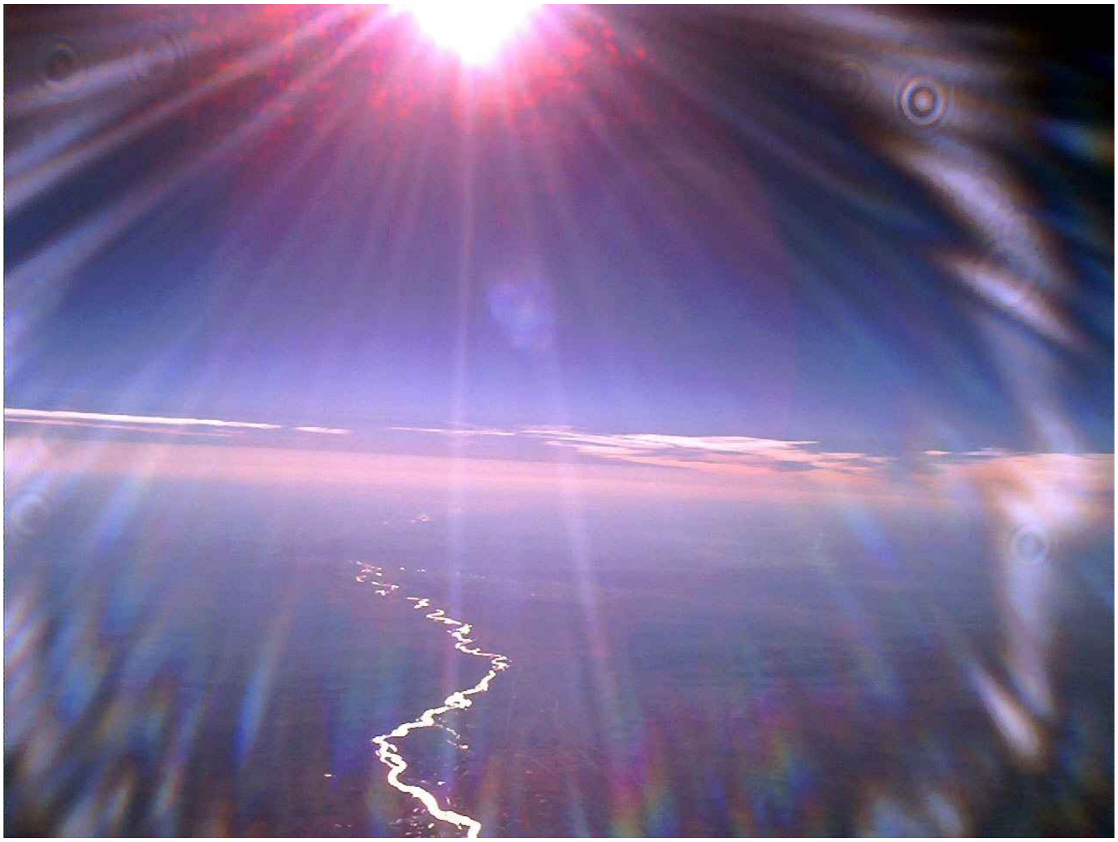


Figure 2: Sun over the Yellowstone River at 45,000 feet.

The great attraction of a high altitude ballooning program is that student-built experiments can be launched to the very edge of space for a trivial amount of money. After an initial investment of a few thousand dollars (mainly ham radio and GPS equipment), a balloon flight to 100,000 feet costs only about $200 – roughly half that for the balloon, and half for the helium, the two expendibles. We spend roughly the same amount of money per flight for travel, chasing the balloon across the state. Due to the mountainous nature of western Montana, we must travel about 75 miles east of Bozeman to reach a launch area where (with favorable winds!) we can hope our payload will not disappear into inaccessible wilderness. Thus, we must pay mileage costs for a few vehicles (in particular, one to carry the helium tanks) and for use of an MSU motor pool van to transport most of the team to our launch site and then to chase the balloon eastward across the state. Add in a celebratory lunch for the team after a successful flight and payload recovery, and total costs for a ride to the edge of space come to only about $500.

It is worth emphasizing that this sort of program truly does reach the edge of space. Our highest altitude flights to date have reached altitudes just over 110,000 feet when the balloon burst. This altitude, over 20 miles high, is above 99.5% of the Earth's atmosphere. The atmospheric pressures at such altitudes are similar to those on the surface of Mars – a useful analog to suggest experiments that students can develop. Pictures taken by our balloon payloads at these altitudes clearly show the curvature of the Earth, and the atmosphere appears as a blue band surrounding the planet, with black space above. It is not inappropriate to picture the balloon at this point as floating on the top of the atmosphere, as a ship floats on top of the ocean.

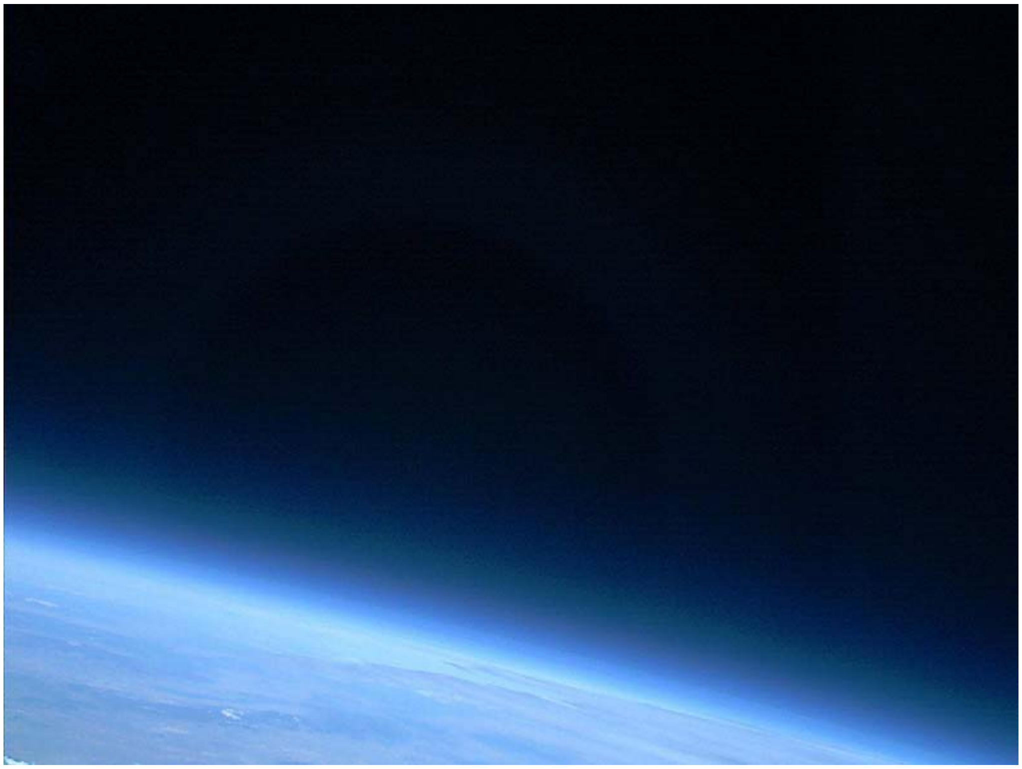


Figure 3: 110,000 feet over Montana

While other student space hardware programs can give similar experience in letting students design and build systems involving sensors, data logging, and telemetry, only ballooning offers our students direct access to space with a launch system that is both affordable on a university/Space Grant budget, and is completely under our control (no worries about launch suppliers or primary payloads that call the shots). In this way, a high altitude ballooning program offers unique opportunities for undergraduates to fly their own experiments in space.

We fly a digital camera on every flight (usually mounted to look out horizontally). It is usually set to take a picture about every 30 seconds, which then provides a complete record of the flight from launch to landing (and beyond – we have post-landing pictures of cows looking curiously at our payload). Having a student-built system that can provide pictures of your locale taken from altitudes higher than an SR-71 can fly is a sure way to attract attention from the local press and the communities imaged.

Some of the experiments we have flown so far include:

- Engineering test of the Geiger counter and microprocessor system for our CubeSat project.

- HOBO temperature sensors: monitor payload environment, measure external temperatures, record with time stamp. Use GPS record of flight to develop temperature vs. altitude record, which allows students to do atmospheric modeling.

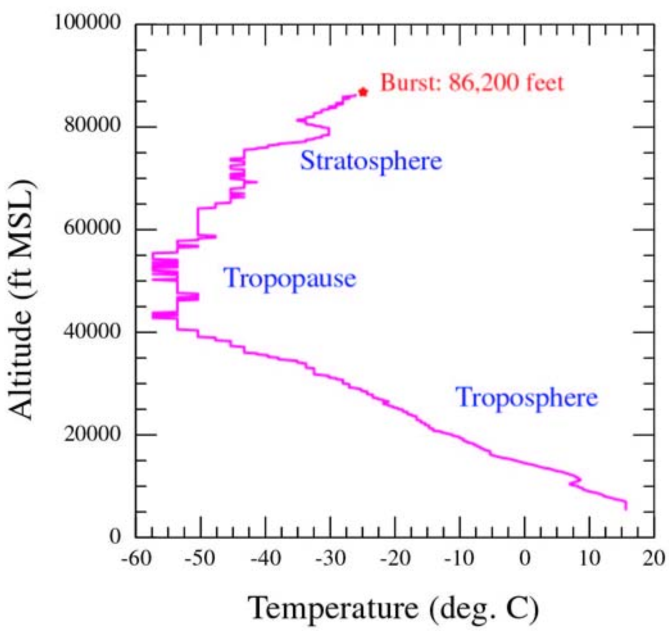


Figure 4: HOBO altitude versus temperature data.

- Geiger counter – measure cosmic ray flux as a function of altitude. See how flux increases with altitude, until the balloon gets above the altitude at which most secondary muons are produced; flux then drops as only primary protons are present.

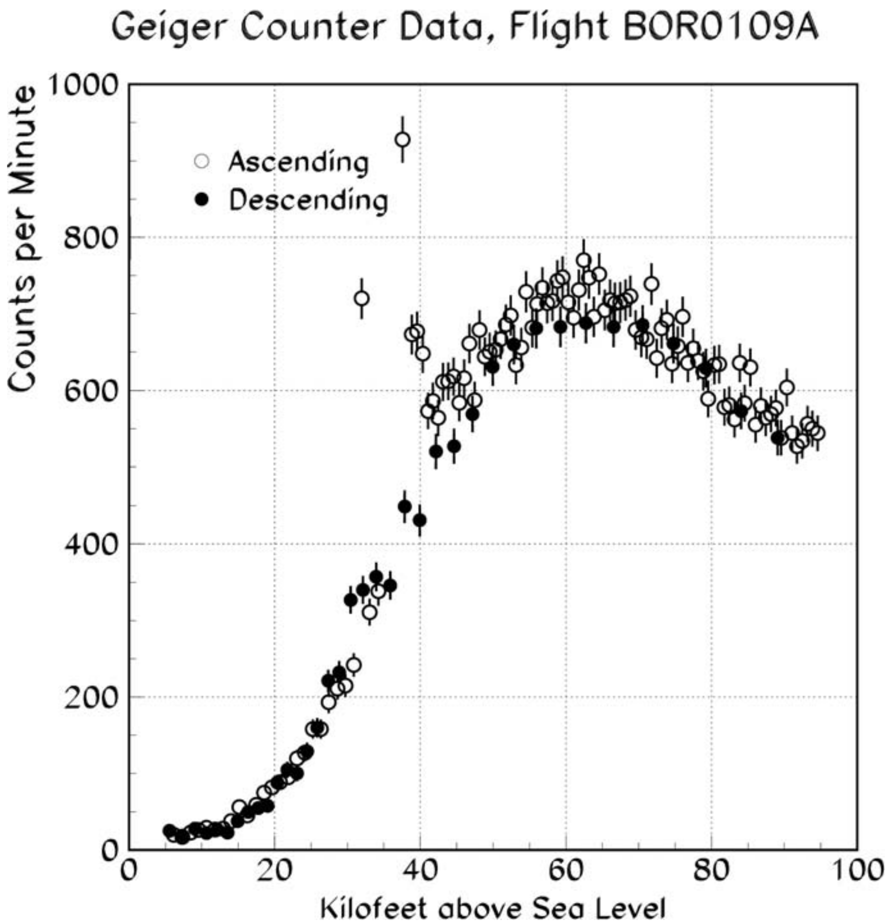


Figure 5: Geiger counter hit rates versus altitude.

- Downward pointing video camera: gives exciting footage of launch, burst, and landing. The engineering purpose was to provide quantitative information on rotation rate of payload capsule, for a future remote sensing test flight of a hyperspectral imager.

- Ozonesonde measurements of atmospheric ozone concentrations vs. altitude. As far as we have been able to determine, our two ozonesonde flights to date represent the first measurements of atmospheric ozone profiles over our state.

- UV Photometer measuring irradiance versus altitude (a Work Force Development Payload)

- IR Thermopile for Ground mapping (a Work Force Development Payload)

Our long range plan for the BOREALIS system is to have the central infrastructure of the ballooning program continue at MSU, but to encourage all affiliates of MSGC (e.g., 4-year and tribal colleges) to develop experiment packages that can be flown with the system. The 2002-3 and 2003-4 Space Grant Aerospace Workforce Development Grants from NASA has allowed us to fund student teams designing, building, and flying balloon payloads at eight MSGC Affiliate campuses across the state.

The following table illustrates some of the experiment ideas we are sharing with students interested in working on BOREALIS projects; asterisks indicate projects that have already flown at least once:

Balloon Technology	**Earth & Atmospheric Science**
Mass reduction strategies*	IBIS II digital still camera system*
Power reduction strategies*	Video camera system*
Volume reduction strategies*	2π horizon camera system
Accelerometers	Hyperspectral imaging
Communications experiments (EBBE)	Ozone altitude profiles (CX-1 tie-in)*
Tracking experiments (GPS, DF, ...)	UV solar radiance (CX-1 tie-in) *
Attitude sensing & control	Atmospheric temperature* & pressure profiles
Microcontroller development*	Smoke & particulate sampling
Cutdown system	Trace gas sampling from upper atmosphere
Parachute delay to enable μg	Measure diameter of Earth (GURU)

Space Science	**Space Hardware**	**Aeronautics**
Cosmic Ray experiments*	CubeSat payload test*	Mars glider
UV solar radiance (CX-1 tie-in) *	CubeSat communications test	Balloon flight modeling*
	Ground station testing*	

Table 1: Potential future projects.

Figure 6: A happy recovery team!

We are also open to the idea of high school science clubs or similar organizations developing experiments for flight. Our ozondesone flights have been done in collaboration with a Butte, MT high school physics teacher and class, and supported by a grant from the Murdoch Foundation.

BOREALIS has been a tremendous success to date, attracting enormous interest across the state at many levels. Newspapers have carried stories about the program with accompanying high altitude pictures. Legislators have enjoyed seeing pictures of their districts taken from the edge of space. During the 2003 state legislative session, we flew our balloon in the state Capitol Rotunda as part of a session on undergraduate research programs. K-12 classes and schools have expressed interest in attending launches (despite being at sunrise); the excitement of the launch is not dissimilar to that of a rocket launch, despite the lack of flame and noise. When the students release the balloon, everyone knows it is headed for the edge of space, somewhere none of us have ever been, in the next hour or so.

Figure 7: Yellowstone Park from 75,000 feet. In the foreground are the Beartooth Mountains, highest in Montana. Yellowstone Lake and West Thumb are visible in mid-center of the picture, as are Lewis and Shoshone Lakes. In the upper left, merging into the high clouds, the Tetons are visible.

FAR 101 – Legal Flight Rules

Any scientific balloon flight in the United States must follow the Federal Aviation Regulations (FAR) associated with unmanned balloon flight, FAR Part 101. FAR 101 divides all unmanned balloon flights into two categories:

(1) flights with small payloads that are exempt from regulation; and

(2) flights with heavier payloads that must conform to detailed regulations for safety reasons.

Our BOREALIS program presently *only* flies payloads that are exempt from regulation under FAR 101. The conditions this imposes on our program (small, lightweight payloads) are actually desirable conditions to impose on the students as a design constraint.

The relevant portion of FAR 101, describing under what conditions a balloon flight is exempt from Part 101, is reproduced in Appendix A (Sec. 101.1(4), in case you have a non-color copy of the Handbook).

The key restrictions are these (these are paraphrased here; see a current version of FAR Part 101 for precise guidance):

(1) total payload must weight less than 12 pounds.
(2) any individual payload package must weigh less than 6 pounds.
(3) the payload suspension line have a breaking strength of not more than 50 pounds.
(4) any individual payload package weighing over four pounds must have a surface density of less than three ounces/square inch (computed by dividing the total weight by the area of the *smallest* surface of the package).

The complexity of flying a mission that does not meet these exemption requirements is significantly higher, requiring substantial additional equipment and reporting.

Despite being legally exempt from FAR 101 regulations, the BOREALIS program takes extra steps to insure safety. These include:

(1) Filing a Notice to Airmen (NOTAM) 24 hours before flight (informs Air Traffic Control and pilots of the flight).

(2) Notifying Air Traffic Control of three critical events:

(a) launch time, location
(b) balloon burst, time, location
(c) landing (balloon is DOWN), time, location.

(3) Providing a Cell Phone number so that Air Traffic Control can reach the BOREALIS team with questions at any time during a flight.

(4) We do not generally launch unless cloud cover is less than 50%. (Clear, Few, or Scattered; not Broken or Overcast; less than 4 oktas cloud cover).

General Flight Overview

A typical BOREALIS flight follows this general plan (launch should occur at sunrise, that being when surface winds are typically lowest). Keeping this sequence of events in mind as you read the rest of the Handbook will be helpful. Our normal launch site is Big Timber, MT so times are for arriving at this launch site.

1. 3:30 AM – Flight team arrives at Lab. Final weather checks are made. All materials loaded in trucks/vans/cars for transport to launch site: payloads, balloon(s), Helium, launch tower, tools, radios, tracking systems.

2. 4:00 AM – Leave the lab for Big Timber, Airport.

3. 5:00 AM – Arrive at Big Timber airport launch site. Inflation team sets up and begins balloon fill. Payload team assembles parachute/command capsule/payload capsule "string" on launch tower; tests all circuits and prepares to attach string to balloon. Flight string is attached to balloon; final check to make sure tracking system is working. Raise the stack in preparation for launch.

4. 5:30 AM – Launch! FAA liaison calls Air Traffic Control and notifies them of launch time. Begin balloon tracking; reload vehicles and begin chase, following ground track of balloon.

5. ~ 7:30 AM – after ascending steadily for about two hours, the balloon will have expanded in diameter by about a factor of four as the external pressure decreases. Eventually the balloon bursts due to this expansion, and the payload and parachute (with balloon fragments) begins its descent. The initial descent is quite rapid, but slows as thicker air below 30,000 feet is encountered. The team continues the chase.

6. ~ 8:30 AM – payload lands. If lucky, the team can receive GPS data from the payload after it lands, providing ideal knowledge of where the payload is located for recovery. Seek permission from local landowners to enter/cross their land to recover the payloads.

7. ~ 11:00 AM – Recovery complete, payload and team back in vehicles

SECTION II: BASIC FLIGHT HARDWARE

General Overview

The basic BOREALIS flight hardware is shown schematically in Figure 8.

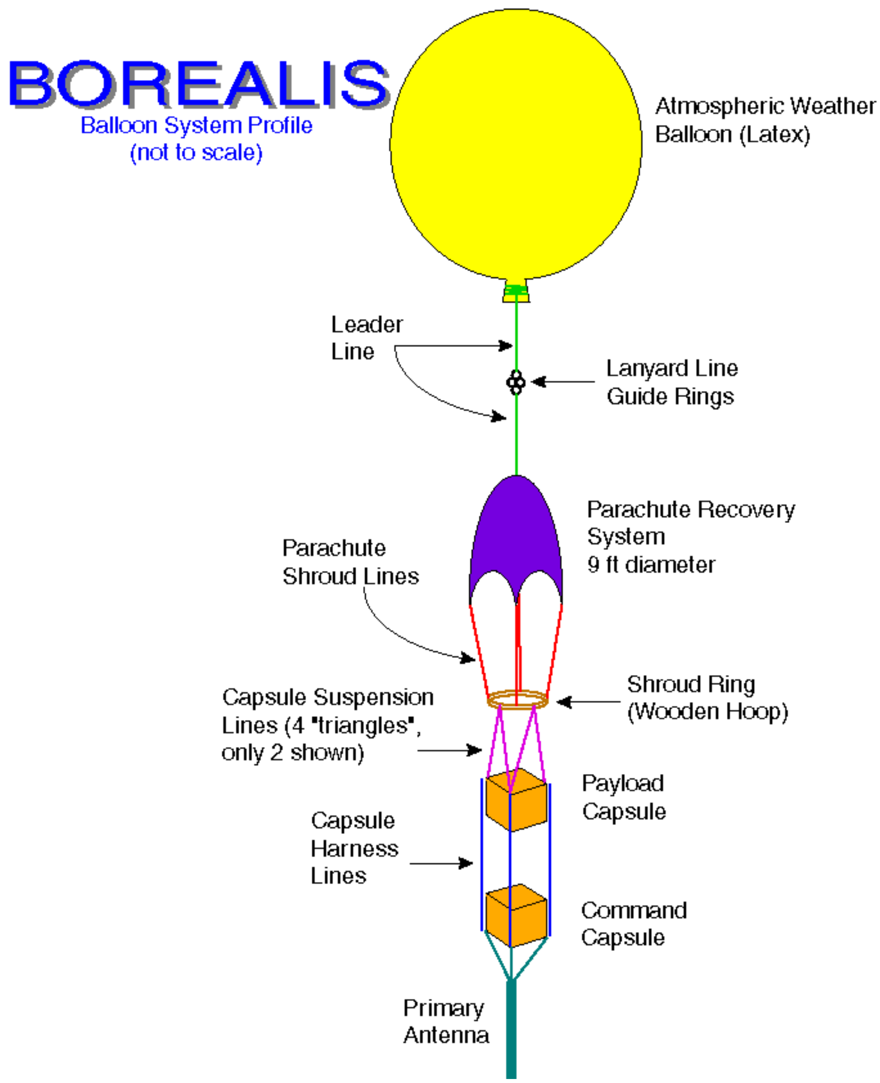


Figure 1: Schematic of BOREALIS flight hardware.

The hardware stack is shown as it is suspended vertically from the latex weather balloon and deployed parachute. In the following sections, we consider each of the items shown in this figure in greater detail.

Balloons and Helium

At the top of the stack is the BOREALIS “engine”, a latex weather balloon. To date we have used sounding balloons sold by Kaymont and Kaysam. Other vendors are listed in Table 2.

Balloon Distributor		Web Page
AEROSTAR	Promotional Balloons and Inflatables	www.aerostar.com
KAYMONT	Meteorological Balloons	www.kaymont.com
KAYSAM	Meteorological Balloons	www.kaysam.com
RAVEN IND.	Engineered Films Division	www.ravenind.com

Table 1: Distributors and manufacturers of latex weather balloons (compiled by Ralph Wallio).

The mass of the balloon used – generally given in grams – is the primary factor which determines the altitude at which burst will occur. On their web pages, Kaymont and Kaysam provide information on what performance can be expected for a given mass balloon. Our experience has shown the Kaysam estimates to be closer to the performance we achieve than those provided by Kaymont. Altitudes achieved by BOREALIS with various Kaymont balloons with 12-pound payloads are tabulated in Table 3.

Company	1000g	1200g	1500g	2000g	3000g
Kaysam	$43.39	$48.32	$63.71	$226.53	$414.10
Average BOREALIS Altitude		84,000	102,036*	106,450	
Number of Flights	0	1	6	1	0
Kaymont	N/A	$45.00	$60.00	$175.00	$225.00
Average BOREALIS Altitude		88,096	94,112		110,028
Number of Flights	0	5	2	0	$1.00

* Note this average includes a flight in which the balloon failed before the minimum specification. Omitting this flight would put the average at 104,950 ft.
All flights were flown with ~12 lb. payloads and ~1000 ft/minute rise rates except for the 3000g Kaymont flight which had an ~8 lb. payload.

Table 2: Comparison of balloons by cost, performance, and size.

The latex balloons are filled with standard bottled helium at 99.99% purity. We typically use 1 ½ K-size helium bottles for a single flight. We obtain our helium through the MSU Physics Department research supply, at approximately $63 per bottle.

In addition to using a standard regulator and Tygon tubing attached to the He bottle, we have manufactured a nozzle coupling device out of PVC pipe (Figure 9) to connect the gas bottles to the balloons. The balloon nozzle fits snugly over the PVC pipe. Note that balloons of different masses may have different sized nozzles.

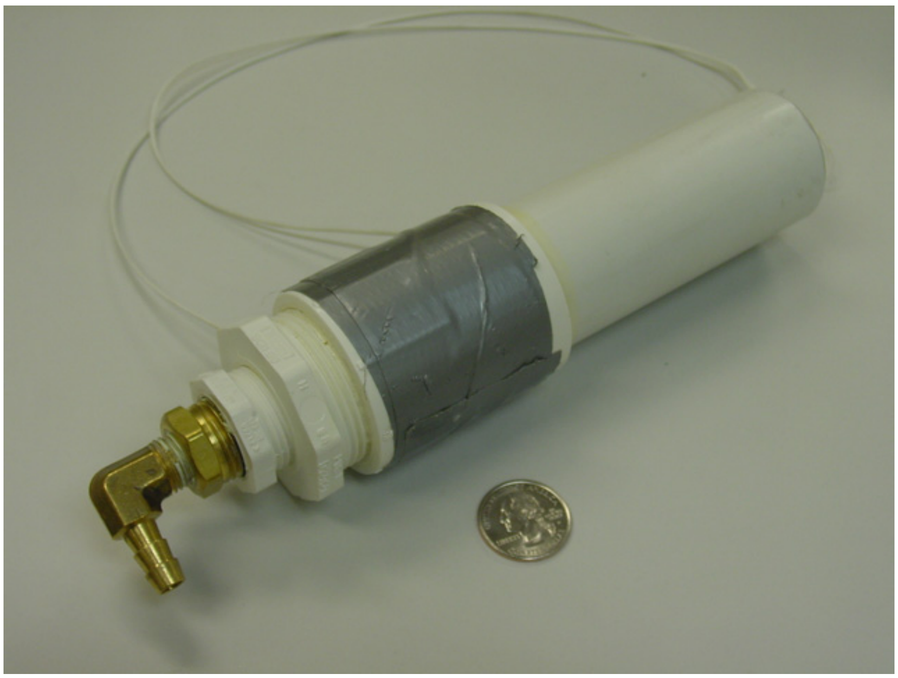


Figure 2: PVC nozzle coupling device. The barbed brass fitting connects to the Tygon tubing from the gas regulator. The balloon nozzle fits over the PVC end. The nylon line which is duct-taped to the coupling device is for securing the balloon during inflation and measuring balloon lift. Also see this device in use in Figure 20.

Lanyard and support lines

The balloon is connected to the parachute with 100-pound test nylon line purchased from Into the Wind (**www.intothewind.com**), a manufacturer of kite supplies. (Note: We have performed laboratory tests confirming that the "breaking force" of this 100-pound line, when knotted, is actually about 50 pounds. This is critical for meeting the FAR-101 exclusionary criteria given in Appendix A) The connection between the shroud ring and modules, and between the modules themselves are made of this same nylon line. During launch, the lanyard lines are also made from 100-pound test nylon. To aid in quick connection at launch time, the nylon line is typically looped through miniature aluminum carabiners (available at most sporting goods stores).

We have manufactured a line separator from delrin plastic to couple the balloon line and parachute, and also to serve as a connection point for the lanyard lines during launch (See Figure 10).

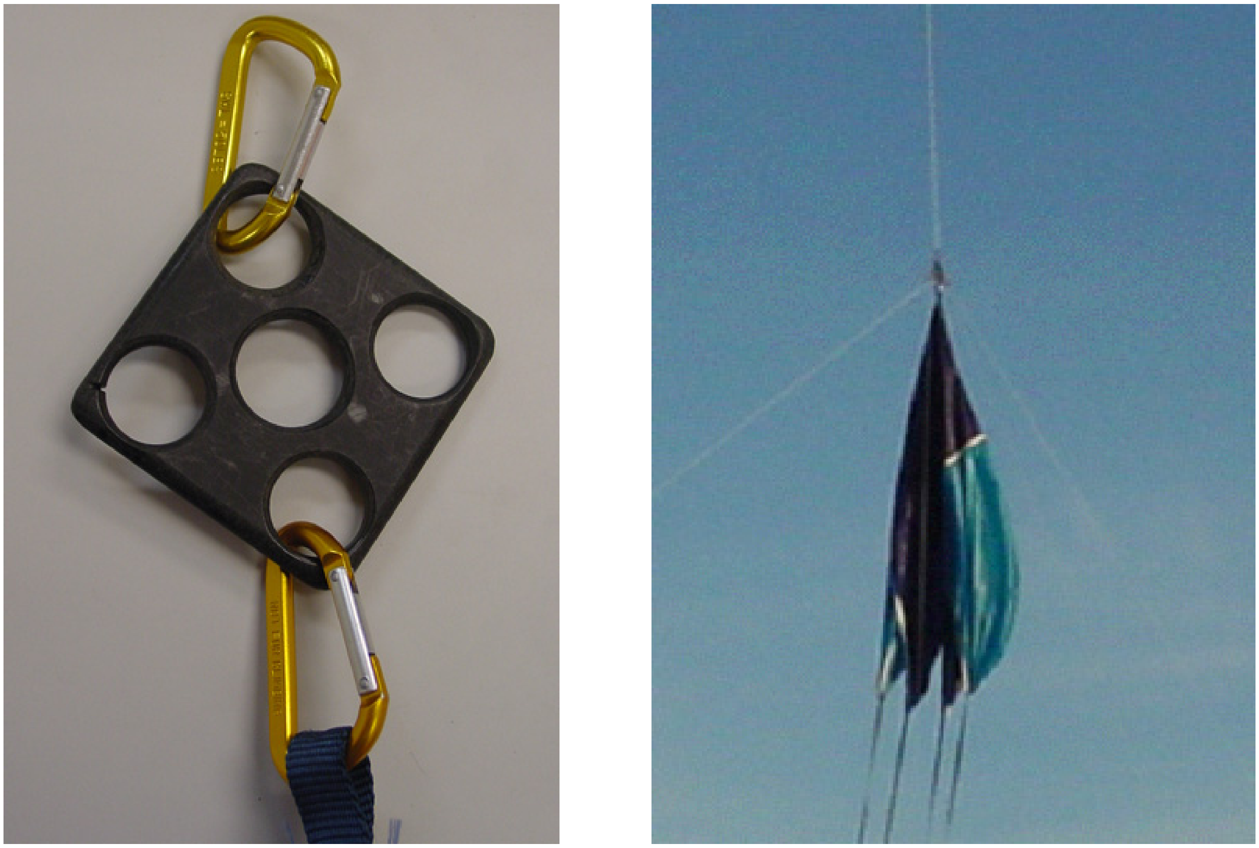


Figure 3: Delrin line separator (left) and illustration of its usage during launch (right). Mini-carabiners connect the separator to the balloon line and parachute, lanyard lines are passed through the additional holes to control the rising stack during launch.

Parachute

We use a commercially manufactured parachute from Rocketman Industries (**www.the-rocketman.com**) to safely return our payloads to earth after the balloon has burst. Other sources include Spherachutes at **www.spherachutes.com**. Our Rocketman chute (Figure 2) is made from low-porosity 1.1 rip-stop nylon, is 9 feet in diameter and is rated to return a 6 to 12 pound payload to earth at a descent rate of 15 to 20 feet per second. It has performed well, but is probably heavier than a homemade parachute would need to be for this use.

Other groups prefer to manufacture their own parachutes; see for example the Treasure Valley Near Space Project at **www.voiceofidaho.org/tvnsp**.

Command and Payload Modules

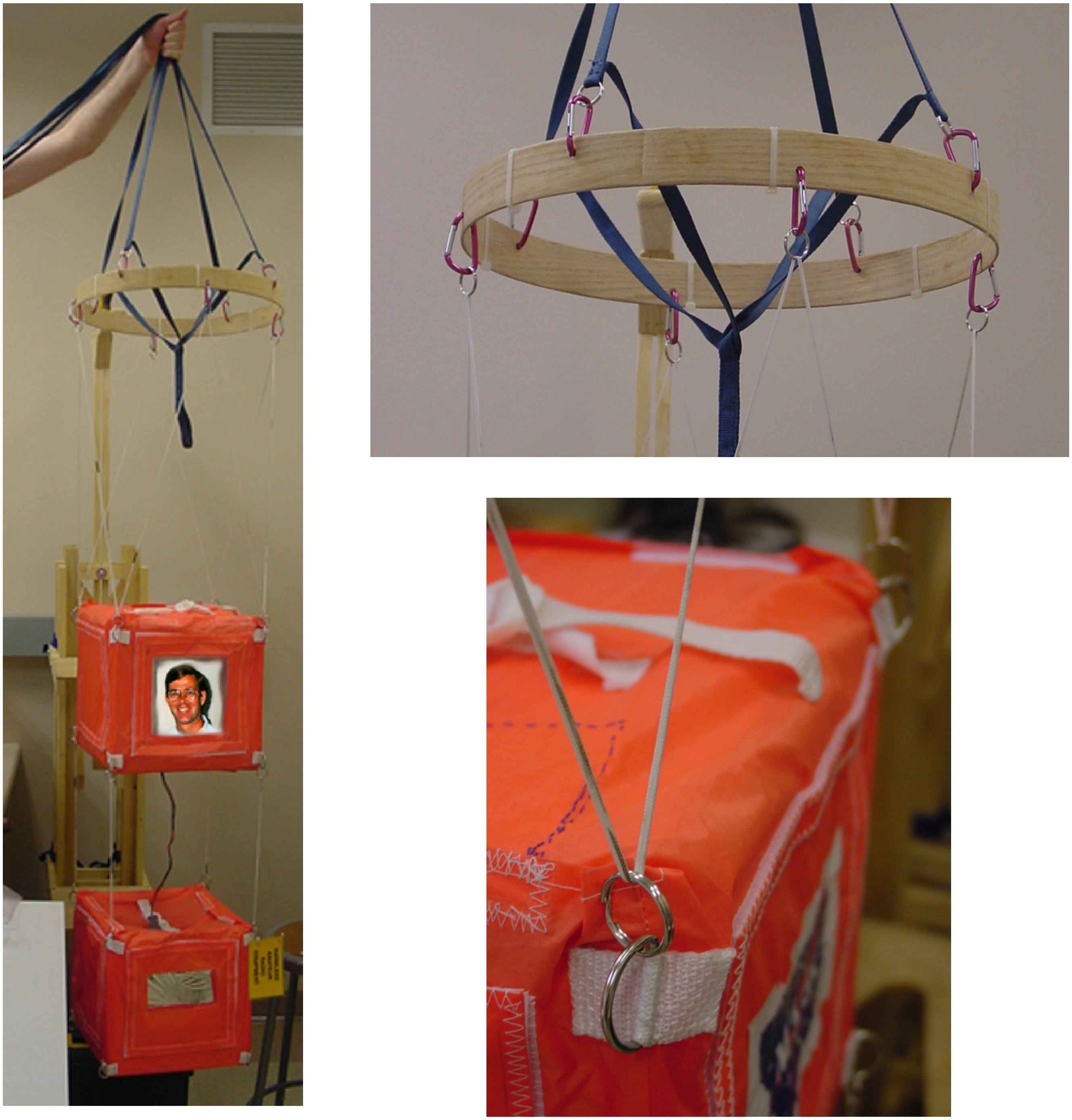


Figure 4: (Left) Borealis payload modules hanging as in flight, from parachute shrouds, shroud ring, and module harnesses. Note yellow tag identifying modules as a "Harmless Amateur Radio Device". (Upper right) Detail of wooden shroud ring showing carabiner and key-ring connections to parachute shrouds and harnesses. (Lower right) Detail of key-ring connection to ripstop nylon bag containing the command module.

The BOREALIS near-space modules are shown in Figure 11 suspended from the parachute shroud lines, shroud ring, and harness lines as they hang in flight. The wooden shroud ring, which we made by wet-warping a strip of layered board, keeps the parachute shroud lines separated during flight to insure proper parachute deployment once the balloon has burst. Again, lightweight (5 gram) mini-carabineers are used for simple connections.

The modules themselves are constructed from one-inch thick extruded polystyrene insulation foam (easily purchased at home improvement centers), typically glued together with silicon rubber (which retains its adhesive properties over a wide range of temperatures). The cube dimensions are approximately 12” x 12” x 12”.

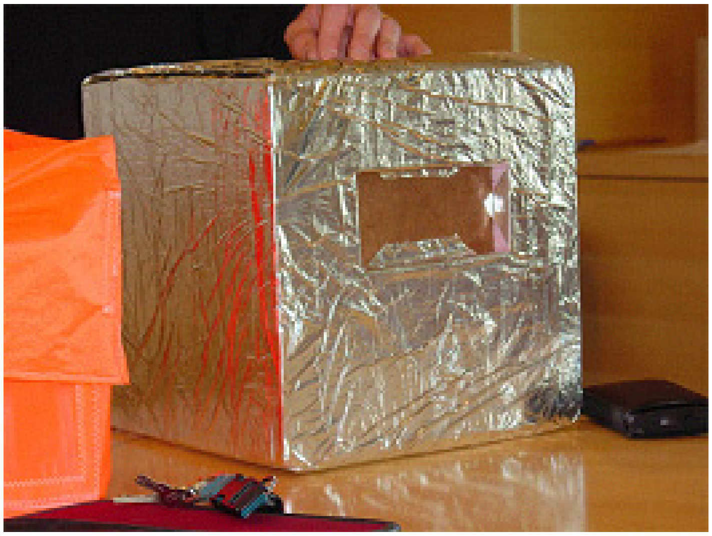


Figure 5: Extruded polystyrene cube wrapped in aluminized mylar “space wrap” layer.

The modules are wrapped first in a layer of “space wrap” (thin aluminized mylar). Anecdotally this helps the module retain some temperature stability, although this has never been confirmed. Finally, fluorescent orange ripstop nylon covers form a protective and highly visible outer layer.
The covers are made in house, with material purchased from the kite material supplier Into The Wind at **www.intothewind.com**. Rings are sewn directly into the covers, to allow easy connection via key ring to the module-module and module-shroud ring harness lines.

Figure 6: New, smaller Command Module with thinner (1/2 inch) foam walls. New mount for 3 MegaPixel IBIS II camera is also shown.

We have recently rebuilt the Command Module in an effort to reduce mass (shown in Figure 13 below). The new module (first flown June 4, 2003) is made of ½ inch foam, and is 12 inches by 12 inches by 6 inches in height. The thinner foam walls of the module, together with a new sewn nylon ripstop bag, have provided us with a large increase in available mass for science/engineering payloads. The glue used to bond the panels of the box has also been changed to Titebond Polyurethane foam adhesive. This is a strong glue and works well in the temperature range encountered during the flight. The Titebond glue expands slightly and so proper clamping of the joints while the glue is drying is a must. Additionally, the bag is made from a non-waterproof nylon with nylon strapping sewn to form the corner loops. This greatly reduces the mass of the carrier bag while retaining all of the functionality. The key ring connectors have been replaced by the small locking carabiners typically sold for use as key chains.

Tracking System Basics

The simplest tracking system for a balloon is based on using a GPS (Global Positioning System) receiver and ham (amateur) radio in the balloon payload transmitting digital packets to the ground giving the balloons latitude, longitude, and altitude. There is an established ham radio method of transmitting such information known as APRS (Automatic Position Reporting System). The key essentials are a GPS receiver that sends its output to a ham radio, which then transmits the information to a ground station tracking the balloon. The ham radio must have a TNC (Terminal Node Controller – the radio equivalent of a modem) either built in or attached externally, to encode the digital packets into the radio signal.

Note: You must have an FCC license to transmit on the ham radio bands (including your balloon!). See Appendix B: “What's this business about getting an Amateur Radio license?”

Radio and antennas

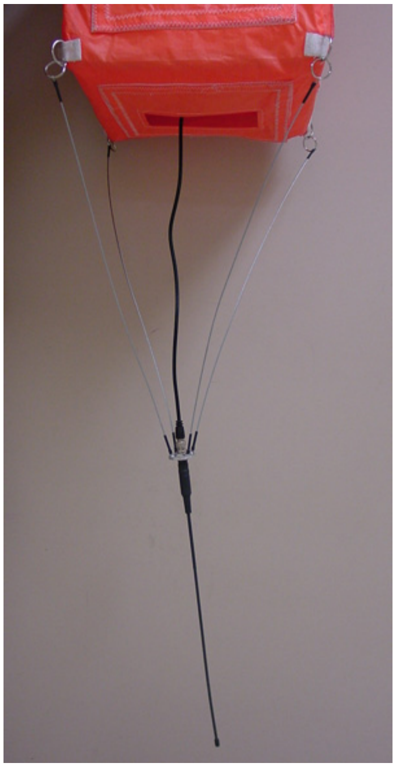
Regarding flight equipment, four things are of utmost importance: small size, low mass, ability to withstand cold temperatures, and ability to withstand impacts from landing. The equipment we chose has stood up to all of these criteria well, but there are many other options that would work just as well.

The flight radio we are using is the Kenwood model TH-D7A (G). This radio is a dual band (2m and 70 cm) handheld HAM radio (HT) with a built-in terminal node controller (TNC) (equivalent to a modem). For ballooning, when one must be very careful about the mass of the flight equipment, a radio such as this is ideal. Also, since this radio comes with a built-in TNC, we do not need a separate external TNC cluttering up our payload box. The transmitter has three power level settings. When supplied with 9.6V, the maximum output in both the UHF (70 cm) and VHF (2 m) bands is around 5W, which is more than enough power for the signal , even at altitudes of over 100,000 feet. We often use the medium transmitter power setting, around 0.5W. With this setting, we still receive roughly 24 out of 25 packets at around 90,000 feet, which is very satisfactory. Two websites where you can buy ham radio equipment are listed below, as well as the sites for the major three ham radio manufacturers: Kenwood, Yaesu, and Icom.

Supplier	Web Page
Ham Radio Outlet	www.hamradio.com
AES	www.aesham.com
Kenwood	www.kenwood.net
Yaesu	www.yaesu.com
Icom	www.icomamerica.com

Table 4: Some Suppliers of Ham Radio equipment.

Figure 14: Kenwood TH-D7A radio.



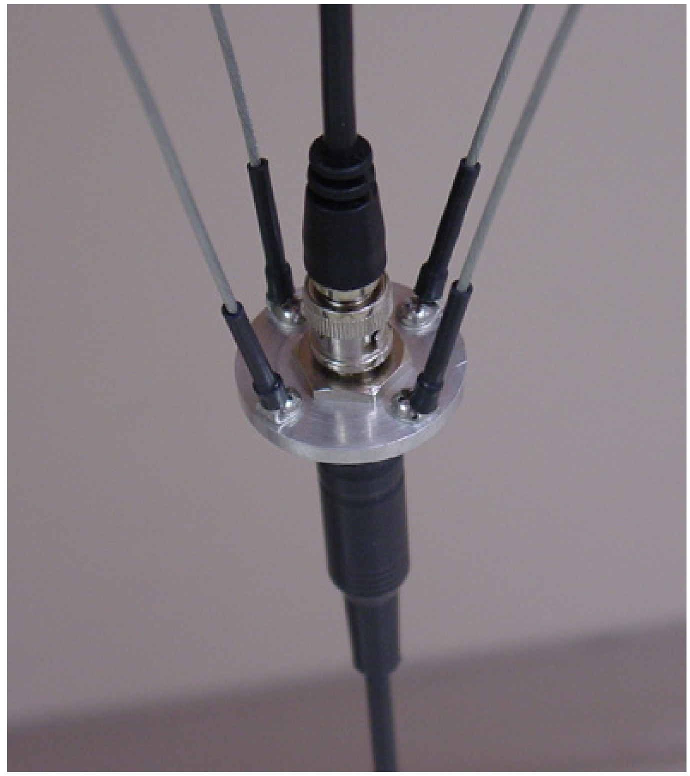


Figure 15: BOREALIS Dipole Antenna. Left: Antenna suspended from command module. Right: Detail of antenna support cable attachment.

Choice of an appropriate flight antenna is as important as selection of a flight radio or GPS. We use a type of ground plane antenna designed and built by BOREALIS team members in our physics department's electronic design lab. This antenna is lightweight, durable, and puts out a good antenna pattern. The four wire cables from which the antenna hangs form a partial ground plane that bends the antenna pattern downwards. We have had a few flights where the antenna was bent under a module after landing, yet we were still able to receive APRS packets when we were over a mile away. An antenna like this needs to be tuned (in design & construction) to the frequency that is being used. In Montana, we transmit our APRS packets on 144.39 MHz, the national standard APRS frequency. However, in more populated parts of the country, this frequency can be quite busy (many people transmit APRS packets from their vehicles, homes, pets, …), and you may wish to choose an offset frequency where things are "quieter".

GPS Receivers

Connected to the radio is the Global Positioning System (GPS) unit, which tells the radio what coordinates to send. The unit we are using is the Garmin GPS 25LP series, GPS25-LVC. This device is very small and lightweight, and has performed flawlessly for our group. A lot of the extra features of a normal GPS unit have not been added to this model (screen, buttons, etc), which keeps the mass at a minimum. An antenna connects to the credit card sized GPS receiver, and can be placed at any location that will optimize GPS satellite reception. We have a pocket on the inside of the outer nylon bag on our command module to hold the GPS antenna, and this has worked well. Two websites where you can purchase GPS receivers are listed below, as well as the Garmin website.

Figure 16: Flight GPS unit (left) and GPS antenna.

Supplier	Web Page
Dealtime	www.dealtime.com
NexTag	www.nextag.com
Garmin	www.garmin.com

Table 5: Suppliers of GPS equipment.

Note that post 9/11, some GPS receivers are software controlled to turn the receiver off if either:
(1) the velocity exceeds Mach 1
OR
(2) the altitude exceeds 60,000 feet
(why couldn't they have made this a logical "AND" instead of an "OR"?).

For a high-altitude ballooning program, it is **very important** to make sure you have a GPS receiver that does not have these restrictions built in. You do not want your tracking datastream to suddenly stop when the balloon passes through 60,000 feet and the GPS turns off.

Salespeople will often say their GPS receivers turn off at altitude, whether they do or not.. Do not accept their word, demand to talk to someone with real technical knowledge connected to the company.

Ground Station Equipment

Tracking equipment need not be as small or light as the flight equipment, so we can utilize more sophisticated technology. For reception of APRS packets on the ground, we use additional TH-D7A handheld radios (the same radio that flies in the payload. However, a better radio for reception is the Kenwood TM-D700A mobile ham radio. This is a much larger radio than the handheld, and its receiver has a higher S/N ratio. Consequently, we receive more packets with this radio, especially at higher altitudes. We connect the TM-D700A to a laptop via serial cable, and the APRS software displays the received coordinates.

Figure 17: Mobile Radio-TM-D700A

While tracking in the chase vehicle, we hook up our radios to magnetic-mount antennae we purchased at our local Radio Shack. The reception is greatly improved by using these antennas, as opposed to the standard "rubber ducky" variety.

Once we have tracked the payload as far as the roads will take us, it is time to start hiking, and another antenna is needed. We leave behind the bulky mobile radio, and use our handheld radios connected to a tuned "Quad" antenna, designed and built by BOREALIS Team members in our physics department electronics design lab. These antennae are light, cheap, and very sensitive. Antennae such as this are best when tuned to the specific frequency being used, which for us is 144.390 MHz, the national standard APRS frequency for the 2 m band. Since these are directional antennae, they can be used for direction finding once we are in the vicinity of the payload. By attaching an attenuator in-between the antenna and the radio, and by adjusting the attenuation so that a very small signal is received by the radio, an angle of location can be obtained. This is especially useful in areas with many trees, where the payload cannot be easily located by sight.

Figure 18: Mag-mount antenna

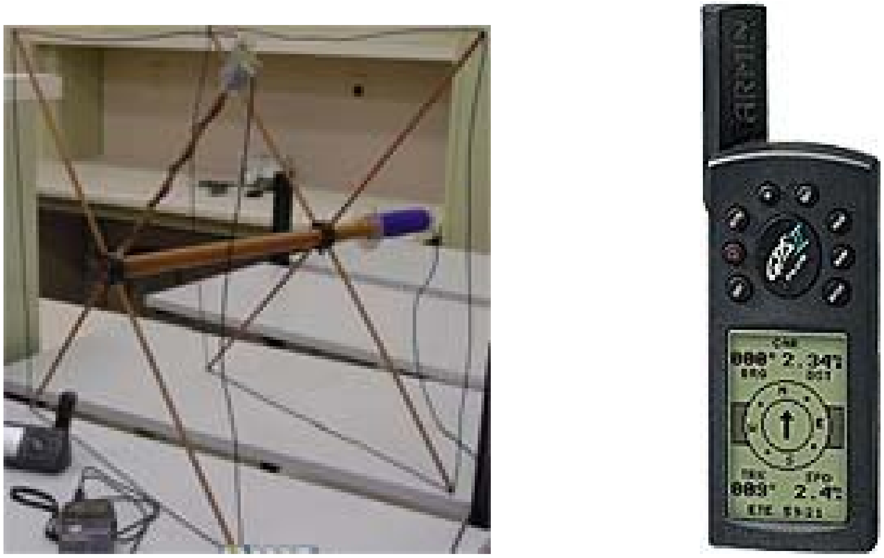


Figure 19: Homemade quad directional antenna (left) and handheld GPS tracking unit (right).

Another very useful piece of tracking equipment is a handheld GPS receiving unit. We are using the Garmin GPS II Plus. Once the last set of coordinates is received from the payload, it can be entered into the GPS unit, and the payload's distance and bearing can be ascertained. This is especially useful when the payload lands in an area inaccessible to a vehicle, and hiking is involved. Also, once the payload has been recovered, the exact coordinates for the landing site can be found and entered into the memory of the GPS. This may be useful in later profile analysis, as the last coordinates received via APRS may be different than the actual landing coordinates.

APRS computer software

APRS software is readily available on the web, easy to install, and use. Many different programs exist, each with their own advantages and disadvantages. As with any software, the more the program can do, the longer it will take to learn and use. BOREALIS currently uses APRS+SA as our tracking software. We chose this program for its easy-to-use history function. This function allows us to save all of the received APRS packets from a single source to a .txt file. Also, the software automatically displays the GPS coordinates from the packet in a readable degrees/minutes format, so we do not need to decipher the GPS code. We have also, in the past, utilized such programs as UI-View and WinAPRS. These two programs have fewer options, but can be up and running in less time. The websites where these three programs can be downloaded are listed below in Table 6.

Program	Web Page
APRS+SA	www.tapr.org/~kh2z/aprsplus
WinAPRS	aprs.Rutgers.edu
UI-View	www.ui-view.com

Table 6: Sources of APRS software.

Integrated Balloon Imaging System (IBIS)

BOREALIS always flies a digital still imaging system (a camera). Digital cameras have a number of advantages, not least their ability to store a very large number of high resolution pictures using modern solid state memory cards.

BOREALIS has developed three still camera systems to date. This Handbook describes the original IBIS I (1 Megapixel) and IBIS II (3 megapixel) systems. IBIS III is a 4 megapixel camera in the same product family as IBIS II.

<u>One important overall lesson we have learned: do not put your camera lens behind a filter or other "window". Condensation (ice) is almost sure to result, ruining your pictures. It is best to simply have your camera lens directly exposed to the outside air (or vacuum). Another option is to attach a high watt, low resistance resistor directly to the "window" to heat the window. However, this costs power and the window generally is not necessary.</u>

IBIS I:

The Integrated Balloon Imaging System (IBIS) is a low cost digital camera system designed to take a series of pictures during the flight of the BOREALIS. It is based around a commercial digital camera and uses some simple modifications to adapt the camera for use on the balloon. In addition to a circuit bypassing the camera switch, external batteries and a timing circuit are used for this adaptation.

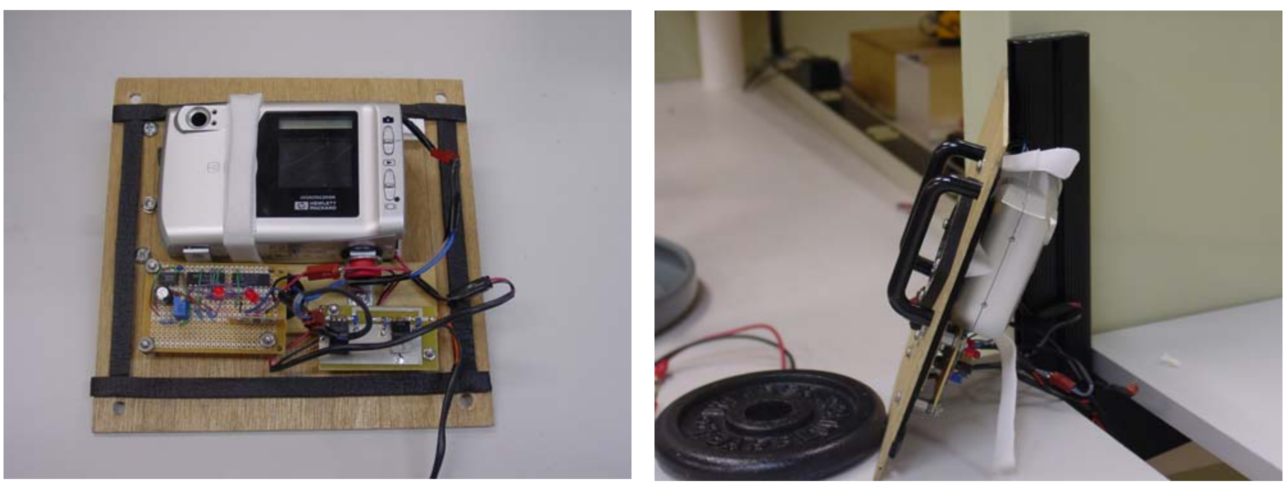


Figure 20: Rear (left) and side (right) views of the IBIS camera system.

The camera selected for IBIS is a HP215C digital camera. The camera's maximum resolution is 1.3 megapixels. It has no optical zoom system to add excess weight and generally flies with a 128 MB Viking compact flash storage card. Additionally, the HP215C's internal structure opens and can be modified relatively easily. Another advantage of using the HP215C is its low cost. The camera cost about $140 when purchased and can now (June 2003) be found for less than $90. However, this camera is no longer in production.

Figure 21: Close up view of the HP215C digital camera (left) and the manual switch bypass leads (right).

The 128 MB compact flash card allows storage of approximately 350 pictures over the duration of the flight. A Viking 128 MB compact flash card cost about $125 when purchased and similar cards from other companies are available for less than $40 now. A SanDisk compact flash card has also been flown. The compact flash cards are well adapted to use in high altitude environments as there are no moving parts and the cards appear immune to the near zero pressure and low temperatures encountered in flight. The compact flash cards can be read by computers through the use of an inexpensive card reader available almost anywhere the cards are sold. This simplifies downloading and reviewing the pictures. Alternatively, most camera come with a cable and software that will allow a computer to download the pictures from the camera directly. This is less intuitive in most cases and the download speed tends to be much slower.

Figure 22: Compact Flash (CF) cards used in IBIS.

To make the camera take pictures, a simple timing circuit was developed to bypass the camera's manual switch. The timing circuit can be set for a specific interval between pictures, varying from six seconds to over three minutes. The timing circuit can actually signal faster than six seconds but the camera requires about six seconds to recycle and be ready for the next picture. A schematic of the timing circuit is included in Appendix C. This circuit requires a few resistors, capacitors, and some logic chips. The least common component is the solid-state power switch. This is the component that bypasses the manual switch on the camera. For this the IBIS uses a Texas Instruments TPS2015 Act Lo switch. This circuit design was selected for its simplicity and the availability of the components. We have also built this circuit onto a printed circuit board to improve reliability. The original wire connect board is pictured below.

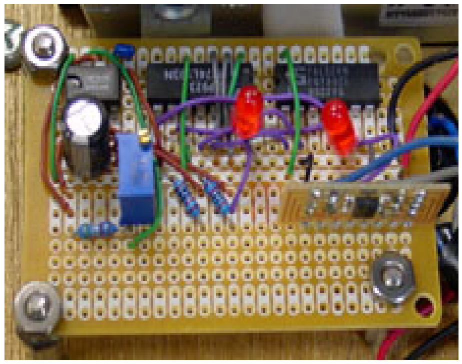


Figure 23: The timer circuit with the variable resistor (blue box) and the solid state switch on the upright board.

Additional camera components include the panel on which it is mounted, a manual interrupt switch, a Kodak UV camera filter and two drawer handles used as “roll-bars” to protect the camera lens. The panel is a laminate of oak panels. Although heavier than a balsa wood or plastic, this panel is much easier to work with and is stiffer while still being within weight limits. Changing the panel to a corrugated plastic only results in a weight savings of 40g and causes increased motion of the camera during flight. The manual interrupt switch prevents the timing circuit signal from reaching the camera stopping the camera from taking pictures. This allows the system to be started and stopped, thus preventing the automatic shut-off feature of the camera from activating, while limiting the amount of wasted pictures (and power) while on the ground.

The UV filter protects the lens from impacts and also enhances the quality of the pictures at high altitude. However, our experience from several flights shows that the filter is prone to condensation (usually in the form of ice), which can quickly ruin a wonderful set of pictures. After trying to solve this problem without heating the lens itself, we determined the lens is not worth the improvement in the pictures.

The roll-bars protect the UV filter from damage if the payload lands on the camera. They also act as handles when moving and installing the camera in the module.

Figure 24: Front view of IBIS showing the switch, roll bars, and UV filter in its mount.

This description of the camera is the original easiest to assemble version of IBIS. A second IBIS with higher resolution, lower mass, and smaller size has been built and flown. A discussion of the IBIS II is included in Appendix D. IBIS III follows the design of IBIS II with the substitution of a different camera.

Batteries and power

Power is a major limiting factor governing the duration of the balloon mission and payload design. Although more batteries can always be added, the extra weight requires a weight reduction in other systems. Therefore, the batteries chosen for use should have as large of a specific energy (amount energy/unit weight) and energy density (amount energy/unit volume) as possible. Naturally, one should not chose batteries that utilize air as a working component, such as zinc-air. The next most powerful batteries are some type of lithium battery. The efficiencies of the voltage converters in the power system also greatly affect the total power requirements and also the thermal properties of the balloon system.

Figure 25: LiIon laptop battery used on current BOREALIS flights.

With lithium batteries, there are two paths to follow, rechargeable and non-rechargeable. Rechargeable batteries provide a long-term usability and may be cheaper per flight when amortized over their useful lives. Also, rechargeable batteries are easily found and purchased with high voltage ratings. A downside to the rechargeable batteries is they are generally more massive than disposable batteries.

An example would be the batteries used in modern cell phones or laptop computers. BOREALIS currently uses a 14.4 V Apple Wallstreet Edition G3 laptop battery. The particular battery used has a capacity of ~5000 mA*hrs. This translates to 72 W*hrs or running the radio and GPS for more than 37 hours. The main disadvantages of rechargeable batteries are the increased cost and the lower specific energy/energy density. Depending on the efficiency of the balloon systems and the duration of the flight, these may still be the best choice.

Figure 26: The $LiSO_2$ batteries previously used on BOREALIS assembled into a 8.4V pack.

The non-rechargeable Lithium Sulfur Dioxide batteries previously used by BOREALIS are significantly more powerful. Each cell contains 21 W*hrs and operates at 2.8 V nominal while massing about 90 g. These cells are from a military surplus radio battery pack disassembled into individual battery cells and then reassembled in packs operating at more appropriate voltages. After shipping charges are added, an individual cell costs about $1. These cells are available from military surplus outlets that carry military electrical equipment.

The main reason the BOREALIS discontinued the use of these batteries is they are *chemically hazardous—in 2002 a set of these batteries vented noxious gases into our lab, causing a safety evacuation of the entire building.* Although the specific gases that were vented in that event remain unknown, materials safety sheets for these batteries indicate carbon dioxide, carbon monoxide, cyanide gas, and sulfur dioxide can be vented by the batteries when outgassing. Since these batteries had not even flown but were in storage awaiting the next flight and because the type of gasses the batteries may emit, we discontinued our use of the batteries and (properly) disposed of all remaining stock.

An additional source of batteries may be Tadiran Batteries (http://www.tadiranbat.com). BOREALIS has no experience with their batteries, although they do have specifications similar to the military batteries used. Their website describes their batteries' capabilities well and also shows some of the applications in which they have been used.

Voltage conversions on BOREALIS were previously done with linear regulators. Although not as efficient as switching regulators, these are simple to use and also provide additional heat to the module. They are also well proven in hostile environments and do not generate high frequency noise like most switching regulators. Linear regulators are available from Maxim Integrated Products, Texas Instruments, National Semiconductor, and On Semiconductor to name a few. Most circuits will only require a pair of capacitors in addition to the chip.

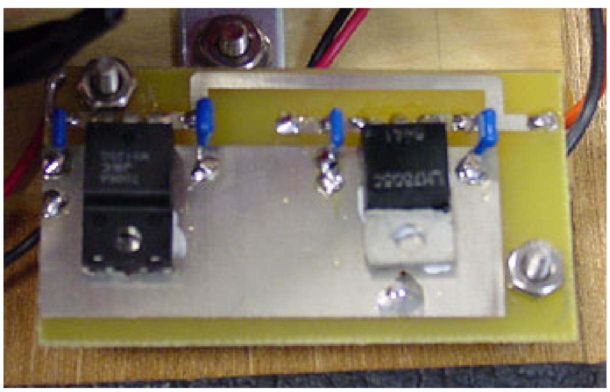


Figure 27: The linear regulators formerly used on BOREALIS.

BOREALIS previously used four different voltage levels to operate its systems. The IBIS requires a 6V regulated line for the camera and a 5V regulated line for the timing circuit. The radio uses an 8.4V nominal unregulated line from the batteries and the microprocessor uses a 5.6V nominal unregulated line. The unregulated lines are possible due to the individual systems incorporating a regulator into their design, meaning another regulation system would be excessively wasteful. Included below is a power consumption table for the major components on BOREALIS prior to conversion efficiencies.

Component	Voltage (V)	Current (mA)	Power Draw (W)	Energy for 3hr flight (Whrs)
Radio (nominal flight)	8.4	ave. 170	1.428	4.284
Camera (30s cadence)	6.0	ave. 300	1.800	10.500
GPS	5.0	~100	0.500	1.500
Timing Circuit	5.0	~100	0.500	1.500
Microprocessor	5.6	~140	0.784	2.352

Table 7: BOREALIS electronics components and their power requirements (old).

Note that the table indicates the total energy used is less than that stored in a single cell of the $LiSO_2$ batteries and BOREALIS operated with six cells normally. This is due to efficiency considerations and also to voltage requirements when not using a step-up switching DC-DC converter. Also, by using more batteries divided into two packs, the radio and GPS are isolated from the IBIS. The additional energy for the radio provides operation time after the package has landed thus facilitating the recovery of the module.

The newer version of BOREALIS using the rechargeable battery implements switching regulators to improve the efficiency of the system. The high voltage of the rechargeable battery allows the use of higher efficiency Buck (step-down) converters. This reduces the amount of heat sent into the module but does not seem to affect the operation of our equipment. We built a centralized power board (schematic and board artwork available on request) that allows for four different voltages. The power board provides a pass through to the radio and three regulated lines at 4V, 5V, and 9.25V.

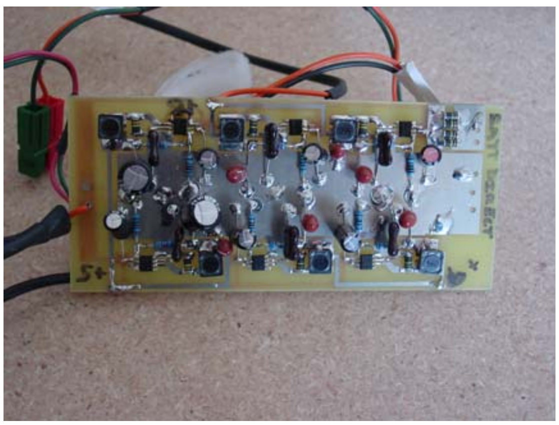


Figure 28: BOREALIS central power board.

The power board allows the battery to run the radio, GPS, IBIS II, and microprocessor for more than 12 hours. With the higher voltage of the battery, the radio can also operate at a much higher output power. This enables the balloon position reports to be received more frequently when we are chasing the packages.

Component	Voltage (V)	Current (mA)	Power Draw (W)	Energy for 3hr flight (Whrs)
Radio (nominal flight)	14.4	ave. 170	2.448	7.344
Camera (45s cadence)	4.0	ave. 200	0.800	2.400
GPS	5.0	~100	0.500	1.500
Timing Circuit	5.0	~100	0.500	1.500
Microprocessor	9.25	~140	1.295	3.885

Table 8: BOREALIS command module power consumption (new).

Another way to provide power to all of the components is to power the individual components by the OEM batteries that they were designed to use. Although this is the simplest and easiest solution, these batteries tend to be heavy and also not large enough to power the system for a full flight (Note in particular that it is desirable to keep the tracking system – radio and GPS – operating for some hours after the anticipated landing, to facilitate recovery efforts). Two extremes are shown to the left with the rechargeable NiCd battery pack for the TH-D7 radio and the LiIon battery for the Pentax camera in IBIS II. Although never attempted by BOREALIS, other groups have flown successfully using this approach.

Launch Tower

The Launch Tower is a rolling structure designed to provide a working area for the launch team while keeping the lines connecting the modules and parachute from tangling. This tower is built from wood and also has shelves for additional workspace. All of the shelves can easily be moved to a new position with a wrench and screwdriver.

The Launch Tower is pictured in Figure 29. Notice the arm at the top of the tower. This arm can be collapsed for traveling and to facilitate attaching the shroud ring. The extended arm is used to pull the lines connecting the upper module to the shroud ring taut and to keep them out of the way of the payload teams. To keep the tower stable a 70 lb. sandbag is placed on the foot of the tower. This foot was specifically made for a sandbag. The lines from the shroud ring to the parachute can be seen running to the right of the picture. The raised arm also keeps these lines from tangling and being in the way of the payload teams as they prepare the modules. The blue straps from the back of the tower to the bottom rear attachment rings on the modules are safety feature to prevent an accidental launch.

Additionally, the wheels on the tower can be seen in the lower left corner. These wheels are general-purpose lawn mower wheels. The larger size of these wheels makes moving the tower through rougher terrain much easier. The attachment points for the wheels are raised so the wheels come completely off the ground when the tower is set upright.

Figure 29: Launch Tower with flight modules.

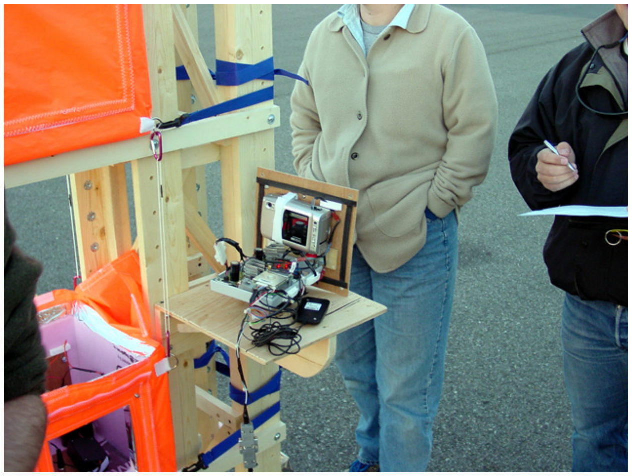


Figure 30: Work shelf on the tower.

Figure 30 shows the equipment work shelf mounted to the side of the launch tower. This shelf provides an additional convenient workspace for teams preparing equipment to be placed inside the modules. Here the camera team is using the shelf to prepare an early version of IBIS. Note the shelf is close enough so that cables can be connected to equipment already inside the modules.

This shelf is removable with a few bolts to allow easier transportation. Additionally, the tower has multiple holes so the height of the shelf can be adjusted.

Figure 31: Module shelf on the tower.

The shelves designed to hold the modules while preparing the system for launch are mounted "forward" on the tower (Figure 31). These shelves are pre-positioned so the lines connecting the modules are taut when the modules are in place. These shelves generally are not moved in the field although the tower is drilled with a series of mounting holes along its height. (These can be seen in Figure 30 just above the lower orange box.)

The shelves are also cut with a "V" in the front to allow the antenna to hang beneath the module. In the case of the upper module shelf, this also allows electrical and data cables to more easily connect the two modules.

SECTION III: FLIGHT PLANNING AND PREPARATION

Pre-flight planning

Doing high altitude balloon flights doesn't just mean having clear skies. It also means evaluating the direction and speed of the high altitude winds so you can (hopefully) get the payloads to land in a reasonably accessible area. The surface weather conditions need to be taken into account as well. The high altitude winds may be perfect, but surface winds above 10 knots make a launch difficult, and above 20 knots, probably impossible. It also means coordinating with air traffic control and the authorities in your area. Although not required by law, these little details make your life easier and help to cultivate good relations with the authorities if you ever need them during a flight.

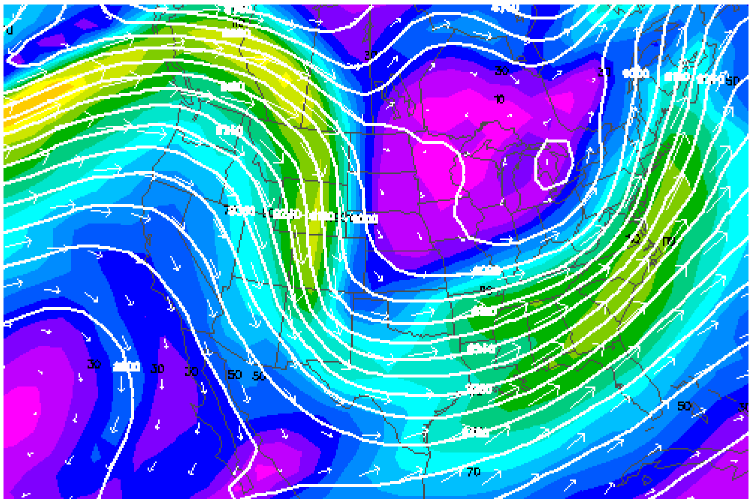
Weather Forecasting:

<u>High altitude:</u>

High altitude wind profiles from actual sounding data are available from the University of Wyoming Department of Atmospheric Science. This data in text file format is what will be needed as input for the balloon tracking software described in the "Balloon Tracking." section below. The sounding data is updated twice each day, at 0:00 and 12:00 Greenwich Mean Time.

Sounding Data:
http://weather.uwyo.edu/upperair/sounding.html

Upper atmospheric weather predictions can be found at the UNISYS weather site. When you get there, look under the index heading and select the "300 mB Plots," then the "4 Panel Plots." From there you can look as much as 10 days out. 300 mB (millibars) indicates an altitude of around 35,000 feet, which is the area most likely to contain the fastest wind speeds.



Upper Air Forecasts:
http://weather.unisys.com/mrf/index.html

Surface:

Of course having reasonably clear weather free of rain and snow is helpful! In the days and even hours before a launch you should consult a number of resources that can provide you with needed data on cloud cover, chance of precipitation, and surface winds.

For example:

University of Michigan Weather Page:
http://cirrus.sprl.umich.edu/wxnet/

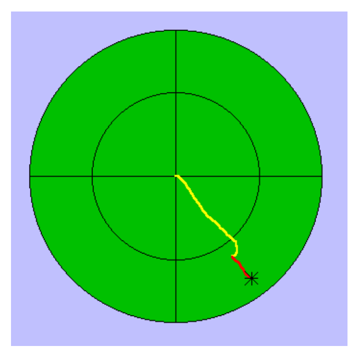
Latest Infrared Satellite View:
http://www.rap.ucar.edu/weather/satellite/latest_US_ir.jpg

National Weather Service:
http://www.wrh.noaa.gov/wrhq/nwspage.html

As a general guide for doing weather tracking, BOREALIS has generated a standard weather form to make sure we check the relevant predictions and as a record keeping strategy. This combined with other forms provide a system of tracking the same data on each flight for later comparison and study. These will also improve the ability of our students to insert the new data into our website. The BOREALIS Weather Tracking form is included in Appendix E with other forms and checklists we use for flights. We also use a separate form to record what actually occurs on the flight so that we can compare the predictions and simulations with reality. This is very useful since we launch from (so far!) three locations in Montana. With the predictions and actual events recorded, we can develop a better understanding of when to fly and when to wait even though the conditions may look good.

BALLOON TRACK PREDICTIONS: Once you know the high altitude wind profiles, you can use a free software package called "Balloon Track for Windows" to predict (roughly) where the balloon is likely to go. We have found that the predicted landing site is usually good to within 10 miles, provided you update the calculations with accurate rise rate data. The software is available from:

http://www.eoss.org/wbaltrak/index.html



Predictions are likely to be more accurate in other states, as Montana tends to lie directly beneath the jet stream – we always have very fast upper level winds, and our flights all tend to go a long distance.

Once you install the software, play with it a little bit to familiarize yourself. "Setup" on the menu bar will allow you to modify the characteristics of your flight simulation. For example, you can input the altitude, at which you expect the balloon to burst, the location of the launch site, and the rise and descent rates. Typically, we try to fill the balloon such that the rise rate is 900 feet per minute and our 9 foot diameter parachute simulates well with a 1100 feet per minute descent rate.

To use the simulation you need to download a sounding data file as described above. Make sure to save the file as a .txt format file. To insert the data into the simulation, select "Open" from the File menu in the menu bar. Next use "Browse" to select the file you saved. The software will then open a new save dialog box. Save the file in the location it provides as the type it selects. This converts the file to a format usable by the software. The software automatically runs the simulation with the settings saved as the default in the "Setup" menu. If you change anything after opening the data file, you should click the force recalculation button to be sure the new settings have taken effect.

The track screen produces a visual depiction of the flight path similar to the one above. The summary screen contains the most important information including the range and bearing to the estimated landing site.

Once you run a profile for the current day, you can use this as a baseline comparison when you look at the predicted wind conditions from the UNISYS web site. This will allow you to come up with some rough estimates on how the trajectory will change for the actual flight date.

FAA REQUIREMENTS AND REGULATIONS: There are a host of FAA regulations for unmanned free balloons. However, many of the stringent (and costly) requirements can be avoided if the system is kept under 12 pounds. In a two-payload configuration, each box must weigh in at less than 6 pounds (you can't load one up to be 10 pounds and let the other be 2 pounds!). You can examine all the regulations online at:

http://www.risingup.com/fars/info/101-index.shtml

While not legally required, as a courtesy you should file a NOTAM (Notice To Airmen) 24-48 hours before each flight with your local Flight Service Station (FSS). This will provide basic information about your planned balloon flight to any pilots planning flights in the region. The FSS will call back if the NOTAM cannot be approved, but it's also advisable to call again on the morning of the flight to make sure nothing has changed (they can be cancelled at a moment's notice due to other conditions, e.g. Air Force One suddenly decides to fly through your airspace). *If for some reason you need to cancel the balloon flight,* ***be sure*** *you call to cancel the NOTAM!*

<u>Information they will usually need</u>:

- High Altitude Balloon under 12 lbs. ("Hi Ball")
- Launch site description and (if necessary) coordinates
- Projected launch time
- Direction of travel and max altitude expected
- Projected landing time (duration of flight)
- Contact information for the flight
- The name and contact information for the person filing the NOTAM

As a helpful guide, the BOREALIS team uses a form that we fill out prior to calling to file a NOTAM. This prevents confusion and wasting the time of FSS personnel who are usually very busy.

If you are talking to someone at the FSS who has not had much experience with small high altitude balloons, you may be asked about some of the FAA regulations. Be prepared to state that you do adhere to FAA regulations for unmanned free balloon systems less than 12 lbs. (FAR101). That means: No, you don't need to have a transponder. No, you don't need to have two independent cut-down systems. Yes, you do adhere to the other parameters (load line rating, payload wall density and overall weights, etc). Be ready to tell them that you track the balloon through amateur radio and receive GPS data and will pass that information along to appropriate Air Traffic Control (ATC) centers. These may be local airport towers near your flight path, or more distant "Centers" which control high-altitude IFR air traffic (e.g., in Montana, we deal with "Salt Lake Center", which controls the high altitude airspace over our flight area).

Again, while not legally required, in the BOREALIS team we always notify ATC of three events (this means being sure you have a cell phone with you):
(1) Immediately after launch you must call to notify them of the launch time.
(2) Call them again at balloon burst (so they know it is descending), including the general location, and
(3) call again at landing.

Many times ATC will want to call you for periodic reports, especially if the payloads are near a major city when the balloon is between 25-40,000 feet (major airways) and again below 13,000 ft. (where you may enter Class C airspace).

If the air space you fly through is controlled by an Air Control station at a larger, more distant airport, you may get a phone call from them directly. They sometimes call on the morning of launch looking for additional information (size of the payloads, color of the components, length from balloon to payloads, etc.) because they will inevitably get questions from pilots like "what is this thing and what does it look like?!"

Whoever is in charge of filing the NOTAM and communicating with the FAA should make sure they have a list of key phone numbers with them at all times (Flight Service Station, Airport Control Tower(s), IFR Center, Sheriff in recovery area). We use a form that also has the basic procedures for contacting the air traffic controllers on the launch day in addition to the necessary phone numbers. This form is included in Appendix E as an example.

CHOOSING LAUNCH SITES AND TIMES: You should run numerous flight profiles at several different times of year to get a sense of the distance and direction your payloads are going to travel. With that in mind, you should look for a recovery area that has the following:

- Relatively flat and open ground (no rugged mountains, wilderness areas, etc.)
- Good road access (less hiking!)
- Low urbanization
- As little open water as possible (including rivers, ponds, lakes, etc.)

From there you can trace the flight path backwards and try to identify potential launch areas. You should look for the following criteria in a launch site:

- Flat ground free of trees and power lines for at least one hundred yards
- Low surface winds (especially at sunrise)
- A nearby building for wind shielding (preferable)
- Good cell phone coverage

Many groups have had the best experience by coordinating with the management of a small airport in the preferred launching area. Most are happy to offer their site and even participate in the operation. This may also make the FAA feel more comfortable, knowing that you are working with knowledgeable flight personnel.

In general, the best time of day to launch is at sunrise, as this is when surface winds are likely to be at a minimum. However, other considerations may come into play. Launching at anytime of the day, excepting so late that the balloon will still be flying at night, can be done. The key to remember is excellent weather planning and it doesn't hurt to have an "Old Salt" around that knows what the weather does simply by experience. This many times is as valuable as forecasts.

As most of the forms indicate, we use checklists on everything that we need to be able to do very early in the morning. This saves on mistakes and allows everyone to feel confident we put everything together. The Flight Director Checklist, also included in Appendix E, provides a pre-departure summary of everything that has to be done. With the BOREALIS project, the Flight Director (FD) handles the arrangement of the transportation, simulations, weather predictions, and coordinating the other teams. Thus the FD gets really busy about launch time and can easily overlook something. The checklist is designed to prevent any major item from being overlooked that could result in not flying or even worse, flying without some key piece of equipment in place or activated.

Much of the work on the balloon projects center about the proper planning to make the rest of the work easier. Proper planning will save time and money when an actual flight occurs and also teaches important lessons to the students working on the project.

SECTION IV: LAUNCH PROCEDURES

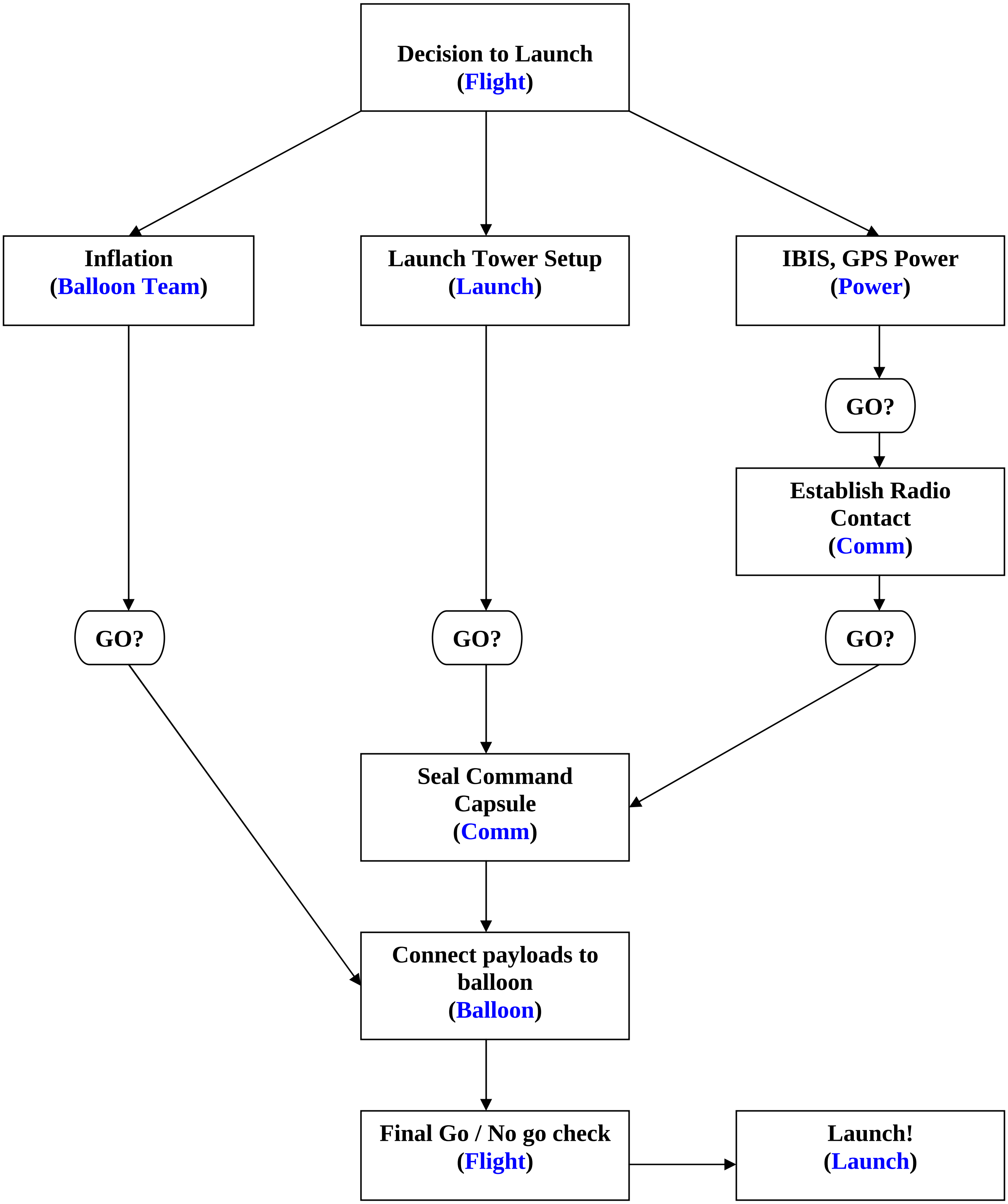


Figure 1: Launch procedure flow chart

Launch overview: The BOREALIS launch procedure is illustrated schematically in Figure 10. The basic strategy is that a single Flight Director ("Flight") maintains overall control of the launch while the subsystem leads ("Balloon", "Launch", "Power", and "Comm") are responsible for executing their system checklists (Appendix E) and readying their systems for flight. When scientific payloads are carried, a fifth subsystem lead ("Science") will work in parallel with the other four.

Balloon inflation: The balloon inflation team starts by finding a safe place to lie out the inflation tarpaulin, gas bottles, and necessary supplies including duct tape and 100 pound test line. The ideal location for inflation is a clean area leeward of any ground winds. The balloon itself is laid out, inspected, and connected via the connection nozzle (Figures 9 and 20) to the gas bottles, then inflation may begin.

The balloon is inflated to the point where its lift exceeds the payload weight by approximately two pounds. Lift is determined by means of a digital fish scale (Figures 20 and 21), relative to the payload mass, which is typically measured before departing for the launch site. We currently use the following equation to calculate the lift that should be seen on the fish scale for about a 1000 ft/minute rise rate.

lift = 1.2 ((payload mass)+(balloon mass))-(balloon mass)

Figure 2: (Left) Measuring the lift of the balloon. An inverted digital fish scale is connected to the loop attached to the inflation nozzle. (Right) Inverted digital fish.

When the desired lift is achieved, the balloon inflation team seals the balloon and prepares the balloon for connection to the payloads. The balloon team leader gives a “GO” to Flight, and awaits the order to connect.

Launch tower operations: It is the responsibility of the “Launch” team lead to set up the launch tower and secure the command and payload capsules to the tower. This allows the other teams to safely carry out their checklists prior to flight. Once the tower and capsules are prepared, and while the other teams set up their systems, Launch connects the parachute to the payloads and carefully lays out the lines by which the balloon will be connected to the parachute. Launch also sets up the lanyard lines for the four lanyard operators to hold the stack vertical immediately prior to release.

Communications and IBIS: During the pre-launch preparations, everything can get rather hectic, so every subsystem has developed their own checklists. For BOREALIS, the communications and power subsystems have a single checklist, since so much of the systems are interlinked. This checklist is included in Appendix E. The basic overview of the pre-launch procedure for power/communications is this: First, the GPS antenna needs to be connected to the GPS unit before power-up. As soon as power is connected to the GPS unit, it begins to look for GPS satellites, so the antenna needs to be connected. After power-up of the GPS unit, radio, and camera, everything else can be connected. The GPS unit needs to be plugged into the radio, and the radio needs to be set to receive GPS coordinates from the unit. For the TH-D7 and Garmin to work together, the TH-D7 needs to be set for the GPS to read in NMEA format. It is important to make sure that the flight antenna is connected to the radio before transmission begins, or the transceiver could burn out due to lack of resistance. Once the radio is receiving coordinates correctly, it needs to be set to send these coordinates in a “beacon mode” setting. This setting allows the radio to automatically send an APRS packet at a chosen interval, which we usually choose to set to the radio minimum of 12 seconds. Once we have successfully received APRS packets with the correct coordinates (verify using a separate GPS unit), we then turn off the auto-shut-off option on the radio, as well as lock out the keypad, so that no buttons can be pushed accidentally during the sometimes bumpy flight. Once this is completed, the connections between pieces of equipment are secured, and the payload box is sealed. From this point until launch, it is the job of Comm to monitor the packets and ensure that the system is working properly. If everything is working correctly when the system is ready for launch, communications gives the last GO, and the pre-launch sequence is finished.

Launching the balloon: After the balloon has been connected to the payloads, and the final GO/NO GO check has been performed by Flight (with particular emphasis on communications with the balloon), Launch takes over the operation.

There are several different techniques that can be used to launch the stack, depending on surface wind conditions. Ideally, surface winds will be low, and a Vertical Launch may be attempted. This provides the most control over what is happening, and the least danger of losing the balloon or damaging the payload.

During low-wind conditions the balloon may be let up a certain distance, enough to pull the payload cords straight below the balloon. This is called a **Vertical (low wind) Launch**. The goal is to let the balloon rise smoothly so as to not risk breaking the payload suspension cord attaching the balloon to the parachute. The BOREALIS system uses a small plastic piece with four holes in it. The holes are positioned such that two are in a vertical line with each other, the other two are in a horizontal line with each other making a + shape with one hole at both ends of each line. The vertical holes are used to attach the balloon to the parachute, and the horizontal holes are used for control of the height of the balloon. This is achieved by using two kite string spools with Dacron cord wrapped on each. By letting enough length out, the loose end of cord is threaded through one of the horizontal holes and a person is given the loose end to hold. The other spool is set up similarly on the other side. The person holding the spool then may control the height of the balloon by letting cord out or spooling it in.

During high wind conditions the Vertical Launch will not work; the balloon will become like a sail and be very difficult to control. It is easy for high winds, pushing on the balloon, to create a force exceeding the 50 pound breaking strength of the payload suspension line.

In such conditions, if a launch is desired (the best choice may be to wait for another day), it is possible to overcome this problem by not letting go of the balloon until the entire stack is in position to be lifted by the balloon. To do this the payload, parachute, and balloon are arranged in a horizontal line along the ground with a person cradling each item in their arms (NOT holding them, but merely providing support underneath). On command from the Flight Director the balloon is let go and the payload is simply cradled such that the balloon picks them up as it rises. This is called a **Horizontal (high wind) Launch** (often referred to as a "Hail Mary" launch). It is important that the line of components is pulled upward <u>smoothly</u> when the balloon is let go so as to avoid the possibility of breaking the connecting cords. The line of components should be stretched out such that the connecting lines are taut, and everyone supporting the components of the stack must be careful to not hold on as the string quickly rises and is snapped from their arms..

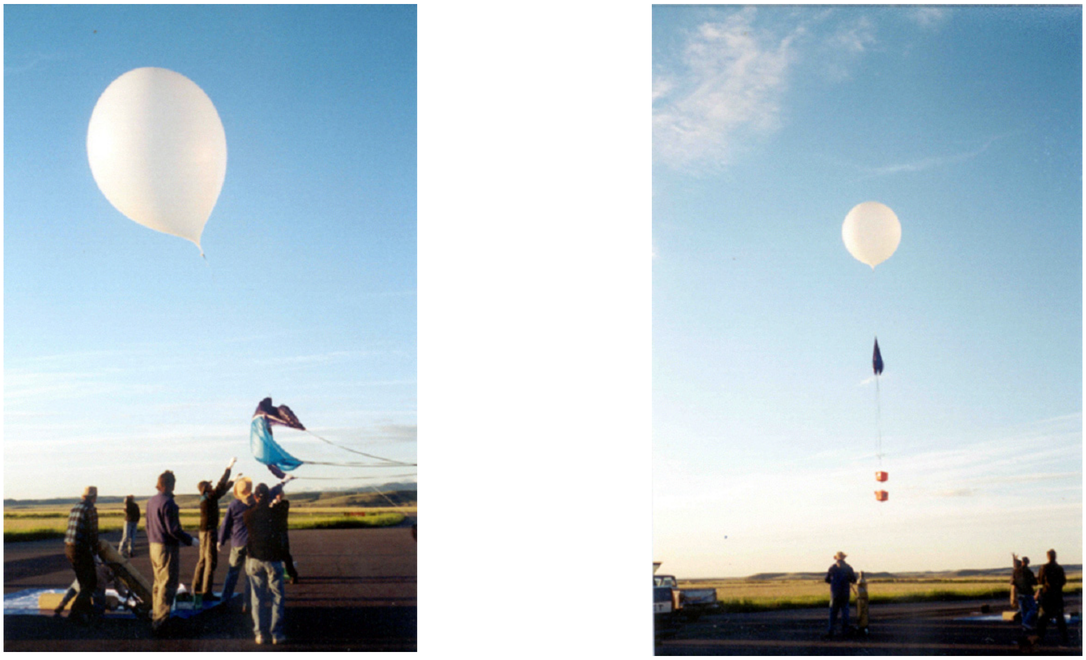


Figure 21: Launching the balloon. (Left) the balloon has just been attached to the top of the parachute, and the stack is being raised to vertical by the lanyard operators. (Right) the stack has been released.

SECTION V: TRACKING AND RECOVERY

Flight overview

A number of criteria will influence the flight pattern of a balloon system. These include:

1. Size and quality of the balloon
2. Weight of the payloads
3. Amount of positive lift in the balloon
4. Speed of the Jet Stream
5. Size of the parachute

Items 1, 2 and 3 will determine the maximum altitude reached by the balloon. Item 3 will have an affect on the rate of ascent (rise rate). In general the rise rate will remain constant during ascent (see diagram below). Typical rise rates for small payloads are in the 700-1000 ft./min range. This is desirable because it avoids having to chase the balloon too far, especially if the Jet Stream is clipping along at 150 mph!

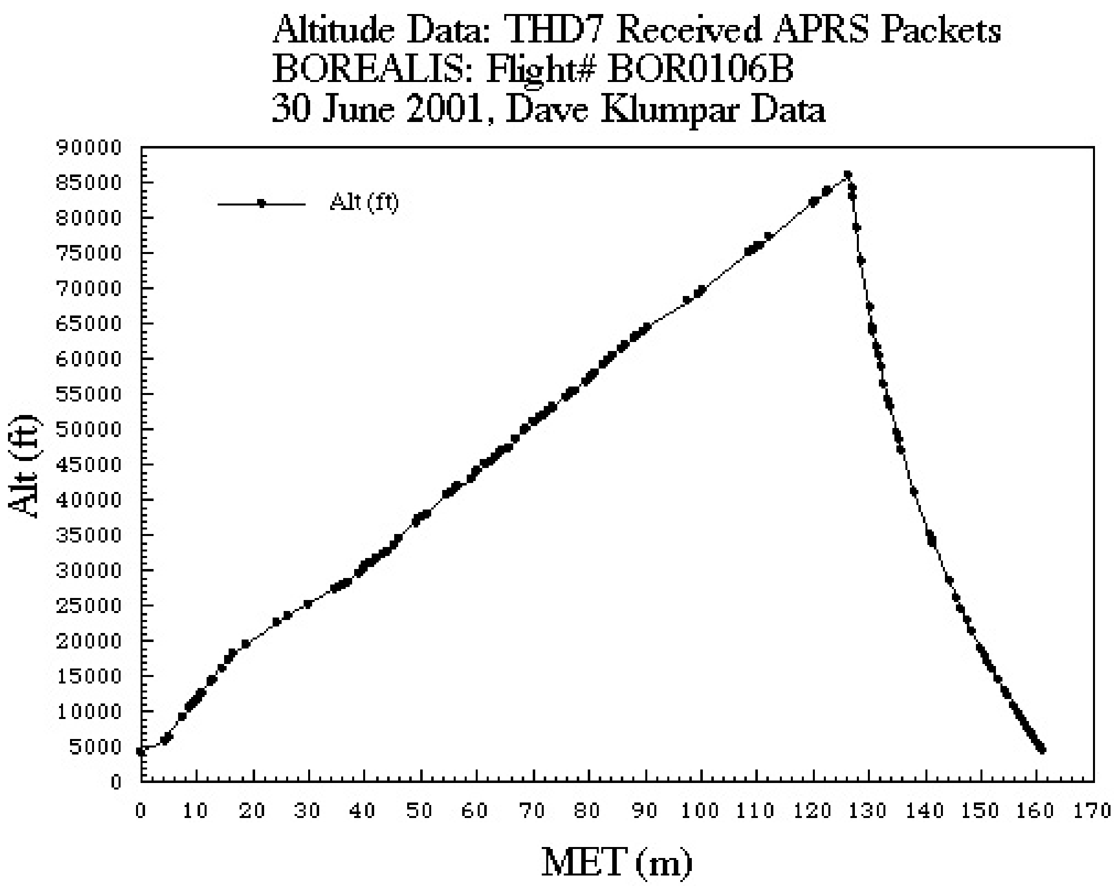


Figure 22: Altitude versus mission elapsed time (in minutes), flight of June 30 2001.

After burst the story is different. Due to the low air pressure at high altitudes, the balloon is likely to fall at a significant rate at first (up to 120 mph in the first minute, even though the parachute immediately inflates), decreasing to about 15 mph at landing. (See graph below.) As an example, the first test flight for the BOREALIS program in Montana used only a 300-gram balloon, taking the payloads to only 45,000 feet. But the rise rate came out lower than expected at only 350 ft./min. As a result we ended up having to drive over 100 miles to recover the payloads! A more "normal" flight profile for let's say a 1200-gram balloon, 12-lb. payload, a rise rate of 900 ft./min., and a moderate Jet Stream velocity (80 mph at 35,000 feet) would be to expect burst at around 85,000 feet and a travel distance of about 75 miles. This translates into a flight duration of about two hours (90 minutes for ascent, 30 minutes for descent).

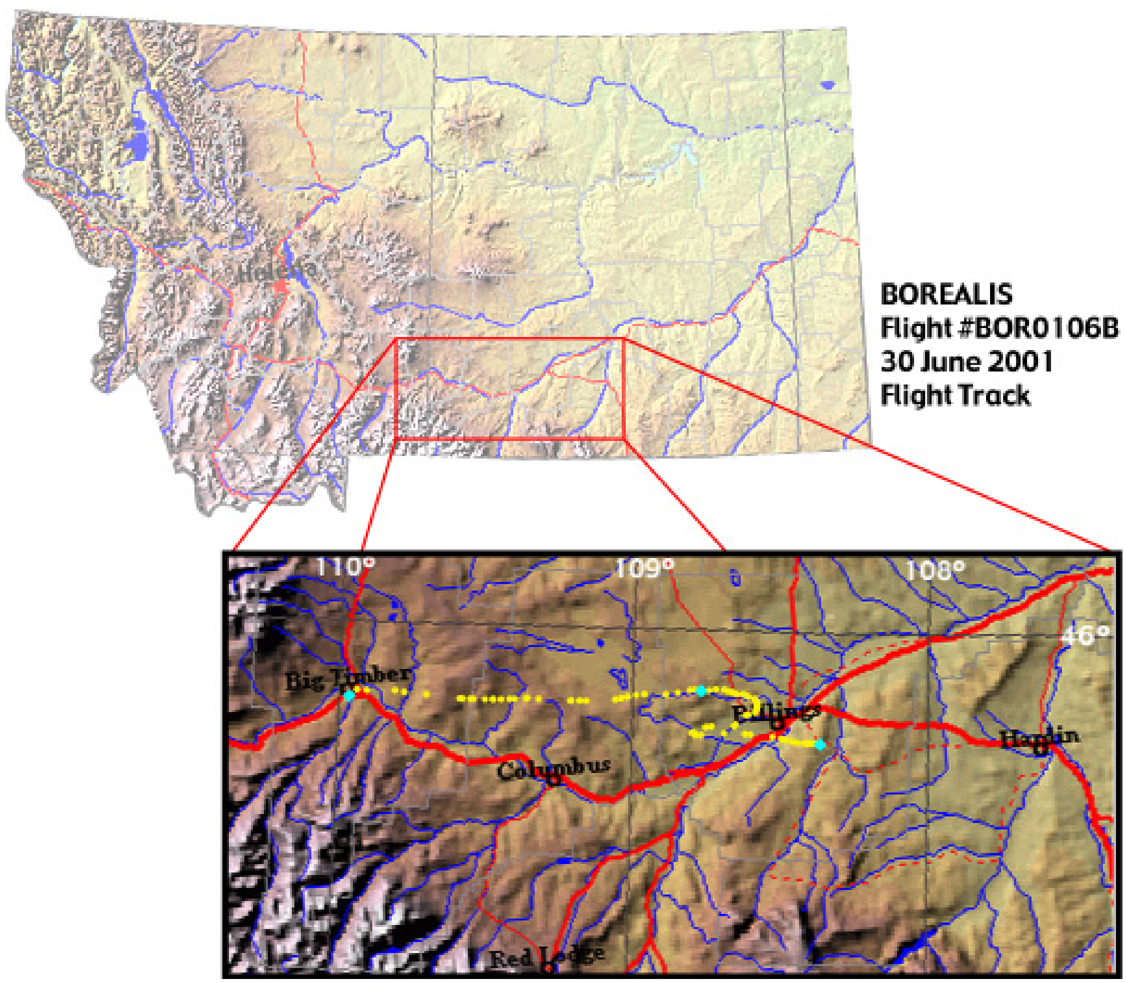
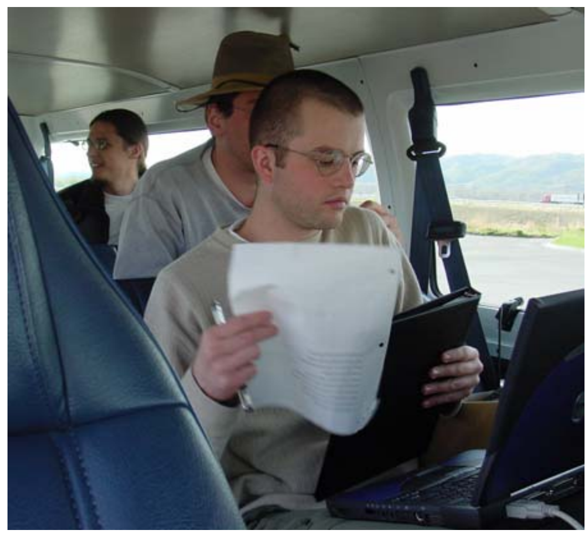


Figure 23: Flight track, 30 June 2001.

Tracking

Receiving APRS/GPS data: Once the payload has been launched, we immediately monitor and log all of the APRS packets we receive. As well as allowing us to track the balloon in real time, this database of packets will also serve as a correlation of other onboard experiments with time, altitude, latitude, and longitude. While we are tracking the balloon from our chase vehicle, we plot a set of lat/long coordinates every so often on a gazetteer map, which allows us to decide which roads to take. Using the APRS software, we can get a horizontal speed at which the payload is traveling, which also helps us decide which roads to take. Since 2-meter ham radio works by line-of-sight propagation, the last packet may be of an altitude much higher than that of the landing site. The goal is to be as close to the payload as possible during decent, so the last APRS packet is as near to the landing site as possible.

Hints for following the balloon



During flight there are many groups who choose to actually “chase” the balloon. This can be helpful for a couple of reasons. One is that it allows the team to reach the downed payload as quickly as possible after landing. This can be important if the payloads land in a compromising situation (on a road, in someone’s backyard, on a power line, in a river, etc.). There have been situations where people find the payload and, seeing no one around, decide to take it! Reducing the time between landing and recovery helps avoid those situations. Another good reason for getting close to the payloads as they descend is so you can get APRS packets as close as possible to the impact point so your search zone can be better pinpointed.

To avoid having team members separated into too many vehicles, many groups find it convenient to use a large passenger van or Suburban. This helps keep everyone together, avoids the potential for accidents or someone getting lost. It’s also good to have the majority of your people together for flight tracking and planning. A magmount antenna hooked up to a HAM mobile unit will allow for receiving APRS packets from the payload, and can even be recorded into a laptop computer as the flight progresses. This can in turn be displayed on mapping software or tracked by hand on topo maps. Topo maps are a necessity anyway because they’ll allow for close examination of roads and terrain so a plan can be made for getting to the downed payloads.

Guidelines for recovering the downed payload

Once a region has been identified as the landing zone, the team should examine a number of maps and topo charts to determine how close they can get by roads. Very important is to determine what kind of property you will be traversing across. If the team must access private property, every attempt should be made to contact the landowners so permission can be secured. You can even consider providing them with a gift like a t-shirt as a token to thank them for their support. At the least you should offer to get their address so a thank you letter and photos can be sent to them afterward.

Below is a list of possible recovery procedures to be taken into consideration after “the chase” in the vehicle has been concluded and hiking must begin.

1. Communication is the key to a successful recovery. Without it, people may get lost, hurt, and objectives will not be met.
2. All members going on the hike must bring sufficient water for the hike.
3. BEFORE anyone leaves the vehicle, a plan needs to be made on where we are going. It is inappropriate for one person to take off alone or without communicating with the rest of the group.
4. Verify that recovery materials are in a backpack and secure. (Payload carry straps, camera, nylon rope, simple tools.)
5. A first aid kit needs to be carried on the hike. Within the first aid kit there should be a reflective blanket. The blanket may provide shade, warmth in the case of shock, or location for air rescues.
6. Persons hiking need to travel in groups. If one person takes off and becomes lost or hurt, it will take longer for medical attention and recovery itself is compromised.
7. Be aware of EVERYONE’S ability level.
8. Everyone should carry a whistle. Should someone get lost, or worse hurt, a whistle allows the person to communicate an emergency without using a great deal of energy. Yelling requires a great deal more energy and is not effective for long distances. Time is precious during an emergency. Even if the injury is not life threatening, shock can be.
9. Consider keeping one or two people near the recovery vehicle on a high point to act as a control center for communication (map tracking, emergency situations, etc.) People assigned to this function could rotate.

Once the payload has been found, it should not be moved (except in case of imminent hazard) until it can be photographed and studied in place. Such close up photographs of the payloads and other flight components (including any remnants of the balloon) can be important in case some post-flight analysis needs to be done on the landing dynamics. For instance, if some internal damage takes place to the components it would be nice to evaluate the positioning of the payloads so one might be able to gather some data and make some preliminary conclusions.

<u>Items for the Recovery Team</u>:

1. Sturdy shoes for hiking
2. Wide-brim hat
3. Sun Screen
4. Spare shoes & socks
5. Back pack (for gear, and to carry the capsule off the mountain)
6. Sufficient amounts of water/Gatorade
7. Breakfast bars and/or fruit (quick energy)
8. Rain gear (just in case)
9. Warm clothing (layers)
10. Compass (the GPS doesn't give your heading unless you are moving)
11. First Aid kit
12. Communications radio (HAM, Family Band, whatever)
13. Whistle (to alert of emergencies)

APPENDIX A

FEDERAL AVIATION REGULATIONS PART 101--MOORED BALLOONS, KITES, UNMANNED ROCKETS AND UNMANNED FREE BALLOONS (excerpted)

For complete up-to-date regulations, see:

http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_14/14cfr101_00.html

Sec. 101.1 Applicability.

(a) This part prescribes rules governing the operation in the United States, of the following:

(1) Except as provided for in Sec. 101.7, any balloon that is moored to the surface of the earth or an object thereon and that has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet.

(2) Except as provided for in Sec. 101.7, any kite that weighs more than 5 pounds and is intended to be flown at the end of a rope or cable.

(3) Any unmanned rocket except:

(i) Aerial firework displays; and,

(ii) Model rockets:

(a) Using not more than four ounces of propellant;

(b) Using a slow-burning propellant;

(c) Made of paper, wood, or breakable plastic, containing no substantial metal parts and weighing not more than 16 ounces, including the propellant; and

(d) Operated in a manner that does not create a hazard to persons, property, or other aircraft.

(4) Except as provided for in Sec. 101.7, any unmanned free balloon that--

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than six pounds;

(iii) Carries a payload, of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

(b) For the purposes of this part, a "gyroglider" attached to a vehicle on the surface of the earth is considered to be a kite.

[Doc. No. 1580, 28 FR 6721, June 29, 1963, as amended by Amdt. 101-1, 29 FR 46, Jan. 3, 1964; Amdt. 101-3, 35 FR 8213, May 26, 1970]

APPENDIX B

What's this business about getting an Amateur Radio license?

D.M. Klumpar, KD7MFJ
June, 2003

Why do we use Amateur (ham) Radio in ballooning?

We all have a strong incentive to track our balloons and recover our payloads (so we can fly them again). Optical tracking is next to impossible, and accurate optical tracking would require triangulation, and even then the odds of being accurate enough to find a downed payload in anything but flat, treeless terrain are not good. Radio tracking can provide a beacon, that specialized direction finding equipment can be used to point the way. Even better, with the advent of the Global Positioning System (GPS) our package can report its position directly to us at all times. With the proper equipment it can broadcast its latitude, longitude and altitude (and other cool things like velocity and direction of travel!) using a system called Automatic Position Reporting System (APRS). The most convenient approach for communications from the balloon is to utilize ham radio, which requires an operator's license.

Ham radios are a consumer product, that means they are mass-produced, and consequently are reliable, relatively inexpensive, and easy to use. What's more, they can be equipped with (or come with) a data modem that allows them to transmit the GPS information via the APRS system. Battery operated portable transceivers, called HTs (HandiTalkies), are small enough to fit in the palm of your hand and weigh only a few ounces, making them ideal for the command capsule.

In addition to providing telemetry from the balloon, Ham radios find another very practical use in ballooning, communications between people in remote and disparate places. Balloonists use Ham radio to stay in contact with their team, during launch preparation, during flight, and especially during recovery when the team may be located at several different locations.

Not just anyone can talk on the frequency bands designated for Ham Radio. One has to have an Amateur Radio license to transmit on these frequencies, and your use of the amateur service has to be for a legitimate purpose.

Why do I need a license?

It's the law. The FCC requires it. The Ham community is very proud of the standards that they have evolved for the proper use of the Ham bands, and they want to be sure that everyone using Ham radios adhere to the simple but necessary protocols. Licensing provides a way for all users to learn "the-rules-of-the-road". Fortunately an amateur radio license is not difficult to obtain.

What is an Amateur (ham) Radio License?

There are actually three different types of Ham Radio licenses in the United States called "license classes": Technician class, General class, and Extra class. The type of license one has determines which frequencies can be used, what methods of transmission (e.g. voice, code, single side band, etc) and how much power one can radiate. The most popular class for beginners, and the easiest license class to get, is the Technician class License. NO MORSE CODE IS REQUIRED. Fortunately, the technician license is all anyone needs to carry out the communications aspect of ballooning. The Technician class license allows one operate on all amateur frequency bands greater than 30 MHz, including the use of popular "FM" two-way radios and repeaters on the VHF and UHF bands. You can also send computer data, television signals or use Amateur Radio orbiting spacecraft with the Tech license. The license is granted by the Federal Communications Commission and is good for 10-years, and may be renewed.

Don't I have to be a real geek and know all kinds of technical stuff including Morse Code?
No! Virtually anyone can get their "ticket". The previous requirement to learn Morse Code in order to obtain any kind of ham radio license was dropped several years ago. While a little basic familiarity with electronics and radios helps in understanding the material to pass the exam, it is not at all a prerequisite. All of the material needed to become a competent ham operator can be learned in a few evenings of study before taking the exam. The material needed is covered exhaustively in a manual put together by the national association for Amateur Radio, the American Radio Relay League (ARRL). More about this later.

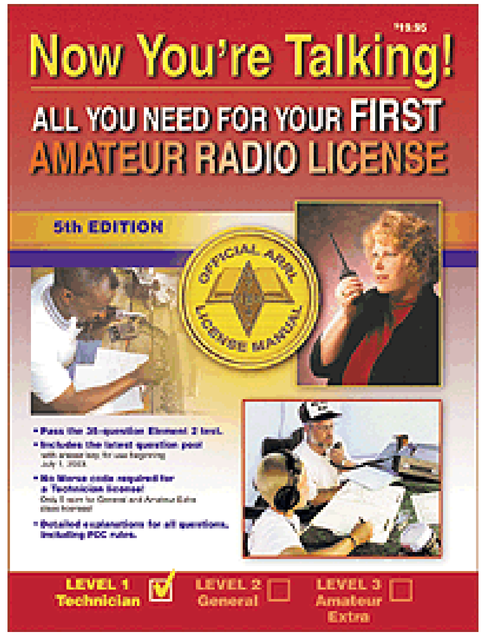
So what are the steps to getting a license?
Getting a Technician's license requires passing a written examination. The exam is a 35 question multiple choice test. The questions on any particular exam come from a universe of pre-established questions. Those questions, and the correct answers are readily available form a multitude of sources, including the study guide published by ARRL. One great source of study material is the internet, where one can take sample examinations with the exact questions taken from the official question pool.

By far the best way to get introduced to Amateur radio and prepare for the exam is through a local Amateur radio club. The license examinations are administered by ham radio volunteers. Best of all, one doesn’t have to study alone. Many local ham radio clubs offer FREE training courses, often augmented by video training material, to assist you in learning ham radio. Such a course can be very useful because it puts you in direct contact with enthusiastic hams who can answer questions and guide your learning. Typically, a club might offer a number of training sessions over the course of a few weeks, followed by a club-sponsored examination administered by a team of three or more Volunteer Examiners. The Examiners handle all of the paperwork and submit it to the FCC who issues the license directly to you.

An excellent starting place for learning about amateur radio, for getting study guides, and for locating an amateur radio club in your area is to visit the ARRL web site at:

http://www.arrl.org/hamradio.html

If you want to begin your studies without the assistance of a local ham club you can purchase the illustrated and easy-to-read study manual (pictured at the right) through the ARRL web site. The manual's title is **"Now You're Talking! All You Need For Your First Amateur Radio License"**, 5th edition © 2003 #8810--$19.95, available through the ARRL.



Recommended Steps:

1) Find a local club near you and determine if one of these clubs is offering a training course. A directory of ham radio clubs can be found at:

http://www.arrl.org/FandES/field/club/clubsearch.phtml

2) Find a testing site (and date) near you:

http://www.arrl.org/arrlvec/examsearch.phtml

3) Study independently, or through the club's help.

4) Practice taking the examination by working through the study guide, **"Now You're Talking! All You Need For Your First Amateur Radio License"**

or

Practice taking the examination on the internet* from such sites as:

http://www.aa9pw.com/radio/
(left hand column, check "Technician" and click on "Take Exam")

http://www.eham.net/exams/

* Note Effective July 1, 2003 the exam pool questions may change, so some of the internet sites offering practice exams might not be up-to-date. The complete list of exam pool questions is available from ARRL at:

http://www.arrl.org/arrlvec/pools.html

5) Take the examination under the supervision of the ARRL Volunteer Examiners. A passing score is 26 or more correct answers. CONGRATULATIONS!

6) Getting impatient? After about 10 days, look on the internet to see if the FCC has issued your license yet and find out what your call sign is (You will receive your license in the mail.)

http://www.arrl.org/fcc/fcclook.php3

7) Start talking on the air. There are far to many variables to offer advice on equipment in this limited space. Talk to our new friends in the local club.

What are the costs of getting a license?

The cost of the examination is $12.00 (There is no additional charge from the FCC for the license)

Got your license? Conduct a "Fox Hunt" with your team.

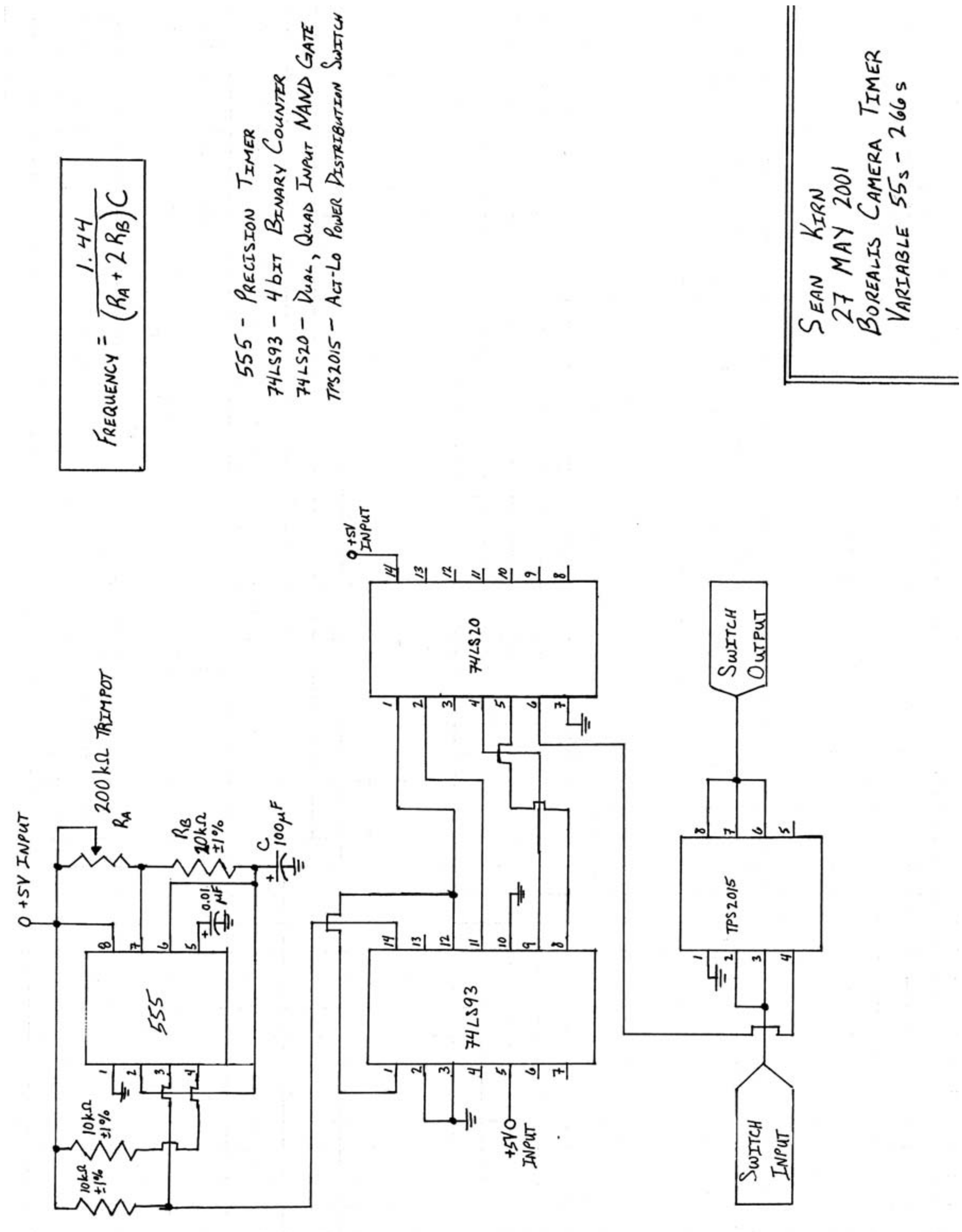
Here's a fun little field exercise to apply your new knowledge and practice the skills needed for flight tracking and recovering your downed payload at the conclusion of its flight. Have one of your team members (a licensed ham) place a ham transmitter ("the Fox") in a hidden location. Set it up to transmit a periodic signal containing the GPS coordinates of its position. Separate the rest of the team into a few groups of two to three individuals, and send each team out to find the "Fox". The team that locates the hidden transmitter in the shortest time wins bragging rights.

There is a significantly more challenging version of the fox hunt that doesn't permit the use of GPS, but instead relies entirely on radio direction finding (RDF). Suppose the balloon GPS system fails to report its position, and the only information you have is the radio beacon. RDF provides a means for tracking down your payload using directional receiving antennas. The basic concept is that the radio waves are emanating from a point source. Using highly directional antennas on your receiver, it is possible to determine the direction that the radio signal is coming from. Successively monitoring this direction as you move about should lead you right to the hidden transmitter. This project will require you to build a direction finding (DF) antenna, an excellent way to learn some new amateur radio skills. Such an antenna can be built for less than $10.00.

One simple DF antenna design is available at http://home.att.net/~jleggio/projects/rdf/tape_bm.htm.

The photo above shows a variant built by the Montana State University BOREALIS team. Hidden transmitter hunts are a popular pastime of amateur radio enthusiasts so there is a vast amount of information available on the internet.

APPENDIX C
IBIS Camera timing circuit



APPENDIX D
Integrated Balloon Imaging System II (IBIS II)

The Integrated Balloon Imaging System II (IBIS II) is the second digital camera system design to fly on BOREALIS. The original IBIS was a 1.3 megapixel digital camera that used compact flash cards to store the image files. The IBIS II not only reduces the mass of the system but also increases the resolution to 3.2 megapixels. Additionally, the image files are stored on secure digital (SD) memory cards. While being a significant upgrade, the IBIS II retains the simplicity of the original in the timing of pictures and powering of the camera.

Costs

This camera, a Pentax Optio S, costs significantly more than the first IBIS would cost to build today. The camera itself cost about $400. Ours was purchased from Costco in a kit that included a 128 MB SD memory card. We chose to purchase a larger 256 MB memory card for an additional $65. Although there are SD cards with even larger capacities, the 512 MB card is typically $400 and we decided the increased capacity was not worth the cost. The timing circuit can be made for about $5 and our mount uses about $25 worth of materials. Without including the cost of labor the IBIS II totals $495. Today, the original IBIS would cost about $90 for the camera, the same as IBIS II for the mount and timing circuit materials, and $45 for a 256 MB CF card. Therefore, the older IBIS could be built for around $165.

Camera

The camera used is a Pentax Optio S 3.2 megapixel digital camera. While also being one of the lightest cameras on the market, the Optio has a rectangular shape, which makes mounting the camera much easier than with the old (curved front) IBIS HP 215C. The new camera also has easy access to the case and the shutter switch. The Optio camera has an optical zoom. This disadvantage increases the mass of the camera while also causing some mounting problems due to the barrel of the lenses being fairly long. As the picture of the complete system (below left) shows, this problem has been solved while also improving the images generated by the camera. Below right shows the camera when hooked up to the power board and the battery.

Figure D1: Close-up of IBIS II (Left) and a picture of IBIS II connected to the power supply (Right).

Mount

This camera mount has several advantages over the older model. First, the camera's tripod mount is only used the keep the camera in place. A panel running the length of the camera supports its weight. The front of the panel also has a sunshade that doubles as impact protection for the lenses. The mount also angles downward 5° to improve the balance between sky and land in images (both IBIS camera mounts have been designed to take pictures horizontally from the command module). The mount is constructed from ¼" balsa wood and quick drying, high-strength glue. The entire mount was painted flat black after assembly. Additionally, a cardboard tube was used to make a closed mount around the lens assembly on the internal side of the mount. Since the camera is smaller and lighter than the old IBIS, the lengths of the balsa panels are short enough to keep the panels from flexing.

Memory

The IBIS II uses the newer Secure Digital (SD) flash memory cards. These cards are currently more expensive but much smaller and lighter than any other memory card. The mass of a typical SD memory card is less than two grams. They also have a very wide operational temperature range in addition to being designed to withstand a ten-foot fall to a hard surface. Currently, they are available in capacities up to 512 MB. A USB 2.0 reader for the cards will run $20 to $40 dollars and most 6 in 1 card readers will read SD cards. The cables and software included with the camera will also suffice in most cases and also are necessary if the camera took images on the internal memory.

Figure D2: BOREALIS's two SD cards. The left card is in a protective carrying case.

BOREALIS WEATHER CHECK AND FLIGHT PREDICTIONS

(Rev. 4—18 June 2003)

BOR__________ Flight Date ___/___/___ Flight:_________________

By: ________________________ Date: ______________ Time: __________hrs. Zulu

Launch Site: ____________________

High Altitude Wind Direction: _______
High Altitude Wind Speed: __________________knt

Launch Site Forecast:

Temp: ___________°F High/Low: _________/________ °F
Winds: ____/______mph Clouds: __________________
Precip: __________% UVI: __________________
Sunrise: __________ ______________________________

Balloon Flight Simulation:

Rise Rate: ________________ft/min
Burst Altitude: ________________ft
Descent Rate: ________________ft/min

Landings Site Bearing: ________________degrees
Landing Site Range: ________________miles

Latitude: ________________degrees
Longitude: ________________degrees

Estimated Flight Duration: ________________minutes

Landing Site Forecast:

Temp: ___________°F High/Low: _________/________ °F
Winds: ____/______mph Clouds: __________________
Precip: __________% UVI: __________________
____

Landing Site Estimated Terrain:
____

Predicted Roads: ____

BOREALIS FLIGHT ACTUAL
(rev. 3 13 June 2004)

BOR______________

By: ________________________ Date: ______________

Payloads:

1. *Command:* □ TH-D7/GPS25 tracking □ BATS Backup Tracking □ IBIS III
   □ Laptop Battery/Power Board □ Microcontroller □ Cut-down
   □ Other ____
2. *Payload:*____

Launch Site:_________________________ ____________°N, ___________°W

Launch Site Conditions:

____

____

Balloon Flight:

Launch Time ________________Zulu
Rise Rate (initial average): ________________ft/min
Rise Rate (before burst average): ________________ft/min
Burst Altitude (Last GPS coordinate): ________________ft

Landings Site Bearing: ________________degrees
Landing Site Range: ________________miles

Latitude: ________________degrees
Longitude: ________________degrees

Estimated Flight Duration: ________________minutes

Recovery Time ________________Zulu
Recovery GPS Landing Site ___________°N, __________°W
Landing Site Weather Conditions:

____

____

Landing Site Terrain:

____

____

Recovery Efforts:

____

____

BOREALIS NOTAM FILING SHEET Flight Number BOR____________

NOTAM Filing Date	___/___/___
"Hi Ball" (High Altitude Balloon)	
"Under 12 lbs."	
Launch Location	___________________________
(Coordinates if not an airport)	______________Latitude ______________Longitude
Flight Date	___/___/___
Launch Time (Zulu)	__________hrs. Zulu
Flight Duration (hrs.)	__________hrs.
Estimated Landing Time (Zulu)	__________hrs. Zulu
Estimated Maximum Altitude	__________ft.
Estimated Direction of Travel	__________
Estimated Landing Distance	__________miles
Contact Name	___________________________
Contact Phone Number	___________________________
Filer Name	___________________________
Filer Phone Number	___________________________

Special Directions From Air Traffic Control:

____
____
____
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NOTAM Confirm #: ___________________________

BOREALIS AIR TRAFFIC CONTROL
CONTACT SHEET AND DIRECTIONS

Contact Phone Numbers:

NOTAM:	Great Falls Flight Service	800-437-1629
Salt Lake City Air Control:	(Regional Airspace Control)	801-320-2560
Doug Ferguson (Manager):	Big Timber Airport	406-932-4389
	Home Number	406-932-4025
Will Morris (Manager):	Harlowton Airstrip	406-632-4545
Control Tower Billings:	(Airspace Contact)	406-245-9271
Helena Regional Airport		406-442-2821
Great Falls International Airport		406-727-3404
Missoula International Airport		406-728-4381
Miles City Airport		406-232-1021

Launch Day Procedures For Contacting FAA Contollers:

___ 1. Call Local ATC If any changes to plan filed with NOTAM.

___ 2. Call Local ATC immediately after launch.
*Inform of successful launch or if mission is scrubbed.

___ 3. Call Local ATC at Burst.
*Give location relative to Local Control Tower at Airport.
*Give Altitude of Burst.

___ 4. Call Local ATC if still in their airspace at 13000ft.
*Depending on the familiarity of the controllers, they may call you first
*Give location relative to Local Control Tower at Airport.
*Make sure they have contact phone number.
*May call for continuous updates until landing.

___ 5. Call Local ATC upon GPS indicated landing.
*Inform ATC the payloads have landed.
*Give location relative to Local Control Tower at Airport.
*Thank the ATC controllers for their assistance.

BOREALIS Flight Director Checklist
Flight Number BOR____________

Preflight Planning

___Weather Checks Completed
___Balloon Track Prediction Okay
___Launch Site Confirmed
___Vehicle Rental
___Chase Team Personnel Totals
___Gas Cylinder Transport Arranged
___NOTAM Filed

Preflight Systems

___Gas Fill Team
    ___Balloon Available
    ___Full Helium Cylinders***QTY___
    ___Equipment Ready
    ___Flight Crew Available

___Imaging/Cameras
    ___Cameras Functioning
    ___Film/Memory Available
    ___ALL Batteries Charged
    ___Flight Crew Available

___Communications
    ___Radios Functioning
    ___Laptop Functioning
    ___Batteries Charged
    ___Power System Ready
    ___Flight Crew Available

___Tower/Hardware
    ___All Flight Boxes in Good Condition
    ___Connection Hardware in Good Condition
    ___Tower in Good Condition
    ___Flight Crew Available

___Payload
    ___Experiment in Working Order
    ___Experiment Data Collection Working
    ___Flight Crew Available

___CPU

    ___CPU Functioning Properly
    ___Data Collection Stream Resolved
    ___Flight Crew Available

___Mission Approval From Project Director

Gas and Balloon Checklist – ver. 1.03, 6/13/04

1. Before Leaving
    a. Stack and Parachute weight: ___________________ lbs
    b. Desired Lift (1.2(a + (Balloon Mass lbs))-Balloon Mass): ____________________ lbs
    c. Check gas level in cylinders to be used.
    d. Place equipment in Transport Automobile.
        i. Ground Cloth
        ii. Weights for ground cloth
        iii. Handling gloves
        iv. Kneepads
        v. Gas
        vi. Regulator
        vii. Hose and Filler Assembly
        viii. Fish scale
        ix. Safety Goggles
        x. Tool Kit
        xi. Balloon

2. At Launch Site
    a. Place Ground Cloth on ground with no sharp objects (weight down corners and put down knee pads).
    b. Attach regulator to cylinder #1.
    c. Make sure regulator output closed (full CCW).
    d. Note Initial pressure of Cylinder #1: _______________psi
    e. Put on handling gloves.
    f. Place balloon on Ground Cloth, inspect for damages.
    g. Tape Lift Gauge loop to Filler Assembly.
    h. Place balloon Nozzle over Filler Assembly.
    i. Clamp or Tape balloon Nozzle onto Filler Assembly.

j. One person should be holding the balloon Nozzle, one person operating the regulator, one – two people guarding the balloon.
k. Begin inflation (use regulator to begin slowly and increase fill rate as balloon takes shape).
l. When cylinder #1 reaches ~100 psi close regulator output.
m. Record cylinder #1 pressure: ______________ psi
n. Pinch off balloon Nozzle.
o. Shut off cylinder #1 valve.
p. Move regulator to cylinder #2.
q. Open cylinder #2 valve.
r. Record cylinder #2 initial pressure: ________________ psi
s. Open Regulator.
t. Release Pinch on balloon nozzle, continue inflation.
u. When appropriate connect fish scale to loop.
v. Carefully let go of balloon nozzle while someone holds fish scale.
w. Take several readings and roughly average in your head.
x. When desired lift achieved, close regulator.
y. Record final pressure of cylinder #2: ______________ psi
z. Close cylinder.
aa. Optional, throw catch over top of Balloon for security.
bb. Tape load loop to balloon Nozzle with small piece of tape.
cc. Pinch off balloon Nozzle.
dd. Twist balloon Nozzle
ee. Duct Tape balloon Nozzle.

3. Notify Launch Tower Team that you are ready for connection to payload.

Power/Communications Pre-Flight Checklist

(rev. 3 13 June 04)

__C) Connect flight GPS antenna to GPS unit (before power-up)

__C) Connect flight GPS to flight TH-D7
P) Connect battery pack power board.

__C) Connect flight TH-D7 to flight antenna

__P) Connect flight TH-D7 to power board

__P) Connect flight GPS to power board

__C) Power on both flight and ground TH-D7
P) Connect camera to power board

__C) Set flight TH-D7 to communicate with flight GPS
P) Power on camera (camera power switch)

__C) Set flight TH-D7 to transmit APRS on 144.390 MHz (beacon mode)
P) Connect timer circuit to power board

__C) Turn off flight TH-D7 auto shut-off (menu 1-2-2)
P) Connect timer circuit to camera

__C) Check for reception of APRS packets with ground TH-D7
P) Verify other scientific payload power up

__C) Confirm APRS packet GPS coordinate functioning properly with on site handheld GPS
P) Connect BATS GPS antenna to GPS

__C) Lockout keypad on flight TH-D7 (hold "f" key for 1 second)
P) Connect BATS GPS to BATS Tiny Trak III

__C) Secure TH-D7 with Velcro straps (2)
P) Connect BATS Tiny Trak III to BATS VX-2R radio

__P) Connect BATS VX-2R to BATS Antenna

__P) Connect BATS LiIon Rechargeable batteries to BATS power connector

__P) Connect 9V Lithium battery to BATS Tiny Trak III power connector

__C) Ensure BATS startup and correct frequency ________________MHz

__C) Ensure BATS transmitting with ground TH-D7

__C) Ensure both GPS antennae is secure on inside panel

__C) Fill capsule with Styrofoam peanuts

__C) Place lid on capsule and place GPS antenna in pouch

__C) Close and secure Nylon casing

__C) Perform second check of APRS (both Primary and BATS) on TH-D7

__P&C) Inform flight of “Launch Ready Hold”

__P&C) Crew move to “non-interfering positions”

__C) Final check for reception of APRS packets

__P&C) Inform FLIGHT “Go for Launch”

__P) Team lead assist in tower separation

__C) Start logging APRS packets on laptop

Checklist for Cosmic Ray Monitoring on a BOREALIS flight:

Terms:

HP 200LX: The small blue-gray palm PC
RM-70: Small beige box with a geiger counter mounted on the top
RM-70 to 200LX cable: Short black cable with a phone connector on one end and special 200LX connector on the other.
200LX to PC cable: Long black cable with a special 200LX connector on one end and serial connector on the other.

At least one week before launch: (for first time users)

- ☐ Acquaint yourself with the monitoring software on the HP 200LX and BOREALIS Lab PC by using the commands listed under "Near launch time."
- ☐ Acquaint yourself with the format of the ASCII files output by the monitoring software. A sample output file is attached along with instructions on how to read it.
- ☐ Write some code that will read the ASCII files and make a few plots. You may need help with this.
- ☐ Practice transferring files back and forth between the 200LX and BOREALIS Lab PC by using the commands listed under "Within a few days after launch."
- ☐ Make sure that you have an account on a public computer somewhere that you can FTP files to. If you are affiliated with the Physics department, speak to Jeremy Gay (jgay@physics.montana.edu) if you aren't sure.
- ☐ Buy two AA batteries or find two UNUSED AA batteries.
- ☐ Buy/find a usable chemical hand warmer pack.

At least one day before launch:

- ☐ Grab the gray foam pad labeled "7" from the BOREALIS lab (it will be somewhere near the BOREALIS launch tower) and place zip ties into the correct holes to secure the 200LX, RM-70, and RM-70 to 200LX cable. You can tie down the RM-70 and cable, but don't tie down the 200LX right away. Use the attached diagram as a guide. You may have to use several zip ties for one loop.

At least a few hours before launch (at MSU):

- ☐ Place the chemical hand warmer pack, foam pad, 200LX, RM-70 and RM-70 to 200LX cable in one of the payload modules and assist the BOREALIS crew with a mass measurement.

Near launch time (at launch site):

- ☐ Replace the batteries in the 200LX with the two new batteries you purchased/acquired a week ago or so.
- ☐ Connect the 200LX to the RM70.
- ☐ Turn on the 200LX. If a DOS prompt shows up, ignore the next six steps.
- ☐ If an appointment book announcement pops up, press ENTER to say OK.
- ☐ Press the blue &… (MORE) key.
- ☐ Press the dark blue MENU key.
- ☐ Press ENTER to open the Application menu.
- ☐ Type t to Terminate All
- ☐ Press ENTER to say OK
- ☐ After the DOS prompt comes up, change your directory to C:\AWARE. Help on a few basic DOS commands is attached.
- ☐ Type aw-srad and press ENTER to launch the radiation monitoring software.
- ☐ Arrow over to Capture and press ENTER.
- ☐ Press ENTER again to select Display Current Input.
- ☐ Specify the file name. It should follow the form: C:\AWARE\MM-DD-YY.dat, where MM-DD-YY is the current month, day and year. Press ENTER to confirm.
- ☐ In the message box, type the number of the current balloon flight. It should follow the form: Data for balloon flight BORYYMMF, where YYMMF stands for year, month, and flight number (A, B, C, etc.). Press ENTER to confirm.
- ☐ Make sure that the data logger is taking data from the RM-70 every ten seconds. If not, start over and try again.
- ☐ Close the viewscreen on the 200LX; the data logger will continue to run even with the viewscreen closed.
- ☐ Firmly secure the 200LX using the zip ties you've already placed in the foam pad.
- ☐ Place the foam pad with its secured components into the payload module. Cover the equipment with a layer of peanuts and place the activated chemical hand warmer on top. (If the hand warmer isn't too hot, the layer of peanuts isn't necessary.) Fill the remaining space with packing peanuts. Secure the payload module with the assistance of tower.
- ☐ Inform flight that you are ready.

Immediately after retrieval:

- ☐ Open the payload module and get out the foam pad with attached components.
- ☐ Cut the zip-ties holding the LX200 and open the viewscreen.
- ☐ If the viewscreen is so cold that it appears black, gently and SLOWLY warm the 200LX until the screen clears.
- ☐ Press ESC, then press F2 to terminate data taking.
- ☐ Press ESC to exit the Capture Data window.
- ☐ Arrow over to Quit, press ENTER. Select YES to confirm.

Within a few days after launch:

- ☐ Cut all the zip-ties on the foam pad and retrieve the equipment. Return equipment to appropriate locations.
- ☐ Connect the 200LX to BOREALIS Lab PC using the 200LX to PC cable.
- ☐ On the 200LX, press the button with a file folder symbol on it, labeled FILER. This button will not work if you are in DOS mode. To exit DOS mode, type 200 at the DOS prompt and press ENTER.
- ☐ Go to BOREALIS Lab PC and open a DOS prompt (a quick-launch button is set up next to the start button on the start bar).
- ☐ In DOS, change your directory to C:\cpack200.
- ☐ Type app200 to launch the file transfer program.
- ☐ Press the Enter key to select FILER.
- ☐ Press F7 to split the screen.
- ☐ Press F6 to connect to the 200LX.
- ☐ In the remote connection screen, use the up and down arrows and the Enter key to change your directory to C:\AWARE on the 200LX. In the local connection screen, use the up and down arrows and the Enter key to change your directory to C:\AWARE on the BOREALIS Lab PC.
- ☐ In the remote connection screen, select the data file you took by pressing the space bar once the file is highlighted.
- ☐ Press F3 to move the selected file from the remote (200LX) to local (BOREALIS Lab PC) computer.
- ☐ Once the file transfer process is complete, press F10 to disconnect the BOREALIS Lab PC from the 200LX.
- ☐ Press Alt to open the Menu Bar, press ENTER to open File, type x to exit the FILER.
- ☐ Press Alt to open the Menu Bar, press Enter to open Application, type x to exit the file transfer software.
- ☐ Disconnect the 200LX and BOREALIS Lab PC, turn off the 200LX.
- ☐ At the DOS prompt on BOREALIS Lab PC, go to the C:\Aware directory.
- ☐ Type aw-srad.
- ☐ Press Enter to open the Display window.

- [ ] Arrow down to Make ASCII Spreadsheet File and press Enter.
- [ ] Select your data file and press Enter.
- [ ] Select Yes to include the data bar.
- [ ] Enter 1 for the horizontal time compress.
- [ ] Select Straight Value Points for the Point Display String.
- [ ] Select No to not add the date and time after every data point.
- [ ] Tell the software where to put the text file. It should follow the form: C:\Aware\MM-DD-YY.txt, where MM-DD-YY is the date on which you took the data.
- [ ] Select No to not add an Output File to the bottom.
- [ ] Select No to not include the Initialization String.
- [ ] Press Esc to exit the Display window.
- [ ] Arrow over to Quit, press Enter, select YES.
- [ ] Exit from the DOS prompt by typing exit at the DOS prompt or by clicking on the X button in the upper right corner of the window.
- [ ] In Windows, open WS-FTP to transfer files from the BOREALIS Lab PC to the public computer that you have file space on. There is a quick-start button for WS-FTP next to the start button on the start bar.
- [ ] Change the profile name to your last name, type the name of the server you wish to connect to and click on OK. At the prompts, enter your User ID and password.
- [ ] Transfer the data and text files to your account on the public computer. You may need help with this.
- [ ] Delete all data and text files that YOU made on both the 200LX and the BOREALIS Lab PC. You can do it in the 200LX in the filer and on the PC in Windows Explorer. You may need help with this.
- [ ] Run your programs on the text file you made and make a few plots.

Launch Tower Operations Checklist

Ver1.02, 6/6/01

- ❑ Locate launch tower on level surface and secure with sand bag
- ❑ Layout balloon filling station approximately 15 feet or 5 paces away from the launch tower
- ❑ Connect extension arm to launch tower
- ❑ Check status of lines connecting the two capsules. Connected? _________ Frayed? __________
- ❑ Connect antenna and assure antenna is safely tucked into tower (between sides), where no one will step on it.
- ❑ Connect shroud ring to capsules
- ❑ Layout parachute and separate lines, then connect lines to shroud ring
- ❑ Place ring on extension arm and raise it up
- ❑ Give go to Payload and Communication Teams
- ❑ Connect parachute to line separator
- ❑ Lightly attach line separator to ground using a stake
- ❑ Thread lanyards through the line separator
- ❑ Connect balloon line to the line separator
- ❑ Place construction tape along lines so people are more likely to see them on the ground
- ❑ Wait for go ahead from Flight Commander
- ❑ Connect to balloon
- ❑ Obtain four people as lanyard operators
- ❑ Balloon is now allowed to rise
- ❑ Activate sonic beacon
- ❑ Release retaining clips from launch tower
- ❑ Pull payload free from launch tower
- ❑ Wait for release command from Flight Commander
- ❑ RELEASE PAYLOAD when balloon is directly overhead and pulling on the payload

APPENDIX F: Getting Started with the TH-D7A

Instructions for FLIGHT radio:

1) Attach the power supply and antenna, then push the power button
2) Select the desired frequency by using either the knob located on the top of the unit or by pressing the ENT key followed by the numbers on the keypad indicating the frequency desired

   -If, for example, you are using the 70cm band, you must select the frequency on the lower of the two frequency bands available. To easily see this, press the DUAL key, and both will show up. Then press the A/B key to move the triangular cursor to either the lower or upper frequency band. The upper selector will allow you to select the 2m band, and the lower either the 2m band or the 70cm band

3) Select the desired output power level (H, L, EL) by pressing the F key, followed by the MENU key.
4) Press the MENU key:
   a) By using the knob located on the top of the unit and the OK button, select menu 1-2-1, and turn APO (Auto power off) to OFF
   b) Menu 1-4-1, and select which band you wish to be the data band
   c) Menu 2-1, and enter the call-sign that will be flying in the balloon
   d) Menu 2-2, and select NMEA for the GPS unit if using the Garmin GPS25-LVC
   e) Menu 2-D, and select the desired interval between packets sent

5) Plug the GPS unit into the GPS port on the TH-D7A. The GPS unit should be powered on before doing so, and the antenna on the GPS unit should be attached. The TH-D7A will take a few seconds to recognize the new data coming from the GPS unit. Once it beeps, you can hit the POS key to see if the radio is in fact receiving current GPS information. If it is, the degrees symbol as well as the period in-between the minutes numbers will be blinking. If they are not blinking, then either the connection is faulty, the NMEA setting in menu 2-2 wasn't set, or the GPS is not powered on.
6) Press the TNC button. A large D should appear next to the data band that was selected in menu 1-4-1. Located at the top of the display should be a bar with TNC written in it. If there is also a PACKET written across the top, press the TNC button twice, as this is the PACKET mode that is used to communicate with a computer.
7) Next press the BCON button, and a BCON indicator should appear at the top of the screen.
8) If everything else is set and ready to fly, depress and hold (for approx one second) the F button. A symbol that resembles a key should appear at the top right corner of the display. This ensures that the rest of the keypad is locked for flight, should the radio be bumped by some other device during a bit of turbulence.
9) Your radio is now ready to fly!

APPENDIX G: Getting Started with the TM-D700

1) Attach the power supply, antenna, screen, and talk unit and power on
2) By depressing the two knobs located in the lower right corner of the screen unit, you can change which band you are selecting. By pressing F, then one of the knobs, you can change which frequency range the particular band is on.
3) Use the large knob to adjust the frequency on the present band, or by using the keypad on the talk unit, press A, then the numbers of the frequency you wish to select.
4) Press the button beside the MNU indicator:
    a) Using the large knob located in the bottom left corner and the ok/back buttons, select menu 1-6-1, and select the desired data band.
    b) Select menu 3-1, and enter the call-sign of the operator
5) While the band you selected as the data band is in focus, press and hold the F key for about one second, release, then press the TNC button. TNC APRS should appear at the top of the screen. If it does not, repeat this step until it does. TNC APRS will allow the TM-D700 to decode any incoming APRS packets on the frequency selected. TNC PKT will allow these packets to be sent to and APRS software you are running, if you have the TM-D700 attached to a computer running such software.
6) The larger knobs located at the base of the two knobs in the bottom right corner are to set the squelch level on the respective bands. Turn these counterclockwise until you hear static, then turn them back clockwise until you hear none.
7) The two knobs located at the lower right corner of the screen unit can be turned to control the volume of their respective bands.
8) Your radio is now ready to receive voice or packet information!

Appendix H: BOREALIS Auxiliary Tracking System (BATS)

The BOREALIS Auxiliary Tracking System (BATS) is a recent development for our command module. BATS is designed to provide a low power APRS beacon for an extended period of time, at least 18 hours. This provides a backup to the main APRS beacon in case of a failure and also allows extra time for a recovery team to get to the payloads before they have no more position reports if the payload should land in mountainous terrain or far from the team. While providing this redundancy, the system also had to mass as little as possible and take up a minimal amount of space.

To this end, we selected the Yaesu VX-2R radio, Tiny Trak III TNC, and the Garmin GPS15L GPS receiver with an active antenna. This system is fairly straight forward to assemble and only requires two voltages. Power is provided by two of Rose Battery's LiIon 4000 mAhr, 3.6 V rechargeable battery packs in parallel for the radio and GPS. A single 9V Lithium disposable battery provides power for the TNC. This power arrangement was chosen so the system would have no efficiency losses due to converters.

The system can be assembled quickly from the datasheets and user manuals that come with each of the main components. Additionally, only a connector for the power needs to be built and so there is no significant board layout to accomplish.

The Yaesu VX-2R was chosen for its small size and fairly high power for a miniature handheld radio. Operating from the LiIon batteries, the radio can output a maximum of 1.5 W on the 2m and 1.0 W on the 70 cm bands. This power is more than sufficient to receive signals from the balloon with a good antenna and radio. The VX-2R is also well suited for balloon flight with its small size and simplicity in design.

The GPS15L is a WAAS enabled GPS receiver core. This minimizes the mass and power consumption but requires the use of a computer to set the GPS. The WAAS allow the GPS to have a maximum accuracy of 3m. This GPS is used with a Garmin active antenna for the best performance. See the Garmin website for the best antenna to use with the GPS at the time you purchase one. The GPS15L also cheaper and lighter with fewer features than the GPS25LVC that is used with the primary beacon.

Figure H1: Yaesu VX-2R

The Byonics Tiny Trak III is a small simplified TNC. It is designed to interface the GPS to a radio. This is its only function as it is not designed to receive and decode packets. This makes it ideal for use with a balloon beacon as it is minimal mass and excess function. The Tiny Trak III is available as a kit or ready made. A nice feature of the Tiny Trak III and the GPS15L is the mounting holes are nearly aligned and so they can be bolted together.

Figure H2: ←Garmin GPS15L
Figure H3: Tiny Trak III →