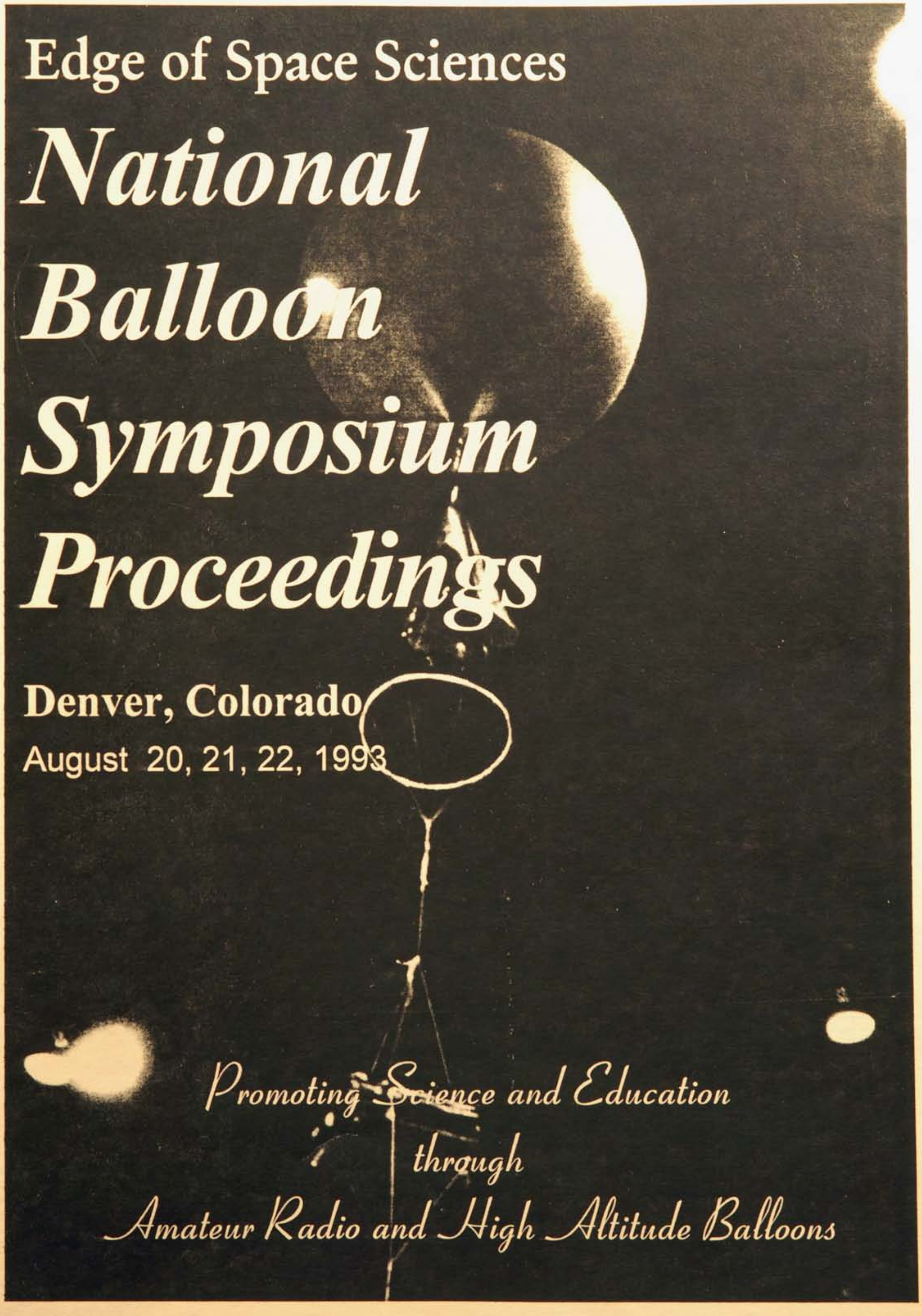

Edge of Space Sciences

National Balloon Symposium Proceedings

Denver, Colorado

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Promoting Science and Education

through

Amateur Radio and High Altitude Balloons

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From the President of E.O.S.S.

Jack Crabtree, AA0P

On behalf of Edge of Space Sciences (EOSS), I would like to welcome you to the National Balloon Symposium. EOSS was formed and operates today to "Promote Science and Education Through Amateur Radio and High Altitude Balloons." We share a common belief, that balloons and balloon platforms are important contributions to education and science. The National Balloon Symposium is dedicated to this theme.

The National Balloon Symposium is bringing together experts from the scientific ballooning field. The fields range from amateur radio groups and science clubs to educational institutions and the professionals, including, balloon and equipment manufacturers. My belief is that there is a need for a technical forum, to share information about our balloon programs and experiences and to also set groundwork for cooperative projects. This forum is the chief goal of the National Balloon Symposium.

The Proceedings of the National Balloon Symposium reflect the outstanding efforts of a number of people. First thanks to the writers, because without their unselfish contributions there would be nothing to share. The editorial staff also deserves our thanks. It was with a great deal of personal effort and sacrifice that these Proceedings were assembled into the fine document it is. Thanks to the ad sponsors you will find in the Proceedings. Their financial support helped to defray publication expenses. And to each of the individuals who helped finance the Proceedings, thanks to you all also.

I am confident that when you leave the National Balloon Symposium you will have made new friends, learned about balloon applications and experiences you have yet to dream about. I hope you were able to share some of your thoughts,knowlege and experiences with others. This is what will make the National Balloon Symposium a success. Whether there will be a National Balloon Symposium next year and the years after depend on you and your organizations. I hope this is the first of many symposiums to come. I envision a different group, whether a club or an university or even a balloon manufacturer, to host a National Balloon Symposium each year. This way we can keep the knowlege pipelines open while spreading the effort required to host such an event.

To all of the National Balloon Symposium attendees and organizers, I give you a sincere welcome and thanks for your participation.

Jack Crabtree, AA0P, President, Edge of Space Sciences

Table of Contents

A Letter from the Chairman

What we have here is a vision. To see Edge of Space Sciences come into fulfillment and be a part of it has a wonderful experience for me.

I've watched EOSS members give unselfishly of their time and knowledge to the young people of their community. All of this interaction comes together during preparations for high school and college students space experiments. When I come away from these meetings the energy and excitement has me walking three feet off the ground.

This same kind of feeling emerged as the authors *PROCEEDING'S* papers came in for the National Balloon Symposium. The authors, who all put great time and effort into their submissions are to be congratulated for their efforts. The diversity of subjects allowed the Proceedings editing committee staff to lay out a story line for a balloon community using the balloon launch as a metaphor.

This first NBS *Proceedings* starts out with a bit of myth building. However, instead of being told around a campfire, these stories will certainly be shared around balloon launch and recovery sites. And just like myths, there's a bit of truth of what to do and what not to do if you are a part of this community. Then you get directions: how to build what will be useful, how and what to use to set your direction; how to figure out where you are; how to pass on the traditions to the young. Every community has a critical event and ours is no exception and of course the heroes return home to accolades from the community.

I ask you to read on, not only because of the quality of papers we have but because the editing staff has put an incredible amount of time in writing both the AUTHOR'S GUIDE, which was needed to help everyone deal with the various methods of submission, and the *PROCEEDINGS.* The *PROCEEDINGS* is a document that we are all very proud of. We hope you like what we tried to do as it's not like most proceedings papers.

We could not have accomplished the editing and layout that we did without the gracious support of Brian P. Bartee and George Westerberg of The File Bank Computer Bulletin Board, [redacted]. They allowed us to use the system to move our papers around electronically. I ask that you give them your support.

This first National Balloon Symposium has had the active support of a great many people who are listed on the inside of the front cover. My heartfelt thanks to everyone on every committee for the outstanding job that has been accomplished.

Also, support has not only been from EOSS. Colorado amateurs have a history of cooperation that is second to none. Many have given support during our balloon quests and you'll read about some of them. But, I want to especially thank the Colorado Repeater Association for all the repeater and link support they have given us.

To the northern part of the state thanks go to The Loveland Repeater Association for the use of their trailer for the ground station during the National Balloon Symposium launch Sunday.

But, most of all, thanks to all who have attended. We have tried to put this symposium together so we could share as a community to make what we do better. We hope this happens again as we all grow and develop.

I'd like to share with you the best thing I have heard about who and what we are as a balloon community. It happened during a TV interview of one of the teachers whose students were participating in a launch. The teacher said that it was so expensive to do experiments involving space sciences but that he was excited about the balloon launch because it was the poor man's NASA. Not a bad identity.

Sincerely,
Ann Marie Trudeau, KA0ZFI

Fantastic Flights Adventures in Ballooning

by

Bill Brown WB8ELK

Abstract:

An intro to government flights and radiosondes as well as description of the ups and downs of the first ATV balloon flight followed by hair-raising tales of flights from across the country.

Early Flights

The idea of sending radio equipment to over 100,000 feet on a balloon is not new. NASA, the military and the U.S. Weather Bureau have been doing it for years. NASA flights operate on a grand scale. Some of their balloons are 500 feet in diameter and take truckloads of helium to fill. Their usual payload is on the order of thousands of pounds (kind of like launching a small car). During the early 1960's, they even had a manned balloon program called, appropriately enough, Man High.

Large Balloons

It was the news accounts of one of these flights that inspired me to pursue my amateur balloon experimentation. Joe Kittinger actually rode one of these flights in a small open gondola to over 103,000 feet (he was wearing a pressure suit and oxygen tank). In some of the most dramatic film footage I've ever seen, he leaped out of the gondola and parachuted back to Earth. During his nearly 20 minute free-fall he became the first man to go supersonic without a rocket or plane (he was falling over 700 mph!).

I wanted to experience the sensation of riding a balloon to the edge of space and parachuting back, but there had to be a way to do this in a way that wasn't quite so risky! That's when I decided to put a live TV camera and ATV (amateur television) transmitter on a small payload and watch the action on my TV set from the comfort of my hamshack!

Radiosondes

Fortunately, the weather bureau launches a much smaller balloon system than the NASA experiments that is very practical for the amateur ballooning enthusiast to duplicate. Twice a day (1100 UTC and 2300 UTC) the bureau launches a 5-foot diameter rubber balloon that carries a 1-pound payload to over 100,000 feet. There are over 73 sites across the country that launch regularly (see Figure 1). The payload is called a radiosonde (or sometimes a rawinsonde - radio wind sonde). The radiosonde transmits a sequence of tones (some newer sondes send down computer ASCII data) that correspond to temperature, humidity and reference tones. Most sondes relay the atmospheric pressure by counting the changes in the tone sequence (as determined by a complex baroswitch (a modified aneroid barometer) with over 150 contacts. Some of the newer radiosondes relay pressure data from a continuous capacitative pressure sensor. The sonde transmits this data in wide-band FM mode (AM modulation is sometimes used) on 1680 MHz. Since the sonde transmitter is a free-running oscillator, the frequency can drift plus or minus 5 MHz during the flight. The launch site receives this signal using an eight-foot dish that provides them with azimuth and elevation readings that are accurate to 0.01 degree.

Since they know the balloon's altitude, the launch site's computer system can accurately determine the radiosonde position and calculate the wind speed and direction at any given altitude. After the flight, they send this data to a national center. The weather bureau center uses this information to give pilots their winds aloft prediction and helps forecasters predict the movement of weather patterns.

If you live within 150 miles of one of these radiosonde sites and have access to a wideband FM scanner that covers this frequency, you can actually track down and recover these payloads. Some receivers that work well for this are the AOR AR-3000, the ICOM R-100, R-7000 and the R-7100. A 14-element quagi antenna works well for pinpointing the sonde's position and is only 3 feet long! The typical flight lasts 2.5 hours and the batteries last about 5 hours. I've located, but never recovered, several radiosondes that were launched from Albany, NY and landed in New Hampshire (usually in deep woods or on the sides of mountains). During a recent trip to Ohio, I finally recovered one payload (launched from Dayton) that landed in a plowed field just 1000 feet off of the road. Tracking radiosondes is a lot of fun and a real challenge. It's also a great way to shape up your balloon chasing skills to prepare you for an amateur radio balloon payload hunt.

A number of hams are involved in radiosonde tracking. Reiner Junge DC3OQ/W5 of El Paso, Texas has located over 40 radiosondes over the past few years and Mike Bogard KD0FW has tracked down 9 radiosondes in the Independence, Missouri area.

The First ATV Flight

I patterned my first balloon system after the weather bureau radiosonde system. The weather bureau balloon (approximately 5-foot inflated diameter at sea level) and appropriate parachutes were readily attainable (and reasonably priced).

My first payload was a test to determine the range a 1-watt ATV transmitter and an omni-directional antenna would provide. From 100,000 feet, I calculated that it was possible to view the TV signal from upwards of 400 miles away from the balloon's location.

The payload consisted of a 1-watt KPA-5 ATV transmitter from P.C. Electronics, an Elktronics VDG-1 video ID board with 4 computer graphic screens, an EPROM CW ID and a surplus 50 milliwatt 2m FM transmitter. The ATV antenna was a turnstile and the 2m antenna was a 1/4 wave groundplane.

In order to keep the weight of the payload under the 6-pound FAA limit, I resorted to mounting all of the modules on a single sheet of PC board material and surrounded everything with 1-inch thick styrofoam (to insulate against the -60 degree C. temperatures at the tropopause (approx. 40-60,000 feet). Fortunately, lithium batteries were available at a fairly reasonable cost. Lithium batteries are ideal for this kind of payload, since they provide the best capacity per weight and work well at low temperatures. The SAFT (or equivalent) D-cell (LX3457) and the C-cell (LX2649) have performed well for me in most of my flights. A very good source of SAFT lithium cells is Avex Portable Battery (they will also assemble custom packs to your specs for a small additional fee) at (800) 345-1295. Surplus 10-cell packs of the D-size SAFT cell are also available from S & G Photographic Equipment at (215) 474-7663.

I was not aware of the above sources for large lithium cells until later, so I chose Polaroid 6-volt flat pack cells (2 sets of 6 cells in parallel). They were certainly lightweight but didn't have the capacity I needed.

My final payload weighed 2 lbs, 8 ounces. Since the parachute weighed about 3 ounces, the balloon needed to lift at least 2 lbs. 11 ozs.

I decided to use the Kaysam 90G (the same as used by the weather bureau - the Totex TA600 is equivalent). We rented a small tank (80 cu. ft.) of helium at the local gas supply house and devised a filling hose out of PVC pipe. We were ready (or so we thought!).

How NOT to Launch a Balloon

I decided to launch the ATV package on my birthday, 8/15/87.

The world's largest birthday balloon! We all assembled at the farm of George Flinchbaugh WA8HDX (near Findlay, Ohio) and started to fill up the balloon. Our first problem occurred when we found out that our filling hose wouldn't fit the balloon nozzle very tightly. After pumping the entire contents of the tank into the balloon (and losing enough helium into the barn to raise our voices slightly), we attached a fishing scale and measured 2 lbs. 3 ozs lift. Hmmmmm, the payload and parachute were 8 ozs heavier than that . . . Ooops!

Since dozens of hams were waiting patiently across the Midwest (most listening to the 40 meter net for launch updates), we scoured the city of Findlay for another tank of helium. We quickly learned that gas supply houses are not open on weekends! We finally found a party supply store that let us have their half-full tank (at an exhorbitant fee). We gleefully returned to the launch site with the tank in hand (and a thinner wallet). We hooked up the balloon and started pumping more helium. It didn't last long, their half-full tank was more like a quarter tank! After we completely emptied the tank we could now lift 2 lbs. 13 ozs, giving us just two ounces of positive lift.

Mel Alberty KA8LWR and Tom Miller rescue the "Moon Balloon" payload (so named since it was launched from Neil Armstrong's hometown) from a tall cornfield nearly 1.5 miles from any road.

As we brought the balloon and payload out of the barn, we noticed that Mother Nature had added another obstacle. Although there was a dead calm for most of the morning, by the time we were ready to fly, the wind had kicked up to 15 MPH or more.

I reeled the balloon line out and let the payload go . . . then CRASH . . . the payload landed about 20 feet away in the soy beans and dug in like an anchor with the balloon flailing around like a kite in the high winds. It took two more tries before the package slowly took off and barely cleared a tall cornfield by about a foot. The ascent rate was only about 500 feet/min due to the small positive lift. Everything worked perfectly for the first part of the flight. At 50,000 feet, we had a snow-free ATV downlink from a distance of 20 miles. They even had a good picture in Chicago at 250 miles (not bad for a 1-watt transmitter). Then at 60,000 feet everything started to go haywire, the ATV transmitter died completely and five minutes later the 2 meter transmitter died. Apparently the batteries had given up. Fortunately, it was an incredibly clear day and we could see the balloon from the ground (as well as from Jim WA8VWY's chase plane). After visually tracking the balloon for 3 hours, we even saw the balloon disappear from the sky as it burst. However, we weren't close enough to see the parachute descend and lost the package.

Six weeks after the flight, I received a phone call from a farmer who lived 26 miles to my north. He said he had found a strange package in his soy bean field that had my name on it. He initially thought it was a bomb until he saw the large reward sign (A reward sign is always a good idea if you want to see your payload again. It's worked for me on many occasions). It turned out the payload had landed just 3 miles north of our search area.

After evicting a spider who had made his home inside of the payload, I plugged in another battery pack and everything still worked perfectly!

We certainly learned a lot from this first flight. Always have twice the helium than you think you need, use a battery pack that will give you at least 6 hours of life, let go of the balloon upwind of the payload and make sure your reward sign is large and visible.

Ludicrous Liftoffs

Since this first flight, I've launched 23 more balloon payloads. In addition, many flights have been made by balloon groups that have been popping up all over the country (and world). Each flight always provides everyone involved with incredible tales of hair-raising liftoffs and seemingly superhuman recovery efforts.

Following are some liftoff stories that will make anything else seem tame by comparison. These stories demonstrate that the apparently delicate weather balloon is usually tougher than you might think:

GREENSBURG, INDIANA (W9PRD - 6/4/88):

This was the first in a series of Indiana ATV balloon flights built by Bob McAuliffe W9PRD. Everything went smoothly until the balloon was in position for takeoff. Just one minute before takeoff, the previously light wind kicked up to over 25 MPH blasts (Mother Nature apparently knows exactly when a balloon is being prepared for liftoff). The balloon stretched out nearly 20 feet long and looked like a thin amoeba-like cigar. Clear bubbles of superstretched balloon billowed up throughout the balloon as the launch crew hung on with all their might against the wind. The balloon survived and, as Mother Nature took a deep breath, they were able to launch during a brief calm period. The flight made it to over 110,000 feet.

Larry Oaks WB9YAJ makes an easy recovery of W9PRD's payload. It was located just 100 feet from a road, stretched across a driveway.

CHAMPAIGN, ILLINOIS (KA9SZX, KA9SZY, N8IYD & WB8ELK - 10/4/88):

This was an expensive payload which included a live TV camera, flight computer with video telemetry overlay and a servo activated mirror. Once again, light winds prevailed until just before liftoff. Then wind gusts approaching 20 MPH stretched the balloon out to ridiculous proportions. Although the team attempted to let the balloon go upwind of the payload, a wind shift caused the delicate payload to smash into the ground (I had treated this payload like it was a carton of eggs in launch preparation). The payload bounced off of the ground, and narrowly missed Debbie KA9JYI who was videotaping at the end of the field. Amazingly everything survived and the payload worked great throughout the flight (although part of the ATV antenna was bent over at a 45 degree angle).

KANSAS CITY, MO (KD0FW):

Mike Bogard KD0FW walked his balloon system out onto a hill during what appeared to be a 30 MPH continuous wind. They were actually able to launch the payload without hitting the ground by keeping everything perfectly in-line with the wind ensuring that the flight train was held taunt.

DAYTON, OHIO (W8BI DARA#2):

Dave Pelaez AH2AR/8 was nearly done filling a Kaysam 105G. A perfect morning with absolutely NO wind. Dave turned to smile for the video cameras. Suddenly there was a large BANG, and Dave's smile quickly turned into a frown as bits of the balloon dropped around him. A defect in what appeared to be a normal balloon caused it to burst. The burst was videotaped from several vantage points and is fascinating to watch in slow motion! Their second balloon worked perfectly.

KNOXVILLE, TN (WA4ADG/N4HBO):

Carl Lyster WA4ADG built a small 10 milliwatt beacon and installed it in a plastic egg (the type that panty hose come in). They launched it with 60 party balloons! It flew for several hours with reception reports coming in from over 100 miles away.

HILLSBORO, WISCONSIN (WB9SBD):

Joe Mayenschein WB9SBD and Tim Tomljanovich K9SB thought they had measured their balloon's lift accurately. As they let go of the payload, they noticed that the balloon was not climbing. It went up 20 feet, leveled out and headed across the farm. After chasing it for a couple hundred yards, it rammed into a barn. Just as Joe grabbed the payload, the barn roof cut through the string and bye, bye balloon!

HOUSTON, TEXAS (BLT Group):

The Balloon Launch Team of the Houston area, let their ATV balloon go from an airport taxiway. The payload headed directly towards one of the hangars and smashed into the side of the building (the Civil Air Patrol hangar of all places!). Although the balloon appeared damaged, it still managed to take off before anyone could grab it. It made it up to about 20,000 feet before bursting and the payload landed 8 miles away. They dusted off the payload and flew it again that same day with excellent results.

FRANKLIN, IN (WB9IHS):

This was the 3rd flight for the Franklin Community High School's Aerospace Technology Class. On board was a package carrying two color TV cameras (transmitting on 439.25 MHz) and a separate payload with a telemetry system on 29.6 MHz FM (designed by Chuck Crist WB9IHS and John Lutz N9JL). During liftoff from the school grounds, the payload caught on some power lines. After 45 minutes of watching the balloon whip about, a power company worker came out and climbed the pole. Just as he was about to turn the power off, the 10 meter package shorted out the line which charred all of the electronics inside. Fortunately, the ATV payload was unscathed and was launched shortly afterwards.

DENVER, CO (EOSS):

This was a flight of a large zero-pressure balloon carrying a student solar telescope experiment (dubbed the Humble 1) and a delicate network of supports for various antennas. During liftoff in a moderate wind, the balloon headed out in front of the payload handler. The payload smashed into the hard pavement of the parking lot. Everyone cringed as the delicate payload scraped along and hit a snow drift at the end of the lot. The payload actually used the snow drift as a ski jump and leaped up into the air. Although the package tilted at a precarious angle, it functioned well during the ascent. After activating the solar camera experiment, the current surge caused the flight computer to glitch and all transmitters except the 10 meter CW beacon shut down. Fortunately, the cutdown system was activated during the glitch and the payload was found hours later by tracking the 10 meter beacon.

DENVER, CO (EOSS):

During a recent mission, variable winds during inflation made it difficult to measure lift accurately. After liftoff, the payload leveled off at 5 feet altitude, dragging their film camera across the ground. The balloon flew across a highway and a hole or two at a nearby golf course (mind if we play through?) before Dave Clingerman's (W6OAL) candelabrum antenna caught on a storage shed. At least we know the candelabrum makes a good anchor! The view from the on board video camera was quite dramatic. The film camera didn't fare so well as it was drug through a water hazard or two on it's trip across the golf course.

FRESNO, CA (WB8ELK):

As part of the Fresno Hamfest, we put together a TV payload that included a Magellan GPS receiver that would display the balloon's position as a video overlay. Thanks to the publicity of the hamfest committee, a large crowd of hams (including Barry Goldwater K7UGA) had gathered on the 40 meter net awaiting the launch. Members of the Southern California T-Hunters had driven in excess of 250 miles to participate in the chase. As I looked through the boxes I had sent from New Hampshire, I noticed with horror that the box with the balloons and heavy-duty string had not arrived (the shipping department sent this box UPS ground instead of 2nd Day Air as I'd requested). Fortunately, I had a large and fairly expensive zero pressure balloon with me but no string. One of the hamfest committee went out in search of string and finally found what appeared to be fairly light duty, but acceptable stuff.

We received clearance from the tower and walked the balloon out to the taxiway. As we let go of the balloon we heard a SNAP as the string broke at the radar reflector. It was quite a sight to watch a $220 balloon head into the sky all by itself as I held the payload (I now know what the expression "Left holding the bag" means). It turned out I could easily break the string with my hand with only moderate effort. We considered filling up a couple hundred party balloons, but thought better of the idea!

Ridiculous Recoveries

The recovery process has to be the ultimate foxhunt. No one knows for sure exactly where the payload will end up. The payload could land right next to a road in someone's front yard, or miles inside a forest in the top of a tree. Sometimes, you may even have to fend off grazing cattle to rescue your package. The chase and search often gives your group a lot to talk about for quite some time. The following are a few of the more amazing recoveries:

GREENSBURG, INDIANA (W9PRD - 10/4/88):

This was the third balloon flight and carried an ATV and 2m FM transmitter. It was a perfectly still morning and the balloon was simply reeled out over the payload. As the payload parachuted back to Earth, it became clear that it would land in some of the most rugged terrain of northern Kentucky. As we closed in with only a hint of signal from the tops of hills, we suspected that it was hidden deep in the sparsely populated hills in the region. Suddenly, Larry Oaks WB9YAJ topped a rise near the town of Sugartit, KY and received an very strong signal. Incredibly, he was able to visually spot the payload stretched out neatly across a driveway just 100 feet from the road. Seven vehicles ended up in the drive as we all marvelled at the incredibly fortunate landing site in this isolated region. No one was home, but I'm sure the neighbors asked about the party in their driveway.

INDEPENDENCE, MO (KD0FW):

Paul Bohrer W9DUU and Larry Oaks WB9YAJ saw the parachute on this payload just before it landed about 2 miles away. They found it way up in a tree near the town of Peculiar, Missouri (balloon payloads apparently like to land near unusual towns - see the town in the previous story). The landowner thought the had a way of bringing the payload down from the tree. He returned with a shotgun and peppered the tree and the package with numerous shots to no avail. They finally used a rock and string arrangement with success.

HANCOCK, NH (WB8ELK - 7/7/90):

This was a small 10 milliwatt 2m CW transmitter with altitude telemetry. Although the foxhunters thought it landed in the metro Boston area, they never could relocate the low power signal . . . Meanwhile Mike Cox was cruising around Boston Harbor in his motorboat. As he approached the lighthouse, he noticed a bright orange parachute and package descending from the sky which splashed into the ocean just 10 feet from his boat. He fished the package from the sea and was surprised when it started beeping at him (a Radio Shack audio beeper was on the bottom of the payload and underwater when it first landed). Thinking it was a bomb, he threw the package right back in the ocean. Then he noticed the REWARD sign and decided to risk bringing it back on board. Except for a little corrosion on the telemetry circuit, the payload was in good shape after it's brief water landing.

DAYTON, OH (W8BI DARA):

Launched from an actual radiosonde site, this was the second DARA (Dayton Amateur Radio Association) flight. Since we had detailed data from the morning radiosonde flight, we thought we could predict the landing point with some accuracy. Larry Oaks WB9YAJ and several other vehicles chased out after the slow moving balloon. As the package descended below 1000 feet, they could see the road they were on via the ATV downlink. Larry watched as the package hit the ground just 100 feet in front of his car. The payload was recovered in under 1 minute. The computer prediction using BALLTRAK was off by just 100 yards, we had the nearest intersection circled on the map just before liftoff.

SALINA, KS (WB0DRL):

This was a 2m packet beacon system which included a film camera taking a photo every 10,000 feet. The payload was designed with struts to hopefully allow the payload to land upright. The payload landed just 20 feet from the nearest chase team member. Although he was close enough to actually catch the package, he let it hit the ground to test out the landing gear concept. It worked perfectly!

DENVER, CO (EOSS - Humble 2, 5/30/92):

After reaching altitude, this large zero-pressure balloon failed to respond to the cut-down command (the firing cable connector had pulled loose during the flight). It flew most of the night and finally landed about 5 a.m. in Nebraska after travelling over 240 miles. The dedicated (and exhausted) chase crew kept under it throughout the lengthy 18-hour flight and was able to recover the payload.

FRANKLIN, IN (WB9IHS):

As part of their Aerospace Technology class, students from Franklin Community High School launched two payloads within minutes of each other. One package carrying an ATV system landed near a creek near the Ohio River (about 90 miles from the launchsite). After rescuing this payload the tireless chase crew (members of the Indianapolis Foxhunt group) continued on to locate the second payload. This carried an aircraft transponder and a 2m beacon. It was much lighter and was ascending much slower than the first package. It landed 100 miles further downwind than the first payload (nearly 190 miles from the launch site) in the hills of central Kentucky (Isenville). They found the payload at 10 p.m. on the side of hill about 90 feet up in a tree. The landowner said he had a way to recover the package and went to his barn. He returned with a chainsaw and cut the tree down.

HESPERIA, CA (WB8ELK - 1/23/89):

This was the first live camera ATV flight. Many of the Southern California T-Hunt group kept under the payload during the flight and provided the chase plane and the chase helicopter with accurate bearings. The parachute failed at balloon burst since it was made of paper (a radiosonde parachute) and apparently too close to the balloon. It was ripped to shreds and only acted as a streamer to slightly slow the package's rapid descent and wild gyrations. The ATV antenna was torn off of the package at about 50,000 feet (the 2m transmitter had earlier succumbed to the cold). Based on their course estimates the T-hunt group told the chase plane the best location to attempt to visually locate the falling payload. Although no one could receive the ATV signal without the antenna, Mike WA6SVT (riding in the plane) shouted out that he was seeing a weak picture on his ATV monitor. Then he mentioned he must be close to the descending payload since he was receiving a snow-free picture. He was watching the same lake and houses on the video monitor that he could see out the plane's window. Then he said he could see an airplane wing on the video screen! Just then the payload streaked by their plane in a white blur. They were close indeed, perhaps a little too close! After landing on a sand dune in the Mojave Desert (very fortunate since it was travelling about 100 MPH on impact), Tom W6ORG landed his helicopter right next to the payload for a quick recovery. Thanks to the sand dune, the package sustained very little damage, although the metal mounting plate holding the modules was pretty warped.

The landing site (in the middle of the Mojave Desert) for WB8ELK's first live camera ATV flight. Since the shredded parachute (shown in the foreground) had very little effect, the payload survived by making a soft landing on a sand dune.

HILLSBORO, WI (WB9SBD/ K9SB):

This was a payload containing CW beacons on multiple bands. It was expected to fly 38 miles. Somehow, they managed to get a standard weather balloon (a TOTEX TA1000) to remain aloft for an amazing 6 hours! Perhaps a small leak may have developed in the balloon. Since one of package designers, Tim K9SB, couldn't make the launch, the balloon apparently decided to travel over 100 miles to visit his house. Just before sunset it was directly over Tim's house near Elgin, Illinois. They could see the package and balloon through a telescope as it hovered overhead. Then it burst and began a descent into surburban Chicago.

Question: What's the best (but also the absolutely worst) location to land a balloon in the Chicago area? Its a large flat area of mowed grass with no houses or trees making for an easy recovery. You guessed it, they did a three point landing right at O'Hare International Airport! The chase crew was escorted across several runways by airport security to recover the payload as it rested in the middle of the airport grounds. Fortunately, the FAA wasn't upset by all this since the Wisconsin group had filed a NOTAM and called O'Hare to warn them that the balloon was descending into their airspace. Also the balloon's radar reflector worked well and the control tower knew the balloon was coming in for a landing.

PEARLAND, TX (KV5G/WB5UXF):

This payload consisted of a large vidicon TV camera, a 10-watt ATV transmitter and lots of D-cell alkaline batteries. They used a styrofoam cooler for the package. The balloon was filled with two large (244 cu. ft.) cylinders of helium. The balloon could lift over 30 pounds and was very near it's burst diameter. I cringed while watching the video tape, expecting the balloon to blow up at any moment, then they put on another tank and continued filling! The package shot up like a rocket and made it to 12,000 feet before the balloon burst. Stations over 150 miles could see the video signal. It landed on a farm a couple of miles away. The farmer who discovered the package thought it was a bomb and fired several shots into it before the chase vehicle found the payload. Unfortunately, one of the bullets went right through the TV camera!

The Houston Balloon Launch Team recover their BLT-6 payload from the backwoods north of Houston using a rifle. Even a steady downpour didn't deter this dedicated chase team.

SAN CLEMENTE, CA (WB8ELK, KC6CCC and WA6SVT):

This ATV payload was launched just before a solar eclipse. It was feared that the weather would be bad and we hoped to at least view the eclipse from the balloon. After seeing an early sunset from 100,000 feet, the package landed on a 4,000-foot mountain. It was well after dark when the chase crew closed in on the package, but they had to abandon their efforts due to a Pacific storm that was dumping snow on them. They alerted a local resident to keep an eye out for the package and told him about the reward. Returning on two successive days, the chase crew was at last able to hack their way through the dense Manzanita brush and estimated the payload to be about 200 yards away. Then their bearings started moving abruptly. It appeared that the payload had grown legs and was walking away from them. They tracked the moving payload down to a cabin and found the package inside. The finder turned out to be the resident who they had earlier alerted about the reward. He had been searching for two days (without DF equipment).

HOUSTON, TX (BLT group):

During a recovery effort of one of their first payloads, the package was pinpointed as being on a large fenced-in ranch. The owner wouldn't allow them on the property until the following day. They thought about going ahead and recovering the payload, but thought better of the idea. The batteries were still working the next day as they were escorted by two workers across the property. It turned out to be a large private game preserve. The package was found about 90 feet up in a tree. One of the escorts headed back to his truck, pulled out a rifle and brought the package down with a couple of shots. He had neatly severed the string just above the payload. I wouldn't want to trespass on this ranch!

HUNTSVILLE, W.VA (WA4GSS):

During this group's first flight with 2m and 10m beacons and telemetry, the package landed in the isolated mountains of SW West Virginia. After hours of searching, a second chase plane finally located the package on top of a 3000-foot mountain. It turned out to be the entrance to a coal mine. Since a coal miners strike was imminent, they actually had to call the president of the coal mine and get permission to drive onto the property. They finally retrieved it just before sunset, although a curious skunk made the recovery somewhat treacherous.

HILLSBORO, WI (WB9SBD):

As their cross-band repeater payload descended, the foxhunters closed in on a wildlife preserve in central Wisconsin. The signals were quite strong after landing and the chase crew had the package pinpointed to within a mile somewhere on the preserve. Suddenly the package quit transmitting and they had to give up the search.

Members of the Wisconsin Amateur Radio Balloon Association (WARBA) recover the WB9SBD/K9SB payload from a tall tree. They really went fishing for this one (note the fishing pole).

Meanwhile, two bored hunters were patiently waiting on the game preserve for some hapless ducks to come their way. They were just about to quit for the day, when their dog became very excited and started pointing up into the sky. Certain that the ducks were coming to visit in droves, they were startled to hear a beeping sound and the incredulous sight of the WB9SBD payload parachuting down to land about 100 feet away. They didn't have any luck with the ducks that day, but they sure bagged WB9SBD's payload! Luckily, they didn't shoot it.

HANCOCK, NH (WB8ELK - 6/26/93):

Dubbed Talk-Back 1, this was a 2 meter simplex repeater using an ICOM 2A and a record and playback telephone toy. It received for 8 seconds and would then retransmit whatever it heard in a continuous loop. This system is one of the easiest ways to fly a 2 meter repeater and eliminates any desense problems. Many stations in several states were able to easily communicate through the repeater using just HT's and mobile rigs.

We launched within 20 minutes of the Dayton, Ohio balloon. They were flying a virtually identical simplex repeater and we were hoping to establish a two-way link between the balloons. Since the two balloons were over 660 miles apart, there were only a few minutes of mutual visibility. I ran out of helium and only had 1 pound of positive lift and ascended at 750 ft/min while they were heading up at 1000 ft./min. Since we were only at 54,000 feet when they reached their peak altitude of 106,000 feet, we just missed hooking up with each other. Nevertheless, we had a great time with stations over 500 miles apart working each other through the balloon (Maine to Pennsylvania).

There was no chase team for this flight since everyone was tied up with Field Day. I decided to head over to the Nashua, NH Field Day site and ask for assistance in recovery. After I left, Gene Balinski WA1UXA spread the word on several repeaters and finally got Glen Belinsky (a distant cousin?) KA1MLH to listen to 144.34 while he was mobile to another Field Day site. He heard the signal almost immediately as he drove just north of Manchester, NH, but only along a half-mile stretch of road on either side of the Merrimack River.

Meanwhile, unaware of this information, I spent the evening bouncing around the back roads of New Hampshire until I saw a road called Purgatory Hill. I decided to give up and head home.

I spent most of the next day assembling my DF equipment (a W9DUU left-right system). Just two hours before sunset, I set out to the landing site. I homed in on the signal on the west side of the search area and arrived at a house at the end of the road. I asked the residents if I could look in their back yard for my balloon payload. They chuckled and said "Sure, but you probably won't get very far." I walked behind their house to find they were directly on the west bank of the river! Sure enough, the bearing showed the package was somewhere on the east side of the river.

Over 37 hours after liftoff, Bill Brown WB8ELK recovers his simplex repeater payload from the bottom of an 80-foot deep gravel pit just north of Manchester, New Hampshire.

After driving 10 miles to find a bridge across the river, I arrived at an industrial park on the east side where I received a strong signal. I parked the car and grabbed my DF gear. As I started walking, I could faintly hear a "Beep-Beep" sound in the distance. I was hearing the audio beeper from the payload! After walking a hundred feet I came to a gaping hole in the ground. Looking much like a meteor crater, it turned out to be an 80-foot deep gravel quarry that stretched out over 200 yards across. Thinking that the payload was in the trees on a ridge on the other side of the quarry, I found a road that led down to the bottom of the pit and started across the quarry toward the other side (sinking several inches into the gravel with each step).

Members of the chase team marvel at the convenient landing site of this payload launched by the Dayton Amateur Radio Association (DARA). It landed just 10 feet from the road and about 50 feet in front of chase team member Larry Oaks WB9YAJ.

As darkness closed around me (it was nearly an hour after sunset), I felt like I was walking across the surface of the moon. The signal was strong and was easy to DF. As I approached the far wall of the quarry, I nearly tripped over the payload. It was lying directly in front of me on the bottom of the gravel pit (at least I didn't have to climb any trees)! A low-power HT lying on its side in the bottom of an 80-foot hole doesn't produce a lot of signal. It was lucky that anyone had heard it at all. Since it was now nearly pitch dark, I turned on my flashlight and just followed my deep footprints to return to my car. I'm still pouring the gravel out of my shoes!

Long Delay Recoveries

DAYTON, OHIO (W8BI DARA#3):

This payload landed deep in the Wayne National Forest in southern Ohio. Few roads were available for the chase crew, and no one could get an accurate fix on the beacons due to the densely wooded and rolling terrain. The chase plane could receive a signal and narrowed the search area to a 2-mile circle. Unfortunately, the package was lost. Although the batteries had long died, the DARA group went back to the woods a week later and set up a command post near the chase plane's fix. A visual search covering several square miles turned up nothing.

An article appeared in the local paper offering a reward for finding the balloon payload. Sure enough, someone soon responded. It turned out they had found a radiosonde that was launched from Dayton a week before the DARA flight.

Eight months later, a turkey hunter finally found the DARA payload hanging up in a tree. It was just 100 yards from the command post DARA had set up for their visual search. The styrofoam package kept everything in good shape and they plan on flying the payload again this June.

GREENVILLE, SC (K4SAO):

Launched by Don Fortner K4SAO on July 4, 1990, this payload carried a voice message/2m FM transmitter designed by Carl Lyster WA4ADG. The message carried a greeting from the Roper Mountain Science Center in Greenville. In addition, there was a 10 milliwatt 2m CW beacon and a 6m CW telemetry system (designed by Pat Bunn N4LTA).

This package was never found by the chase team and was assumed to be very lost in the mountains. After 21 months, a hunter gave Don K4SAO a call after recovering the payload from a tree in the mountains near Clarksville,

Pete Sias WB0DRL tests out the landing gear system for his 2m packet/film camera payload. It landed just 20 feet from one of his chase crew members in a perfect upright position.

Georia. It turned out he had seen the styrofoam package hanging from a tree for over a year while out bow hunting on the mountain. He had assumed it was debris from a tornado that had torn through the woods in December of 1990. Finally, he decided that the piece of styrofoam would make a good archery target and shot it down from the tree with a rifle. Fortunately, he was a good shot and cut the string just above the payload. He decided to find another target when he saw the reward sign. After sitting out in the woods for 21 months, getting hit by a tornado and surviving several rifle shots, the payload electronics were still in good shape!

Create Your Own Balloon Adventure

I'm sure I missed writing about a few harrowing balloon experiences. Most flights are fairly easily retrieved (depending on your terrain and the experience of your foxhunt team). Obviously, the plains of Kansas or the farmlands of Ohio will be a little easier than trying to find a payload in the hills of West Virginia or the mountains of New Hampshire. Even if you lose your payload, there is a reasonable chance that someone will eventually find it. It seems that just about any portion of the Earth is visited by a human every so often. I've only lost 4 payloads out of 24 flights. We know their approximate location, but couldn't get to them. One is on an island in the middle of Lake Erie (it was a digipeater and worked for 24 hours). Several stations worked through it during the night thinking it was a new packet node. The other big payload (ATV and 2 meters) was lost in a swamp near Derry, NH. The chase crew fought knee-deep mud and killer mosquitos, but just couldn't locate the package.

The other two payloads were simple CW beepers on 10 meters worth about 6 dollars. I didn't expect them back, but after launching 4 of these, two were found and returned to me. One by a farmer three days after the launch and the other was found three months later by a mushroom hunter in the middle of a woods.

It's a lot of fun to correspond with the people who find my payloads in this manner. At least one of them was so fascinated by their discovery, they've decided to take ham radio classes.

Figure 1. Map of active radiosonde sites in the U.S. (Courtesy of WeatherBank, Inc. [downloaded from their WeatherBrief dial-up service])

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+RAOB/M
Raob plot of U.S. Stations: Station list

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Foamcore Payload Construction

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[redacted]

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ABSTRACT

Foamcore sheet is a versatile and inexpensive material for use in fabricating custom balloon payload enclosures. Salient properties, design and construction techniques and flight experience are described.

INTRODUCTION

Life for a high-altitude balloon electronics package can be rough. At birth, it's crammed full of radios, electronic goodies and batteries, and its skin is perforated with connectors and antenna feedlines and emblazoned with ham graffiti. Unnecessary appendages are chopped away to save weight. It flops around a workbench for weeks while its guts are tweaked and twisted with accelerating fervor as launch day approaches.

At the crack of dawn on the appointed day, it's rustled up and jostled out to some desolate spot, where it gets a few more pokes and jabs for good measure before being bound and strung up like a horse thief.

With a sudden jerk and a sigh of relief, it's hoisted up and away from its earthly turmoil. But soon it faces even more grueling insults. As it ascends at over 10 mph, rushing air tugs at its supports, and wind shear tosses and twists it like a small boat on high seas. Its internal gasses belch forth as it rises through ever thinning air. Passing through the depths of the tropopause makes New Year's Eve at the North Pole seem like a tropical beach party. Rising into the stratosphere provides a welcome respite, as the nearly nonexistent air becomes calm, and everything warms up in the intense, unfiltered sunlight blazing forth from the black sky.

Just as life seems to getting a bit cozy, the support lines suddenly go limp, and our package finds itself plummeting helter-skelter down into the sky below. Whatever vestige of warmth may have penetrated its skin is ripped away by 200 mph winds, and the frigid tropopausic air forces its way into every crack, chilling its viscera to the core. After surviving another roller-coaster ride through the jet stream, the infiltrating air begins to warm, allowing it to carry quite a bit of water. In fact, the welcome shade of a cloud can fill our package with fog which readily condenses all over its frigid guts.

The ever-calming ride back to the planet ends with perhaps the most severe assault of all: a collision with the earth which would total a modern car. If the surface wind has picked up since the launch, the parachute will keep on plugging, bouncing its dazed passenger across whatever the surface may be until something strong and stationary snatches the package and wins the tug of war.

After what seems like an eternity in an even more desolate site, a swarm of fiercely-armed T-hunters converge on our voyager, attracted by plaintive cries for help driven by dying batteries though an antenna which may be buried up to its feedpoint. After a primitive ritual, the victorious captors load their quarry once again into a vehicle, this time with much less ceremony, for a considerably longer jostle back to its spawning grounds.

The next day, its creators commence their poking and jabbing again, scratching their heads in search of an explanation of how such a hastily crafted package could have survived its ordeal without dumping its contents all over the recovery site or even showing moderate signs of wear.

"Foamcore", they finally proclaim, "It might have been the foamcore!"

PACKAGE REQUIREMENTS

The foregoing story is fiction, of course, but it attempts to give the reader a feel for the environmental rigors which a high-altitude balloon payload should be prepared to endure. A well-designed and built payload package will reliably protect its contents from the environment without adding excessive weight.

If the package fails, then so will its contents in which you and your balloon group have invested so much time and money. Mechanical package failure can leave priceless goodies strewn along the flight path. Or, more likely, electrical connections may be damaged during landing shock thus shutting down the tracking beacon so important to the recovery task. Thermal failure can cause onboard electronics to malfunction from a combination of low temperatures and condensed moisture.

Design of a strong, well-insulated package becomes nontrivial when the burden of minimized weight is tacked on. Helium and balloon costs rise exponentially with payload weight, and once the several FAA weight limits are passed, flight clearances and logistics are complicated.

PACKAGING MATERIALS

Edge of Space Sciences (EOSS) has flown packages made from molded styrofoam packaging material, built-up insulation-grade styrofoam sheet, bulk closed-cell polyethylene foam and foamcore sheet.

Although low density styrofoam exhibits excellent thermal insulation properties, it is difficult to cut cleanly and is easily damaged by landing shock. It is also difficult to find molded styrofoam packaging even close to the right size and shape to fit the intended contents.

Bulk polyethylene foam is even rarer, being used primarily as packaging buffers for heavy, high-cost products. Being more rigid, it can be formed somewhat more easily than styrofoam and exhibits excellent shock resistance. Airtight seams and fine details are impractical to form, however, and common adhesives will not stick well to it.

Foamcore is readily available in large sheets. It cuts and forms easily with sheet-metal precision, bonds with practically all adhesives, is exceptionally strong in shear stress, resists puncture, is very lightweight and offers moderate thermal insulation. Precision details, such as pc board mounting slots, are easily fabricated. Using foamcore, one can design an near-optimal payload package for the contents rather than trying to work around other materials' limitations.

FLIGHT EXPERIENCE

The EOSS ATV module, Fig. 1, was built entirely from 0.21 inch foamcore in one weekend. The U-shaped package form was designed to protect the mirror from landing impact while housing the camera, servo, title board and ATV transmitter with minimal wasted space. The mirror, its drive and servo are integrated into a single module which slides into a mating slot in the package wall. Extra space was designed in to accommodate a filter wheel and servo for future video experiments.

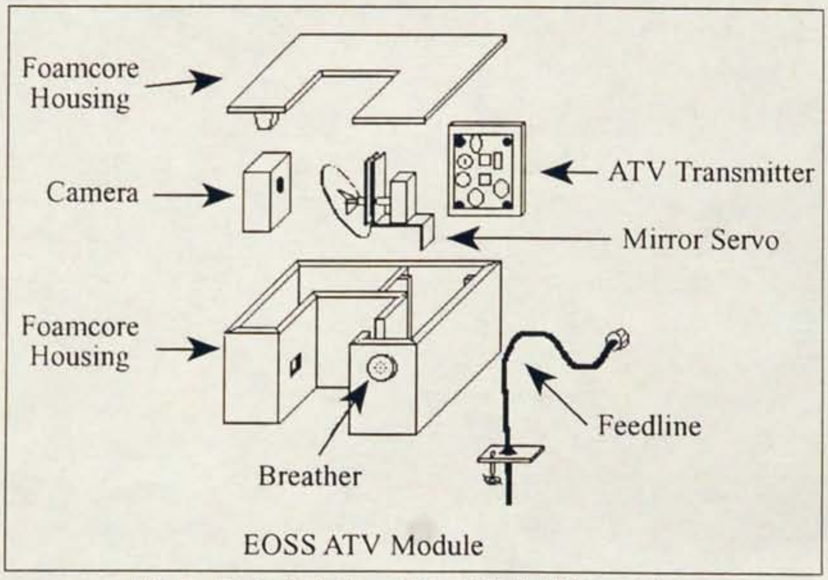


Fig 1. Exploded view of the EOSS ATV module.

This 5 ounce housing has survived the rigors of six launches and recoveries. The only repair required was strengthening the camera hold-down strut after its first flight. Since then, preflight preparation consists of no more than cleaning the mirror and fitting dry desiccant.

The loran-C receiver preamp is supported 8 feet below the main payload package to reduce interference from the payload computer. It is packaged in a 2 inch diameter septagonal approximation to a cylinder with conical ends to minimize drag. It has survived five flights and a number of field disassemblies to troubleshoot loran reception problems.

FOAMCORE PROPERTIES

Foamcore, also known as matboard, is a composite sheet material comprising a core of closed-cell, high-density styrofoam sandwiched between two sheets of thin posterboard. It is sold in hobby and art supply stores in thicknesses ranging from 0.2 to 0.4

inches. Although used primarily for matting pictures for framing, it is occasionally used in architectural models and packaging mockups of proposed electronic products. A 2 x 4 foot sheet of white 1/4 inch foamcore, enough for several large payload packages, retails for about $5.00.

The 0.21 inch thick material used for the ATV package weighs 2.12 ounce per square foot. Despite its light weight, foamcore is surprisingly strong and rigid. The optical alignment between the camera and mirror has remained unchanged through six landings.

The styrofoam core material provides an moderate thermal R-value. The 175 cubic inch interior of the ATV module held above above -30 F during a 2.5 hour flight to 93,000 feet and back with less than 5 watts interior heat dissipation. Thicker foamcore provides more insulation, but an ordinary low-density insulation grade sheet foam liner inside a thinner foamcore shell is more weight-effective.

SURFACE TREATMENTS

The posterboard surface tolerates moderate amounts of water without damage. Moisture resistance can be improved with a light coat of acrylic spray paint, however. Interior condensation during descent through a cloud may be averted by including a desiccant-filled breather. We used a plastic pill bottle with each end perforated by about ten 1/16 inch holes. The bottle cap is glued with RTV into a matching hole in the package wall, and the bottle is filled with 1 ounce of dry silica gel desiccant before the flight. This 2 ounce of prevention may be dispensed with if your weather forecast is clear.

EMI shielding is easily applied by gluing ordinary aluminum foil to the foamcore surface using Elmer's glue. Good electrical contact to the foil is achieved by taping down 1/2 inch wide strips of copper foil. The copper is roughened to form gastight contact into the aluminum foil with sharp dimples made with a center punch. Similar strips with points on both sides of the foil are used to bond cover seams.

ADHESIVES

Ordinary silicone sealant (RTV) has proven to be an excellent adhesive for balloon payload packages. Its adhesion and resilience appears to be unaffected by the extremely low temperatures encountered in flight. Its only disadvantages are long curing time and outgassing of acetic acid vapor. Where an ultra-reliable joint is a must, RTV is the adhesive of choice.

Epoxy is very strong and can set up fairly fast, but it's picky about the surfaces which it will bond to and embrittles in extreme cold.

Cyanoacrylate (super-glue) is great for quick bonding nonporous surfaces which mate closely. We use it to bond critical knots in the payload string just prior to launch. But it is expensive, bonds poorly to rough or porous surfaces and probably embrittles when chilled.

Another excellent joining material is 3M Kapton tape, also known as "space tape." It is very strong, and the acrylic adhesive bonds very well to nearly anything. It is also outrageously expensive; we have found industrial sources of recently outdated tape which is still quite sticky. Watch out for bargain basement deals; the adhesive on long-outdated tape may not stick as well as needed. Test a piece before you buy; you should need a knife to remove it from your fingernail! We use a few patches of space tape to hold the covers closed on the package just prior to launch.

We have had excellent results using low-temperature hot-melt glue on foamcore joints. Hot-melt is resilient at room temperature, but more rigid than the same width bead of RTV. So far, it has shown no signs of cold embrittlement. Hot-glued joints are stronger than the foamcore. The only joint failure we have encountered to date was attributed to delamination of the foamcore paper; this was corrected by enlarging the joint area.

A freshly-glued joint cools slowly on this material, providing a few seconds of free time for alignment. In about a minute, the joint reaches full strength, so you needn't plan your project around a series of overnight adhesive cures. The high-temperature variety of hot-melt is usable with foamcore, but it tends to melt away the foam before it cools. A high-temperature glue gun operated at about 50% line voltage from a variac or light dimmer works fine with low-temperature glue; if the gun is too hot, the glue discolors.

FOAMCORE JOINERY

Foamcore is a stiff, planar material which crimps when overstressed, so curved shapes can not be formed. But it can be cut by hand with near-machine precision, and strong, straight bends of practically any angle can be formed quite easily. With a few simple tools, some patience and a fertile imagination, one can quickly fabricate some pretty elaborate shapes.

Tools required:

- Modeling knife with a good supply of sharp blades. Single-edged razor blades will also work in a pinch.
- Machinist's square.
- Metal straightedge. The scale on the machinist's square works fine for most work. Longer cuts and bends may need a metal yardstick clamped in place at one end.
- Hot-melt glue gun and glue. The low temperature variety is preferred.
- A large piece of cardboard for a cutting surface.
- A flat work table.

Other common hand tools, such as needle-nose pliers, may be helpful for handling smaller pieces. A sewing needle pressed into the end of dowel is handy for holding small pieces and for marking the centers of holes on both sides of a sheet. Straight pins serve well to help align less manageable joints prior to gluing.

SIMPLE CUTS

The keys to making clean, precise cuts are a sharp blade and metal straightedge. Mark the cut line with a pencil or pen directly on the paper surface. Then place your workpiece on a cutting surface which extends past both ends of the cut. Align the straightedge directly over the cut line and plan on holding it steadily in place until the cut is complete. A C-clamp is handy for long cuts, but in most cases, the edge can be held in place fine with one hand while you cut with the other. Be careful not to crush the foam; it is especially susceptible to crushing at cut edges.

The cut should be made in at least three end-to-end passes. The first pass should just penetrate through the upper paper surface and only slightly into the core. For accuracy, the blade should be aimed slightly into the straightedge so that it will not drift away; this will also minimize the gap between the cutting edge and the straightedge.

Start the cut by poking the blade point squarely into the surface through the top paper layer. Then reduce the angle between the material surface and the blade edge to no more than about 30 degrees to avoid tearing the surface. Using a steady motion, pull the blade through to the end of the cut. Remember, the first pass should only cut the upper layer. A dead end cut may be terminated precisely with a near-vertical poke of the blade.

Keeping the straightedge in place, make the second pass like the first, except this time, cut through the foam and slightly into the surface of the bottom paper layer. This pass establishes the angle of the cut edge. If you want a simple square cut, then be careful to hold the blade perpendicular to the foamcore surface through this pass. Square up any dead ends with vertical pokes completely through the lower paper.

The third pass should cut completely through the lower paper. You may dispense with the straightedge this time, but if you are not careful it is still possible to let the blade drift at this phase. Keep the blade angle steady from end to end, and use enough force to cut completely through the lower paper. If the lower paper is not cut through end to end, turn the workpiece over. Incomplete parts of the cut line should at least be visible as a distinct ridge; if so, insert the tip of the blade into a cut portion and carefully pull it through the ridge, allowing the blade to self-align on the opposite side. If a ridge is not visible, then get a new blade and repeat the third pass from the first side.

A sure sign that your blade is getting dull is ragged cut edges in the foam or tearing of the paper. A fresh blade is good for about 3 - 5 lineal feet of cutting. Blade life is definitely extended by use of a clean cardboard cutting surface. I have had a little luck resharpening Exacto blades with a fine oilstone, but I have never gotten them any better than "half-dull". A brand-new blade is a pleasure to use; make sure you have enough on hand before you start your project.

MAKING HOLES

Rectangular and polygonal holes can be made simply by a series of straight dead end cuts.

Round holes require a blade with an acutely pointed tip used like a saw on both sides of the workpiece. Even the smallest holes, as for a #4 screw, are best made using this technique. A twist drill will pull the paper away from the foam, and forcing a punch through will crush the surrounding foam.

Start a round hole by marking its center, then draw the cut line on one side of the workpiece with a drawing compass. Extend the center mark through to the opposite side using a straight pin or the needle tool. Be careful to align the pin perpendicular to the surface before pushing it through. Turn the workpiece over and repeat the cut line with the compass.

Using a sharp pointed model knife aimed nearly perpendicular to the surface, cut just through the paper surface along the compass line using short, sawlike strokes. Do this on both sides of the workpiece, then carefully complete the cut through the foam, halfway from each side. The plug should push right out. This process is also handy for making disc-shaped pieces.

Elliptical holes, as used on the ATV mirror backing plate joint to the servo shaft, are a bit more tedious. First, mark the center of the hole with a pencil on the foamcore and draw in the major and minor axes; extend the ends of the major axis so it is visible on the opposite side. Then cut a cylindrical object of the proper diameter to the desired angle; for the ATV servo, this was the actual mirror drive dowel. Hold the cut surface down on the foamcore, aligned properly per the axis marks, and trace around it with a sharp pencil. Then use the needle tool centered on the ellipse center and tilted to the same angle and along the axis to transfer the ellipse center to the opposite side. Turn the workpiece over and mark the major axis; this line should fall through the pinhole and both major axis end marks made from the other side. Draw in the minor axis, and trace the ellipse as before.

The elliptical hole may now be cut using the same technique as for round holes. When cutting through the foam, bear in mind that the blade angle relative to the surface will vary from perpendicular when crossing the minor axis to the full angle crossing the major axis; allow the blade to self-align by passing it through both sides while cutting the foam.

MAKING BENDS

The simplest "bend" is just an end-to-side butt joint between two separate pieces of foamcore. This method leaves an ugly raw end showing, which can also allow moisture penetration. It's strength depends solely upon the paper peel strength.

Strong, accurate and stable linear bends can be made by first cutting a full-thickness V-groove on the inside of the bend without cutting into the outside paper. After the V-shaped strip is removed, hot-melt glue is applied to the slot and the bend formed to close the slot. When the glue sets, the bend is permanent and in most cases does not need reinforcement. The outside corner is neat in appearance since the paper runs continuously around it; this also contributes to strength and moisture-resistance.

The width of the V-groove for a right-angle bend is two sheet thicknesses. Smaller bend angles require smaller groove widths, and vice-versa. For you precision freaks, the groove width W may be calculated for any material thickness T and bend angle @theta:

W = 2*T*tan(@theta/2)

To cut the groove, mark the two edges of the groove equidistant on either side of the center. Plan to cut each side of the groove in two passes. The first pass may be done with the blade perpendicular to the surface, just to cut the paper. The second cut should be done with the blade angled so the tip just contacts the inside of the bottom paper at the midpoint of the groove; ideally, the blade angle from vertical is one-half the desired bend angle. The care with which this pass is made on both sides will determine the straightness of the outside joint and the precision of the inside seam.

After the cuts are made on both sides of the groove, the V-shaped scrap should pull out cleanly. If not, don't fret; any gaps in the foam will fill with glue. At this point, it may be a good idea to form the bend and check it for accuracy before committing it to glue. If the outside bend is a bit uneven, place the inside of the bend over a square corner of the bench and lightly burnish both sides of the outside corner with a 1/2 inch diameter dowel or some such tool.

With the groove lying open, apply a bead of hot-melt glue with a diameter about 1/2 the groove width. Then form the bend and hold it at the proper angle until the glue sets. A couple of square-cornered blocks of wood or metal also serve nicely in this role if you are compelled to a higher calling.

Key points regarding bends:

- Make sure the groove is cut on the INSIDE of the bend; I blew about an hour's work on the ATV module walls with this stupid trick.

- Dimension the location of the bend on the INSIDE surface to the EDGE of the V-groove, not its center. When the bend is made, the two edges will come together to form a sharp inside corner.
- Cut the grooves for all of the bends in one piece before you glue the first one. A flat workpiece is easier to manipulate.

UNFOLDED JOINTS

All balloon payload packages eventually must completely enclose a volume. It is not possible to form such a structure from a single sheet with with all joints folded and no exposed seams; at least I haven't figured out how to do it. Even if it were possible, it would still be very desirable to be able to open the structure in order to put something useful inside. The bottom line is that unfolded joints, such as butts, laps and mitres are unavoidable. They can be made quite serviceable, however.

If you are making a closed form where two cut ends must come together, make the final joint as a mitre at one corner. Rough out your workpiece to allow at least 1/2 inch extra at both ends; it is very hard to cut a clean mitre right at the end of a square cut, since the foam tends to crush easily there. Glue the mitred ends together and add a 1/4 inch square stringer inside for strength. A piece of space tape over the outside corner will finish the joint.

If a butt joint is unavoidable, reinforce it with a 1/2 inch or wider strip glued to lap the joint. Glue the reinforcement strip to one side first, then apply a bead to the exposed foam edge and the open surface of the reinforcement before closing the joint.

The strength of any joint can be significantly improved by adding triangular reinforcement webs on the inside corner. The cost is added weight and lost interior volume.

"CURVED" SHAPES

Foamcore does not bend without crimping, since paper does not stretch. So don't plan on forming a truly curved wall. A curve can be approximated by a series of parallel, close-spaced small-angle bends to form a polygonal cylinder. It should be possible even to form a near-spherical polyhedron, such as a dodecahedron (geodesic dome), from a single sheet.

The width W of each side of an N-sided polygon circumscribed around a circle with radius R is:

W = 2*R*tan(@pi/N) computed in radians

Example: an octagon which will fit snugly over a 5 inch radius (10 inch diameter) cylinder has INSIDE panel widths of:

2 * 5 * tan (3.1416/8) = 4.142 inches (4-9/64 inches)

When laying out the cuts on your workpiece, remember to add one groove width to the inside width of each panel.

CONICAL SHAPES

Again, a true cone can only be approximated. But a pyramid extension can easily be added to a polygonal cylinder. This can be done in two ways: Make the polygonal cylinder sides first and fold the end pieces to form a pyramid, or make the pyramid end first and fold down the polygonal cylinder sides.

To make the polygonal cylinder sides first and fold the end pieces to form a pyramid, lay the workpiece flat with cylinder grooves already cut, and make a cut parallel to the base of the pyramids at a distance equal to the side of the pyramid above the intended pyramid base. For a pyramid height H, and pyramid base B across opposite outside flats, compute the side length S as:

S = SQR [H^2 + (B/2)^2]

Extend the MIDPOINT of each side from the base of the pyramid up to the cut edge. Draw light reference lines from midpoint marks at top cut to the centers of each adjacent cylinder groove. You should end up with a sawtooth-looking pattern when you are done. Then draw two cut lines parallel to each reference line from the ends of each groove to the top. Cut V-grooves on these cut lines. Then cut through the bottom paper of each of these new grooves and pull away the triangular scrap pieces. You will end up with a crown-shaped workpiece.

Form and close the cylinder in as above, then pull the pyramid pieces together and hotmelt the butt joints together. The seams may be sealed with space tape.

Or, make the pyramid end first and fold down the polygonal cylinder sides: Form the same structure with closed outer seams by making a series of grooves radiating outward from a common center point corresponding to the tip of the pyramid. In this case, the cylinder at the bottom will have butt-joined seams. This method may be preferable where the strength of the pyramid is deemed more critical than that of the cylinder. Details of such a layout are left as the traditional exercise for the reader.

A closing observation on pyramids: if the height of the pyramid were to approach zero, one would end up with a flat cap closing the end of the polygonal cylinder. This end might be more easily achieved with a separate piece glued in place.

PLANNING THE PACKAGE

A well designed package will minimize unfolded joints and place them where they do not carry much load, or add reinforcement if they do. The floor of the package is likely to bear the greatest load, such as batteries. The floor should be joined to the walls of the package with at least reinforced butt joints; this was the method used for the ATV package, but that floor bore only the weight of the camera.

A sturdier floor-to-wall joint will result if the walls are formed as bent-up extensions of the floor. The walls can be joined as mitred, reinforced butt joints. This approach might be best for shallow packages with wall seams less than 4 or 5 inches high.

If the wall structure is complex, the bottoms of the walls can be bent inward to form 1/2 inch or so wide flanges; the ends of these flanges should be cut at the proper angle to form a tight mitre when they are all folded inwards. After the floor is cut to size, it can be pushed in from the top and glued to the flanges to form lap joints. The exposed edges of the flanges can be protected by cutting a smaller second floor which just fits inside the area circumscribed by the flange edges and gluing it in place; this will add weight, but it more than doubles floor strength and R-value. It is probably an excellent approach to use if the floor is over a foot square.

Reinforcement strips should be located inside the package to present the smoothest possible surface to air and to grabby objects on the ground.

During a rough drag over the ground, battery mounts are heavily stressed. They should be designed to take it, and to prevent shorting and damage to other components if the mount fails. The EOSS Shuttle is provided with an internal foamcore battery box with a lid. The box is located near the center of the floor to control the center of gravity, and its bottom is glued to the package floor. We have encountered no structural problems so far with this method.

Distributing the cells over a wide area and supporting them near the inside corners would be structurally sounder than concentrating them all in the center of the floor. Some weight savings may be realized by eliminating reinforcement. Battery replacement would be more tedious, however.

Access to the interior of the package is best made from the top via a removable lid. The ceiling is unlikely to carry much load, and it is the least likely surface to contact the ground during landing. Thus its joints do not require much strength. The ATV module lid is a flat sheet which carries alignment strips on the inside. These strips fit snugly inside the top edges of the walls. The strips not only keep the lid aligned, but they also add to the package's torsion resistance and prevent a straight shot for water and EMI penetration. The raw edges of the lid and walls are separately sealed with space tape before aluminum foil shielding is glued on the external surface. A few space tape tags hold the lid in place during flight.

A stronger lid might be formed as a cap which fits over the tops of the walls, but one is then faced with a bigger snagging target.

FITTING IN THE GOODIES

Printed circuit cards may be mounted in the conventional fashion using standoffs and threaded hardware through the package walls. It is quite easy to form card guides out strips of foamcore glued to the package walls, however. This makes access and preflight replacement a snap. If the there is not at least 1/8 inch free edge on the card to clear the slot, then the card can be mounted to a separate sheet of thin foamcore which slides into its own slots.

Captive machine threads may be included for ease of disassembly using T-nuts, commonly used in cabinet carpentry. Ordinary machine nuts may also be glued or space-taped in place on the foamcore surface, where screw tension pulls the nut into the surface. Large-diameter flat washers will prevent the nut from pulling through if the screw is overtightened or subject to high stress.

External connectors for ground power, antenna feedlines, etc. may be hot-melted into snug-fitting holes in the package wall. Connectors which are expected to be heavily stressed may be secured to patches of printed circuit board material before being glued into the package. Connectors which project out from the sides of the package are subject to drag damage. They should be avoided or shrouded; suitable shrouds may be made from foamcore. These shrouds may also be designed to mount strain reliefs for cables or their messenger lines.

Load-bearing attachment points, such as for payload support lines, are best made on vertical walls near the outer corners. It is also possible to cradle the package in macrame fashion, but this can create a challenging tangle for the post-flight crew. Single-point attachment to a the center of a flat lid is not recommended except for very small packages. A steeple-topped package will tolerate this well, but a pyramid of nylon line is much lighter. We have had some success with dowel-backed holes in the sides which accept loops at the line ends. After the loops are attached, the holes are sealed with RTV. This method avoids projecting snag targets.

If your payload comprises a number of packages strung together, design your support system to avoid transferring the weight of the lower packages through the upper package structure. It is far better to let the support lines carry that tension past the structure than it is to burden it with heavy reinforcements. The support lines may be tied together at single points above and below the package. Compressive stress is reduced significantly by placing these points at least 3 package widths away.

Package spin during flight is probably unavoidable. Its adverse effects are windup of cables running between strung-together parts of the flight system and motion sickness by those who watch the ATV image of the ground for too long. Spin has a slow, basal rate intrinsic to balloon dynamics, so I am told, plus a faster oscillatory component. Wind shear causes suspended parts of the system to sway horizontally, creating a horizontal component of airflow around the package. Asymmetrical projections will weathervane downwind, resulting in an oscillatory yaw rates which may be much faster than the basal spin rate. Oscillatory spin might be reduced by making the package nearly cylindrical to reduce the horizontal drag coefficient, and large asymmetrical projections should be avoided.

SUMMARY

Foamcore material has proven to be an attractive material for high altitude balloon payload package construction. The design and construction techniques described have been used successfully on several EOSS flights. They were developed over just a few projects, however, and are by no means the pinnacle of the art. Others will develop significant improvements in materials and techniques. In the meantime, it is hoped that some of you in the high altitude balloon community will be encouraged to fly innovative new payloads using insights gained from our experience.

Parachute Contstruction

by Merle McCaslin, K0YUK

One of the important requirements for a balloon flight is a parachute to return the payload to earth safely. Edge of Space Sciences (EOSS) went through several stages of parachute use, starting with a donated weather service parachute and progressing to EOSS-constructed parachutes made for various payload weights.

The first launch (EOSS-1) used a paper, weather-service parachute. The weather service flies low-cost payloads weighing less than a pound. These parachutes were not made for four-pound payloads requiring reliable recovery. On the first EOSS flight descent, the paper parachute split down the middle. We were not able to locate a parachute that fit our requirements. The alternative was to make the parachute ourselves.

The first parachute was made the same size as the paper one. It was made from blue nylon parachute material. The paper parachute was used as a pattern, using the same dimensions. A plastic spreader ring, the same size as the wooden ring on the weather-service parachute, was used.

This parachute worked well. It did not rip, but as the payloads became heavier, it became apparent that a larger parachute was required. In addition, on one flight it got badly tangled with the balloon as the balloon burst. This caused us to start working on a cut-down system to release the parachute prior to burst.

Figure 1 (next page) is a calculator that was designed to predict descent rates. It can also be used to determine the parachute diameter required for a given descent rate with a known payload weight.

The second parachute was much more of a challenge because there was no pattern. The solution was to use the same angle as the smaller parachute, extending the side lengths.

The following formulas were developed for the design of a parachute.

$$D = A / 360 \text{ degrees} * 4 * B. \quad (1)$$
$$B = D * 90 / A. \quad (2)$$

where,

A = Apex Angle, deg.
B = Side Length
D = Skirt Diameter

Example: The (HM-2) parachute (Figure 2) has a 56-inch side length and a 112.5-degree apex angle.

Diameter, D = 112.5 degrees / 360 * 4 * 56" = 70" (Eq 1)
Side Length = 70" * (90 / 112.5) = 56" (Eq 2)

A quarter-panel pattern of the parachute was made of paper. The material used was bright orange ripstop. Four pieces of ripstop were cut and sewn together. A small hole was left in the top to reduce oscillation. One-half-inch wide Grosgrain ribbon was sewn in each quarter panel seam approximately six inches from the top of the parachute and made into a loop for a place to tie the balloon. Three-inch lengths of Grosgrain ribbon are also sewn in at eight equally spaced points around the skirt of the parachute to serve as reinforcements for the payload support strings. Small brass eyelets are then installed at each point.

Eight payload support strings are cut equal to the side length of 56 inches and are secured to the eyelets. The strings are then wrapped around the spreader ring twice and tied off. These ties are left loose enought to allow them to slide along the the ring. The spreader ring used was a bamboo type salvaged from the weather service parachute. The strings are then brought together and tied off 18 inches below the spreader ring. The remaining strings extend another 12 inches below the tie off point.

One of the problems we had was getting the string lengths equal. The parachute was hung in a stairwell so the strings could be let out full length. The strings ties around the spreader ring are left loose to allow for adjustment when tension is put on the strings below the ring. This makes it much easier to achieve equal lengths.

This parachute has flown six times. We have both video and visual sighting of its performance and it has worked very well. No problems with oscillations on descent have been seen.

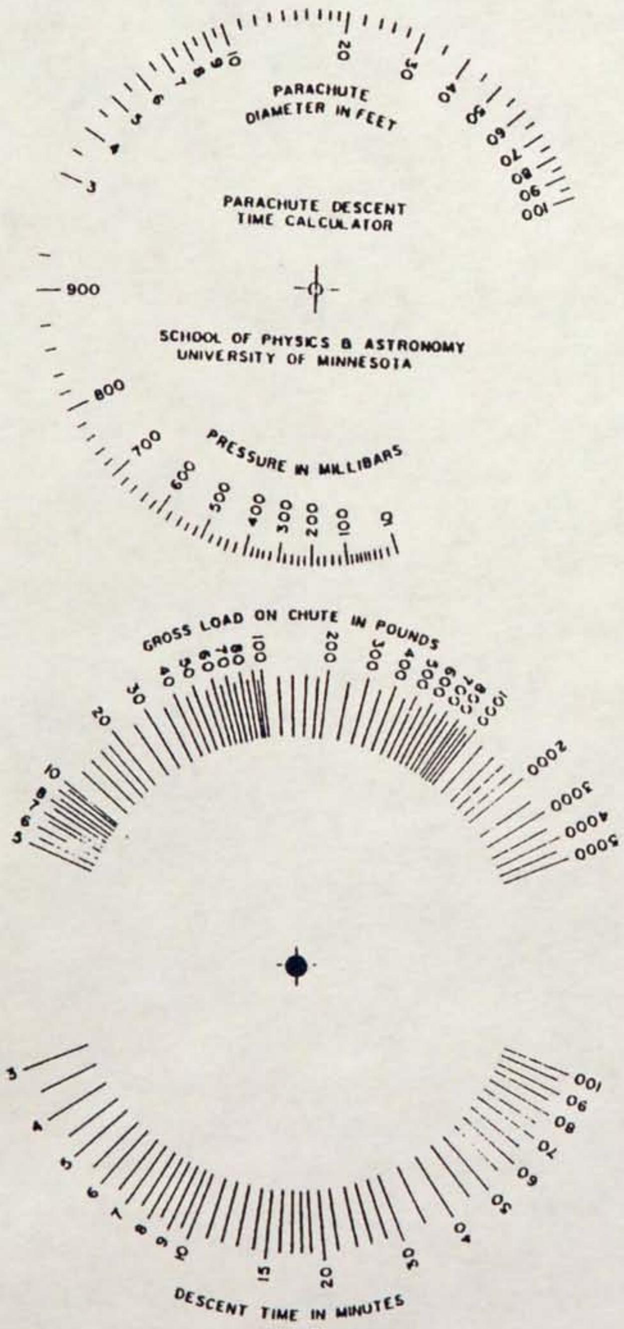
General Comments

The payload support strings are made from 220-pound-test braided polyester kite flying line. The braided feature helps reduce spin and tangling. We use super glue on the knots as an extra precaution.

The ripstop material is very rugged. It is heavier than we would like to use and plan to use a nylon material on the next generation of parachutes.

Another parachute (HM-3) with a diameter of 90 inches was also made using the method listed above, and it worked well on two flights, with payload weights of 18 pounds. We also used a bamboo-type spreader ring on this parachute. The bamboo from two weather service spreader rings was combined to make a 28-inch diameter ring.

The parachute performance calculator in Figure 1 can be glued to thin card stock and the two pieces cut out. The two pieces can be mounted together with a eyelet. We have found this to be a good tool (not an exact calculation) to get an approximate estimate of descent time and also to estimate parachute sizes required for a given payload weight.



Parachute Performance Calculator

Figure 1

Home Made Parachute

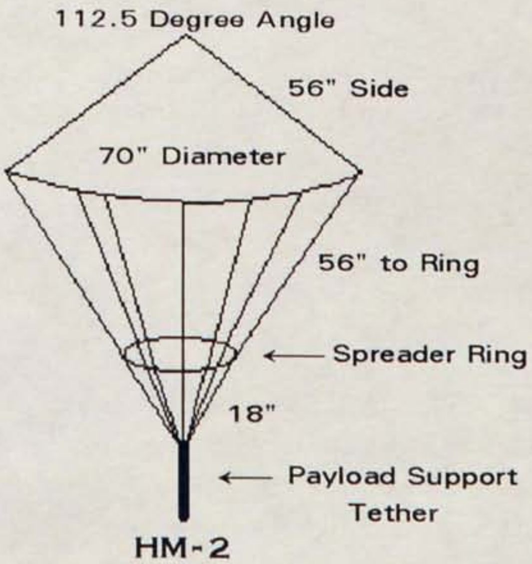


Figure 2

Off the Shelf Telemetry System

by Rob Kelly - N0SMR

A simple, easy to use, and inexpensive data telemetry system can be constructed with off-the-shelf components. A single board computer, the Micro 440 from Blue Earth Research, is used to read your sensors and format your telemetry packets. This computer contains an on-board BASIC language which simplifies programming and makes it an excellent platform for students. The system is downlink only, with no provision for a command uplink. Using a standard packet TNC, data is sent to the ground station allowing anyone with a packet station to receive your telemetry and therefore feel more a part of the mission. Reception reports can include first and last packets heard to determine the coverage.

A small group of amateur radio operators in Salina, Kansas including of members of the Kansas State University-Salina ARC and the Central Kansas ARC launched two balloons last winter containing a payload consisting of a single board computer, a 2m transmitter, a packet TNC, and a 10m beacon. The system was powered by a lithium battery pack. Sensors measuring air pressure and temperature as well as G forces on the payload were connected to the computer system and readings were transmitted to earth on 2m packet at five or ten second intervals. q The heart of the system is the Micro 440 from Blue Earth Research. It is a single board computer consisting of an 8052AHF microprocessor with a masked-ROM floating-point BASIC and 32K of battery backed RAM. The package also includes an eight channel, eight bit A/D (analog to digital) converter, a real time clock, and an eight bit digital I/O port. The connections to the outside world, including power and RS-232 port, are on DB-25 connectors. One connector is on each end of the package, which simplifies interfacing. The board contains many other features that were not used.

Any computer with a serial port, even a serial terminal, can be used for programming. The memory is non-volatile, so your programs remain when power is removed. Some of the memory is devoted to a RAM disk of sorts. It can hold several small BASIC programs and load them to RAM to be edited or executed.

I use a PC compatible with Procomm Plus as the communications software. Procomm has a means of doing an ASCII upload which will not overrun the BASIC interpreter. When a line of BASIC code is entered, the interpreter "tokenizes" the line into it's own internal format. This takes time — time in which the interpreter cannot accept more characters. The trick is to do a "prompted" upload. This causes Procomm to wait until the BASIC interpreter has sent a prompt signal, indicating that the line has been tokenized. Procomm then sends the next line, and the process repeats. This allows you to use your favorite ASCII text editor to write the programs and your hard drive to store them.

All of this makes it very easy to write and change your program to accommodate changes in payload experiments and sensors.

The Micro 440 interface circuitry was built on a piece of Radio Shack perf board. On our first launch, we wanted to check the spin of the payload. Four CdS (Cadmium Sulfide) photocells were attached to four of the eight-bit internal A/D inputs. This type of photocell acts as a variable resistor, and when connected in series with a fixed resistor, acts as one leg of a voltage divider. See Figure 1. The voltage at the photocell is proportional to the amount of light it sees. This information can be used to tell how the payload is being spun by the wind.

Also shown in Figure 1 is the battery voltage divider. This was used to scale the battery pack's voltage to something in the A/D converter's range. The voltage seen by the A/D is 10K/49K+10K, or about 1/6. Precision resistors were not used; the errors were accounted for in the software.

Early on in the design phase, we decided to use a 12-bit A/D converter for greater resolution. A model of the Micro 440 is now available with a built in 12-bit A/D. Most of the microprocessor's pins are brought out to the DB-25 connector, including the address bus and data bus.

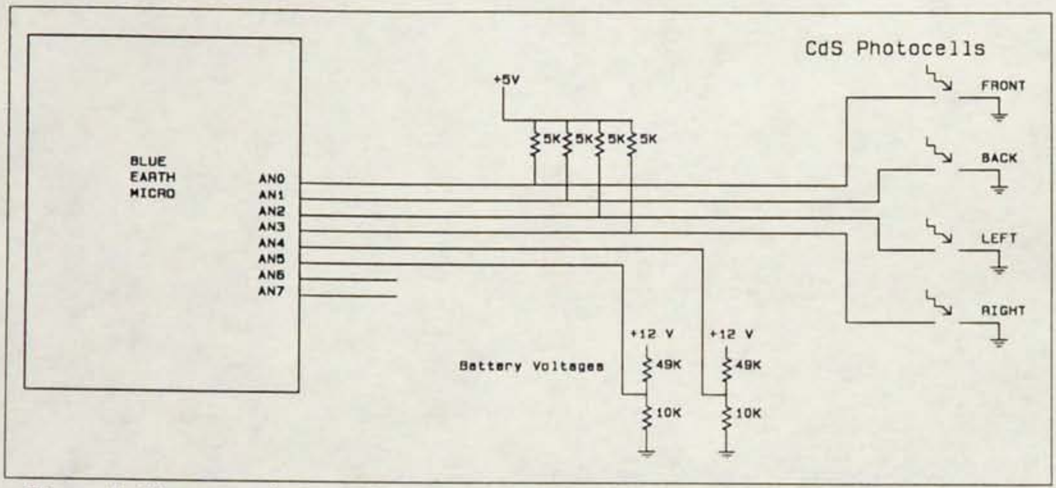


Figure 1: Illustrates the use of the internal A/D inputs. The photocells act as a variable resistor in a voltage divider. Also shown is a voltage divider for measuring a 12V battery.

The on-board A/D and the real time clock take up the upper few bytes of the memory map. We decided not to place our A/D in the memory map, since this would take some address decoding and more parts, current, and space. Most of the I/O port was still unused, so five control lines were run to the A/D and the data bus was connected as shown in Figure 2. This was all constructed using point to point soldering.

Figure 2 also shows the interface to a Motorola MPX5100D pressure sensor. This sensor is very easy to interface, all it needs is +5V, ground, and the pressure signal output.

The A/D could not be accessed from BASIC. A few gyrations had to be done on the I/O lines to select the A/D, write the channel number, wait for end-of-conversion, then read the results. I wrote a small assembly language program which was CALLed from BASIC. It toggled the proper control bits, wrote and read the A/D, and placed the results in an area of RAM. When it returned to BASIC, the program read those RAM locations and processed the results using BASIC's floating point math routines.

The remaining bits were used as digital I/O. We didn't use any of them as inputs; one good use would be a launch/crash switch. This would mark the data at the moment of launch, and if someone is close enough at landing to receive packets, mark the end.

The digital outputs were set up with transistor drivers to handle more current than the microprocessor pin could. See Figure 3. One of these outputs was used to apply power to the TNC. This overcame a communications problem between the Micro 440 and the TNC. The TNC used was the Kantronics KPC-3. It has the advantages of its small size, its very light weight, and its ability to run from its own 9V battery. The TNC was removed from its case to save weight, and the circuit board was stacked next to the computer board. The packets were sent from the TNC in "unprotected" mode. This means that there was no connect to the ground station, and the TNC would not wait for an acknowledgment from the ground.

Only four parameters differ from the factory configuration.

MYCALL	- the "from" callsign
UNPROTO	- the "to" callsign or text
ECHO OFF	- this MUST BE DONE !!!
LEDS OFF	- to save power

These are "perm"ed into the TNC's non-volatile RAM. That is all the configuration there is!

The digital output from the computer board was used to overcome a communications glitch. When the Micro 440 is powered up, it sends a line feed character, this confuses the TNC, and it will refuse to work. The computer and TNC need to be powered up in sequence. This was done manually —once. It proved to be too cumbersome at launch time. Then I came up with the idea of powering it from the computer board.

When the payload is powered up, the computer comes up and auto-executes a program stored in RAM. The default condition on power-on is for the port pins on the microprocessor is to be at a 5V level. This turns on the transistors and the TNC. By the time this program is run, the line feed character has already been sent, and has confused the TNC. The TNC is then turned off for a second then powered back on. The computer waits while the TNC sends out its copyright message, which it ignores. The computer then sends a K to the TNC to enter "converse" mode. The TNC is now ready to send telemetry.

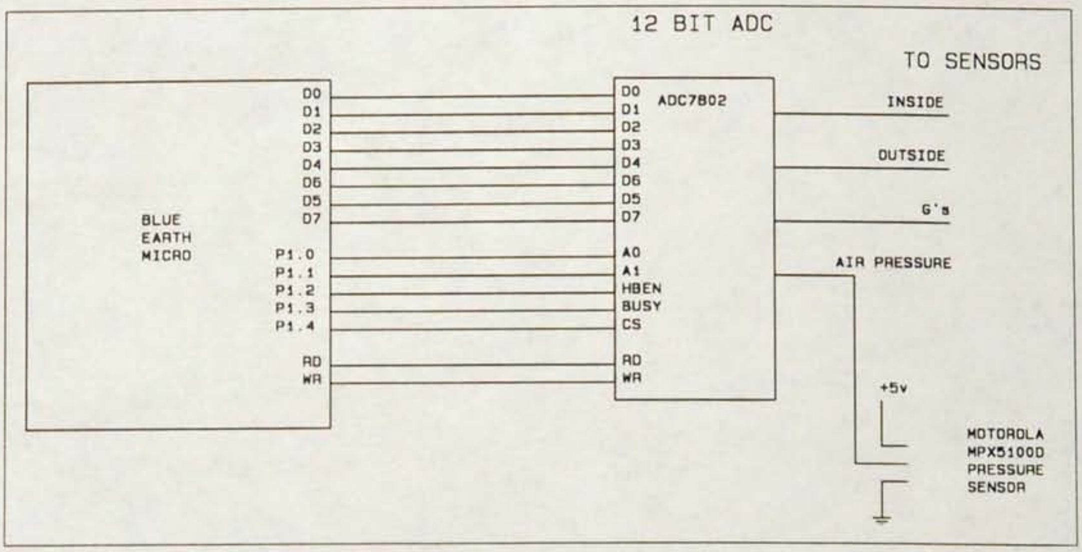


Figure 2: Shows a simple method of interfacing another component to the Micro 440. In this case it is a 12 bit A/D. The advantage is that no other chips are needed. The disadvantage is that most of the Port 1 I/O lines are used.

The TNC handles the tough job of building the packets and sending them to the radio. The characters from the Micro 440 are buffered in the TNC so your BASIC program doesn't have to worry about waiting on the TNC. If it does fill the TNC's buffer, the TNC will send an XOFF character to the computer, which will stop the transmission. The TNC will send a packet when it has received "paclen" characters from the computer or has received a carriage return. The first of our launches sent two 80-column lines of data at 10 second intervals. The second launch sent one 80-column line of data at five second intervals. The 1200 baud packet downlink can easily handle these rates.

The software that makes all of this happen is shown in Figure 4. The program begins initializing variables, the time between readings, and the frame number. It then powers down the TNC, waits, then powers it back up. It waits while the copyright message is sent and then sends a K to the TNC to put it into converse mode. The last thing to do is to set up the clock interrupt for five second intervals. The program then goes into a loop waiting for an interrupt.

When an interrupt occurs, the rest of the program is executed. The frame number is incremented, and the current time is stored in the variable NOW. Lines 120 to 190 read the internal A/D and store the results in variables A0 to A7. A byte must be written to the memory address of the A/D channel to start a conversion.

On the second launch, we only used two of the internal A/D inputs. These monitored the battery pack's voltage through a voltage divider. The readings are first converted to volts by multiplying by 0.0195, then scaled to compensate for the voltage divider shown in Figure 1. The input "sees" about 1/6 of the battery pack's 12V, so the reading is multiplied by approximately six. These values were arrived at through experimentation.

The assembly language routine to read the A/D is a bit more complex. Refer to Figure 5. The routine is located in an unused area of memory. This is battery backed, so this routine only needs to be loaded once. The first thing the routine must do is preserve the status of the microprocessor so we may return to the BASIC program. This MUST be done or the processor could lock-up the first time the assembly routine is executed.

The data pointer register (DPTR) is set to an address of non-existent RAM. This is done so that reads and writes to the A/D chip don't actually effect RAM. At the time of a read or write to the A/D, only the A/D is selected and it is on the bus to be accessed — no RAM is selected. The program then sets the channel number to read on the A/D. This particular A/D convertor has four channels. Reading the others is done in a similar fashion, only the addresses change. At this point, the A/D is selected and a write is performed. The value written is not important, just the write, as this starts the conversion process.

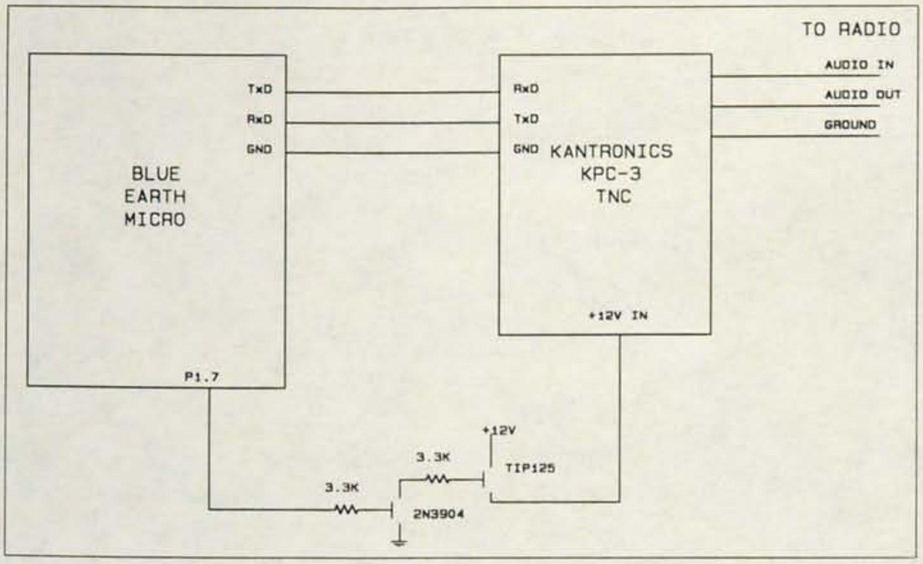


Figure 3: Shows the TNC interface. Powering the TNC through the Micro 440 overcomes a communications problem.

Since we are at the assembly level now, where things happen in microseconds, we must wait for the end-of-conversion signal before trying to read the results. When the conversion is complete, we are ready to read the results. The lower byte is selected, the A/D is selected, and a read is performed. DPTR must now be set to point to some *real* RAM so that the data is stored. A location was selected in the same area as the code. The A/D is de-selected so the write to RAM won't effect it. The byte is then written.

Then the most significant byte is selected. DPTR is moved back to the non-existent RAM, the A/D is selected, and another read is performed. This time only the lower four bits are valid; the upper four bits are set to zero by ANDing the byte with 0F(hex) or 15(decimal). DPTR is then set to point to the next RAM storage location, and the byte written. This completes reading of the A/D's first channel.

In practice, all four channels were read and stored before returning to BASIC. Before the routine returns, it must restore the state of the microprocessor stored earlier. The DPTR and ACC registers are popped from the stack, and the register bank used by BASIC is selected. The return statement returns control to BASIC. At this point, the values are stored in RAM. The values are PEEKed using the XBY (external RAM byte) statement. Notice the most significant byte is multiplied by 256, as it is the upper part of a 16 bit value. The lower byte is simply added and stored in the variable. This technique is used for all four channels of the A/D.

At line 260, the outside temperature sensor is read. Before being stored, it is scaled to degrees C. The sensor output is 1mV per Kelvin. The reading from the A/D is first converted to volts by multiplying by 0.122 volts per bit. This was arrived at as follows:

5V A/D Reference / 4096 bits (2^{12}) = 0.00122 V / bit
0.00122 V/level * (bits from A/D) = volts from sensor
volts * (1K / 0.001 V) = temperature in K
Subtract 273 to convert to degrees C.

The inside temperature sensor was handled in a similar fashion. The pressure and G sensors both have an offset that needs to be removed during the conversion process. The G sensor that we used reads -1 to +1 G over the range of 0 to 5 volts. This means that 0 Gs is somewhere around 2.5 volts. A lot of trial and error yielded a fairly good estimate of the 0 G point. This offset is subtracted at the beginning of the conversion process. The scale factor is then applied, and the result is acceleration in Gs. The scale factor was arrived at by the following:

A/D reading at +1G - A/D reading at -1G = A/D reading at 0 G

In this case, the A/D reading was 2908 for +1G and 993 for -1G, which results in 1950.5 for the 0 G point. This is subtracted from the reading to set the result on a 0 scale. Since there is a span of 1915 from the A/D, for a span of 2 Gs, there is 957.5 for 1G. The inverse of this gives .001044 Gs per bit.

This is the scale factor applied to the reading. Now we have Gs in a scale from -1 to +1.

The pressure sensor doesn't read 0 at a pressure of 0. Experiments in a bell jar resulted in the following data.

Measured Pressure mBar	A/D Reading Avg 100 reads	Change in Pressure over Change in A/D
975.50	3637.87	
916.20	3449.73	.2682
728.30	2831.25	.3150
364.20	1622.08	.2997
164.50	959.72	.3020
110.30	762.50	.3013
49.30	572.02	.2748
0.20	413.21	.3200

In order to remove some noise, the reported readings from the A/D are the average of 100 readings. I have doubts about the accuracy of our data at the very low pressures. I imported these numbers into a spreadsheet and came up with an offset and scale factor combination shown in line 330. It is only approximate; the sensor did read slightly below 0 millibars at altitude.

All that is left to do is to format and print the data to the TNC. The BASIC in the Micro 440 has an easy to use PRINT USING statement. The format of the number to be printed is shown with a pound sign. The catch is this statement will print a carriage return and line feed unless the statement ends with a comma. Lines 350 through 410 simply print a text string showing each variable and the value of each variable. This is all printed as one line; the carriage return is suppressed until the last print statement. This causes the TNC to transmit the packet.

Line 420 resets the real-time-clock-interrupt to the time of the start of the reading plus five seconds. This interrupt technique results in readings that are within milliseconds of being five seconds apart. Line 430 returns from the real work to our do-nothing loop at line 99.

Before this program can be implemented, there are a couple of things that need to be taken care of. The first is the serial port baud rate. It is normally auto-detected when the computer is powered up and is sent a space character. The port needs to be fixed at a baud rate and the auto-detect code bypassed. This is done by writing three bytes at locations 6001-6003(hex) as shown in Figure 6. The value BB(hex) will cause the auto-detect routine to be bypassed. The next two bytes set the serial port to 9600 baud. The last line causes the first program in the simulated disk area of RAM to be auto-executed on power up. Once these bytes are set, they remain after power down. The payload then will automatically start running when it is powered up.

Figure 7 shows how the data looks to a ground station. The receiving TNC has time stamping turned on and also HEADRLN ON. This causes the call signs and the time to be printed on a separate line from the data, making it easier to manipulate later. The GWBASIC program shown in Figure 8 shows a simple way to prepare the data for importing into a spreadsheet. The program opens the input and output files that you specify. It then reads in a line looking for the characters "Sec". It skips lines that don't start with these characters by looping back to line 130, removing all the call sign lines and blank lines. The position of each field in the data line is fixed, so the program simply breaks up the string based on the character position in lines 170 to 250. In lines 260 and 270 the fields are printed both to the screen and to the output file. The fields are separated by commas. Figure 9 shows a file prepared with fixed columns for importing into Lotus 123. The program was changed so that GWBASIC printed a tab after each field. This data can now be graphed and analyzed.

Ed Note: Figures 4, 5, 6, 7 and 9 are on the following pages.

```
2615  523  -13.6   6.9  562.9  1.037  10.90  11.09
2700  540  -14.7   6.5  533.8  1.024  10.90  11.09
2725  545  -15.0   6.5  523.3  1.022  10.90  11.09
2730  546  -15.4   6.3  523.6  1.037  10.90  11.09
3305  661  -32.6   3.6  362.0  0.953  11.02  11.09
3485  697  -34.0   2.7  330.6  1.039  11.02  10.96
3525  705  -36.4   2.4  322.7  1.014  10.90  11.09
3555  711  -38.1   2.2  316.3  1.025  10.90  11.09
3660  732  -42.5   1.6  296.4  1.052  10.90  10.96
3710  742  -43.1   1.3  287.6  1.051  10.90  11.09
3740  748  -44.1   1.2  281.6  1.022  10.90  10.96
3930  786  -47.1  -0.0  245.6  1.048  10.78  11.09
4275  855  -42.9  -2.2  199.3  1.043  10.78  10.96
4380  876  -39.0  -3.0  186.3  1.036  10.78  10.84
```

Figure 9: Output file from the conversion program. Lotus 123 will import columnar data in this format.

```
10 REM Balloon Launch #3 ———————— 01/24/1993 ——— Rob Kelly
20 period=5:f=1              Set to read every 5 seconds and frame #1
30 PORT1=27                   Setup the output port - TNC off
40 for x=1 to 500:next x        Delay for a while
50 port1=59                  Turn on TNC
60 for x=1 to 500:next x        Wait until copyright message is done
70 print "K",cr,             Send a "K" - TNC into converse mode - no LF
80 for x=1 to 100:next x        Delay a while
90 ONTIME PERIOD,60                RTC interupt every (60*5mSec)
99 GOTO 99                   All work is done in interrupt routine
100 REM ———————————————————————————————————— Read Internal ADC
110 F=F+1:NOW=INT(TIME)        Increment frame and get time of reading
120 XBY(65280)=8:  A0=XBY(65280)     A/D is memory mapped at these locations
130 XBY(65281)=9:  A1=XBY(65281)     write configuration byte to start
140 XBY(65282)=10: A2=XBY(65282)      conversion.  BASIC is slow enough
150 XBY(65283)=11: A3=XBY(65283)      that the A/D is done by the time it is
160 XBY(65284)=12: A4=XBY(65284)      read.
170 XBY(65285)=13: A5=XBY(65285):
180 XBY(65286)=14: A6=XBY(65286):
190 XBY(65287)=15: A7=XBY(65287):
200 REM ———————————————————————————————————— Scale ADC
210 A0=A0*.0195:A0=A0*6.32       Each bit is .0195 Volts and is multiplied
220 A6=A6*.0195:A6=A6*6.013       by a scale factor as necessary for sensor
230 REM ———————————————————————————————————— Read 12 bit ADC & Scale
240 CALL 19696                Call assembly routine to read 12 bit A/D
250 O=XBY(19956)+XBY(19957)*256:   Read 16 bit number from memory
260 O=O*.122:O=O-273            convert to volts, then to degrees C from K
270 I=XBY(19958)+XBY(19959)*256:   Read 16 bits
280 i=i*.122:I=I-273          convert
290 G=XBY(19960)+XBY(19961)*256:   Read 16 bits, subtract offset since
300 G=G-1950:G=G*.0010444        0 g's = 2.5 V and then apply scale factor
310 P=XBY(19962)+XBY(19963)*256:   Read 16 bits
320 P=P-413.05:P=P*.3025         Subtract offset since 0 psi doesn't read 0
330 REM ———————————————————————————————————— Send Data
340 PRINT USING(#####),:PRINT "Sec",NOW,     Print each field with the format
350 PRINT USING(####),:PRINT "Frame",F,     shown in the using statement.
360 PRINT USING(###.#),:PRINT "Out",O,"In",I,
370 PRINT USING(####.#),:PRINT "Pres",P,    Comma suppresses carriage return
380 PRINT USING(#.###),:PRINT "Gs",G,       and line feed until all of the line
390 PRINT USING(##.##),:PRINT "B1",A6,       is sent to the TNC
400 PRINT USING(##.##), :PRINT "B2",A0      This ends line and packet is sent
410 ONTIME NOW+PERIOD,60:              Setup the ontime interrupt for
420 RETI                      5 seconds from now and then return
```

Figure 4: Listing of the program in Micro 440 BASIC. Most of the program is run as a timer interrupt routine. Note that this BASIC is a floating point BASIC and that sensor scaling can be done with a few lines of code.

```
;***********************************************************
;*  This program reads the first channel of an ADC7802 A/D  *
;*  converter connected to the Micro 440 computer from      *
;*  Blue Earth Research.                                    *
;*  Rob Kelly   11/17/92                                    *
;***********************************************************
    ORG    4CF0H        ;LOCATE CODE IN UN-USED MEMORY
    PUSH   PSW          ;BASIC IS RUNNING SO WE MUST PRESERVE
    SETB   PSW.3        ;THE STATE OF THE MICROPROCESSOR
    SETB   PSW.4        ;PSW.3 AND PSW.4 SELECT AN UNUSED REGISTER BANK
    PUSH   ACC          ;BASIC USES THE REST OF THE BANKS
    MOV    A,DPH        ;SAVE THE OTHER REGISTERS NOT SAVED BY THE
    PUSH   ACC          ;BANK SWITCH
    MOV    A,DPL
    PUSH   ACC
    ;------------------------------------------ A/D 0
    MOV    DPTR,#32768  ;POINT TO LOCATION WITH NO RAM
    CLR    P1.0         ;PORT 1 BITS 0 AND 1 SET THE CHANNEL
    CLR    P1.1         ;NUMBER TO READ
    CLR    P1.4         ;SELECT THE A/D CHIP          CS=0
    MOVX   @DPTR,A      ;WRITE TO "RAM" TO TOGGLE WRITE LINE TO START A/D
    SETB   P1.4         ;DESELECT THE A/D CHIP        CS=1
    JNB    P1.3,$       ;WAIT UNTIL BIT 3 GOES HIGH END-OF-CONVERSION
    CLR    P1.2         ;SELECT THE LEAST SIGNIFIGANT BYTE   HBEN=0
    CLR    P1.4         ;SELECT THE A/D CHIP          CS=0
    MOVX   A,@DPTR      ;READ THE LOW BYTE
    SETB   P1.4         ;DESELECT THE A/D CHIP        CS=1
    MOV    DPTR,#19956  ;POINT TO LOCATION TO STORE DATA
    MOVX   @DPTR,A      ;WRITE BYTE TO RAM
    SETB   P1.2         ;SELECT THE MOST SIGNIFIGANT BYTE    HBEN=1
    MOV    DPTR,#32768  ;POINT TO NOTHING AGAIN
    CLR    P1.4         ;SELECT THE A/D CHIP          CS=0
    MOVX   A,@DPTR      ;READ THE HIGH BYTE
    SETB   P1.4         ;DESELECT THE A/D CHIP        CS=1
    ANL    A,#0FH       ;CLEAR THE UPPER 4 BITS OF HIGH BYTE
    MOV    DPTR,#19957  ;POINT TO LOCATION TO STORE DATA
    MOVX   @DPTR,A      ;WRITE BYTE TO RAM
    POP    ACC          ;RETRIEVE REGISTERS SAVED
    MOV    DPL,A        ;SO THAT WE ARE READY TO RETURN TO BASIC
    POP    ACC
    MOV    DPH,A
    POP    ACC
    POP    PSW          ;RETURN TO REGISTER BANK BASIC WAS USING
    RET                 ;RETURN TO BASIC
    END
```

Figure 5: Listing of the assembly language program used to access the external A/D. This was necessary since accessing the A/D from BASIC would cause the Micro 440 to lock up.

```
1 xby(6001h)=0bbh:REM tells startup code to bypass auto-detect routine
2 xby(6002h)=0ffh:REM next 2 bytes determine baud rate
3 xby(6003h)=0d9h:REM these set it to 9600
4 xby(6007h)=0ddh:REM autoexecute first program from ram disk
```

Figure 6: Listing of a short program to setup the Micro 440 to a fixed baud rate and to auto-execute a stored program.

```
N0SMR>WB0DRL [01/01/80 00:52:02]:
Sec 2395 Frame 479 Out -8.2 In 7.9 Pres 650.6 Gs 0.995 B1 11.02 B2 11.09

N0SMR>WB0DRL [01/01/80 00:52:07]:
Sec 2400 Frame 480 Out -8.5 In 7.7 Pres 650.6 Gs 1.027 B1 10.90 B2 11.09

N0SMR>WB0DRL [01/01/80 00:52:12]:
Sec 2405 Frame 481 Out -8.3 In 7.8 Pres 647.3 Gs 1.044 B1 10.90 B2 11.09

N0SMR>WB0DRL [01/01/80 00:52:17]:
Sec 2410 Frame 482 Out -8.1 In 7.7 Pres 643.7 Gs 1.005 B1 10.90 B2 11.09

N0SMR>WB0DRL [01/01/80 00:52:22]:
Sec 2415 Frame 483 Out -8.5 In 7.8 Pres 642.1 Gs .049 B1 11.02 B2 11.09

N0SMR>WB0DRL [01/01/80 00:52:27]:
Sec 2420 Frame 484 Out -8.5 In 7.8 Pres 642.1 Gs 1.010 B1 11.02 B2 11.09
```

Figure 7: Raw data as captured by a ground station. Note that HEADRLN is on. This causes data to be printed on a line by itself.

```
1 CLS
10 INPUT “Input Filename: “,IN$
20 INPUT “Output Filename: “,OT$
40 OPEN IN$ FOR INPUT AS 1
50 OPEN OT$ FOR OUTPUT AS 2
130 LINE INPUT #1, N$
140 IF MID$(N$, 2, 3) = “Sec” THEN 170 ELSE 130
170 SEC$ = MID$(N$,5,6 ): FRAME$ = MID$(N$, 17, 5)
230 O$ = MID$(N$,26, 6): I$ = MID$(N$, 35, 6)
240 P$ = MID$(N$, 46, 7): G$ = MID$(N$, 56, 6)
250 B1$ = MID$(N$, 65, 6): B2$ = MID$(N$, 74, 6)
260 PRINT SEC$;”,”;FRAME$;”,”;O$;”,”;I$;”,”;P$;”,”;G$;”,”;B1$;”,”;B2$
270 PRINT#2,SEC$;”,”;FRAME$;”,”;O$;”,”;I$;”,”;P$;”,”;G$;”,”;B1$;”,”;B2$
280 IF NOT(EOF(1)) THEN 130
290 CLOSE
```

Figure 8: Listing shows a GWBASIC program to read raw captured data and convert it to a format for importing into a spreadsheet.

Balloon VOR Navigation Experiment

by Mike Manes, W5VSI

During the first two EOSS balloon flights, in-flight tracking and final recovery of the payload depended strictly upon 2-meter direction finding by the field T-hunt Team. Although recovery was successful in both cases, the in-flight tracking left some uncertainty regarding the balloon's actual path.

The first flight, which ended near Stratton, CO was a real white-knuckle operation, since all the DF bearings were taken from nearly due west of the bird, yielding essentially no range data. Because of beacon antenna damage on landing, the touchdown site was discovered only from the air.

In May 1991, the balloon flew due north along the hogback (foothills of the Rocky Mountains, just west of the Plains). Lessons learned from the earlier flight resulted in a well-dispersed T-hunter team, and recovery was swift and sure from a spot only 200 feet from a road. But even so, a post-flight review of DF bearings called out during the flight showed that at best, the bird could be located only to about a 5 or so mile radius. In this case, bearing errors were attributed to reflections from the mountains, since all were taken generally from the east.

Payload recovery in both cases depended upon the functionality of the single 2M beacon. Only one or two T-hunters had 10-meter DF capability, and bearings at that frequency are not as precise as on 2-meters. If their search had extended into the night, final recovery would be slowed considerably. And the batteries have but finite life, so it could have been ugly.

EOSS can not easily afford the loss of a payload, so a redundant source of relatively accurate location data seemed to be a nice piece of insurance. We had discussed carrying a GPS or receiver aboard, but the price was well beyond our budget. Loran-C receivers were less costly, but the mid-continent chain was not yet operational.

We decided to try out a lower cost and reasonably accurate approach using the same method used by aircraft for years, VOR, or VHF Omnidirectional Range. VOR has been in commercial use since the 50's, so it doesn't require a lot of high-tech hardware. So unlike GPS and Loran, homebrewing from scratch isn't out of the question.

The VOR System

VOR stations are located all over the country, and there's one at most major airports. They are spaced such that a pilot is guaranteed to be within 40 miles of a station wherever he is over the lower 48. In operation, he simply tunes in the desired station and his bearing, relative to magnetic north, to or from that station appears on an instrument on his panel. This instrument, a VOR decoder, typically has a manually adjustable 360-degree bearing dial and a zero-center meter needle showing deviation between the dial and the actual bearing. The needle centers up at two bearings 180 degrees apart; a small TO/FROM flag shows whether that bearing is how to fly TO the station or FROM it. To find his location, the pilot can plot bearings from two different stations on a special aeronautical map, and the intersection is his fix. The FAA requires VOR bearings to be accurate to better than 2 degrees, so bearings from stations 30 miles away will yield a position accurate to within a mile.

VOR stations operate in the 112 to 118 MHz band with 100 KHz channel spacings. Each station transmits continuously and has a 1 KHz CW ID to confirm proper tuning. VOR transmitters operate at about 200W and radiate a horizontally-polarized AM signal. Ground-wave propagation is intentionally suppressed to minimize multipath errors, so the usable reception range on the surface is only a few miles. In keeping with air navigation convention, VOR bearings are referenced to magnetic, not true, north.

A VOR receiver comprises a channelized front end, 30 KHz wide IF and AM demodulator. The received audio is fed to a decoder for display of the bearing. The CW ID may be monitored by ear to confirm the location of the received station. The antenna should be horizontally polarized and reasonably omnidirectional; a horizontal V dipole with about a 90 degree apex angle is typically used on aircraft.

The VOR Signal

A VOR signal comprises three components. One is a 1 KHz CW ID which carries no bearing data. The second is a 30 Hz signal produced by a directional antenna electronically rotated at 1800 RPM (30 rev/sec). The easiest way to visualise this signal is by imagining a beam rotating continuously on a vertical axis. A receiver some distance away will see the signal strength vary through one full cycle every revolution, peaking when the beam is pointed directly at the receiver. Another receiver at a different bearing will see the same signal, except that the peak will occur at a different time.

If both receivers know exactly the instant in time when the beam is pointed north, then they can figure their bearings simply by timing from the north reference to the peak of the signal. At 30 rps, the beam moves 360 degrees times 30 per sec, or one degree every 92.6 usec.

The third VOR signal component, a 9960 Hz subcarrier, provides the north reference. The frequency of this component is modulated sinusoidally at the same 30 Hz rate of the beam rotation. The phase of this 30 Hz reference is set to pass through zero precisely when the beam is pointed north. The subcarrier is transmitted by a fixed omnidirectional antenna, so its signal strength remains constant throughout the cycle. By FM-demodulating the subcarrier, one now has a 30 Hz north reference for comparison to the 30 Hz AM component. One's bearing to the VOR station, then, turns out simply to be the phase lag in degrees of the 30 Hz AM part from the 30 Hz reference signal.

Design Considerations

Reception and decoding of VOR data is strictly passive, and the receiver doesn't have to be terribly hot. It does have to reject nearby FM broadcast signals up to 108 MHz, though, and must recover both a 30 Hz and 10 KHz subcarrier with little amplitude distortion. Phase error between the received 30 Hz RF and the demodulated audio shows up directly as a bearing error, so demodulator and AF amp response should go essentially to DC. Received signal strength can vary all over the map, depending on altitude and distance, so good dynamic range is important as well.

Although it's feasible to homebrew filters and PLLs to demodulate and display this phase angle, it's easier to use an surplus aircraft VOR demodulator. Thanks to Dennis, W0EPG, of Denver Avionics, EOSS became the proud owner of a working, used Narco VOA-9 decoder, along with a VOA-4 which needed work and full-up Mark 16 COMM/NAV transceiver. This gear weighs over seven pounds, though, and extraction of the bearing signal requires manual tweaking of a knob until the needle centers. As such, neither can go in the payload.

Decoding can be done on the ground using downlinked VOR audio from a balloon-borne receiver. The payload thus must carry only a 112 - 118 MHz AM receiver and horizontally-polarized omni antenna. The 10 KHz audio bandwidth is wider than a normal voice channel, so the downlink must be on the 70 cm band or higher. If ATV is carried aboard, its audio channel may be used for this purpose.

A VOR fix requires bearing data from at least two different VOR stations, so the receiver must be tunable in flight. A synthesized VOR receiver local oscillator (LO) provides both precision and flexibility, but a set of selectable crystals is simpler to implement. Preset LC tuning tanks may also work, but temperature stability is essential. Tuning commands may be uplinked to the balloon controller in real time, or a selected set of VOR frequencies may be loaded into the controller prior to launch. The controller scans through the channels, dwelling about 30 seconds on each to allow time for the operator on the ground to adjust the decoder for a null, catch the 10-sec ID and log the bearing. The controller also inserts a beacon callsign in CW every 10 minutes for legal identification.

The EOSS Implementation

A Ramsey AR-1 hobby-grade aircraft band receiver was used as the foundation for the flight receiver. This inexpensive device has a fixed-tuned 6-pole bandpass front end, an NPN RF amp, a varactor-tuned LO, an NE602 mixer and a 10.7 MHz AM IF. A simple Ge diode demodulator followed by a quad op-amp provides audio and IF AGC. An LM386 audio amp provides enough power to drive a small speaker. The entire receiver is designed to operate from a single 9-volt battery.

Considerable modifications were incorporated to elevate the performance of the AR-1 receiver to the minimum requirements for VOR reception. The more significant were:

- Front end redesign to improve selectivity and dynamic range. The bipolar RF amp was replaced with an MPF102 J-FET. The bandpass filter was replaced with a lightly-loaded coupled LC tank pair. The RC coupling to the NE602 mixer was replaced with a tuned transformer.

- The tuning pot was replaced with a Plessey NJ88C30 single-chip VHF synthesizer. A J-FET gain stage was added to the NE602 LO circuit to meet the synthesizer's input drive level requirements. We used a 5 MHz crystal in the 88C30 reference oscillator. The synthesizer circuitry was built upon a small piece of double-sided G10 and glued to a vacant area on the AR-1 board.
- The bias supply for the NE602 mixer and IF preamp stage was regulated to +5V to permit stable operation from the 10 - 15V payload battery bus.
- A small amount of forward DC bias was added to the detector diode to lower the minimum detectable signal level.
- The AGC time constant was increased by a factor of 20 to prevent AGC-induced attenuation and phase shift of the 30 Hz AM component.
- The audio output stage was modified to produce a low-level DC-coupled output signal for the downlink ATV transmitter audio line.

An outboard AF gate was added to cut in the CW ID from the W6ORE Balloon Controller. The ATV transmitter audio stage was modified to pass the 30 Hz signal without phase shift.

The two-wire synthesizer bus was driven directly from TTL-level signals originating on the controller; ferrite beads and light bypassing capacitors were added to keep CPU hash out of the receiver. During receiver development, a Tandy Model 100 was used to generate the bus signals from the printer port STROBE and DATA.0 lines. BASIC source code appears in Appendix A.

For the ground station end, a small DC-operated TV was fed by an ATV downconverter. The raw, DC-coupled output from the TV's audio discriminator was brought out and processed through an outboard op-amp to obtain the proper level and polarity signal for the VOR decoder.

A block diagram of the the VOR subsystem appears in Fig. 1.

Preflight Testing

The only VOR signal readable from the author's QTH was over 10 miles away, and it didn't fully deflect the TO/FROM flag (S-meter). The bearing was correct per the Denver TCA chart, but no cross-bearings were available to verify system operation.

The full-up Narco system was used as a referee for performance verification. When the balloon system delivered performance on the bench at least equal to that of the Narco, we considered it ready to fly. This was never fully achieved, however. The AR-1 minimum detectable signal was 1.1 uV (-107 dbm), or 10 db better than Narco, but it still suffered intermod from nearby airborne VHF communication signals, and it's maximum usable signal of 3mV (-37 dbm) was about 15 db lower than the Narco's. At that point, a 70 db dynamic range was judged adequate, so the time and trouble to add front end AGC was not deemed worthwhile.

A trip up to Bill Green's (W0GVT) awesome mountain QTH overlooking Denver yielded astoundingly strong signals from the DEN VOR, plus quite readable ones from Gill and Kiowa over 35 miles distant. The plotted bearings formed a triangle about one mile on a side. It's center was 1.5 miles from the true position, however. The Narco system yielded nearly identical results, however, so this error was attributed to multipath from the surrounding high peaks.

The system was carried out to some hilltops in the eastern plains, but none of the sites yielded two simultaneously decodeable VOR bearings. The best test, it was decided, was to fly it on a balloon.

Flight Experience

Prior to the first flight, the locations and local magnetic north references for all of the VOR stations in eastern Colorado were plotted on EOSS's standard tracking and recovery map. A file, Appendix B, showing that data was prepared and supplied to the tracking and recovery crew. The VOR data would be integrated into the conventional field DF bearing data as if each VOR were a separate tracking station.

The VOR system first flew in April, 1992 on EOSS-5. The ground station was set up in the field near the expected flight midpoint. An 11-element yagi and downconverter with no preamp fed the TV receiver. Although ATV was acquired only 3 minutes after launch, the best signal over the entire flight was P3, and there was a lot of white noise and vertical sync buzz in the audio. The decoded bearings were unstable and obviously incorrect. None were considered reliable enough to be called in to the tracking team. Post-recovery testing indicated that the VOR subsystem had not suffered a hardware failure, so poor signal quality was blamed for the disappointing performance.

The planned fix for the next flight was to get the best possible ATV signal. So on EOSS-6 a month later, the ground station was set up at the launch site and and fed from the main EOSS ATV receiver. The 22-element az-el mount and 1 db noise figure preamp had always produced fine quality P5 video. AC power at this site also permitted use of an oscilloscope to monitor the recovered VOR audio.

Moments after launch, the first VOR signal came pounding through. Its audio was much cleaner sounding than during the previous flight. But the 30 Hz audio was badly distorted as monitored on an oscilloscope, and the bearings were still obviously wrong! They seemed to be changing in the right direction and at the right rate as the flight progressed, however, so we suspected that there might be some fixed offset which could be subtracted out. A solid 90 degree error could be caused by loss of one of the audio components, so that was tried first. This trick worked reasonably well only on the DEN signal. The Kiowa bearing seemed more like 180 degrees out, though, and Gill was somewhere in between.

Once again, the postmortem revealed no physical damage. Judging from the excellent audible signal quality and the peak clipping observed on the 'scope, simple receiver overload was judged to be the prime culprit. Monday morning quarterbacking pointed to the decision not to include front end AGC as having been a fatal one.

Conclusion

With two flights under it's belt, we decided that VOR had consumed enough helium, lithium and sweat. Since then, EOSS has incorporated a modified commercial Loran-C receiver in the payload. The controller code was modified to read the National Marine Electronics Association (NMEA) serial data from the receiver. Flight operations with this system requires little ground station involvement, since lat/long and bearing/range from the launch site are downlinked in plain text every 30 seconds via the 2m packet link. It's not likely that we will ever resurrect the VOR experiment.

Nonetheless, VOR does offer the potential for a low cost, lightweight balloon navigation system requiring minimal flight system support. The scanning and ID logic can be implemented with a few CMOS chips, and any 70 cm wideband FM transmitter can serve for the downlink. In fact, a stand-alone transmitter might work better than an ATV subcarrier with it's 60 Hz and 16 KHz sync buzz.

A few tips for those who might be encouraged to carry on this work:

- The VOR receiver should be able to operate with signals in the -100 to -20 dbm range and should exhibit good intermod and out of band rejection. The Ramsey AR-1 can be made to work, but it may be possible to find a full-up VOR receiver board at your local avionics maintenance shop.
- The wish list for the scrounging mission should include access to a VOR test set. It will make system development and test independent of nearly non-existent live signals on the ground. (At the time we got our VOR decoder, we turned down the generous offer of a working Collins test set. This 100-pound behemoth had been obsolete for years, and was moldering away in the corner of the hangar. By the time we realized the value of this "boat anchor", the owner had already scrapped it.)

Notes:

1. LAT/LONG format deg:min.tenths. LOCATION format is in degrees True, Statute Miles FROM the cryptically abbreviated spot identifiable on the Pierson Colorado Recreation Map. "/"="intersection". Frequency is in MHz. Class H=Hi power, L=low. ID is CW identifier on VOR signal every 15 sec. Data compiled from FAA VOR listing, Jeppeson Sectional & Pierson map.

2. VOR audio from an onboard receiver will be downlinked on the ATV audio. Ground station decoding requires phase-error-free demodulation from 30 Hz to 10 KHz and an aircraft VOR indicator such as the Narco VOA4 or VOA9 or equivalent. Audio from a HiFi VCR may exhibit adequate frequency and phase response for accurate decoding from tape.

3. During the 4/11 flight, W5VSI will report bearings from each of three VORs as if they were taken from ordinary tracking stations. The spacecraft controller scans through a commandable set of three VOR stations, dwelling about 30 sec on each. Thus VOR plots can be updated at 90 sec intervals; however, I don't plan on calling in plots any more often than 5 minutes, and more likely at the 15 minute interval used by the tracking team.

4. Initial VORs will be Denver, Kiowa and Gill. Others will be commanded up en route if required.

5. VOR bearings (radials, in aviation parlance) are referenced to magnetic north and are (ideally) accurate to +/-2 degrees. The reported bearings will be converted to true north by ADDING the indicated variation to the magnetic radial readings.

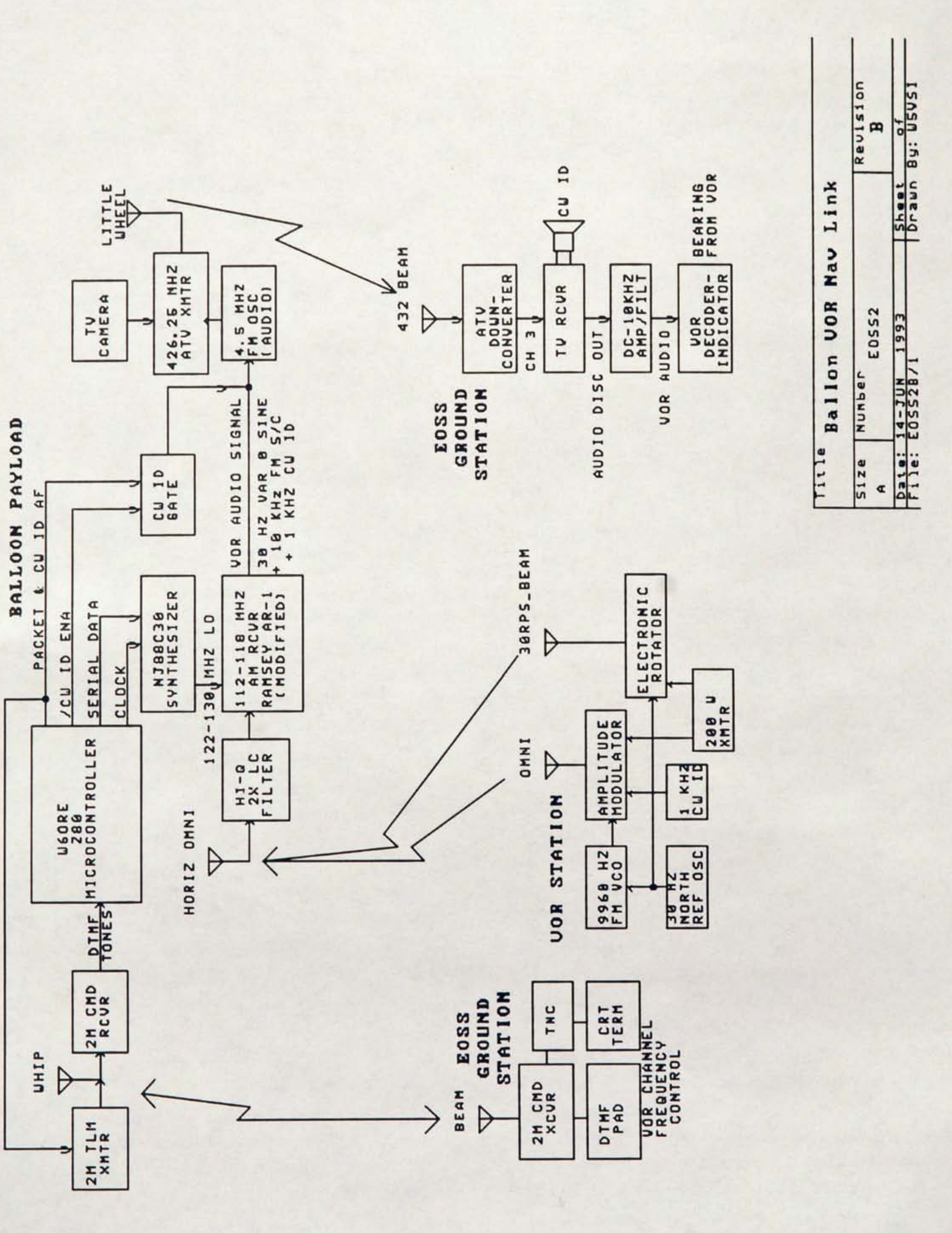


Fig 1 - VOR Block Diagram

APPENDIX A

Tandy Model 100 BASIC source code to drive a Plessey NJ88C30 CLK and DATA pins from the printer port STROBE and DATA.0 lines.

```
1 REM vorsyn.bas for m100 11/16/91 MRM
10 XT=5E6:FI=10.7              ‘Set ref osc and IF freqs.
20 NR=100:HDR$=”111"             ‘Ref div value and synth ref word.
30 FR=XT/NR:PRINT”Fref=”;FR/1000;” KHz”
40 INPUT “Rcv Freq, MHz”;FV:FV=FV+FI ‘Await rcv freq; find LO freq.
50 ND = INT((FV * 1E6)/FR)       ‘Compute prog div ratio.
60 REM PRINT ND                ‘Display it for debug.
100 GOSUB 200                 ‘Assemble serial data string
110 LPRINT SER$;               ‘and sent it to printer port.
180 GOTO 40                  ‘Loop back for next request.
190 END
200 REM build serial string of ASCII “1”s and “0”s.
210 N1 = 2^15:B$ = “0”           ‘Clear the serial string.
220 ND = (ND-N1)XOR(-N1)          ‘Conv 2’s compl to 16-b unsigned
230 IF ND < 0 THEN B$ = “1”       ‘for NJ88C30 prog div.
240 SER$ = HDR$ + B$             ‘Form ref div header & prog div MSB.
250 FOR X=14 TO 0 STEP -1         ‘Conv remaining 15 bits to ASCII
260 B$ = “0”
270 IF (ND AND 2^X) THEN B$ = “1”
280 SER$ = SER$ + B$             ‘and append to the string
285 NEXT X                   ‘until done.
287 REM PRINT SER$              ‘Display the string for debug.
290 RETURN
300 END
```

APPENDIX B

VOR listing provided to the EOSS Tracking and Recovery Team.

Edge of Space Sciences
Balloon VOR Navigation
Flight Area VOR Data

4/5/92 W5VSI

NAME	LAT/LONG	MAP LOCATION	Cl	ID	FREQ	VAR
DENVER	N 38:48.0	078, 5.6	H	DEN	117.0	12
	W 104:53.2	I25/I70				
KIOWA	N 39:26.1	049, 9.0	LW	IOC	117.5	13
	W 104:53.2	Kiowa CO				
	(E Cast Rock)					
GILL	N 40:30.2	124, 2.3	LW	GLL	112.8	13
	W 104:20.2	Galeton CO				
	(NE Greeley)					
CO SPRGS	N 38:56.7	298, 1.6	LW	COS	112.5	13
	W 104:38.0	Falcon CO				
	(NE Co Sprs)					
CHEYENNE	N 41:12.7	027, 15.6	H	CYS	113.1	13
	W 104:46.3	I25/St Line				
HUGO	N 38:48.9	120, 4.8	HW	HGO	112.1	12
	W 103:37.5	Punkin Ctr CO				
	(S Limon)					
THURMAN	N 39:41.9	182, 3.0	LW	TXC	112.9	12
	W 103:12.9	Anton CO				
	(US36/CO63)					
AKRON	N 40:09.3	109, 1.4	LW	AKO	114.4	13
	W 103:10.8	Akron CO				
	(E Ft Morg)					
LAMAR	N 38:11.8	032, 3.1	H	LAA	116.9	12
	W 102:41.2	Wiley CO				
	(NNW Lamar)					
GOODLAND	N 39:23.4	079, 18.9	?	GLD	115.1	10
	W 101:41.4	Kanorado CO				
	(I70/St Line)					

Landing Site Prediction using BALLTRAK

A practical guide for predicting balloon flight performance.

by Bill Brown WB8ELK

ABSTRACT:

How to run the BALLTRAK program and associated utilities, with guidelines to choose the proper balloon and parachute for your payload weight and where to obtain upper air wind data.

The BALLTRAK Program

After my first few flights, I decided there must be a way to use the FAA winds aloft forecasts and radiosonde observations to predict where my payloads might come down. Giving the foxhunters a target search zone eliminates the need to keep under the balloon at all times (they just have to drive to the drop zone and wait for the payload to fall near them). A good prediction also gives you an idea whether you should actually launch or not (not a good idea to land in the middle of the ocean, a lake or a large city). If you have alternative launch sites, you can choose where to launch from based on the most ideal landing site.

I set out to write a program that would predict flight paths and finally came up with BALLTRAK. It's written under GWBASIC and as a result can be easily updated. The BALLTRAK program essentially works on a data file that contains wind speed and wind direction information at fixed altitudes. This wind data is available from several sources: FAA phone briefers, the FAA DUATS BBS, CompuServe and WeatherBrief (by WeatherBank, Inc.) as well as several others.

The BALLTRAK program and it's associated utilities is available from the 73 Magazine BBS [tel: (603) 924-9343] and the File Bank BBS [tel: (303) 534-4646] as BALLTRAK.ZIP. You can also download it from the HAMNET forum on CompuServe as BALTRK.ZIP.

Predicting Maximum Altitude

There are three utilities you need to run before starting up the main BALLTRAK program. First, you need to determine the peak altitude of your balloon system using a utility called BALLIFT. This program takes the burst diameter information that is available from the balloon manufacturer and determines the maximum altitude you can expect for the amount of lift you require. The program first calculates the maximum possible expansion ratio the balloon can withstand based on the initial volume of helium at launch. A subroutine then calculates the altitude that gives you this expansion ratio (based on the atmospheric pressure at altitude vs sea level.) In addition, the line-of-sight range (in miles) is calculated by using the formula:

Distance = 1.22 * SQR (Height in Feet).

This is a conservative optical line-of-sight formula; for an optimistic radio line-of-sight range use a factor of 1.41 instead of 1.22 in the formula. I find that narrow band FM (such as 2 meters) will follow the 1.41 factor and wide-band modes such as ATV will correlate with the 1.22 factor.

The latest version of the program (BALLIFT9) incorporates the ASCENT.BAS program (described in the next section) in it and gives the ascent rate you can expect for different nozzle lift values (as long as you know your payload/parachute/radar reflector combined weight). It also calculates the balloon system's total positive lift. Just look at the printout from the BALLIFT program for your particular balloon type and select the nozzle lift (without payload attached) you need to obtain around 1000 ft./minute ascent rate.

To get you in the ballpark, I usually recommend you start with a nozzle lift of the balloon that is 1.5 times the payload plus parachute weight. Example: For a 4 pound payload/parachute weight, you should fill the balloon to lift 6 pounds. When you attach the payload, you will then have a Free Lift (positive lift of the whole system) of 2 pounds. This should give you around 900-1000 feet/minute ascent rate (about a 1-1/2 hour flight to altitude for larger balloons). If you are in a high wind situation, or there are nearby obstructions, you may want to pump up the balloon substantially more than that to increase the ascent rate. If you want a long duration flight, use less lift. Although I've flown with as little as 2 ounces of positive lift (I ran out of helium), I don't recommend much less than 1 pound of positive lift (also known as free lift) for larger payloads (you could get into trouble with downdrafts with less than this).

Once you know your final payload weight, you can run BALLIFT with different balloon types to get an idea how high you'll fly with each model. Generally, for payloads of 4 or more pounds, I recommend a Totex TA600, TA800, TA1000 (KAYSAM equivalents are the 70G, 90G or 105G). A few larger balloons are available but become fairly expensive and take a lot of helium to fill (some groups have flown the TA2000, for example which could get you up to 130,000 feet. Payloads under 2 pounds can get by with the Totex TA300 and for payloads under 1 pound you can even use inexpensive sounding balloons such as the Totex TA200 and TA100 (or KAYSAM 50P). With a 4 pound payload, you'll generally be able to fly between 85,000 to 105,000 feet with the three models mentioned above.

If you have the earlier version of BALLIFT that doesn't give you the ascent rate and free lift, you'll need to use the ASCENT.BAS program described next. You'll also need to calculate your descent rate at sea level before running the main BALLTRAK program.

Predicting Ascent Rates

There are two utilities in the BALLTRAK zip file (included as of 7/93) that allow you to determine your ascent and descent rate. They are not intended to be super accurate, in practice there are a lot of variables that determine actual ascent/descent rates, but they will get you in the ballpark. For the larger balloons (anything equivalent to 300 grams balloon weight or more), the following formula is a good estimate of ascent rate:

(1) Ascent Rate = 142 * (Square Root of (Free Lift)/Cube Root of (Free Lift + Gross Lift))

FREE LIFT = Nozzle Lift of the Balloon (no payload attached) - Payload Weight (includes weight of parachute, string and radar reflector)
GROSS LIFT = Free Lift + Payload Weight + Balloon Weight

The following steps will guide you on your way to ascent rate prediction:

1) First determine the final weight of your payload, string, radar reflector and parachute and call this the payload weight (PW).
2) Next, calculate your Free Lift (FL). This is the lift at the nozzle of balloon (without anything else attached) minus the payload weight calculated in step 1.
3) Now calculate your Gross Lift (GL). Gross Lift is determined by adding the Free Lift + Payload Weight + Balloon Weight. The Balloon Weight is usually marked on the data sheet or the box it comes in. Example: A Totex TA600 weighs 600 grams and a KAYSAM 90G weighs 650 grams.
4) Convert all final values to weights in grams.
5) Using the above formula will give you the ascent rate in meters/minute. Just multiply by 3.28083 to give the rate in feet/minute.

Example: What is the ascent rate for a 600 gram balloon (Totex TA600) with a nozzle lift of 6 pounds, a payload weight of 3.5 pounds, a parachute weight of 3 ounces and a radar reflector weighing 5 ounces?

Balloon Weight = 600 grams
Payload Weight = 4 pounds = 1589 grams
Parachute Weight = 3 ounces = 85 grams
Radar Reflector = 5 ounces = 142 grams
Nozzle Lift = 6 pounds = 2724 grams

Free Lift = Nozzle Lift - (Payload + Parachute + Reflector)
Free Lift = 2724 - (1589 + 85 + 142) = 908 grams (2 pounds)
Gross Lift = Free Lift + Balloon Wgt + (Payload Wgt + Parachute Wgt + Reflector Wgt)
Gross Lift = 908 + 600 + 1589 + 85 + 142 = 3324 grams
Ascent Rate = 142 * sqr (908)/cube root (3324) = 286.7 meters/min
Ascent Rate = 286.7 meters/min * 3.28083 = 940.6 feet/minute

To make life easier, you can use the program called ASCENT.BAS (See Listing 1) which will calculate everything for you in easily input units. All conversion factors are determined within the program. i.e. you can enter the balloon weight in grams, the parachute weight in ounces and the free lift in pounds giving the ascent rate in feet/minute.

Predicting Descent Rates

Choosing the right size parachute is important. You want the package to land softly but on the other hand, you don't want to extend your landing site location to ridiculous distances. After all, you don't want the chase crew to run out of gas in their pursuit. I typically like to see between an 800-1500 feet/minute descent rate. Much more than this can be rough on the payload (and whatever it hits) and much ess than 800 feet/minute will cause your payload to drift for some distance. For most payloads, a 44- inch diameter parachute is a good selection. Three foot parachutes are a good choice for payloads weighing in under 2.5 pounds. This will give you about a 30-45 minute descent from 100,000 feet. A total free fall (no parachute) will take about 15-18 minutes to hit the ground (depending on the size and shape of the payload) and will probably scatter your precious payload across the countryside!

The formula for determing the parachute descent rate at sea level is:

(2) Velocity = SQR * ((2*SW)/(CD*SA*DE)),

where SW = system weight (parachute weight + payload), CD = coefficient of drag (usually 0.7), SA = surface area of the parachute and DE = air density at sea level under standard conditions (0.0023769). All units are given in pounds and square feet and will result in descent rate calculated in feet/second. Multiply by 60 for feet/minute.

[Equation 2 above is valid for any altitude, provided the correct value for DE at the altitude of interest is plugged in. At 5000 feet, DE = .002027 . -Editor]

Example: Determine the descent rate for a 4 pound payload (include radar reflector weight, parachute weight and any other attachments) when using a 44-inch diameter parachute that weighs 3 ounces.

Parachute Diameter = 44 in.
System Weight = 4 lbs. (includes parachute, payload and reflector weight)
Velocity = SQR * ((2*4 lbs)/(0.7*10.56 sq.ft.*0.0023769 lb- ft^4/sec^2)) = 21.34 ft./sec
Velocity = 21.34 ft/sec. * 60 sec/min = 1280 ft./min.

You don't need to do this calculation by hand, just use the basic program DESCENT.BAS which will allow you to enter units in ozs and pounds and calculate your descent rate in feet/minute. See Listing 2.

Running BALLTRAK

OK, now we've determined our ascent and descent rates and figured out just how much helium to pump into the balloon. Next, we need to collect some wind data information to create a data file for BALLTRAK.

There are several sources for this information. The FAA winds aloft forecast will provide you with wind speed and direction at fixed altitudes up to 53,000 feet. These forecasts are available 24 hours in advance and are calculated from a computer model of the atmosphere based on radiosonde and wind profiler data. They are usually pretty accurate. You can obtain these forecasted winds directly from a flight briefer at the FAA at (800) 992- 7433, from the DUATS FAA dial-up computer service, from CompuServe under the Aviation Weather SIG by typing GO AWX-1 after signing on, or from the WeatherBrief dial-up service (call (801) 530-3181 to subscribe). I find that a service such as the WeatherBrief service is essential since it is one of the few that will provide you with the actual radiosonde observation data in addition to the FAA winds aloft forecast. Although the radiosonde data is only given at significant levels, it is detailed enough to give you a good flight prediction. This radiosonde data is the ONLY way to obtain wind data above 53,000 feet (unless you've made friends with the folks at your local radiosonde site).

Locate the radiosonde station or winds aloft forecast city nearest to your launch site (see Figure 1 for U.S. radiosonde stations). Then dial up one of the services mentioned above and download the FAA winds aloft forecast for your projected launch window. Next, dial up WeatherBrief and download the most current radiosonde data from the nearest site.

If you're doing a prediction the night before your flight, enter the FAA winds aloft data into the BALLTRAK program up to and including 53,000 feet. Then enter the information from the latest radiosonde flight to fill in the information from 61,000 feet on up to your projected burst altitude (don't enter data above your burst altitude). You'll have to convert the radiosonde altitude information from meters to feet (just multiply the radiosonde altitude by 3.28083). By mixing the FAA forecast for altitudes at and below 53,000 and using the current radiosonde information for 61,000 on up, you should be able to calculate a very close landing site prediction for the following day.

Radiosondes are launched twice a day at 1100 UTC and at 2300 UTC. The flight data is usually available by around 1300 UTC and at 0100 UTC. If you launch before the radiosonde data is available, use the mixed FAA winds aloft/previous radiosonde information for your flight prediction. If you launch after the current radiosonde flight data is available, you can recalculate your landing site using ONLY the radiosonde data for a very accurate prediction. Even if you fly before the sonde data is ready, you can recalculate as soon as it is available to refine your search area.

For example, if your flight is scheduled for 1200 UTC (8 a.m. EDT), use the FAA winds aloft forecast up to 53,000 feet and the previous night's radiosonde data (61,000 feet and above) for your prediction; if your flight is scheduled for 1300 UTC or later, use ONLY the current morning radiosonde data (surface to peak altitude). If you try to calculate a landing site using just the previous night's radiosonde data, you'll find it is not very accurate at this point. That's why you should use the FAA forecast for the first part of the data. You can get away with using older radiosonde data for the upper altitudes since the winds don't change quite as radically as in the troposphere and are usually quite a bit slower than in the jet stream region.

You can sometimes make a quick estimate of your landing prediction just by looking at the wind speed and direction at 34,000 or 39,000 feet. The winds here are usually the strongest (the middle of the jet stream) and have the most influence over your balloon's trajectory. Example: If the data shows a wind speed of 50 knots at a heading of 270 degrees (indicating a wind coming out of the west), a rough estimate would show your landing site to be 50 nautical miles (57.5 statute miles) at a heading of 90 degrees from your launch site. Since wind direction forecasts are given as the direction they are coming from, you have to subtract or add 180 degrees to calculate your balloon's drift direction. This quick rule-of-thumb prediction is sometimes fairly close, but usually falls apart during the summer when the jet stream winds die down and become less of an influence. In fact, during July -September you'll often find your package landing to your west when the easterly winds (winds coming out of the east) in the stratosphere become the biggest influence. As reported by some radiosonde sites, there have been instances where their balloon flew east at first, drifted back over them to the west and actually landed right back at the liftoff point after flying to 100,000 feet!

If you live between radiosonde sites or winds aloft forecast locations, you may have to run two predictions (one for each site) and average the two results for the best estimate.

After you've entered the last wind data level into BALLTRAK, just hit enter for the next level's three entries (altitude, wind direction and wind speed) to end the file. Please note that you should only enter data up to the maximum flight level you expect your balloon to reach. Name your file and you're now ready to run a prediction based on this data.

Next enter your ascent rate and descent rate information and watch the program do its prediction. BALLTRAK calculates the time your balloon will be between flight levels and assumes the wind speed and direction will be constant before it hits the next altitude level (the flight levels are close enough together that this is a good approximation). It then calculates the drift during the time the balloon spends between these levels. The displayed output is the expected position of the balloon as it hits each altitude level given in miles and the bearing from the launch site. Since the FAA winds aloft data and the radiosonde information are in knots (nautical mi/hr), these predictions are in nautical miles downrange. However, the final landing point calculation converts nautical to statute miles downrange by multiplying by a factor of 1.15.

Editing Wind Data Files

You can edit your wind data file by using a simple text processor that works on ASCII files and doesn't compress them into word processor formats. Some of the simple ones that work well are idekick or TED (a simple word processor published by Ziff Communications in one of their magazines). I prefer TED because it's very easy to use and does all I need to manipulate the data files. In fact I generally create my wind data files directly with the word processor rather than using the data entry portion of BALLTRAK. It's faster and its easy to edit the files. Just follow the following format when entering your own wind data files:

Altitude,Wind Direction,Wind Speed

Example:

```
3000,270,20
6000,280,30
9000,240,55
12000,230,67
18000,220,79
24000,210,85
30000,220,97
34000,230,99
39000,230,97
45000,240,70
53000,240,53
61000,250,30
68000,260,20
78000,090,10
86000,080,15
98000,070,25
```

Then save the file with a .DAT extension (i.e. ALB0625A.DAT). I usually name the file for the airport identifier of the wind data source followed by the date and a letter (in case I have more than prediction each day).

A Practical Example

Now that I've thoroughly confused you, let's go over a real life example of how to use these programs for balloon/parachute selection followed by an example of a landing prediction.

Example: Dayton Amateur Radio Associaton (DARA) flight #4 (6/26/93)
Payload Weight = 5.5 lbs
Parachute Weight = 5 ozs
Parachute Diameter = 72 inches
Reflector Weight = 3 ozs
Balloon Weight = 1200 grams (KAYSAM 105G)
Nozzle Lift = 11.5 lbs

1) Run BALLIFT9 and enter 105G for balloon type.
2) Enter your Payload/Parachute/Radar Reflector weights at the prompts.
3) Enter a starting and ending balloon fill diameter and the program will print out a range of nozzle lifts vs. maximum expected altitude and resultant ascent rate.

Example Printout from BALLIFT:

```
DIA       VOL    LIFT  LIFT     ALT  RANGE  EXPAN.  ASCENT  FREE LIFT
FT.       CFT.   OZS.   LBS.    FT.    MI.  RATIO   FT./MIN   LBS.
---------------------------------------------------------------------
7.0       179.6 135.8  8.49  107000  399   103.0     912.6    2.5
7.1       187.4 143.6  8.97  106000  397    98.1     983.4    3.0
7.2       195.4 141.4  9.47  105000  395    94.6    1047.8    3.5
```

This tells us that to achieve an ascent rate over 1000 ft/min (i.e. 1048 ft./min.) we need to fill the balloon to lift 9.47 lbs at its nozzle with no payload attached.

4) If running the old version of BALLIFT, calculate your ascent rate using the ASCENT.BAS program:

Example Result from ASCENT.BAS:

Balloon Wgt (gms): 1200
Nozzle Lift (lbs): 9.47
Payload Wgt (lbs): 5.5
Parachute Wgt (ozs): 5
Radar Reflector Wgt (ozs): 3

Ascent rate = 1047.6 ft/min

5) Now calculate your descent rate from the utility called DESCENT.BAS:

Parachute Dia. (in.): 61
Parachute Wgt. (ozs): 5
Radar Ref Wgt (ozs): 3
Payload Wgt. (lbs): 5.5

Descent velocity at sea level:
18.85 ft/sec
1131.08 ft/min
12.85 mi/hr

6) Now dial-up CompuServe (or DUATS or a FAA flight briefer) for the FAA winds aloft forecast:

Example CompuServe session using the nearest reporting city Columbus, Ohio (CMH) [Note that since Columbus, Ohio only reports up to 39,000 feet we need to take the next closest site of Indianapolis, Indiana (IND) forecast for 45,000 and 53,000 feet.]:

Low Altitude Winds
Current time is: 02:26 UTC Enter city name, identifers, or H for HELP

```
FDLO ID: cmh
   For   Hours
ID Use Z    From Now 3000  6000   9000    12000   18000   24000
CMH  21-06      **-04 2223 2228+14 2328+08 2327+04 2326-08 2324-19
CMH  06-17      04-15 3116 2918+11 2721+06 2526+03 2538-09 2545-21
```

FDLO ID: fdhi

High Altitude Winds
Current time is: 02:26 UTC Enter city name, identifers, or H for HELP

```
FDHI ID: cmh
   For   Hours
ID Use Z  From Now   24000   30000  34000  39000  45000  53000
CMH  21-06      **-04 2324-19 242535 253044 253255  N/A    N/A
CMH  06-17      04-15 2545-21 254637 254947 255456  N/A    N/A
```

Since Columbus doesn't report winds at 45 and 53,000 feet we need to find the nearest city does (Indianapolis - IND):

```
FDHI ID: ind
   For   Hours
ID Use Z  From Now   24000   30000  34000  39000  45000  53000
IND  21-06      **-04 2434-20 234635 235144 235154 243663 251964
IND  06-17      04-15 2645-22 274938 265547 266056 254962 242863
```

This wind data is encoded somewhat. You can decipher the wind data as follows:

For example, look at the bottom entry under the 53,000 foot heading in the IND listing. This is the wind direction, wind speed and temperature for that altitude and it is valid between 0600 UTC through 1700 UTC (the next morning).

Looking at the number 242863, the left two digits are the wind direction (multiply this number by 10 to give you 240 degrees), the next two numbers (28) is the wind speed in knots and the (63) number indicates the temperature in degrees C. All temperatures above 24,000 feet are assumed to be negative, so this indicates - 63 degrees C. When the wind speed is greater than 99 knots, a 5 is added to the leftmost digit of the wind direction number (i.e. a sequence of 750538 indicates a wind direction of 250 degrees, a wind speed of 105 knots and a temperature of -38 degrees C).

Now we can start building our wind prediction data file using the forecast for 0600-1700 UTC (the planned lift off time was set for 1200 UTC).

Example: The BALLTRAK data file based on the CMH forecast (with IND data used for 45 and 53 thousand feet) information will look like this:

```
3000,310,16
6000,290,18
9000,270,21
12000,250,26
18000,250,38
24000,250,45
30000,250,46
34000,250,49
39000,250,54
45000,250,49
53000,240,28
```

7) Now log onto the WeatherBrief system for the most recent radiosonde observation (Dayton has a radiosonde site called DAY):

```
Example radiosonde observation for Dayton from WeatherBrief:
+RAOB DAY 72429 DAY  2600Z  RAOB DATA
   MANDATORY LEVELS  SIGNIFICANT LEVELS      WINDS
PRMB  HMTRS     TEMP  DPD   WDR  WDS    PRMB  TEMP  DPD   ALTD  WDR  WDS
====  =====     ====  ===   ===  ===    ====  ====  ===   ====  ===  ===
1000      SRFC  22.6  1.4   220   10    811   13.0  0.6   SRFC  220   10
 925       805  19.2  1.6   225  36     97.1  -65.5 2000  225   32
 850      1530  15.4  0.8   215  37     79.7  -62.7 3000  220   38
 700      3156  5.8  0.8    200  26     67.7  -64.5 4000  220   40
 500      5850  -6.9  1.0   235  23     58.1  -57.1 6000  215   35
 400      7560  -17.7  1.8  250  26     22.4  -45.9 7000  215   35
 300      9650  -33.9  7.0  250  31     16.3  -46.1 8000  210   31
 250  10900  -44.7   250   37    14.6  -42.7 9000  205   29
 200  12360  -56.3   250   40    13.4  -42.7 12000 205   25
 150  14130  -65.3   245   27    97.1  -65.5 14000 195   25
 100  16590  -64.7   230   15    79.7  -62.7 15000 190   25
  70  18780  -64.5   100   5     67.7  -64.5 16000 195   24
  50  20880  -57.7   40    5     58.1  -57.1 19000 230   22
  30  24160  -51.5   100   16    22.4  -45.9 20000 240   22
  20  26830  -46.3   70    16    22000 250   24
  10  29870  -43.1   80    18    25000 250   26
 156      TROP  -66.3 245   25
MEAN LAYER WINDS: SFC-5
   5K-10
```

8) Convert the upper level radiosonde altitudes to feet instead of meters by multiplying by 3.28083 (since we're just adding to the FAA forecast, we just need the data above 53,000 feet which starts at the 70 millibar level).

Extracting from the above radiosonde printout we get:

Millibar	Altitude (ft.)	Wind Dir	Wind Speed
70	61614	100	5
50	68504	40	5
30	79264	100	16
20	88025	70	16
10	97998	80	18

9) Now you can finish your BALLTRAK data file (either from the entry portion of BALLTRAK or by directly creating a data file from a text processor). Enter the Winds Aloft forecast information up to and including 53,000 feet followed by the radiosonde information for the higher altitudes.

An example of the finished file created by using the TED (or similar) text processor:

```
3000,300,19
6000,300,23
9000,300,28
12000,280,29
18000,260,41
24000,260,45
30000,270,49
34000,260,55
39000,260,60
45000,250,49
53000,240,28
61614,100,5
68504,40,5
79264,100,16
88025,70,16
97998,80,18
105000,80,18
```

Note that since the BALLIFT9 program indicated that our 105G balloon will make it to 105,000 feet, we have added that altitude to the data file and just repeated the wind direction and wind speed from the previous altitude.

10) Now run BALLTRAK, enter the filename you wish to work on, enter the ascent and sea level descent rate (as calculated by the ASCENT and DESCENT programs) and the program will crank out your estimated flight path and predicted landing site. Example of the BALLTRAK prediction for the Dayton flight (calculated at 10 p.m. the night before the flight with mixed FAA winds aloft and previous night's radiosonde data):

CMH0625F (forecast for Dayton launch at 1200 UTC on 6/26/93 based on the CMH and IND FAA forecast and 6/25 evening radiosonde (DAY).

Landing Site = 53.0 mi. @ 69.7 degrees. (distance and bearing from the launch site)

11) Now let's look at the prediction based on ONLY the Dayton radiosonde flight taken on the morning of the actual flight (the ATV balloon was launched from the actual radiosonde site about an hour after the radiosonde lifted off). The DARA balloon was almost at its maximum altitude when this prediction was ready:

The WeatherBrief radiosonde data for the morning flight on 6/26/93 from Dayton:

```
+RAOB DAY 72429 DAY  2612Z  RAOB DATA
   MANDATORY LEVELS  SIGNIFICANT LEVELS      WINDS
PRMB  HMTRS    TEMP  DPD   WDR  WDS    PRMB  TEMP  DPD   ALTD  WDR  WDS
====  =====    ====  ===   ===  ===    ====  ====  ===   ====  ===  ===
1000     SRFC  18.0  1.9   300   4     964   20.2  9.0   SRFC  300   4
 925     825   18.4  8.0   315   21    794   7.4  6.0    2000  310   22
 850     1543  12.0  6.0   330   20    776   6.8 11.0    3000  320   21
 700     3147  5.6 21.0    265   28    749   9.2 20.0    4000  325   20
 500     5840  -7.3 30.0   245   40    686   5.6 20.0    6000  330   18
 400     7530  -21.5 16.0  240   48    644   1.4 19.0    7000  310   15
 300     9600  -34.7  3.2  225   59    624   1.6 30.0    8000  270   19
 250  10850  -44.9   225   70    582   -1.5 30.0   9000  265   22
 200  12300  -56.7   245   76    559   -1.7 20.0   12000 265   40
 150  14080  -64.7   230   55    372  -24.9 10.0   13000 260   42
 100  16560  -63.5   255   17    355  -26.9  2.7   14000 235   35
  70  18770  -62.5   5     7     327  -29.9  2.5   16000 245   34
  50  20860  -56.1   90    20    272  -39.9  4.0   19000 250   42
  30  24150  -50.5   75    22    184  -60.9  20000 250   42
  20  26820  -44.7   70    29    25000 240   48
  10  29870  -42.8   60    20
 140     TROP  -66.1 240   53
MAX WIND & VERT SHEAR: 192mb  19 125   295   19
MEAN LAYER WINDS: SFC-5
   5K-10
```

This information can be reduced to the following BALLTRAK data file after converting the altitude from meters to feet:

```
3,300,4
2705,315,21
5061,330,20
10322,265,28
19155,245,40
24698,240,48
31487,225,59
35587,225,70
40343,245,76
46182,230,55
54316,255,17
61565,5,7
68420,90,20
79211,75,22
87969,70,29
98000,60,20
105000,60,20
```

Once again we've added a listing for 105,000 feet since the radiosonde doesn't report winds that high. We've just repeated the next lower altitude's wind data. Sometimes you'll find some holes in the radiosonde data. When this happens just repeat the next lower wind information until the hole is filled (while not as accurate, its better than nothing at all).

The BALLTRAK Prediction based on the morning radiosonde launch:

```
TIME  ALT    DIST  HEAD   EL    DESCENT
MIN.  FT.    MI.   DEG.  DEG.   FT/MIN
==========================================
...   .....  ....  ..    ....   ......
131   19155  39.9  61    4.90   1372.2
136   10322  39.9  61    2.51   1241.2
138    5061  40.1  62    1.08   1188.1
140    2705  40.2  62    0.44   1130.9
```

Landing Site: 45.8 miles @ 61.2 degrees

The package was located quickly just southwest of the town of Marysville, Ohio. It had travelled 47 miles at a heading of 63 degrees from the launch site! The morning's radiosonde prediction was almost dead-on target (only about 1.5 miles off the target) while the prediction made the previous evening was off by about 7 miles, but still good enough to greatly aid the chase crew.

Since the DARA balloon was launched from the actual radiosonde site just one hour after their liftoff, the Dayton group's balloon flew in essentially the same winds which resulted in a very accurate prediction. The farther you are away from a radiosonde site (and the amount of time since their last flight), the less accurate your prediction. If you're between two radiosondes sites, you may want to average the two landing predictions. If you are launching several hours after the radiosonde flight, you may want to look at the FAA forecast combined with the upper levels from the radiosonde, just as you would the night before.

When making two predictions based on different wind data sources, I'll sometimes position some of the chase team at the secondary touchdown location.

Future Versions

I hope this program helps stack the recovery odds in your favor. The prediction usually gets you within a 10-mile circle and substantially narrows your search area. Depending on how far your launch site is from a forecast city or radiosonde location, you can get within a couple of miles on the prediction (several prediction have been within a mile and one missed by only 200 yards). Obviously if you launch from a radiosonde site soon after their flight, you'll have the most accurate prediction possible!

BALLTRAK 2.0 will incorporate the ASCENT/DESCENT and BALLIFT utilities as menus in the main program and will incorporate subroutines to grab text output from the winds aloft forecasts and radiosonde data directly into the program without having to re-enter and convert the data from meters to feet. BALLTRAK 2.0 should be available by the end of the summer.

(A map of Radiosonde Sites is included in Bill Brown's first Paper - Ed.)

Listing 1. Ascent Rate Program.

```
10 REM *************************************
15 REM * ASCENT.BAS  *
20 REM * Ascent Rate Calculation (6/21/93) *
25 REM * by Bill Brown WB8ELK    *
30 REM *************************************
40 CLS
45 INPUT “Balloon Weight (gms).: “;BW
50 INPUT “Nozzle Lift (lbs.): “;NL
60 INPUT “Payload Weight (lbs.):”;PW
70 INPUT “Parachute Weight (ozs.): “;PA
80 INPUT “Radar Reflector Weight (ozs.): “;RW
90 K=142:REM ** Factor for 300-1500 gram balloons **
110 PW=PW*454
120 PA=(PA/16)*454
130 RW=(RW/16)*454
140 NL=NL*454
150 FL = NL-(PA+PW+RW)
160 GL = FL+BW+PW+PA+RW
170 GOSUB 1000:REM ** CR is cube root of GL returned from subroutine **
180 AR = 142*((SQR(FL))/CR):REM ** Ascent Rate of balloon system **
185 PRINT “”
190 PRINT AR*3.28083;” ft/min ascent rate”:REM ** Ascent Rate of balloon **
195 PRINT “”
200 GOTO 45
1000 REM ** Cube Root Subroutine **
1005 QQ=GL
1010 FOR Z=1 TO 100
1020 ZF=Z*Z*Z
1030 IF ZF>QQ THEN GOTO 1050
1040 NEXT Z
1050 Z1=Z-1
1060 Z2=Z1*Z1*Z1
1070 IF Z2>QQ THEN GOTO 1100
1080 Z1=Z1+.1
1090 GOTO 1060
1100 Z2=Z1-.1
1110 Z3=Z2*Z2*Z2
1120 IF Z3>QQ THEN GOTO 1150
1130 Z2=Z2+.01
1140 GOTO 1110
1150 Z3=Z2-.01
1160 Z4=Z3*Z3*Z3
1170 IF Z4>QQ THEN GOTO 1200
1180 Z3=Z3+.001
1190 GOTO 1160
1200 Z4=Z3-.001
1210 Z5=Z4*Z4*Z4
1220 IF Z5>QQ THEN GOTO 1250
1230 Z4=Z4+.0001
1240 GOTO 1210
1250 CR=Z4-.0001
1290 RETURN
```

Listing 2. Descent Rate Program (parachute formula courtesy of Larry Epley of Winzen Research.)

```
10 REM ******************************************
20 REM  * Parachute Descent Calculation (6/21/93 *
25  REM * - by Bill Brown WB8ELK                *
30 REM ******************************************
40 CLS
50 INPUT "Parachute Diameter (in.): ";PD
60 INPUT "Parachute Weight (oz.): ";PA
65 INPUT "Radar Ref. Wgt (oz.): ";RW
70 INPUT "Payload Weight (lbs.): ";PW
80 CD = .7:REM ** Coefficient of Drag for parachute **
90 AD = .0023769:REM ** Atmospheric density at sea level (lb-ft4/sec2) **
100 PR = PD/24:REM ** Parachute radius in feet **
110 PA = PA/16:REM ** Parachute weight in pounds **
115 RW = RW/16:REM ** Radar Reflector weight in pounds **
120 SA = 3.14159*(PR*PR):REM ** Surface area of parachute (sq. ft.) **
130 V = SQR((2*(PW+PA+RW))/(CD*SA*AD)):REM ** Descent velocity in ft/sec **
140 VM = V*60
142 PRINT ""
145 PRINT "Descent Velocity at Sea Level"
147 PRINT ""
150 PRINT V;" ft/sec"
160 PRINT VM;" ft/min"
165 PRINT (VM*60)/5280;" MPH"
170 PRINT ""
200 GOTO 50
```

Ground Station Hints and Kinks

by Rich Volp, NØPQX

[redacted]

[redacted]

During my time with Edge of Space Sciences, most of my experience has been with the ground station. There are many hints and kinks which I have picked up over the seven or eight launches which I have been a part of. The first thing I have learned is that the ground station must be organized. Whoever is assembling and coordinating the station must know exactly what is needed and exactly where it is coming from. Getting equipment for our ground stations has never been too great a challenge. It may take a little nagging, but there are plenty of people willing to give up a piece of their station equipment for a day to help out.

Our basic station equipment consists of five parts: the ATV equipment, the packet station, the command equipment, the net station, and finally and most importantly, the package testing and balloon launch area.

The station's ATV is receive-only. We have an ATV downconverter, built by a few of our members, and a few televisions around so anybody can watch. A VCR is also a must, to record those precious views. In the packet station, we use a laptop computer, a small TNC such as the KPC-3, and usually an HT. The antennas for the ATV on 70 cm, and the packet on 2 meters, are both long-booms. They are mounted on an azimuth-elevation rotator which is on a short piece of mast, which itself is mounted on a tripod. This makes for easy setup at any launch site, while still taking advantage of the ease of operation of an az-el rotator and the gain of the long-booms. Our command station usually uses the same radio as the packet station. If it is an HT, an amplifier is put in line for effective transmission of commands. This also utilizes the same long-boom antenna to send commands to the package. The commands are sent using the sixteen standard DTMF tones. The net radio is a very important link to the trackers in the field and to anyone who may be listening for information about the event. This radio is kept very busy passing vital information and routine traffic. The fifth part is the package testing and launch area. Our package has a serial port on it for connection to a terminal while it is on the ground. The terminal issues commands and tests package functions. The launch area also contains helium tanks and an area to string-up all of the different components of the balloon package.

As can be seen above, the station is broken into five main areas. It is a good idea to assign one person to each of these areas. This keeps people organized and focused on just one goal, instead of four or five people trying to run the entire station. If needed, our team will also add extra people. One may plot all of the bearings, or another may take bearings and report them to the trackers. Occasionally our balloon may carry experiments from students or others. An additional section may be added to the station to allow the experiment data to be collected or studied.

The running of the ground station can go very smoothly if everyone at the station communicates and stays focused on their particular goal. It is an enjoyable and rewarding experience to be part of a team which cooperates to get the job done. There is only one reason any of us are involved in Amateur Radio and balloon flights, and that is to have fun. While it may sometimes get very hectic and busy at the ground station, it is easy to see that everyone is having a great time.

Balloon Tracking With an Apple Macintosh Computer

by Paul A. Ternlund, WB3JZV

[redacted]

Abstract

Once Edge of Space Sciences, Inc. (EOSS) based in Denver, CO, launches a balloon carrying amateur radio gear, tracking and recovery becomes the job of a skilled radio direction finding (RDF) team. A Macintosh PowerBook computer running *augmented* triangulation software aids the team. A summary of this system is descibed, including the implementation strategy, trigonometric expression derivations, program descriptions, Tracking Team guidance, and a comparison with results from a LORAN-C receiver carried aloft.

Photo by Stephen Ternlund

Left to Right - Author Paul Ternlund (WB3JZV), Mac Powerbook and Tim Moffitt (N0NXI)

Introduction

Radio Direction Finding (RDF) contests among radio amateurs are known as foxhunts. I have enjoyed the individual challenge of foxhunting since my association with the Maryland Mobileers ARC in the late 70s. However, few will argue that *cooperative* RDF techniques are best for recovering a balloon with an expensive payload. EOSS payloads have included, for example: a control computer, telemetry and control transceiver, two and ten-meter beacons, amateur TV (ATV), and a scientific package. The technique described below has been helping the EOSS Tracking and Recovery Team successfully track and recover nine balloon payloads since EOSS launched its fifth balloon on 11 April 1992.

When tracking EOSS balloons before using this technique, our Field Coordinator did balloon position estimations "on-the-fly." While this worked amazingly well, due to the coordinator's skill, they were prone to error; therefore, risky.

I developed the system with the goal of providing prompt balloon location estimates using *all* available bearing data from a cooperative RDF team. My objective is to know where the balloon is located to within 40 square miles[1]. My implementation requires that *most* reported bearings for a given sample time are "decent." The implementation is tolerant of erroneous bearings (due to multipath, etc.), as long as these are in the minority for the particular sample.

Augmented Triangulation

"Augmented" triangulation is key to this system for balloon tracking. It consists of four automated parts: (1) triangulation, (2) position estimation, (3) plotting, and (4) station performance monitoring.

Part 1 - Triangulation

Webster's Ninth New Collegiate Dictionary defines "triangulation" as a "...trigonometric operation for finding a position or location by means of bearings from two fixed points a known distance apart." I will derive triangulation expressions later. My results are equations for the X and Y coordinates of the target beacon signal. These equations are a function of two RDFing stations' coordinates and their bearings to the beacon. The triangulation part is the systematic solving of these triangulation equations for every unique pair of bearings.

When there are more than three stations reporting bearings for a given sample time, the result is more than one triangulated point. The number of unique triangulation calculations is an "n choose 2" situation, where n is the number of reporting stations for a given sample time. For n stations reporting bearings at a given sample time, the maximum number of triangulated points is:

$$n! / 2! (n - 2)!$$

Therefore, while 3 bearings can produce 3 triangulated points, and 10 bearings can produce 45 points, 20 bearings can produce 190 points.

Part 2 - Position Estimation

In the real world, most of these points are scattered with little overlap. So, therefore, which point is right? Which points are wrong? Are any points right? This is a real problem due to erroneous bearings. Causes for bad bearings include: (a) signal multipath, (b) improper antenna aiming, (c) incorrectly adding a fixed magnetic variation (this is 11 degrees in the Denver area; although the Mac can easily do this arithmetic, our Tracking Team prefers to do it themselves), (d) local magnetic variances, (e) poor hunter position geometry (i.e., single quadrant bunching), (f) incorrect knowledge of a hunter's position, and (g) reading a compass incorrectly. In short, I have found that precise bearings are rare, and that every RDFer can take erroneous ones.

Therefore, while triangulation is the underpinning of this algorithm, more must be done to give the Field Coordinator *one* estimated position for the balloon from the scattering of triangulated points. There are many ways to determine a position estimate from a scattering of fixes including seat-of-the-pants guessing. After experimenting with a few methods I settled on the following multiple-averaging technique:

Given n bearings, B1, B2, ...Bn. Form station pairs i,j to triangulate, where i = 1,2, ..., n - 1; j = i + 1, i + 2, ..., n.

1) Compute all triangulated coordinates (Xij,Yij), exempting any calculation if the bearings diverge or are parallel.
2) Let Xavg = the average of all triangulated Xij.
3) Let Yavg = the average of all triangulated Yij.
4) Let the initial transmitter location estimate = (Xavg,Yavg).
5) Compute the distances between (Xavg,Yavg) and each of the triangulated points (Xij,Yij).
6) Let Dist Avg = the average of all distances computed in 5.
7) Drop any point (Xij,Yij) that is further away from (Xavg,Yavg) than Dist Avg.
8) Let Xt = average of all residual triangulated Xij.
9) Let Yt = the average of all residual triangulated Yij.
10) Let the refined transmitter location estimate = (Xt,Yt).

To say it another way, individually average the convergent triangulated X and Y results, and consider the resultant coordinate, (Xavg,Yavg), as the "initial location estimate." Next, drop any convergent triangulated point that is further than the average distance between each point and the initial location estimate. Finally, take a new average X and Y from the "surviving" points. This resulting average point (Xt,Yt) is the "refined location estimate" and is the point that gets reported to the Field Coordinator.

This technique produces a perfect result given perfect input data. With imperfect input data, it produces an estimate near the major cluster of triangulated points - as long as more than half of the bearings reporter are decent. In other words, the technique tolerates some bad data. Nonetheless, the better the bearing accuracy from each RDF team member, the better the program's results.

$$\text{Bearing 1 } = b1 \text{ degrees true}$$

$$\text{Bearing 2 } = b2 \text{ degrees true}$$

$$\text{But, } a2 = 360 - b2$$

$$\text{Therefore, } \tan a2 = \tan(360 - b2)$$

$$\begin{aligned}\text{From a trig identity, } \tan a2 &= \frac{\tan 360 - \tan b2}{1 - \tan 360 \tan b2}\\ &= \frac{0 - \tan b2}{1 - 0}\\ &= -\tan b2\end{aligned}$$

$$\text{Therefore, } \tan b2 = -\tan a2 \qquad \textbf{[Equa 1]}$$

Next, because D and E are right angles,

$$\tan b1 = \frac{Xt - X1}{Yt - Y1} \qquad \textbf{[Equa 2]}$$

$$\text{and, } \tan a2 = \frac{X2 - Xt}{Yt - Y2}$$

$$\text{Because of Equa 1, } \tan b2 = \frac{Xt - X2}{Yt - Y2} \qquad \textbf{[Equa 3]}$$

Now we solve Equa 2 and 3 simultaneously for the two unknowns, Xt and Yt...

$$Xt - X1 = (Yt - Y1)\tan b1$$

$$Xt = (Yt - Y1)\tan b1 + X1 \qquad \textbf{[Equa 4a]}$$

$$\text{and, } Xt - X2 = (Yt - Y2)\tan b2$$

$$Xt = (Yt - Y2)\tan b2 + X2 \qquad \textbf{[Equa 4b]}$$

$$\begin{aligned}\text{Therefore, } (Yt - Y1)\tan b1 + X1 &= (Yt - Y2)\tan b2 + X2\\ Yt\tan b1 - Y1\tan b1 + X1 &= Yt\tan b2 - Y2\tan b2 + X2\\ Yt\tan b1 - Y1\tan b1 &= Yt\tan b2 - Y2\tan b2 + X2 - X1\\ Yt(\tan b1 - \tan b2) &= Y1\tan b1 - Y2\tan b2 + X2 - X1\end{aligned}$$

$$Yt = \frac{Y1\tan b1 - Y2\tan b2 + X2 - X1}{\tan b1 - \tan b2} \qquad \textbf{[Equa 5]}$$

Equations

Part 3 - Plotting

Following each calculation, this part creates a chart to show: (a) the relative positions of the hunters, (b) the surviving triangulated points, and (c) the estimated transmitter location. This chart permits the computer operator to easily behold all relevant coordinate data. Any conspicuously clustered Tracker positions will stand out.

Part 4 - Station Performance Monitoring

This part counts whenever a station's bearing is parallel to, or divergent from another's, and when a fix is too far from the major cluster of fixes. The program keeps these counts for each reporting station at each sample time, and can be used for follow-on analysis. The counts equate to the number of times the program ignored a station's fix during the estimation calculation. We can suspect an RDF station with uniquely high numbers of having some systematic problem. This station is advised to investigate his equipment or skills by RDFing on a transmitter of known position. Conversely, stations with the lowest numbers are generally good performers. Station geometry, (one station's location with respect to another's) can be a factor also. A Tracker who is alone in a quadrant about the balloon may fair better than clustered Trackers.

Implementation

My PC of choice is the Apple Macintosh. The man-machine interface that the Mac provides is outstanding. Software selection is another matter. While I reviewed the choices for source code, my foxhunting partner and fellow Apple aficionado, Tim Moffitt, N0NXI, suggested using Microsoft Excel. The more I thought about Tim's suggestion the more it made perfect sense. Excel provides the means for exploiting the Mac's excellent graphical user interface. Having a mouse to zip from cell to cell in an Excel spreadsheet is ideal. It is just what I wanted for entering bearing data during the heat of a balloon chase. Excel also provides a plethora of mathematical functions, a macro language, and a charting capability. As you will see, I put Excel's scatter charts to good use. The software complement chosen for the implementation consists of the Macintosh Operating System 7.0, and Microsoft Excel 4.0 driven by two of my own Excel macros.

First Some Trigonometry; Then Triangulation

Next, I derive the triangulation expressions I use in the macro. The derivation begins by assuming we know the coordinates of two hunters (X1,Y1) and (X2,Y2), respectively (Fig 1). Assume that they take perfect bearings b1 and b2, respectively toward the beacon. These bearings are referenced to true north. Let these bearings converge at the location having coordinate (Xt, Yt), the site of the beacon. We now derive equations for Xt and Yt in terms of the hunters' locations and bearings.

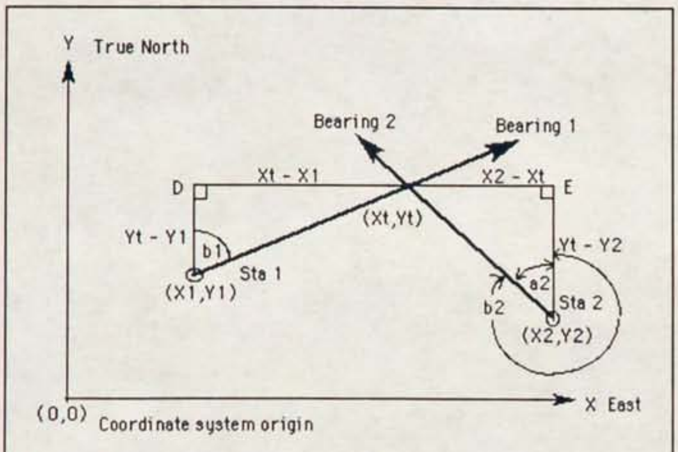


Fig 1-Diagram for Triangulation Equation Derivations

Equations 4a, 4b, and 5 are the triangulation equations that I use in the macro.

(Ed Note: See Equations on previous page)

From Fig 1 we see that no solution is possible if bearing b1 equals b2 (parallel bearings), or if $| b1 - b2 | = 180$ degrees (opposite bearings).

Because of Tangent function properties, Equations 4a, 4b and 5 have special solutions when b1 or b2 is either 90 or 270 degrees:

- If b1 is either 90 or 270 degrees, $Yt=Y1$ by observation - see Fig 1 - and therefore, $Xt = (Y1-Y2) \tan b2+X2$.
- If b2 is either 90 or 270 degrees, $Yt = Y2$ by observation - see Fig 1 - and therefore, $Xt - (Y2-Y1) \tan b1 + X1$.

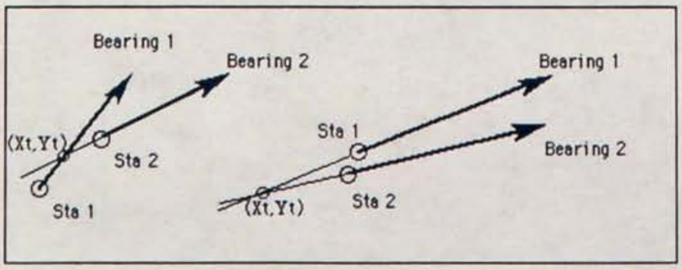


Fig 2-Two Examples of Divergent Bearings

Otherwise we have the general case where Equation 5 determines Yt, and either 4a or 4b determines Xt.

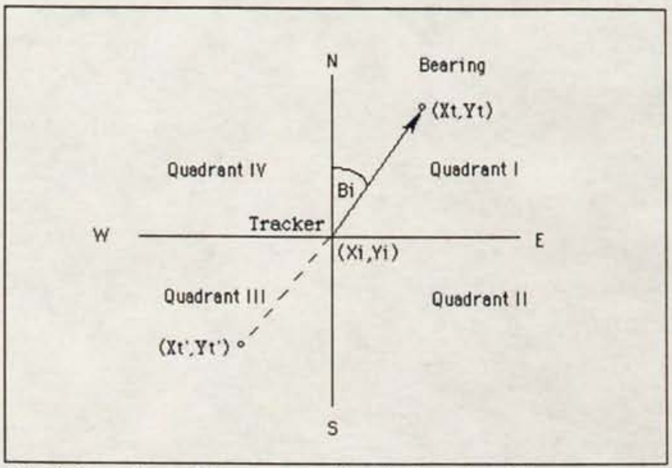


Fig 3-Quadrant Diagram to Verify Bearing Convergence

Testing For Convergence

Unfortunately, a triangulated point sometimes falls in a direction opposite to where a bearing implies it should be. This occurs when two bearings diverge. See Fig 2 for two examples of divergent bearings.

One way to decide if a triangulated point is the result of convergent bearings is to determine if the point (Xt,Yt) falls in the expected compass quadrant about the Tracker's position (Fig 3). If (Xt,Yt) falls in the opposite direction as with (Xt',Yt'), the point must be the result of two bearings being divergent.

The fix is good (the two bearings are convergent)

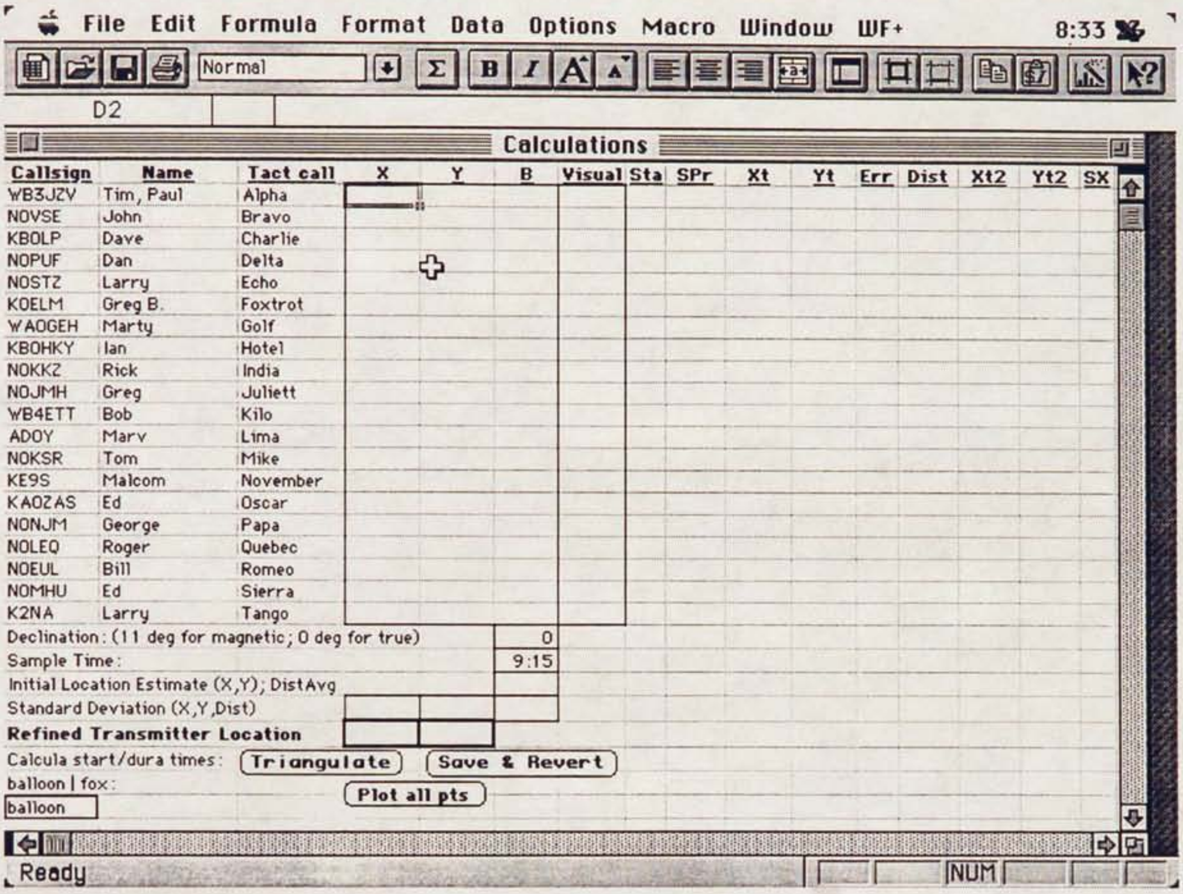
when:	if:
$0 \le Bi < 90$	$Xt \ge Xi; Yt \ge Yi$
$90 \le Bi < 180$	$Xt \ge Xi; Yt \le Yi$
$180 \le Bi < 270$	$Xt \le Xi; Yt \le Yi$
$270 \le Bi < 360$	$Xt \le Xi; Yt \ge Yi$

Fig 4-Convergence Testing

Use the test in Fig 4 for both i = 1 and 2, to determine if a triangulated point (Xt,Yt) is good (results from convergent bearings), given bearings, Bi, are taken from (Xi,Yi). The program ignores a fix from divergent bearings.

Macro Overviews

To accomplish the augmented triangulation scheme described above[2] I wrote two Microsoft



Callsign	Name	Tact call	X	Y	B	Visual	Sta	SPr	Xt	Yt	Err	Dist	Xt2	Yt2	SX
WB3JZV	Tim, Paul	Alpha													
N0VSE	John	Bravo													
KB0LP	Dave	Charlie													
N0PUF	Dan	Delta													
N0STZ	Larry	Echo													
K0ELM	Greg B.	Foxtrot													
WA0GEH	Marty	Golf													
KB0HKY	Ian	Hotel													
N0KKZ	Rick	India													
N0JMH	Greg	Juliett													
WB4ETT	Bob	Kilo													
AD0Y	Marv	Lima													
N0KSR	Tom	Mike													
KE9S	Malcom	November													
KA0ZAS	Ed	Oscar													
N0NJM	George	Papa													
N0LEQ	Roger	Quebec													
N0EUL	Bill	Romeo													
N0MHU	Ed	Sierra													
K2NA	Larry	Tango													

Declination: (11 deg for magnetic; 0 deg for true) 0

Sample Time: 9:15

Initial Location Estimate (X,Y); DistAvg

Standard Deviation (X,Y,Dist)

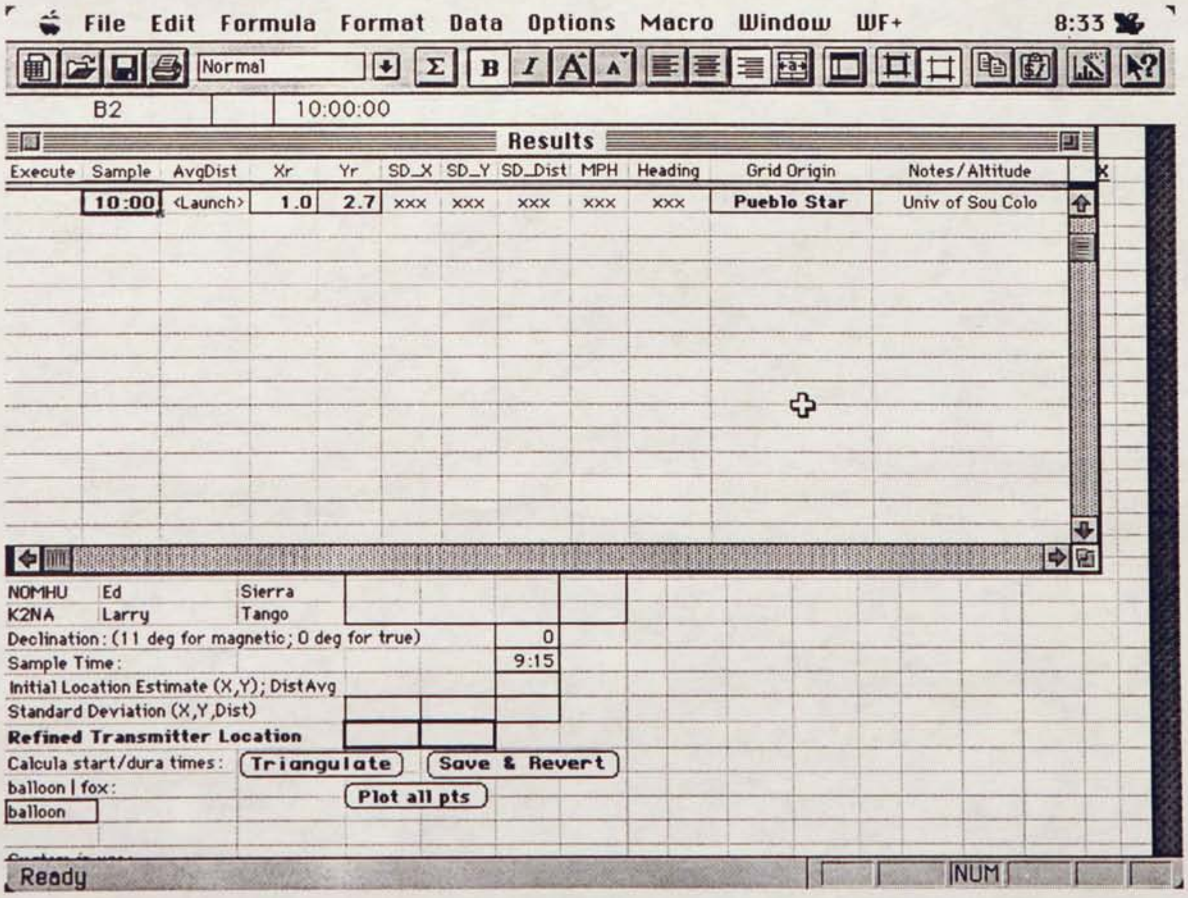
Refined Transmitter Location

Calcula start/dura times:

balloon | fox:

balloon

Fig 5-*Calculations* Template



Execute	Sample	AvgDist	Xr	Yr	SD_X	SD_Y	SD_Dist	MPH	Heading	Grid Origin	Notes/Altitude
	10:00	<Launch>	1.0	2.7	xxx	xxx	xxx	xxx	xxx	Pueblo Star	Univ of Sou Colo

N0MHU	Ed	Sierra
K2NA	Larry	Tango

Declination: (11 deg for magnetic; 0 deg for true) 0

Sample Time: 9:15

Initial Location Estimate (X,Y); DistAvg

Standard Deviation (X,Y,Dist)

Refined Transmitter Location

Calcula start/dura times:

balloon | fox:

balloon

Fig 6-*Results* Template

Excel macros that operate on two Excel spreadsheet templates. The macros are *MacroFast* and *Save&Revert Macro*. The two spreadsheet templates are *Calculations* (Fig 5) and *Results* (Fig 6).

MacroFast begins by reviewing the data in the X, Y, and B cells of the *Calculations* spreadsheet. These are the hunter position coordinates, and their bearings, respectively. If any of these three fields is blank on the *Calculations* spreadsheet, the program will remove that row during the next ["balloon" mode] triangulation calculation.

Next, *MacroFast* generates unique station pairs. It will not perform the triangulation calculation for a station pair if it finds their bearings are parallel. Otherwise the program performs the triangulation calculation for each station pair, and subjects every resultant fix to the convergence test of Fig 4.

Next, the program averages the convergent triangulated X's and Y's. Then, it calculates the distances between each triangulated point and the point resulting from this average. Next, it averages these distances in *Dist Avg*. Then, it discards distant points and computes the final location estimate for display to the operator.

The macro continues on to produce the station "hit" list, in column "SX." Finally, the program produces a chart containing hunter locations, a transmitter location estimate, and all surviving triangulated points.

I placed special emphasis on implementing a speedy Excel macro for the triangulation portion, hence the macro name, *MacroFast.*

I wrote *Save&Revert Macro* for tracking a moving transmitter. From the *Calculations* sheet, it copies *Sample Time*, the refined transmitter location (Xr,Yr) and *Dist Avg* data to the *Results* sheet. It then calculates a speed and heading for the transmitter based upon the previous sample time and location estimate contained in *Results*.

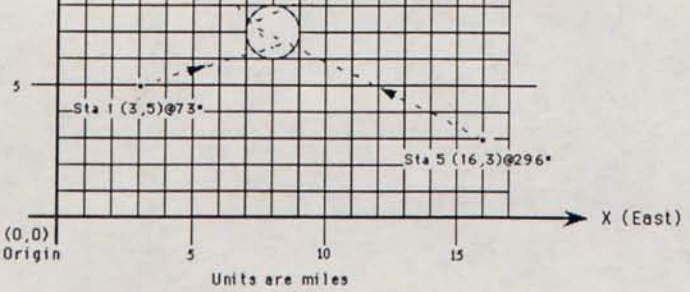


Fig 7 - Fabricated Example Diagram

Finally, it saves the *Calculations* sheet with the name "Calculations@1015" (using the actual Execution Time), and brings up a fresh copy of *Calculations* in preparation for the next sample time. The operator can refer to the *Results* sheet at any time during a chase since it is in its own Excel window.

To illustrate the augmented triangulation macro let us fabricate an example. We begin with a piece of graph paper and draw X and Y axes and an origin at the lower left (Fig 7). The plus and minus X axis denotes miles east and west of the origin, respectively. Similarly, the plus and minus Y axis denotes miles north and south.

Next, we draw five points to represent five RDFer positions and note their coordinates. Then, we draw a circle with a one mile radius (for some realism) that we will say contains the transmitter to locate. Next, we draw bearing lines from hunters 1, 2, 4 and 5 to somewhere in or on this circle. Let us say that station 3 has taken a bad bearing for some reason, and consequently its bearing goes a few miles north of our circle.

Now, using a protractor, we note the bearing angles for all five bearings relative to true north (zero degrees true is straight up along the Y axis). Next, we enter the hunter's (X,Y) coordinates, and their bearings into the computer Calculation Sheet (see Fig 8). After data entry, we mouse-click the *triangulate* button.

About 17 seconds later the computer reveals the estimated transmitter location coordinates as (7.5,7.1). From the *Err* column in the Calculation Sheet we see station pairs (1,3), (1,4), and (3,4) each has divergent bearings and was therefore, ignored. The triangulated points produced by station pairs (1,5), (2,3), and (3,5) were too far from the centroid and were therefore, ignored. In this example the only residual points were those due to bearings from station pairs (1,2), (2,4), (2,5), and (4,5). The computer tallies station performances in the *SX* (station "hit") column. A station's *SX* number gets incremented by one each time one of its bearings produce a point that the system chooses to

Callsign	Name	Tact call	X	Y	B	Visual	Sta	SPr	Xt	Yt	Err	Dist	Xt2	Yt2	SX
WB3JZV	Tim. Geo. Paul	Alpha	3.0	5.0	73		1	1,2	8.0	6.5		2.1	8.0	6.5	3
N0VSE	John	Bravo	4.0	11.0	138		2	1,3			Div5				1
KB0LP	Dave	Charlie	16.0	13.0	257		3	1,4			Div5				4
N0PUF	Dan	Delta	13.0	10.0	245		4	1,5	8.5	6.7	Far	2.4			2
N0STZ	Larry	Echo	16.0	3.0	296		5	2,3	4.6	10.4	Far	3.1			2
Declination: (11 deg for magnetic; 0 deg for true)					0			2,4	7.3	7.3		1.0	7.3	7.3	
Sample Time:					9:15			2,5	7.4	7.2		1.2	7.4	7.2	
Initial Location Estimate (X,Y); DistAvg			6.4	7.9	2.2			3,4			Div5				
Standard Deviation (X,Y,Dist)			2.1	1.4	1.3			3,5	2.1	9.8	Far	4.8			
Refined Transmitter Location			7.5	7.1				4,5	7.2	7.3		1.0	7.2	7.3	
Calcula start/dura times:															
13:18:51	00:00:17														
balloon | fox:															
balloon															
System in use:															
Mac IIcx															

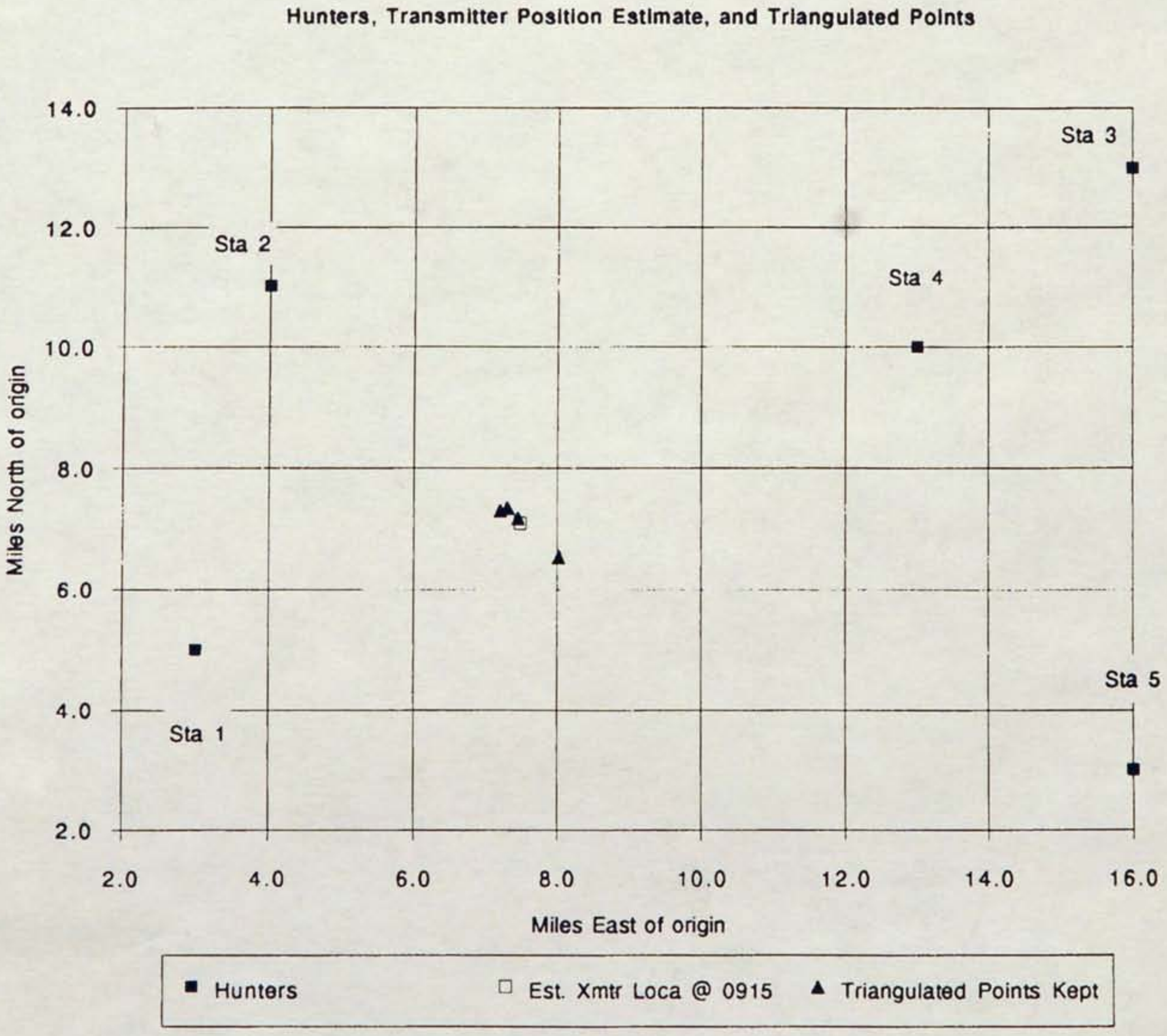


Fig 8 - Calculation Sheet and Chart for Fabricated Example ignore. In our example, station 3 was "dinged" 4 times making its performance most suspect.

Balloon RDF Team Preparations

I provide each member of the Tracking and Recovery Team instructions similar to the following in preparation for using the triangulation system to help track EOSS balloon flights:

- Each volunteer RDF tracking station takes a bearing at a specified time samples (initially on 15 minute marks; on 4 to 6 minute marks near the end of the flight).
- Upon request, Tracker location and bearing data is reported via 2-meter net by mobile and fixed stations alike.
- The number of bearings input for any sample time is limited to twenty[3].
- An official EOSS transparent overlay is used and consists of labeled, 5 by 5 mile grid squares with origin (0,0) in its lower left corner.
- We use the *Pierson Graphics Colorado State Recreational Map.*
- Grid overlay alighment is specified on flight day after the Paratrak (Balltrak) Program predicts the touchdown point.
- Each tracking station is pre-assigned a tactical call sign (Alpha, Bravo, etc.) before launch to simplify data collection by the Computer Net Control operator.
- EOSS balloon Trackers have opted to report all bearings referenced to True North. Therefore, each tracker adds 11 degrees to his magnetic (i.e., compass) reading for True North (in the Denver, Colorado area).
- A tracking station reports "pass" if it does not have a bearing to report when called upon.
- Computer Net Control relays the estimated transmitter location coordinates to the Field Coordinator after the program calculates same.

Bearing Passing Protocol

Trackers always use a standard reporting format when Computer Net Control calls for bearings. An example using our protocol follows:

This is station Foxtrot
Location X by Y (i.e., 15 by -3.5)
Bearing 032 degrees True
WB3JZV
Clear

Where:
X = the number of miles East of the origin
Y = the number of miles North of the origin.

Trackers use negative X and Y numbers to represent miles West and South of the origin, respectively.

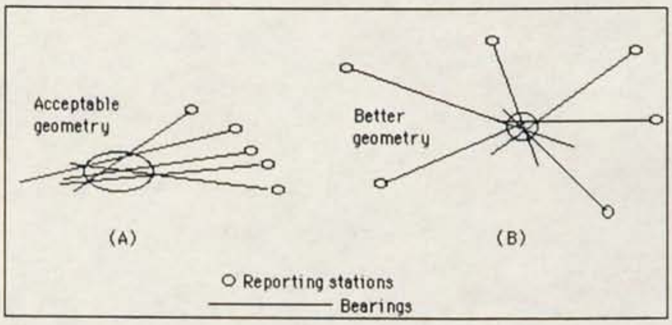


Fig 9-RDF Mobile Station Geometries

Tracker Position Guidance

To help us to achieve the best accuracy from our collective efforts I mention that:

The least helpful bearings come from a tight cluster of Trackers (Fig 9 (A)).

The most helpful bearings come from positions *around* the balloon (Fig 9 (B)).

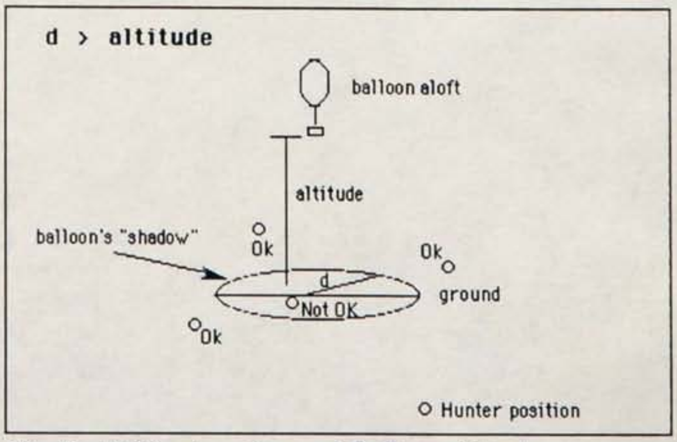


Fig 10 - RDFer Location and Balloon Altitude Relationships

When a Balloon Passes Overhead

Unless a Tracker's antenna can aim upward toward the balloon when it is overhead, the following applies. The distance, d, (Fig 10) between a reporting station and the ground

Comparison of Tracking Team Triangulation with LORAN-C

	Tracking Team Triangulation Results								LORAN-C		
Sample Time	AvgDist	Xr	Yr	SD_X	SD_Y	SD_Dist	MPH	Heading	X	Y	LOS Miles between Triangulation and LORAN fixes
	<Pickup>	47.0	20.0	xxx	xxx	xxx	xxx	xxx			
14:43	0.2	46.7	19.9	0.2	0.1	0.1	159	335			
14:40	18.1	50.1	12.7	15.9	10.6	6.2	87	182			
14:36	19.1	50.3	18.5	20.8	14.2	16.4	78	112	No Lock		
14:32	6.3	45.5	20.5	6.2	5.3	5.1	56	167	on		
14:28	10.0	44.6	24.1	12.5	8.1	11.0	19	44	LORAN		
14:23	9.3	43.5	23.0	14.0	5.2	11.6	47	133			
14:15	7.3	38.9	27.3	8.0	1.8	3.7	22	111			
14:04	7.1	35.1	33.2	8.3	4.7	6.4					
14:02	3.0	31.6	35.3	2.4	2.7	2.1					
13:55	1.1	25.4	33.7	0.7	0.8	0.1					
13:45	5.1	24.9	31.2	4.7	3.9	3.4			22.0	35.0	4.8
13:30	6.3	21.3	32.2	6.0	3.4	2.9			20.0	35.0	3.1
13:15	8.1	22.7	29.5	8.1	5.9	6.0			20.0	33.5	4.8
13:00	13.9	18.8	30.7	22.0	14.9	22.7			18.0	34.0	3.4
12:45	12.2	12.7	35.7	14.9	5.8	10.3			8.0	38.0	5.2
12:30	15.3	8.4	40.0	18.7	4.7	11.7			2.0	41.0	6.5
12:22	<Launch>	-0.5	42.5	xxx	xxx	xxx	xxx	xxx	Avg Dist -->		4.6

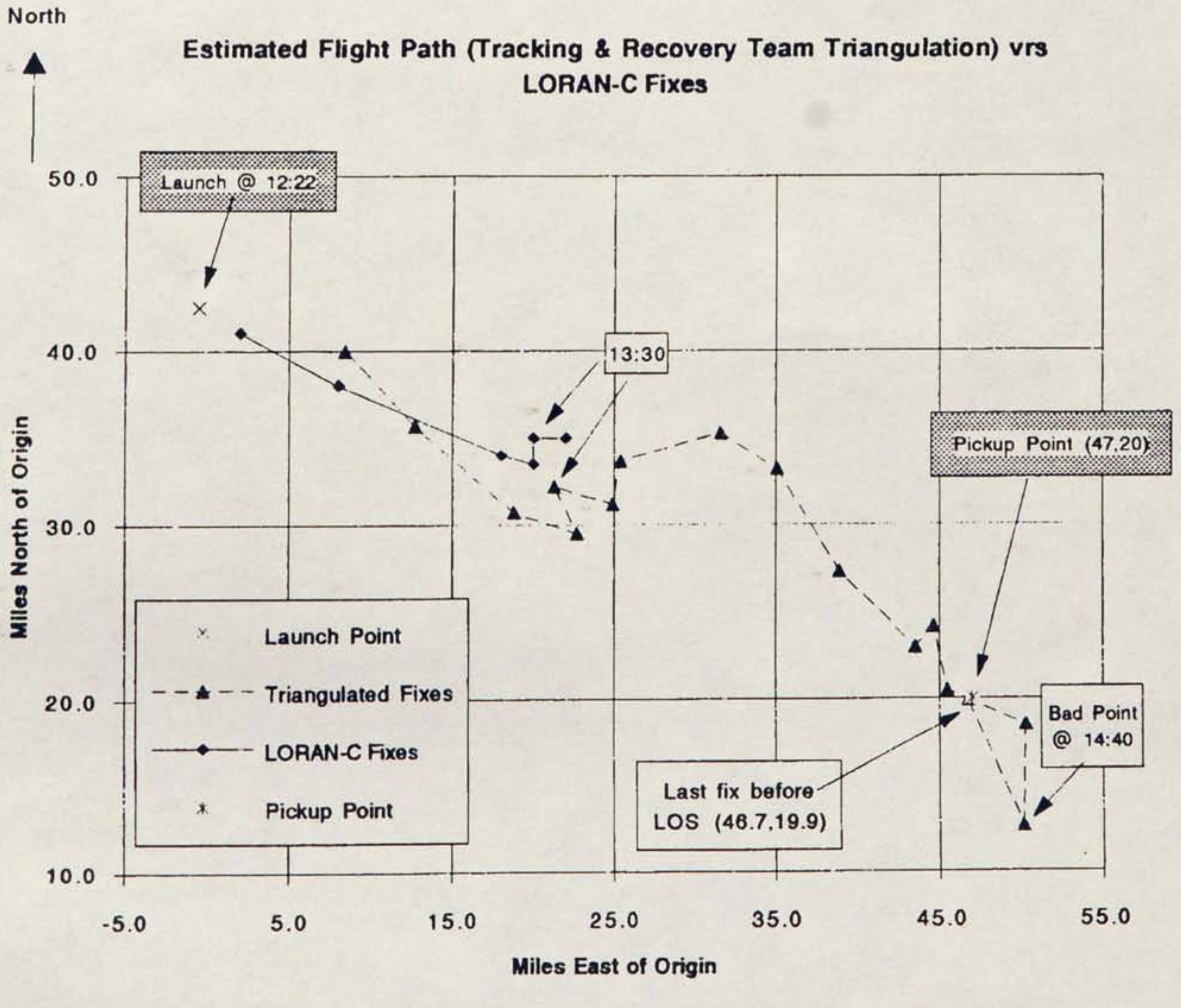
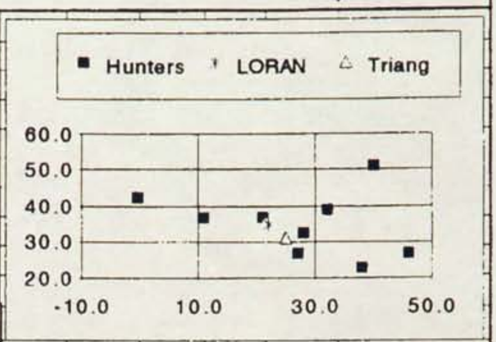


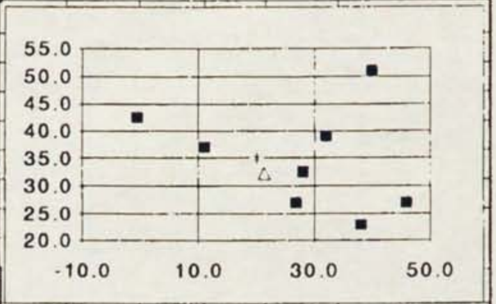
Fig 11 - EOSS Flight 11 Tabulated Results and Balloon Tracks

Tracking Team Bearing Errors (assumes the LORAN-C Fixes were Correct...)

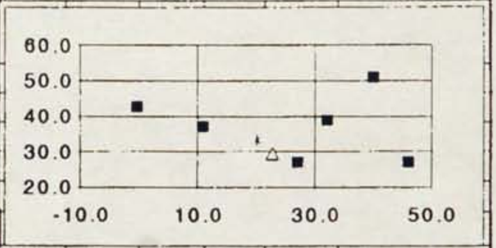
13:45	Beacon Location:		22	35	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
WA0GEH	Marty	Golf	21.0	37.0	155	153.4	1.6
WB4ETT	Bob,Dawn	Echo-v	27.0	27.0	332	328.0	4.0
N0STZ	Larry	Foxtrot	46.0	27.0	298	288.4	9.6
N0KSR	Tom	India	-0.5	42.5	121	108.4	12.6
AD0Y	Marv	Delta	40.0	51.0	214	228.4	14.4
K0ELM	Greg Burnett	Hotel	11.0	37.0	117	100.3	16.7
N0JMH	Greg	Charlie	32.0	39.0	229	248.2	19.2
WB3JZV	Paul,Tim,Geo	Alpha	28.0	32.5	273	292.6	19.6
N0PUF	Dan	Bravo	38.0	23.0	333	306.9	26.1



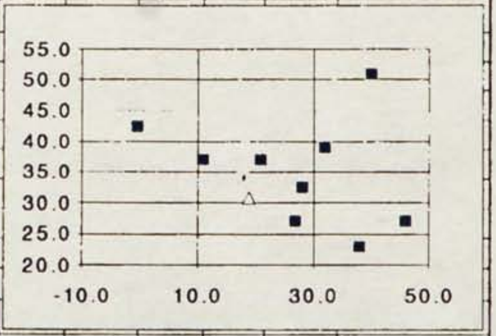
13:30	Beacon Location:		20	35	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
WB4ETT	Bob,Dawn	Echo-v	27.0	27.0	323	318.8	4.2
N0STZ	Larry	Foxtrot	46.0	27.0	292	287.1	4.9
N0KSR	Tom	India	-0.5	42.5	117	110.1	6.9
N0JMH	Greg	Charlie-v	32.0	39.0	241	251.6	10.6
WB3JZV	Paul.Tim,Geo	Alpha-v	28.0	32.5	266	287.4	21.4
K0ELM	Greg Burnett	Hotel	11.0	37.0	125	102.5	22.5
N0PUF	Dan	Bravo	38.0	23.0	329	303.7	25.3
AD0Y	Marv	Delta	40.0	51.0	200	231.3	31.3



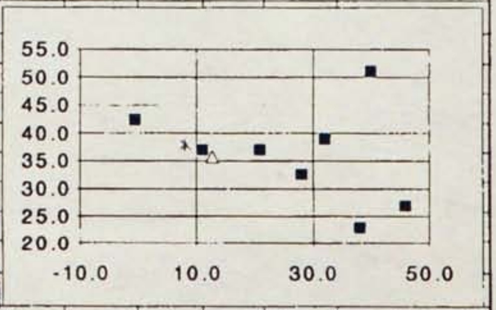
13:15	Beacon Location:		20	33.5	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
WB4ETT	Bob.Dawn	Echo	27.0	27.0	319	312.9	6.1
K0ELM	Greg Burnett	Hotel	11.0	37.0	101	111.3	10.3
N0KSR	Tom	India	-0.5	42.5	124	113.7	10.3
N0JMH	Greg	Charlie	32.0	39.0	235	245.4	10.4
AD0Y	Marv	Delta	40.0	51.0	211	228.8	17.8
N0STZ	Larry	Foxtrot	46.0	27.0	257	284.0	27.0



13:00	Beacon Location:		18	34	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
N0PUF	Dan	Bravo	38.0	23.0	301	298.8	2.2
WB4ETT	Bob.Dawn	Echo	27.0	27.0	302	307.9	5.9
AD0Y	Marv	Delta	40.0	51.0	226	232.3	6.3
N0KSR	Tom	India	-0.5	42.5	125	114.7	10.3
N0JMH	Greg	Charlie	32.0	39.0	234	250.3	16.3
WB3JZV	Paul,Tim,Geo	Alpha	28.0	32.5	257	278.5	21.5
K0ELM	Greg Burnett	Hotel	11.0	37.0	136	113.2	22.8
N0STZ	Larry	Foxtrot	46.0	27.0	253	284.0	31.0
WA0GEH	Marty	Golf	21.0	37.0	310	225.0	85.0



12:45	Beacon Location:		8	38	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
WB3JZV	Paul,Tim,Geo	Alpha	28.0	32.5	288	285.4	2.6
N0KSR	Tom	India	-0.5	42.5	123	117.9	5.1
N0PUF	Dan	Bravo	38.0	23.0	304	296.6	7.4
AD0Y	Marv	Delta	40.0	51.0	240	247.9	7.9
N0JMH	Greg	Charlie	32.0	39.0	257	267.6	10.6
N0STZ	Larry	Foxtrot	46.0	27.0	272	286.1	14.1
WA0GEH	Marty	Golf	21.0	37.0	300	274.4	25.6
K0ELM	Greg Burnett	Hotel	11.0	37.0	261	288.4	27.4



12:30	Beacon Location:		2	41	(per LORAN)		Absolute
Callsign	Name	Tact call	X	Y	B	Correct B	Error
N0JMH	Greg	Charlie	32.0	39.0	273	273.8	0.8
N0STZ	Larry	Foxtrot	46.0	27.0	289	287.7	1.3
K0ELM	Greg Burnett	Hotel	11.0	37.0	289	294.0	5.0
AD0Y	Marv	Delta	40.0	51.0	247	255.3	8.3
WB3JZV	Paul,Tim,Geo	Alpha	28.0	32.5	279	288.1	9.1
N0PUF	Dan	Bravo	38.0	23.0	285	296.6	11.6
WB4ETT	Bob,Dawn	Echo	27.0	27.0	325	299.2	25.8
N0KSR	Tom	India	-0.5	42.5	61	121.0	60.0
WA0GEH	Marty	Golf	21.0	39.0	355	276.0	79.0

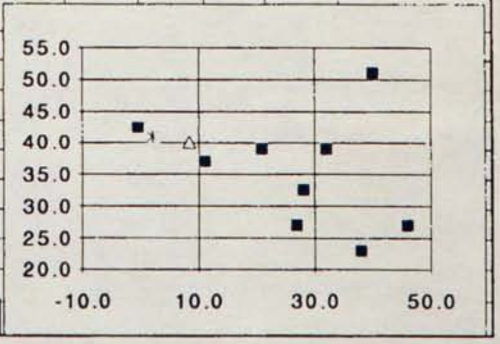


Fig 12- Tracking Team Bearing Errors by Sample Time

Station Performance Sheet

		Number of Rejected Points at each Sample Time																Total Triangula Pts		Rejection
Callsign	Name	12:30	12:45	13:00	13:15	13:30	13:45	13:55	14:02	14:04	14:15	14:23	14:28	14:32	14:36	14:40	14:43	Rejected	Possible	Rate
N0JMH	Greg	4	3	2	2	2	3		2	1		1		2	1			23	73	32%
AD0Y	Marv	2	1	2	2	$\boxed{7}$	3	1	5	2	1	0	1	2	1			30	85	35%
WB3JZV	Paul,Tim,Geo	7	3	2		3	4		2	2	2	3	3	2	3	2	2	40	84	48%
N0STZ	Larry	5	6	8	$\boxed{4}$	6	7	0	5	2	3	0	2	1	1	0	1	51	91	56%
WB4ETT	Bob,Dawn	5		4	2	4	4	1	2	4	3	3	5	6	3	2	3	51	84	61%
K0ELM	Greg Burnett	6	$\boxed{6}$	3	3	5	4											27	43	63%
N0PUF	Dan	7	4	5		7	$\boxed{8}$		2		4	2	3	2	3	2	2	51	78	65%
N0KSR	Tom	6	3	4	3	4	7			6		4		5	6			48	68	71%
WA0GEH	Marty	$\boxed{8}$	6	$\boxed{8}$			4			3	3	5	4					41	54	76%
Number of Possible Points:		8	7	8	5	7	8	2	5	6	5	7	5	6	6	3	3			
(due to any station)		Comparisons made with LORAN																		

☐ Boxed numbers are the largest for the sample time.

Explanations:

For stations that submitted one or more bearings during the balloon chase, this table lists the number of times that the program rejected points originating from a station's bearing at a given sample time. In the triangulation process, the program will not calculate a point from a bearing if it is parallel, or diverges from another station's bearing. Likewise, it will reject a point stemming from a bearing if the triangulated point is deemed too far from the main cluster of triangulated points. In general --for a given sample time-- high numbers indicate poor station performance, and low numbers indicate good station performance. "Rejection Rate" is the percentage of total triangulated points rejected based on the given station's participation. A station's performance can be improved by: a) being better dispersed about the balloon, b) not submitting a bearing when the elevation angle to the balloon is greater than 45 degrees --if the DF antenna cannot be angled-up at the balloon, or c) correcting a deficiency with RDF technique. Most bearings at a given sample time must be accurate for the rejection count to hold meaning. A "0" entry means there were no rejections for that station at that sample time (the perfect situation). Stations with BOLD callsigns were reporting from fixed locations. The other stations were mobile.

Fig 13- EOSS Flight 11 Station Performance Sheet

point directly under the balloon should not be less than the balloon's altitude in miles.

For example, a distance, d, under 20 miles, could produce bearings of questionable accuracy when the balloon has an altitude greater than 106,000 feet (20 miles). In this case the Tracker should refrain from submitting a bearing and "pass." The tracker might consider relocating further out from the balloon's "shadow."

Results Comparison: Triangulation versus LORAN-C

On 4 April 1993, EOSS launched its eleventh balloon. The payload included a LORAN-C receiver that radioed position data to ground stations. Fig 11 shows this data along with the triangulation results of the Tracking Team. LORAN did not produce any fixes after the sixth sample time at 13:45 due to a locking problem. Fig 11 also gives the Line-Of-Site (LOS) distances between the six fixes of both systems, the average of which was 4.6 miles. Fig 12 shows the Tracker bearing errors - assuming LORAN was correct - for each of the six sample times that LORAN was working. In every one of the six sample times, the station having the greatest Absolute Error (see Fig 12) had also logged the greatest Number of Rejected Points (See Fig 13). It appears that absolute bearing errors under 14 degrees (see Fig 12) are "decent."

Conclusions

Mobile with a Mac PowerBook 140 running augmented triangulation software complements other contrivances of an RDF team tracking a balloon. It helps make good use of a Tracking and Recovery Team's cooperative efforts. It gives tracking results using a consistent algorithm.

The goal to promptly provide a Field Coordinator with good estimates of balloon location, using all available bearing data (20 bearings per sample maximum), worked as intended. The skill of our experienced RDF team permitted the system to achieve the objective of tracking a moving transmitter to within 40 square miles of its actual location. The algorithm's position estimates compared favorably with fixes from an airborne LORAN-C system. The augmented triangulation algorithm (Part 4) successfully ferreted out the worst bearings taken at each sample time for which we had LORAN data available as a benchmark for comparison.

This augmented triangulation system can also be an effective tool to combat the occasional jammer. All it takes is a callup of RDF-capable stations for their bearings to the bad guy. Knowing the coordinates of each RDF station ahead of time would be ideal. Within 2.5 minutes of the data entry, the system can reveal the coordinates of the perpetrator's estimated location. Mobile hunters can then take over and move in.

Other RDF groups can use this software with these triangulation augmentations for any cooperative purpose, be it tracking a moving transmitter, or locating a stationary[4] one. They might want to experiment with their own augmentations.

While I implemented this technique using Excel for the Apple Macintosh, Microsoft claims the same macros will work with Microsoft's Windows' Excel.

Credits

I found the book "TRANSMITTER HUNTING Radio Direction Finding Simplified" by Joseph D. Moell, K0OV and Thomas N. Curlee, WB6UZZ to be a great source of practical RDF information. Chapter 20 deals with coordinate systems and basic computer triangulation.

I would like to thank Tim Moffitt, N0NXI for the idea to use Microsoft Excel. Thanks to Tim and to Jim White, WD0E, for the use of their Mac PowerBooks. Thanks to Greg Burnett, K0ELM, the EOSS Tracking and Recovery Group Lead, for his confidence and support for my augmented triangulation technique, and to both Greg and Dr. Warren Williams, N0PBY for their encouragement to write this paper. Most importantly, I would like to thank the skilled Denver area RDF team (Fig 5 lists its principal members) for their vital participation and outstanding cooperation in putting the technique to the test. Thanks also to Apple Computer, Inc. for supplying equipment for two of the early chases.

Finally, I would like to recognize our leader, Jack Crabtree, AA0P, President of EOSS, and the special people who comprise EOSS. Their abilities are extensive, and their enthusiasm is contagious. Their balloon flights are fun, and educationally enriching for all.[5]

Notes:

[1] In practical application of the augmented triangulation routine, forty square miles seemed like a reasonable target size for the "haystack in which to find the needle." An RDF team can comb-search such an area with good chance for success. However, the augmented triangulation routine will give perfect results if given perfect bearing and hunter position data.

[2] The WB3JZV augmented triangulation system, complete with User Guide, Microsoft Excel (3.0 and 4.0) macro programs, spreadsheet templates, and sample results from balloon chases and foxhunts, is available from the author on a Macintosh compatible 3.5-inch floppy disk for $10.

[3] An RDF Team size limitation of 20 was due to the amount of time to poll and enter the data into the computer by way of a 2-meter radio net. This limit was *not* because there are 190 triangulation calculations for 20 stations. Indeed, with the maximum number of stations reporting (20), a Mac PowerBook 140 can provide the estimated balloon location in under 2.5 minutes.

[4] In "fox" mode, successive triangulation calculations use the same Calculations sheet. Old bearings can be changed, and new bearings added before re-triangulating for a refined position estimate. This mode is ideal for locating a stationary transmitter.

[5] For EOSS information, contact Marty Griffin, WA0GEH, EOSS Publicity Chairman, [redacted]

Paul Ternlund, WB3JZV, received a B.S.E.E. from Georgia Tech, an M.S.E.E. and Professional degree in Computer Science from the George Washington University, Washington, D.C. He has been a U.S. Department of Defense employee for 28 years. His current assignment is to Detachment 3, Headquarters Space Division. His original call sign was NV2OUN while a teen, and became WB3JZV in 1977. He operated with the call DA2ZZ while assigned in West Berlin from August 1982 to August 1985. He is a Denver area "foxhunter," and a member of EOSS Inc., ARES, and the ARRL.

LORAN-C Errors Determined With GPS

by Andy Kellett, N0SIS

Abstract

The discrepancy between LORAN-C and GPS fixes during the flight of EOSS-12 were greater on the ground than at altitude. Discrepancies near the ground were about 280 meters along the balloon's local meridian and 1700 meters along the balloon's longitudinal line. Near maximum altitude (28,700 m) the discrepancy was about 111 m along the meridian and 340 m along the line of longitude. The LORAN-C fix was consistently East-Northeast of the GPS fix. The accuracy of GPS was confirmed on this flight, so mechanisms for the LORAN/GPS discrepancy are looked for within the parameters that affect LORAN-C. Error due to GPS Selective Acquisition (SA), lack of clock synchronization, skywave contamination, geometrical distortion and terrain effects is considered. While no error mechanism was clearly responsible for the discrepancy, terrain effects seem to be the most likely candidate. A complete, quantitative explanation of the error mechanism will require more analysis.

The purpose of this paper is to present a preliminary error analysis of the LORAN-C fixes obtained during the flight of EOSS-12. The accuracy of LORAN-C is well established for many traditional applications; boats and airplanes use LORAN-C on a daily basis to find their location. Detailed descriptions of LORAN-C are contained in references 1, 2 and 3. However, the accuracy of LORAN-C in a wildly swinging balloon at altitudes where few if any airplanes can fly is not well known. In this paper I will describe how the bearing information was collected. Next, some basic flight information will be presented. Discrepancies between GPS and LORAN-C coordinates are then presented. An explanation of differential GPS and a description of the GPS error measured during EOSS-12 is presented. Some possible mechanisms for the observed discrepancies are then considered. Finally, additional data analysis yet to be performed is described.

Navigation and surveying have never been so accurate or easy as with the recently completed NAVSTAR global positioning system (GPS). A source of detailed information about GPS is reference 4. When the University of Colorado Amateur Radio Club proposed a flight of a GPS receiver, it seemed like a good chance to evaluate both GPS and LORAN-C capabilities. While the flight was proposed as a test of GPS, there was enough confidence in the accuracy (if not precision) of GPS to consider it an adequate "yardstick" against which we could measure the performance of LORAN-C.

Data Collection

EOSS-12 sent back both LORAN-C and GPS data via packet radio. The EOSS LORAN-C receiver sent back information on 144.34 MHz, while the CU group's GPS receiver sent its packets back at 432 MHz. In addition, a GPS data downlink manufactured and monitored by A.I.R. Industries sent back encoded GPS signals, but these were not received or used by EOSS. On the ground, the CU group added a correction to the GPS fixes. CU's GPS antenna was placed on a precisely surveyed benchmark. The difference between the GPS fix and the surveyed fix was the amount of correction added to the balloon's GPS fix. This correction technique is called differential GPS (DGPS).

Two logs of the flight were produced, one cataloged the various parameters measured by the EOSS package, including LORAN-C measurements of latitude and longitude. The other was produced at the CU ground station and showed GPS fixes for the balloon latitude and longitude, along with fixes for the benchmark (for differential GPS calculations), and the differential GPS fixes for the balloon.

$$\text{dist.} = \text{sqrt}(\text{dist}_{\text{lat}}^2 + \text{dist}_{\text{lon}}^2) \qquad (1)$$

$$\text{dist}_{\text{lat}} = R_{\text{earth}}\Delta(\text{lat}) \qquad (2)$$

$$\text{dist}_{\text{lon}} = R_{\text{earth}}\Delta(\text{lon}) \cos \theta \qquad (3)$$

Where:

R_{earth} = the average radius of the earth = 6,371,228 meters
Δ(lat) = difference in latitudes
Δ(lon) = difference in longitudes
θ = balloon's latitude

Equations

Basic Flight Information

Figures 1 and 2 show the ground track of EOSS-12. Figure 1 fixes were taken from LORAN-C data, Figure 2 fixes were taken from DGPS fixes. The flight began on the campus of the University of Colorado, Boulder and ended 36 miles away, about 0.5 miles East of the new Denver International Airport. The balloon's maximum altitude was 28,723 meters (about 94,000 ft.). The minimum outside temperature was about -50 degrees F, and the minimum temperature inside the EOSS "shuttle" was about -4 degrees F.

DGPS/LORAN-C Discrepancies

The difference between DGPS and LORAN-C fixes for the EOSS shuttle is shown graphed against altitude in Figure 3. In Figure 4, the DGPS and LORAN-C fixes were combined and sorted according to time of measurement. The resulting ground track gives an indication of the relationship between DGPS and LORAN-C fixes. Using equations 1, 2 and 3, the ground distance between DGPS and LORAN fixes is calculated to be about 1.7 km (1.1 miles) near the ground, and about 0.4 km (0.2 miles) at maximum altitude.

Both Figures 3 and 4 show that the difference between DGPS and LORAN-C fixes is systematic. LORAN-C consistently reports the balloon's location E-NE of the DGPS fix. From Figure 3 it is apparent that the longitude discrepancy is much greater than the latitude discrepancy. The discrepancy between GPS and LORAN-C diminishes with increasing altitude. That the error grows smaller with altitude is perplexing because, as will be shown later, most potential error mechanisms should result in larger errors at altitude.

The LORAN/GPS discrepancy follows some function of altitude. Any potential error mechanism must produce a function of altitude which has the same form as the measured discrepancy. It is hard to determine, just by looking at the data in Figure 3, whether the discrepancy diminishes linearly with altitude, or as some other function. Figures 5 and 6 are the same as Figure 3, but with linear and second-order (respectively) best-fit lines superimposed on them. Figure 7 shows the results of linear regression performed on the latitude data of Figure 3.

The first result is for the latitude error vs. altitude, the second is for the log of the absolute value of the latitude error vs. altitude. Taking the log of the latitude error linearizes it, assuming it follows a power law function [5]. The "R Squared" parameter serves as the measure of the quality of the regression line. The closer "R Squared" is to one, the better the fit. The results show no appreciable difference between a fit to a linear interoplating line and a line that follows an x^2 function. More data points for regression analysis will be required before the form of the error function can be determined.

GPS Error

The LORAN/DGPS discrepancy observation only gives information about the *difference* between the two navigational methods. To determine the error of LORAN-C alone it is necessary to measure the accuracy and precision of GPS. Because the CU group had a fixed GPS station at a

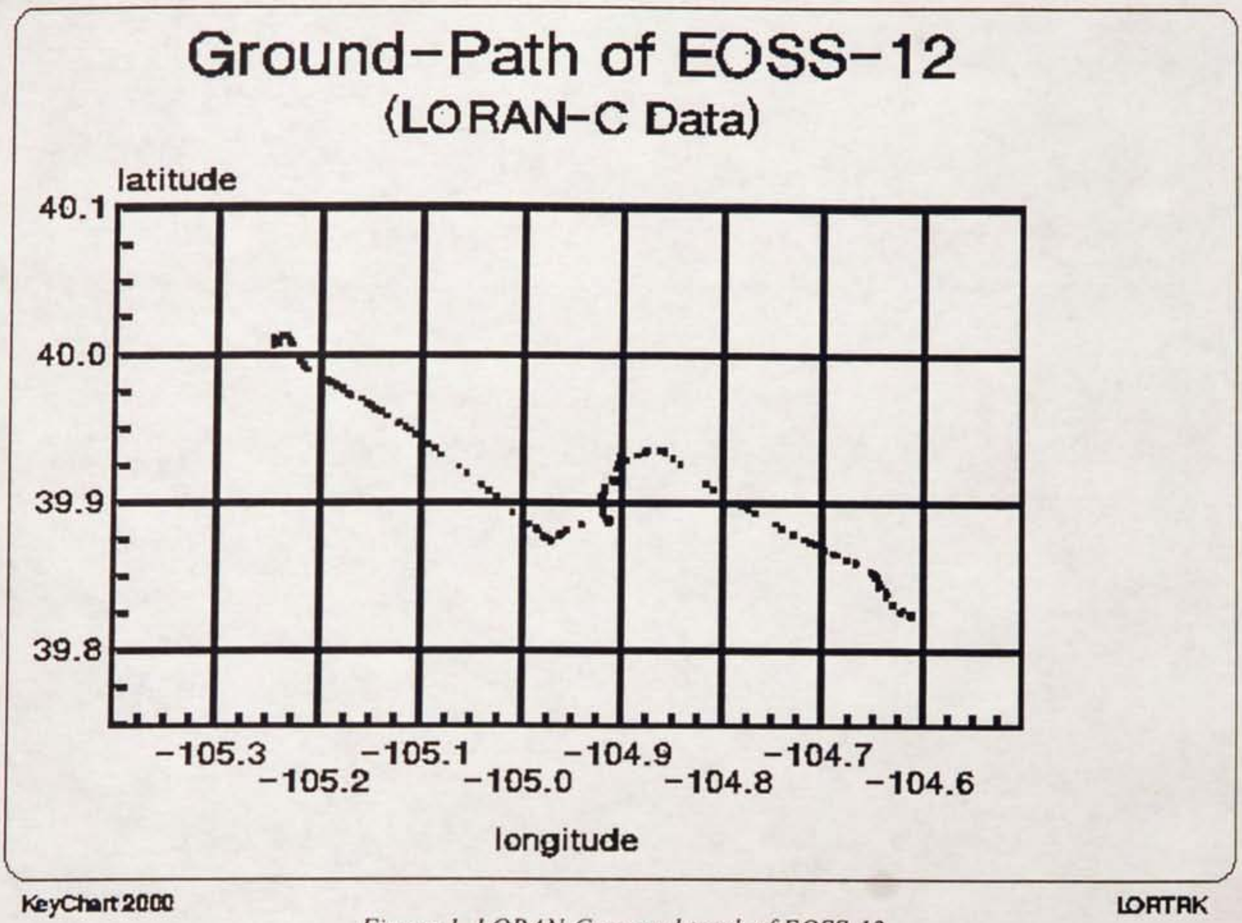


Figure 1. LORAN-C ground track of EOSS-12.

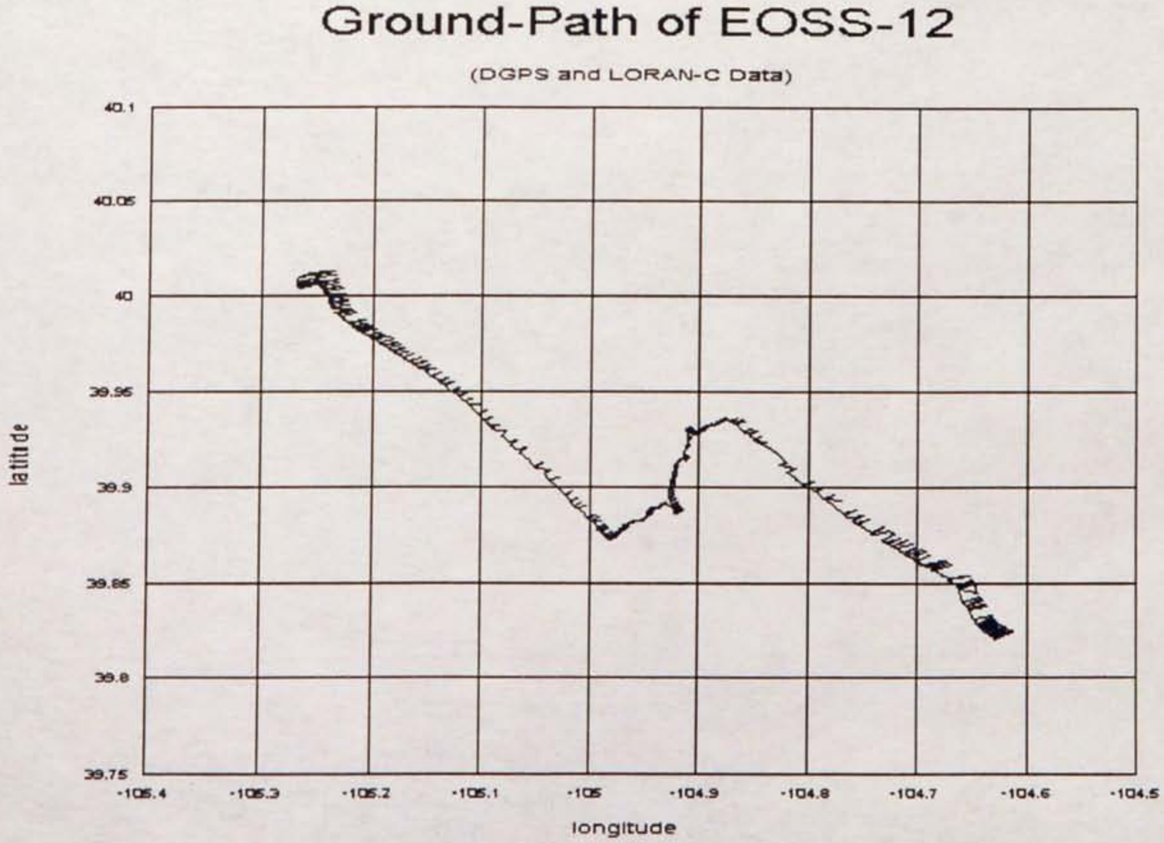
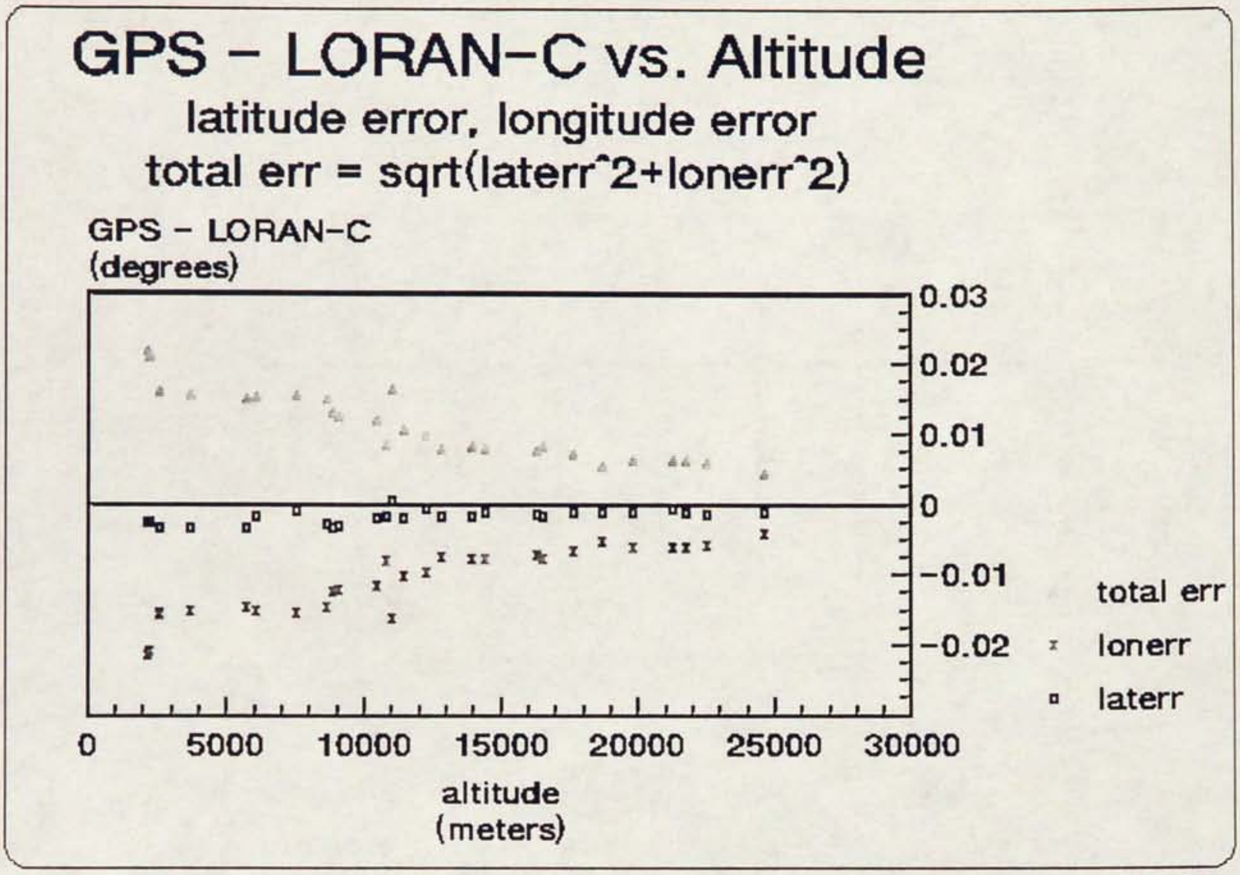


Figure 2. DGPS ground track of EOSS-12



KeyChart 2000 ERRALT

Figure 3. Difference between simultaneous DGPS and LORAN-C fixes (DGPS lat - LORAN-C lat, DGPS lon - LORAN-C lon).

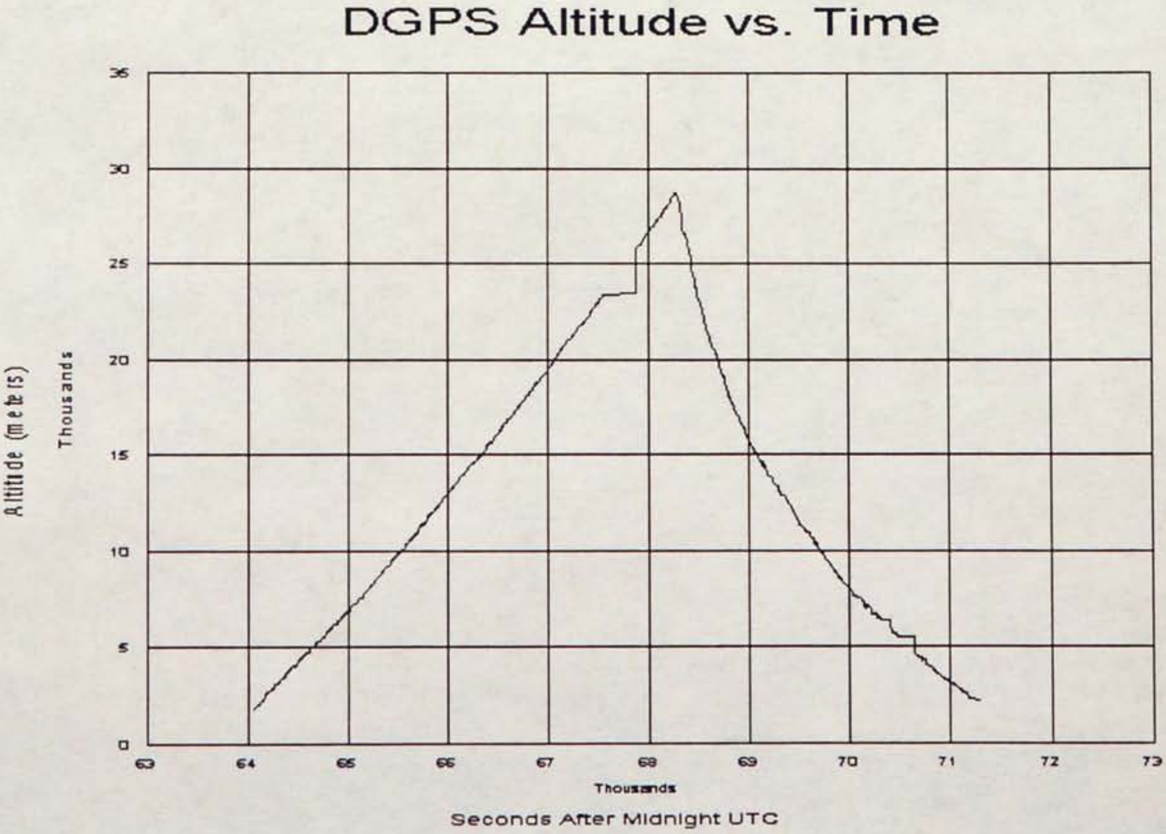


Figure 4. Ground track using both DGPS and LORAN fixes.

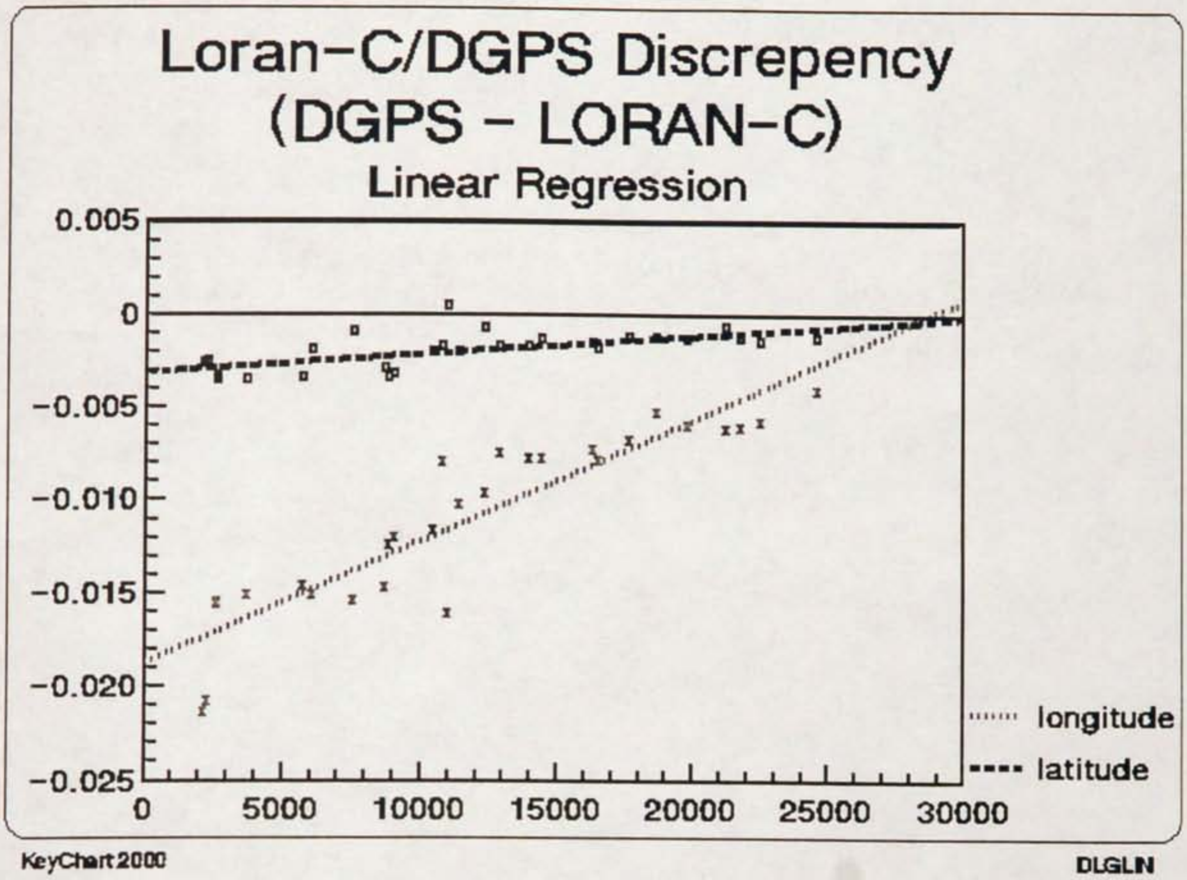


Figure 5. LORAN/DGPS discrepancy fitted to linear best-fit line.

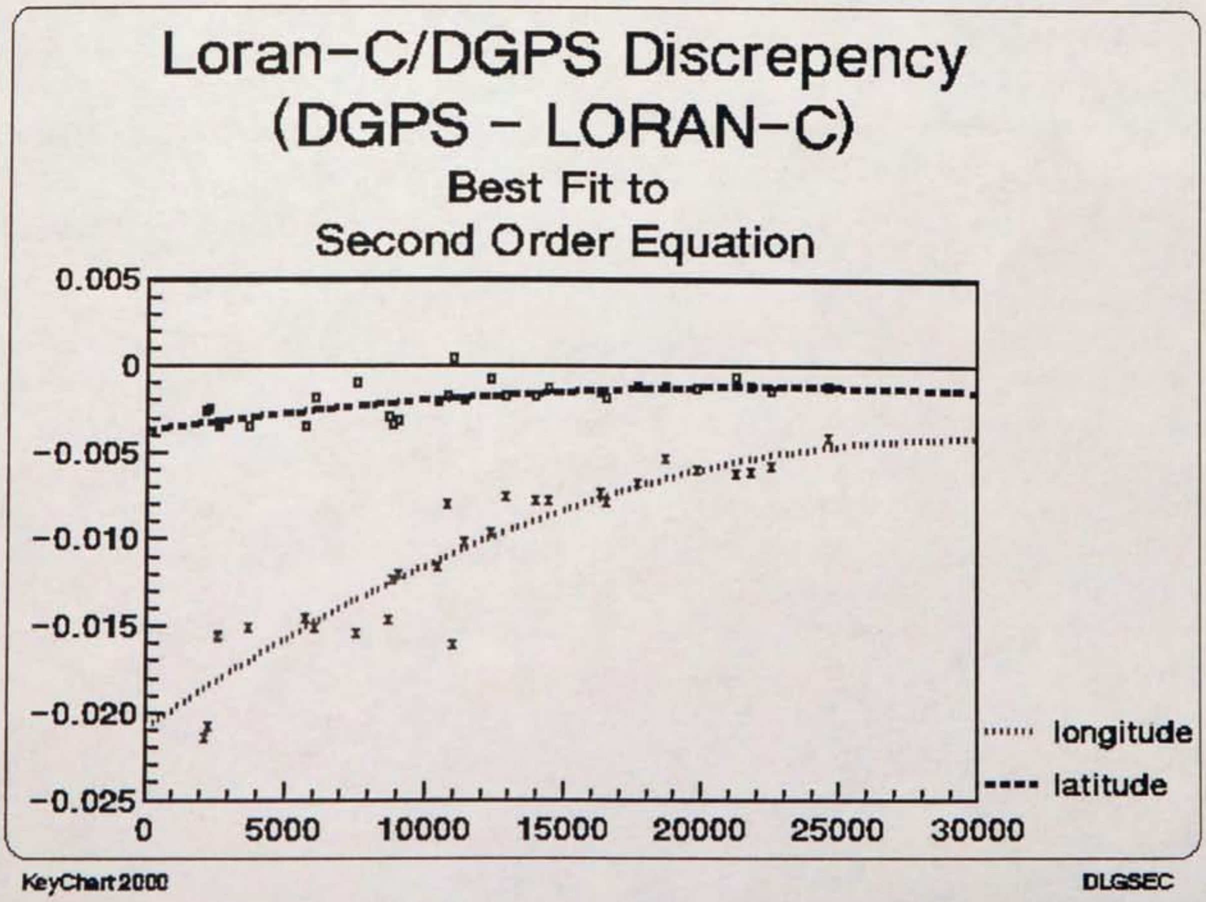


Figure 6. LORAN/DGPS discrepancy fitted to 2nd order best-fit line.

Regression Output

Constant	-0.01877
Std Err of Y Est	0.001999
R Squared	0.832225
No. of Observations	28
Degrees of Freedom	26
X Coefficient (s)	6.5E-07
Std Err of Coef.	5.8E-08

Regression Output:

Constant	-1.67209
Std Err of Y Est	0.065495
R Squared	0.891325
No. of Observations	28
Degrees of Freedom	26
X Coefficient (s)	-2.8E-05
Std Err of Coef.	1.9E-06

Figure 7. Results of regression analyses on LORAN/DGPS longitude discrepancy. Linear best-fit (top) and second order best-fit (bottom).

surveyed position, it was possible to estimate the error in GPS bearings over time. GPS coordinates at a fixed location are expected to fluctuate over time because of an intentional degradation applied to GPS C/A signals. This degradation is called Selective Availability (SA) and is under the control of the Department of Defense (DOD). During the field trials of NAVSTAR GPS it was found, to the DOD's surprise, that position fixes made with receivers that use only the C/A code were accurate to within tens of meters as opposed to the expected 100 meters [4]. Because anyone can receive and decode the C/A signal, the DOD decided to intentionally degrade the C/A signal.

The corrections to the CU base station latitude and longitude are graphed against time in Figure 8. The corrections fluctuate around a general linear increase. Because both the latitude and longitude follow roughly the same linear trend line, the same effect must be working on both. Again using equations 1, 2 and 3 the variation around the linear increase translates to a distance of about 90 meters (295 ft.). The linear increase in error amounted to about 44 meters (144 ft.) over the course of the flight. At least at the CU ground station, GPS is working within its "advertised" 100 m accuracy.

Potential Error Mechanisms

Could the linear increase in GPS error be responsible for the observed LORAN/GPS discrepancy? The answer in no for two reasons. First, this explanation would make the correlation between altitude and the LORAN/DGPS discrepancy coincidental. While this is possible, it is highly unlikely. The second reason is that since the discrepancy seems to go through a minimum in the middle of the flight, if the GPS error continues to increase, the discrepancy should change sign. The discrepancy decreased and increased during the flight but did not change sign in either latitude or longitude.

Clock Synchronization Error

The differences between DGPS and LORAN fixes were measured assuming the GPS clock and LORAN clocks were synchronized, (the EOSS shuttle's real-time clock provided time stamps for the LORAN fixes). If the clocks were not synchronized, a discrepancy between the two measuring methods would result. This discrepancy would be directly proportional to ground speed. The faster the balloon travels with respect to the ground, the larger the error introduced by having the clocks unsynchronized. Figure 9 shows groundspeed versus altitude. Maximum ground speed ocurred as the balloon passed through the jet stream, at approximately 39,000 ft. (11,900 meters). However, the maximum discrepancy ocurred when the balloon was nearest the ground, both during ascent and decent. If clock synchronization were the error mechanism, the maximum discrepancy would occur as the balloon passed through the jet stream. It is interesting to note that outlying points are present in Figure 3 at about 12,000 meters, the point of maximum airspeed. This indicates that there may have, in fact, been some inaccuracy in the synchronization of the GPS and LORAN clocks.

Skywave Contamination

Propagation conditions are always a concern when dealing with LORAN-C. The accuracy of LORAN-C position determination depends on

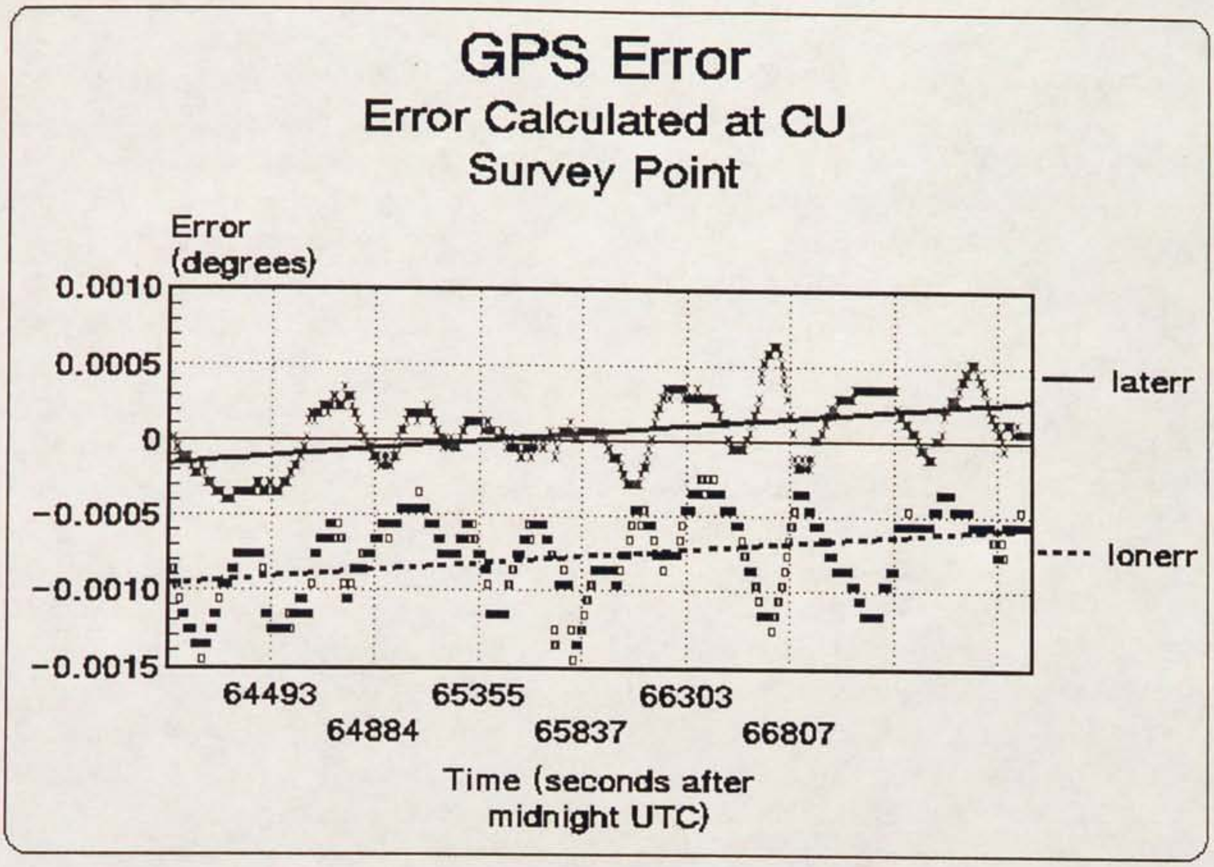


Figure 8. Corrections added to GPS fix at CU survey point vs. time.

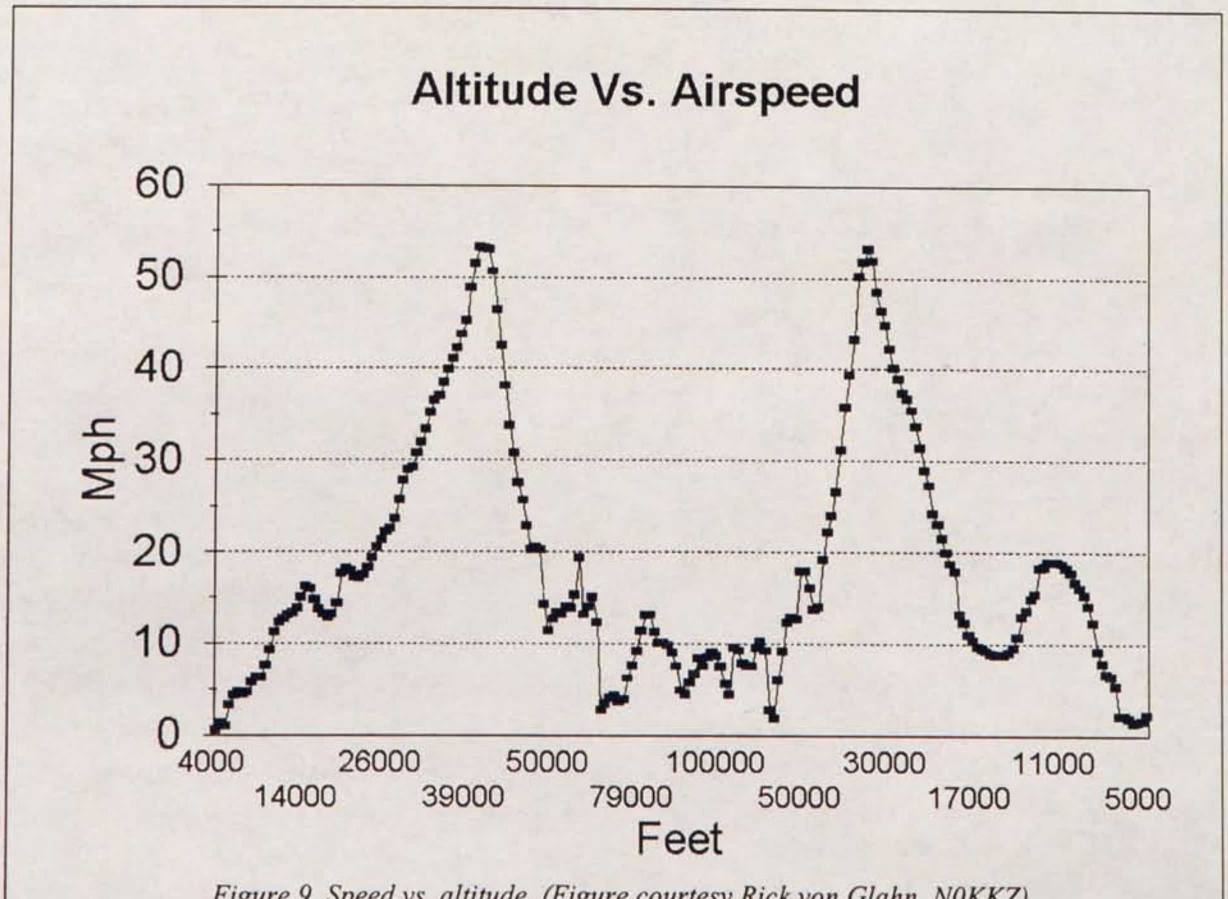


Figure 9. Speed vs. altitude, (Figure courtesy Rick von Glahn, N0KKZ).

precise knowledge of the LORAN-C signal's propagation velocity. LORAN-C works by measuring the difference in the time of arrival of pulses sent by one station, called the master station, and another station, called the slave station. The master station and its slaves make-up a LORAN-C chain. The pulses are modulated on a 100 kHz carrier. Both ground and sky waves propagate from the LORAN chain stations to the receiver, but only the ground wave is used. The difference between the time of arrival of the ground wave and the time of arrival of the sky wave is called the sky wave delay. The sky wave bounces off the E-layer in the ionosphere, which can be anywhere from 60,000 to 90,000 km above the earth. Because of the sky-wave-path's variability, it yields inaccurate fixes.

LORAN receivers lock into the ground-wave component of the LORAN signal by phase locking to the third zero crossing of the 100 kHz signal within each pulse. By the time the sky wave reaches the receiver, the receiver has already locked onto the ground wave. At altitude (100,000 ft.) the balloon is that much closer to the ionosphere, the layer from which the sky wave is reflected. The sky wave travels a shorter distance to a receiver at altitude, therefore, the sky wave reaches the receiver slightly sooner than it does on the ground. The sky wave delay is reduced by an amount that puts the start of the sky wave pulse in the vicinity of the 3rd zero crossing of the ground wave.

Whether this is enough to interfere with locking on to the ground wave signal is not clear. A more thorough analysis of the delays and signal strengths is required. However, if some kind of interference does occur, it seems the effect would be either loss of LORAN lock or an abrupt and severe change in the LORAN fix. It seems sky wave should degrade instead of enhance the LORAN accuracy.

Geometricl Error

The LORAN receiver does not "know" it is 28 km above the earth's surface. The signals received at altitude are interpreted as if they were received on the ground. Once again, however, this type of error would increase with altitude and should degrade the accuracy, not enhance it.

Terrain Effects

Modern LORAN receivers store tables which contain factors for correcting the LORAN signal propagation velocity. The parameter which most effects the propagation velocity of LORAN signals is ground conductivity. LORAN receivers contain look-up tables which contain ground conductivity information and perhaps other information used to add corrections to the nominal propagation velocity. Frank [2] describes surveys which determine ground impedances, but does not say whether the effects of local structures such as buildings and mountains have been included in such surveys. If local structures such as these are not included in a receiver's look-up table, substantial error could result. The Verranzo Narrows Bridge in New York City resonates near 100 kHz and can throw off LORAN readings by as much as 100 meters for boats passing underneath it. LORAN correction charts have been updated several times for the area off Florida's West coast because of the building ocurring there [3].

EOSS-12's launch site, Boulder, Co, is certainly near a structure which could be a source of reflections, the Front Range of the Rocky Mountains. If jitter caused by a reflection can alter the time-of-arrival between LORAN pulses by just 10 us, an error of 3 km is introduced. LORAN receivers located at the base of a mountain range would first receive the LORAN pulse propagating along the earth's surface, and shortly after, a pulse reflected from the mountains. At altitude, any reflected pulses that would reach the receiver would be greatly attenuated by the distance between the balloon and mountain. In addition, the mountains look less like a brick wall than a gentle bump at high altitudes. This error mechanism is a plausible candidate for the explanation of the LORAN/GPS discrepancy because it does effect ground readings more than readings at altitude, but some characteristics of the discrepancy are not explained by this error mechanism. The difference between DGPS and LORAN fixes shrinks but does not disappear at altitude. Also, the amount of error at the launch site, just a few miles from the mountains, and the error at the landing site, more than 30 miles from the Front Range, are about the same. More thorough analysis must be made before this can be labeled the source of the discrepancy.

Additional Analyses to be Done

Only those LORAN and DGPS fixes that occurred simultaneously were used to calculate the discrepancy. The number of LORAN and GPS fixes that occurred simultaneously were only a small percentage of the total number of data points. No more than a few seconds elapsed between reported DGPS fixes, so an interpolated line between DGPS data points will be fairly accurate. Calculating an interpolating line for the DGPS data will allow a comparison between every LORAN-C fix and an interpolated DGPS fix.

As stated earlier, a detailed analysis of skywave contamination, geometrical errors, and the effects of terrain on LORAN fixes must be done.

Throughout this paper, the LORAN-C and GPS receivers were treated as "black boxes", consuming radio navigation signals and spitting out fixes. Some knowledge of the insides of these boxes is required to completely understand their outputs. The algorithms designed into these devices may already account for some of the error mechanisms described here, and may contribute errors of their own. The conditions these algorithms are designed to handle must be found.

The author intends to have more complete analyses of the above concerns, and will supply updated information at the National Balloon Symposium.

The conditions under which this comparison of LORAN-C and differential GPS took place were as controlled as they could be. Still, there are many factors which could confound the explanation of any observed discrepancy. Another balloon flight carrying both GPS and LORAN-C navigation equipment might eliminate some factors.

Calculations

The author's calculations were done with paper, pencil and a calculator. Time constraints prevent me from transferring these calculations to a publishable format. The calculations will be available at the National Balloon Symposium.

Conclusion

LORAN-C and DGPS fixes differ by as much as 1700 m near the ground, and by as little as 400 m at 28,700 m. Errors measured at a fixed GPS station seem to indicate that GPS worked as expected and that the majority of the observed LORAN/DGPS discrepancy must come from LORAN error. Several error mechanism were proposed, but rejected, mostly because they should degrade LORAN performance at altitude instead of at the ground, where the error was greatest. The effects of terrain on LORAN do show up most strongly near the ground, making that explanation plausible. However, some features of the observed discrepancy are not explained by terrain effects. Further analysis is required before any explanation can be labeled anything more than plausible. More detailed analyses will be available by the time of the National Balloon Symposium.

References

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4. Parkinson, D., Gilbert, F., "NAVSTAR: Global Positioning System", *Proceedings of the IEEE*, Vol. 71, No. 10, October, 1983.
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Using GPS for Balloon Payload Tracking

by Bob Bruninga, WB4APR
[redacted]

(Parts of the following article appeared in the March/April 1993 issue of AMSAT Journal)

This paper describes the use of GPS and amateur packet radio for tracking moving objects. Although it describes the assembly of GPS and a HAM radio modem inside a football helmet, the same hardware could easily be applied to balloon tracking.

Using miniaturized Global Positioning System (GPS) satellite navigation equipment and amateur packet radio, the 110 members of the 13th Company arrived on course and on schedule to deliver the game ball for kick-off ceremonies of the 1992 Army/Navy game. The 13th Company of midshipmen annually runs the football from a final Pep Rally at noon on Friday in Annapolis to the start of the game in Philadelphia at noon on Saturday over a 128 mile distance using pairs of runners every two miles. This year, to permit timely and accurate reporting of the progress of the football back to the brigade of midshipmen, the outputs of the GPS receivers were transmitted back to Annapolis using amateur packet radio. The position data was received at the Naval Academy and repeated onto the academy wide local area network. A software program running on PC computers throughout the yard provided graphic displays of the route and the position of the football and chase vehicles.

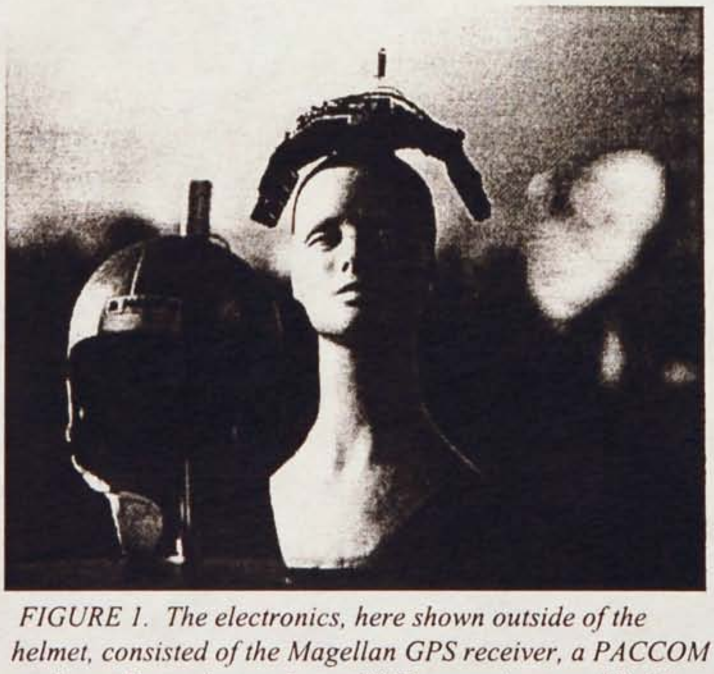

FIGURE 1. The electronics, here shown outside of the helmet, consisted of the Magellan GPS receiver, a PACCOM packet radio modem, a 1 watt VHF transmitter, and 8 AA batteries good for about 8 hours of continuous operation.

The initial idea had been to put a handheld GPS receiver, handi-packet and HT inside the football! The football would digipeat via the mobile rig in the nearby chase vehicle and then on to other digipeaters back to Annapolis. As experience with the handheld commercial GPS receiver developed, and as game time approached, the decision was made to place the electronics inside a football helmet instead of the football itself. On the helmet, the GPS antenna would have an unobstructed view of the sky, and the equipment would be less vulnerable to fumbles. Surprisingly, the GPS receiver, the packet radio modem and the HT transmitter plus eight AA batteries fit in place of the usual water/air filled compression pads so that the only external effects of the system were the small GPS quadrifilar helix antenna and the VHF whip antenna. A low profile GPS patch antenna and loaded VHF antenna could have minimized these external effects, but we ran out of construction time. In fact, the helmet was not completed until 1:00 AM on the morning of the run!

VHF RELAY NETWORK

To accomplish the data transmission over the extended 128 mile route, members of the Naval Academy Radio Club, W3ADO, joined with the 13th Company to provide the necessary communication and data links. The midshipmen installed 2 meter mobiles, TNC's and the GPS receivers in each of the two official chase vehicles and augmented these vans with three ham-equipped private vehicles. A series of three 2-meter voice repeaters along the route provided excellent coverage over the entire 128 mile range. The GPS receivers in the two vans permitted their movements to be tracked while shuttling runners to each of the 64 waypoints. The GPS receivers in the football helmet and the two vans were programmed to transmit a position and velocity packet once every two minutes over the same channel as used for voice communication. Since the three VHF repeaters were independent and not normally linked together, two additional volunteer stations, Dan WD4LTO and Bob W3WCQ, midway between the three repeaters provided automatic relay of the data from repeater to repeater back to Annapolis by operating as digipeaters with their receivers on one repeater and their transmitters on the other.

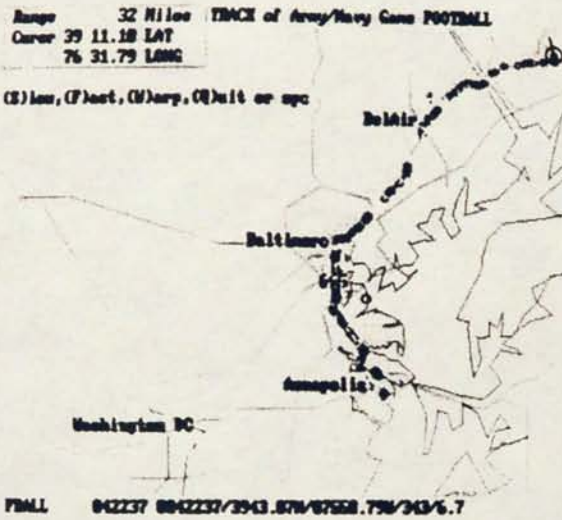

FIGURE 2. The APRS displays the final leg of the run through Baltimore showing the football about 40 miles out of Philadelphia at 2237 on 4 December. The chase vehicle is back at the rest station in Oxford, PA, exchanging runners for the next leg.

In Annapolis, the data packets were not only distributed to midshipmen throughout the yard, but also retransmitted on HF and via amateur satellite. The Military Affilliate Radio System (MARS) provided an HF frequency for retransmission to military activities and the Amateur Satellite organization, AMSAT, permitted use of the OSCAR-21 satellite for relay to fans across the country. All stations running the Automatic Packet Reporting software could see instantly the progress of the football.

PLAY-BY-PLAY

Although the experiment was considered a complete success, it was not uneventful. When we went to pick up the vehicles for installation the day before, we found one with a flat tire and the other one unaccounted for. By the time a vehicle was available, it was 1430 and the motor pool wanted it back by 1530. Fortunately, the first installation was straightforward, but a real setback occurred during the installation in the second vehicle. While making a final transmitter level adjustment for the microphone gain, the screwdriver slipped and a blue puff of smoke filled the air. A quick replacement of the burned out series choke in the power supply did not restore operation and further repairs were abandoned. The third unit that had served as the prototype for the whole project and had been operational for more than a week in the author's car was cannabalized for the chase vehicle, but all the connectors and interfaces had to be modified. This setback cost us four critical hours and reduced the number of GPS vehicles from three to two.

The second vehicle was completed at 2100 and all effort focused on the football helmet which had still never been powered up! The Handi-packet TNC and transmitter came up as planned, but the GPS receiver would not respond. After an hour of troubleshooting, the problem was identified as incompatibility in the RS-232 to TTL converter circuit and the unit was responding at the wrong baud rate. An extra pullup resistor solved the interface problem and the baud rate of the TNC was modified to match the incorrect rate coming from the GPS receiver. The unit was finally operational by midnight and taken outside to see full sky. The GPS receiver quickly synchronized and within minutes was downloading ephemeris. An hour later it was retrieved and final assembly within the helmet began.

After precious little sleep, the midshipmen began distributing the display software and setting up displays in public places throughout the Yard, the main duty office,

AUTOMATIC PACKET REPORTING SOFTWARE (APRS)

The key to the success of the packet reporting system is the APRS software which provides graphic information on the position and status of all units. The EGA graphics shows an outline map of any portion of the country at any scale between 0.5 to 1024 mile range. As of this writing, detailed maps for the Cheasapeake Bay, Washington DC area to Philadelphia, Norfolk, New York and Rhode Island are available. Map creation information is provided so that anyone may develop dedicated detailed maps for any local area in the country. Using the cursor, any unit may be selected for a detailed display of data on that unit. Further, a single key stroke will dead reckon all unit positions to their estimated current positions based on course and speed from their last reported position. The APRS software is a dramatic improvement on the MONITER HEARD capability found in most TNCs because it displays all callsigns geographically when heard. A glance at the screen shows which stations are currently active.

The key to this system, of course, is knowledge of every station's geographical position but this does not mean beacon packets forever! In fact, as more and more stations run this software and collect position reports from cooperative stations, a community file of station locations can be assembled and distributed via BBS files! BBS code could even be modified to monitor beacons and collect and maintain the position files and also ask new users for their positions (this is already done in DX clusters). Stations need to only update their position data when they move or go portable! Then only one properly formatted beacon need be transmitted successfully for the community to grab your change in status.

APRS BEACON FORMATS:

Since there are many different applications for this position reporting system, the APRS recognizes several formats of position and status reporting. The following table shows the basic formats which include provisions for both automatic and manual reporting. Most fields in these formats are fixed length except for the comment field which goes to the end of the line. In these examples the LAT/LONG is 3858.57 North 07629.55 West, moving at a speed of 55 Knots on a course of 030 degrees true. The time in the mobile station is in Date-Time-Group format, whereas the time in the GGA sentence is UTC in HHMMSS.

```
FIXED STN:  W3XYZ>APRS:!3858.57N/07629.55W/comments as needed
MOBILE STN: W3XYZ>APRS:@142329/3858.57N/07629.55W/030/055/Comments
GPS POSIT: W3XYZ>APRS:$GPGGA,232900,3858.57,N,07629.55,W,.....
GPS CSE/SPD: W3XYZ>APRS:$GPVTG,030.00,T,027.00,M,055.0,N,....
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the midshipmen radio station, the snack bar, the 13th Company command post and the wardroom. A portable packet laptop was set up at the site of the Pep Rally so the Admiral could see how it worked. With 30 minutes to go, both chase vehicles, the football and all displays were operational. The helmet was initialized and everyone headed for the send-off Pep Rally.

Amidst speeches and cheers, the football was passed by Admiral Lynch, the Superintendant of the Academy to the lead runner and his companion donned the GPS helmet as the run began. At the west gate, the runners joined with the lead chase vehicle and the long distance portion of the event began. The laptop display showed the position of the two vehicles, but the football helmet was still reporting itself at the starting point!

We gathered together our bag of tricks and headed off to overtake the errant helmet. We caught up to the ensemble at the first two mile exchange point and the runner saddled with the helmet was only too happy to relinquish it for analysis. Although we were now down to two out of the original four GPS systems, we realized that the the lead chase vehicle was always within eyesight of the runners and that if we changed its callsign to FBALL instead of CHASE-1, the objective of reporting the position of the football would still be met. We brought the football helmet back to the lab for troubleshooting, but never quite got to it. The emergent logistics and communications needs of the runners soon overtook us.

Coordinating the positioning of over a hundred individuals stretched along a 128 mile route over an 18 hour period provided enough distraction for the remainder of the evening. After sunset in the worst section of Baltimore, the chase vehicle lost track of the runners in rush hour traffic and the shuttle vehicle had a flat tire (and no spare). Desperate searching by the van with John N2HAQ and several midshipmen cars was unsuccessful for almost a half hour until the football and two runners stepped out of a taxi at a subsequent checkpoint. They had become hopelessy lost and hailed a taxi to help them find the proper intersection. Then the spare tire of the chase vehicle was used to repair the shuttle van and another 50 mile round trip back to the motor pool was inserted to get two spares.

Monitoring the local area network from the satellite control room, we could see the software proliferating. By 2100 as many as 15 displays throughout the Academy were on line. By this time the excitement of tracking the football was catching on in the local amateur radio community and dozens of stations along the route came online to observe the movements of the entourage using the Automatic Packet Reporting Software (APRS). The chatter on the voice net was exciting as everyone shared the same graphic display picture.

HARDWARE

Interfacing GPS to packet radio is simple. The Magellan 5 channel OEM GPS engine outputs position data over a standard RS-232 port. We selected the Magellan device, because it was the only one that we found that allowed the user to specify the reporting rate and what data items were in the standard NMEA-0183 reports. By turning off all reports except for the position and velocity reports and setting the periodicity to once every minute, we had an output that was ready to be transmitted. For modems and data integrity, we used amateur packet radio AX.25 TNCs to transmit the information. The only requirement on the TNC was to first place it in the UNPROTOCOL CONVERSE mode so that all data coming in the serial port was transmitted. We had to carry along a laptop terminal to initialize the TNC into the UNPROTO-CONVERSE mode each time it was powered up. Since then, we have found a two byte patch, that allows the modem to come up in the proper mode without any intervention. For a balloon, this would not be necessary, since it is easy to configure before launch after power is applied.

FIGURE 3. This photo shows the GPS tracking hardware which includes the Magellan GPS receiver and antenna, the Ham radio transmitter, and the (Podet or pocket-AT) radio modem.

SOFTWARE

The key to the use of packet radio to transmit GPS position is the use of mapping software to track the object in real time at all receive sites. The Automatic Packet Reporting Software (APRS) was written just for that application. All packets that contain a properly formatted position report are plotted in real time. Objects reporting a course and speed can further be dead-reckoned to their present position based on past reports. APRS accepts both a customized position format for normal packet radio operations without GPS but also accepts packets containing the raw NMEA-0183 position formats. It accepts the GGA, GLL and VTG sentences from either LoranC or GPS devices. Map scales from ¼ mile up to 2048 miles are accommodated. The software fulfills a niche requirement for displaying real-time tactical information via amateur packet radio. Not only are objects on the map tracked, but also short messages can be transmitted between stations. The software is ideal for tracking a balloon! In fact, the software is being considered for tracking the space shuttle and also for displaying the location of amateur radio operators across the country in real time as they communicate with the shuttle.

SUMMARY

The use of GPS in the football helmet was considered an outstanding success. We demonstrated to the midshipmen a combination of HF, VHF and satellite communications and introduced them to the technology of miniaturized GPS receivers. Members of the radio club gained hands-on communication experience in a tactical environment and had a lot of fun. The 110 members of the 13th Company learned the advantages of radio communication in managing logistics over an extended range and hundreds of midshipmen were able to share in the excitement of the 13th Company as they observed the progress of the football on display screens throughout the yard. The distribution of the position reports via the recently installed high speed Naval Academy local area network demonstrated the capabilities of distributed processing power similar to the future networks anticipated on Naval ships. Until next years run, the GPS position reporting capability will see application on the Naval Academy boats during summer cruises, keeping track of over 400 midshipmen on as many as 20 units at sea.

REFERENCES:

The APRS is distributed as shareware and may be copied for any amateur application. Registered copies are available from the author for $19. [redacted]

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Persistance Gets the Derelict

by Warren Williams, N0PBY

[redacted]

This article appeared in the August 1993 issue of *QST*. Reprinted with permission.

It was with confidence born of five previous successful flights, that we approached the May 30, 1992, flight of our sixth and largest balloon. Edge Of Space Sciences(EOSS), a non-profit group of hams, high school and college students, and other prople interested in science, space, radio, and astronomy, devoted to educational experimentation, were confident of a spectacular large balloon flight. Little did we know what the next 31 hours would hold. The record for the longest successful balloon chase in the history of Amateur Radio was about to unfold.

Jack Crabtree, AA0P, obtained FAA approval for a flight to more than 100,000 feet with a payload of more than 20 pounds. The launch site was just north of the Terminal Control Area for Stapleton International Airport in Denver. Little difficulty was encountered in getting the approval because the previous five flights were completed without significant trouble. The earlier experiments didn't always work as planned, but we had a perfect record for release and recovery of the payload. The FAA didn't know that it would be dealing with a "derelict balloon" for the next 18 hours.

THE BALLOON AND PAYLOAD

The balloon was a "special-order Raven" filled with 54,000 cubic feet of helium, 71 feet long, and designed to hover at 100,000 feet. The projected size of the balloon at altitude was 37 feet high and 52 feet wide. The 14-pound balloon was the largest launched from Colorado in recent history.

The payload included packet telemetry on 144.34 MHz, sending inside and outside temperatures, altitude, and voltage levels. Power output was one watt to a vertical antenna. Amateur Television (ATV) on 426.25 MHz was taken with a black-and- white camera that was gimbaled and controllable in the vertical direction. Power output was one watt. The ATV audio output was used to send the VHF omnidirectional radio range (VOR) audio to be used for real-time tracking and position plotting.

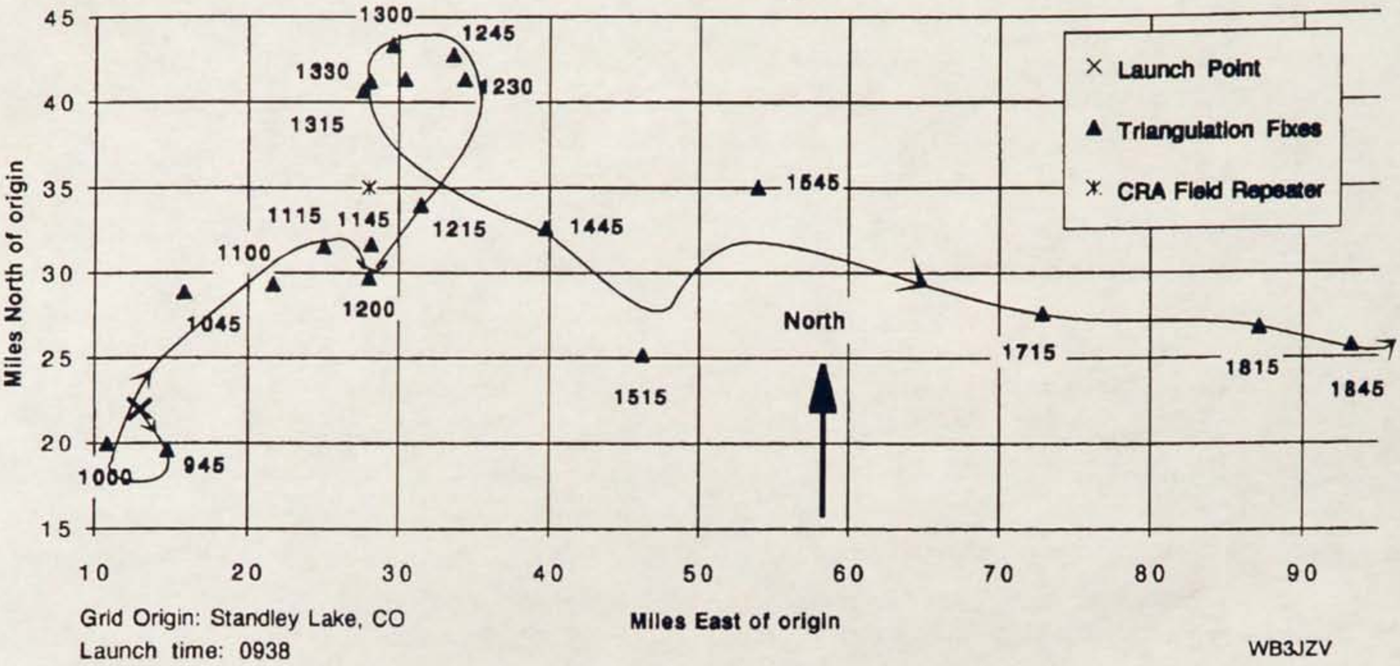
Photo by Ann Trudeau, KA0ZFI

Partially inflated, the balloon is nearly ready for launch.

In addition, there was a 2-meter tracking beacon on 147.555 MHz with a one-second beep and CW ID every 10 minutes. The antenna was vertically polarized, and output was 250 mW. Neal Tenhuzen, WB0ADU designed and built the beacon. It was housed in a Styrofoam "Big Wheel" designed by the science students at Heritage High School. The design was a winner of a contest to see which team of high school students could design the best container to withstand a drop from 200 feet

Fig 1-Estimated Balloon Flight Path From 0945 to 1845 hours

EOSS #6 Balloon, 30 May 1992



and land with the antenna in an upright position. There was also a 10-meter backup tracking beacon on 28.321 MHz with a vertical antenna and 250 mW power output.

The prime experiment was the "Humble II" telescope experiment designed by Tim Kelliher, N0RHE, a student at the University of Colorado, and students from Green Mountain High School. This was an experiment to record the ultraviolet images of the sun from 100,000 feet through a magnesium filter on 400-speed black-and-white-film.

The VOR experiment was designed by Mike Manes, W5VSI. The purpose of this experiment was to see if it was feasible to use three VOR stations in the Stapleton International Airport area for real-time positioning and direction finding (DFing). The directional AM signals from the Gill, Denver, and Kiowa VORs were received and retransmitted to ground tracking on the audio signal from the ATV link. The command receiver and flight computer were designed by Bob Schellorn, W6ORE, and a five-cell lithium battery made up the remainder of the payload. The total balloon and payload weight was 35 pounds.

LAUNCH AND CHASE

The morning of the launch was cloudy, but the surface winds, our biggest concern, were calm. The FAA granted approval for the launch despite the cloud cover but requested expediting the launch because of incoming air traffic at Stapleton. The tarp material needed to cover the alfalfa field to protect the balloon arrived late. We were feeling time pressure.

EOSS Chief Scientist Dave Clingerman, W6OAL, and Merle McCaslin, KØYUK, began filling the balloon with the four bottles of helium, just enough to lift a 40-pound bucket of sand. The tensions and drama began to build. At 0938 MDT, the balloon was sent aloft in calm surface winds. Tom Isenberg, NØKSR, and a group of high school students had already obtained the winds aloft and projected the flight path and touchdown point with Tom's computer program. The foxhunters were already headed downwind with sufficient geographic separation to assure good cross-bearing DFing. There were 20 sophisticated mobile recovery vehicles stationed as far as 50 miles downwind. Some were equipped with packet to receive the telemetry from the balloon, ATV, and 2- and 10-meter DFing gear.

A 2-meter mobile repeater was stationed on high ground southeast of Greeley by the Colorado Repeater Association to provide field communications on 147.835 MHz. The location by grid square from an overlay of the Colorado Recreation Map was called in on this frequency by each station, with their true bearings every 15 minutes, and this information was plotted with a computer programmed by Paul Ternlund, WB3JZV. The program threw out inconsistent readings and plotted the estimated position, speed, and direction of the balloon. Fig. 1 shows the computer plotted position of the balloon at each reporting period. The flight path takes two interesting loops before taking off to the east. With all this organization and effort, how could we miss?

The shroud lines to the papachute ran through an eyebolt affixed to the bottom of the balloon. Unfortunately the painter—a rope to hold the balloon while the payload is readied for launch—also ran through the eyebolt. As it turned out, pulling the painter out of the eyebolt at launch had partially cut the shroud lines, but this wasn't known at the time. Within moments after launch the payload dropped several feet from the bottom of the balloon. It was hanging from the rip panel of the balloon. The sudden jerk separated the power hookup to the camera, telescope and the computer, and the shape of the balloon appeared abnormal.

The balloon rose to 75,000 feet and hovered there. Packet telemetry continued to report temperatures, altitude, and voltages. Video of the balloon ascending through the cloud cover was spectacular including a snow storm within the clouds. The quality of the video was P5—beautiful!

At 1225, the command for separation was given, but there was no response. At 1300 an automatic timer signalled release to the nichrome wires on the shrouds, but without effect. Several more attempts at commanding release were given, all without effect. We were in for a long haul.

We notified the FAA and the balloon was given a "derelict" designation. We were required to report the position of the balloon every 15 minutes to the FAA at Stapleton. At 1400, the balloon was drifting over Greeley. The chase teams were preparing for the long haul, getting gasoline and food. Shortly thereafter, the balloon began moving east at an increased speed, and the chase teams began moving east, but continued to maintain geographic separation. By 1600, the chase teams had moved far enough east that the field repeater was no longer effective. Field communications moved to the 146.94-MHz wide-coverage repeater of the Rocky Mountain Radio League. Eventually, field communications were accomplished by simplex VHF FM in the field and on 40 meters from the field to the base in Denver. As evening approached, communications back to Denver changed to 80 meters for the night.

There were large thunderstorms in the area, and by 1745, the last bearing was taken showing the balloon moving east of Sterling, 100 miles northeast of the launch point. Shortly thereafter the 147.555-MHz beacon and 10-meter beacons were lost. Occasional packet bursts were heard, but it was difficult to DF on such a short signal burst. An altitude of 54,000 feet was reported by balloon packet, so it was slowly descending at about 2000 feet per hour.

A repeater trustee, David Richendifer, WD0HNQ, from Denver, called net control to report a "funny sounding" CW beep on his repeater. This was identified as our beacon which had apparently gotten too cold and lost the phase-lock loop resulting in an upward wandering frequency. It's interesting that the frequency rose from 147.555 MHz to as high as 147.91 MHz, so the chase team not only had to DF the balloon, but also had to change frequencies and grope to establish reliable coordination frequencies for the chase teams and long haul communications to Denver on 80 meters.

The chase continued into Nebraska, and only one chase team, Marty Griffin, WA0GEH, had a Nebraska map. Country roads were difficult to find and navigate at night. All teams were heading east as fast as possible to keep up with the balloon and not allow it to get beyond the horizon. Mike Manes, W5VSI, and Geno McGahey, AL7GQ, remained on 40 and 80 meters in Denver to provide what support they could and to notify the FAA of the location and progress of the balloon and hunters.

At 0100, there were five chase teams still active and moving into Nebraska. Calls were made on the 146.94-MHz repeater in North Platte. As the teams neared that area, a local ham, Randy Allen, N0MPF, came to the rescue and helped with road locations. The balloon was plotted to be north of North Platte. The chase teams, headed by

Gregg Burnett, K0ELM, turned north. No main roads heading north could be found, so it was on back roads, in knee-deep sand at night that the chase continued.

At 0200 on Sunday, May 31, the 147.55-MHz beacon, back on its proper frequency, was on the horizon, and Bob Ragain, WB4ETT, and his two daughters, Dawn, N0QCW and Colleen, N0QGH, were picking up the beacon with an S7 signal level with 60-dB attenuation in place. The signal disappeared at about 0330, and then was picked up in a large field by the chase leader, Gregg. He was unable to tell the other chase teams of his location, however, because of the lack of a map. Bob Ragain did what any good foxhunter would do: He DF'd him. The teams finally met at the field and waited for sunup to begin the walk.

Photo by Lary Cerney, N0STZ

The proud chase team displays its direction-finding gear, used to track the balloon's beacons.

At about 0515, the teams walked the 1 1/2 miles to the payload. The 2-meter beacon, which dangled below the main payload was stuck to a yucca plant, and the remainder of the payload and parachute were strung out downwind. In a remarkable feat, one member of the chase team, Dan Griffin, driver and navigator for Marty, hiked several miles downwind and found the balloon—another first.

The five chase teams returned home to a tumultuous greeting on the Denver Radio League 146.64-MHz repeater. It had been about 31 hours since they last saw home, and they had logged more than 1000 miles each in their fine effort.

EPILOGUE

The final statistics for the flight:

Distance: 219.5 miles (record)
Flight Duration: 18 hours (record)
Launch to recovery time: 19 hours and 30 minutes (record)
Maximum altitude: 75,000 feet
ATV was received with P5 quality.
Touchdown site: 38 miles northwest of North Platte, Nebraska

Postflight payload inspection revealed that the shroud lines to the balloon had been severed, probably by the painter as it was pulled from the eyebolt at launch. The drop of the payload put tension on the power leads to the flight computer and camera, rendering them inoperative. When power was reestablished back at home base, the nichrome cut down mechanism worked on the first try. If only the painter hadn't cut the shroud lines!

The film in the telescope camera was unexposed, although evidence that the telescope had properly tracked the sun was in evidence by the burned track marks along the plastic body of the camera leading to the lower area of the lens. The mirror had focused the sunlight well enough to produce enough heat to leave its mark.

The FAA later stated that it was pleased with the conscientious effort and persistence of the group. What a magnificent smorgasbord of communications and dedication by a great group of hams.

Ed Note: Fig 1 created by Paul Temlund's triangulation program. See his article on page 53 in the *Proceedings*.

Advanced Payload Recovery Techniques

by Will Marchant, KC6ROL

[redacted]

Balloon payloads can drift hundreds of miles before recovery; is this an advantage or disadvantage? Certainly transmitter hunters may find this chase the most entertaining part of any balloon flight! But what about others? In this paper I'll discuss some, mostly theoretical, options that might be used to reduce the effort needed to retrieve payloads.

One option is to reduce the drift by increasing the rate of descent by delaying the deployment of the full recovery system. Another is to employ a steerable recovery system. Obviously these options could be combined.

These ideas presume the need for some form of "soft" landing. Early planetary landers considered technologies that used hardened payloads that could withstand rough landings. Some used various energy absorbing, collapsible structures to cushion impact. Others used retro-rockets to slow the final descent. These options are probably not viable for the amateur ballooning community. Ruggedized payloads require careful engineering and are often expensive. Retro-rockets, although an entertaining and spectacular technology, are certainly too dangerous to be considered for the typical earthly applications.

Delayed Deployment The model rocket community sometimes uses altitude-sensing payload deployment systems. An altitude sensor (activated at liftoff) will eject a drogue parachute shortly after apogee, and the main parachute system when the rocket returns below a pre-set altitude. The recovery system elements are deployed by small gas-generating charges. Perhaps the drogue could be used to extract the main parachute from its housing. Unfortunately the model rocket systems already in use have altitude limits of under 20,000 feet.

Another option is to "reef" the pre-deployed main parachute. Reefing holds the parachute partially closed to increase the sink rate of the payload. The main chute is fully deployed at a lower altitude.

Activation systems could be fully automatic (possibly involving pressure sensors, or data from an on-board navigation system such as LORAN or GPS). Or deployment systems could be ground commanded, either with commands sent automatically by a ground system (utilizing data from sensors that form part of the science payload) or by an operator with quick reactions and nerves of steel.

Steerable Systems Systems that allow vectored motion can take on a multitude of forms. Some common examples are: rigid wings (such as a model glider), parafoil or parachute type soft structures, and hybrids such as the Rogallo wing.

First generation parachutes drifted completely at the mercy of the wind. Those military pilots having strong stomachs, would reach up and cut a few rear shroud lines on their conventional parachute to give them an, admittedly crude, form of glider. Later parachutes were designed to include this level of control. Modern sport jumping parachutes are in reality Jalbert parafoils and are very maneuverable.

One measure of the efficiency of a glider is the "glide ratio". This is commonly expressed as the ratio of the horizontal distance traveled, to the vertical distance traveled. (If a glider flies 20 feet for each foot it descends, it has a glide ratio of 20:1 or "twenty to one".) A payload that flies to 100,000 feet and normally drifts down-wind 200 miles would need a glide ratio of roughly 10:1 to return to the launch area. This is probably a worst case example.

One can easily imagine taking an instrumented, radio controled glider and lofting it with a zero pressure balloon. Radio controled gliders are somewhat heavy and also require a high level of training to fly. Nevertheless, the ham radio literature is filled with examples of successful flights of R/C gliders, powered planes, and helicopters. Gliders often have a glide ratio in excess of 20:1.

I have one example of a radio controlled parachute in the model rocket field. I talked with Matt, the president of North Coast Rocketry, about their experiments with radio controlled parachutes. Their system uses a square chute with four shroud lines to get reliable deployment. They have plans to offer a commercial version sometime next year.

One advantage of balloon flight is that parachutes can be left in a virtually deployed state. Model rocket designers must go to considerable lengths to enclose parachute systems within the airframe of their models and trust the skill of their design and packing abilities to avoid entanglements upon chute deployment. I do not know what the glide ratio for a modern parachute might be. I would guess that it is nowhere near the desired 10:1. Perhaps that is not the death knell for steerable chutes. They might still be useful for reducing the distance of the chase and indeed may suffice for all but the worst case scenarios.

Parafoils have weights comparable to conventional parachutes. The disadvantages of any steerable system, when compared to a conventional chute, become apparent when one considers the actuators, and their power sources, necessary to effect course corrections. I am awaiting literature from a company that sells radio-controled model-sized parafoils to look at the success of existing systems.

Rogallo wings, although sometimes containing no stiff structural members at all, most often have a set of stiffened longerons. NASA made a number of test flights aimed at using inflatable Rogallos as recovery devices for their series of crewed capsules. These arrangements were deemed too complicated for the advantages. Rogallos probably fall in between parafoils and rigid wings; they have better glide ratios than parafoils, but they are heavier.

I would favor a parachute for an initial experiment. The addition of actuators to an established technology seems like a prudent first step. Failure of the guidance system will probably not make the recovery effort much more difficult. Optimal operation of the recovery system should have enough effect to be easily studied.

A parafoil would be the logical second step, and in my opinion the ultimate step. A problem with using a pre-deployed, thrusting structure is that it will vector the payload during ascent. And yet trying to address this defect with a deployable Rogallo or rigid wing will inevitably lead to an even more complex, weighty, and failure-prone system. Parafoils can be successfully packed, (witness the sport parachuting community), and would offer little interference to an ascending balloon.

Guidance for Gliding Recovery Guidance systems could come in three forms.

The first is to not do any guidance at all. The transmitter hunters will love this since, most of the time, the payload with a gliding recovery system will move even further from the launch area.

The second is to guide the payload from the ground station. Most people will prefer a payload that gets closer to the launch area (or a designated recovery) area. (However, there is no need to return to the launch site. The payload could easily be targeted for somewhere in the next state. Imagine the chase you could give the hunters!) The guidance systems would operate via steering commands from the ground system. The ground system would need to know the payload's current position. The location could be supplied by data from the on-board systems or by direction finding fixes from the ground system. The ground station would also need to know which direction the payload is moving. Direction is probably most easily determined by a machine-readable magnetic compass on-board the payload. One can imagine using sun sensors, mechanical or laser-ring gyros, or calculating the heading of the payload by detecting its movements over a short period of time. Steering commands could be generated by a human or automatically by the ground station.

The last option would have the payload contain a processing system that would utilize sensors to steer itself to the desired landing spot. Landing areas could be designated by a radio beacon (for payloads that have radio direction finding ability) or by latitude/longitude coordinates for "navigating" payloads that have location/heading sensors on-board.

Since the EOSS "shuttle" already contains a LORAN navigation receiver, the addition of a machine-readable compass to form a navigation-based guidance system seems like the best option. The compass would yield interesting scientific information on payload yaw rates and the pointing direction of other sensors. The LORAN sub-mile accuracy would be adequate to get the payload to the general vicinity of the targeted recovery area. It would be an obvious advantage to include a manual command mode so that the payload could be "joy sticked" for the final portion of the voyage.

Software will need to be fairly smart to resolve the wandering readings from LORAN and GPS systems. Even differential GPS will probably only yield accuracy in tens of meters. This could be enough to cause a sensitive software system to over-control and waste valuable battery power.

Conclusion Any deviation from a standard parachute system will increase the weight, complexity, and cost of a balloon payload. Increased complexity can easily translate into increased mission failures. Perhaps the advantages of a recoverable system are outweighed by the dangers. However, recoverable systems may be the only feasible option for groups that cannot field a dedicated, trained recovery team. And guided recovery systems may make it possible to avoid difficult, dangerous, or payload-damaging recovery sites.

Sources Transolve Corporation (4060 E. 42nd St., Cleveland, OH 44105) produces an altitude-sensing parachute deployment system for their rockets: (216)-341-5970

The number for North Coast Rocketry is 800-877-6032.

Supporting Primary Science Education
with
High Altitude Balloon Experiments
or
This Stuff is Too Good to Keep to Ourselves

by Ralph Wallio, W0RPK

Several groups of Amateur Radio operators across the United States have become proficient at designing, building and launching ham radio and scientific payloads borne by helium balloons. Created with a distinct ham radio orientation, projects have been designed to carry voice, digital and video transmission payloads to altitudes which allowed reception and two-way participation to a maximum radius of 650Km.

A few of these groups have recently modified their payloads to include increasingly sophisticated environmental sensors and telemetry links to ground stations. These groups have also started to provide the educational community with input and access to their experiments, before, during and after missions.

This discussion advocates further involvement with the educational community, especially primary scientific education. Topics include reasons for support commitment, hooks to scientific education, how to communicate with educators, science education and the need for complete financial support. Attachments include a sample newsletter front page and a sample lesson plan.

Why should we go to the trouble?
This is an opportunity to repay a debt

Each of us who finds experiments with high altitude balloons and payloads to be exciting stuff, has a debt to repay. At some time and place in the past we have each been given the love of technology. We have had teachers, professors, Elmer's and friends who have given of themselves to pass on their knowledge and delight. It is our responsibility in turn, to pass on this knowledge and concern to the next generation.

There are youngsters out there under our balloon flights who are having fleeting thoughts about matters of environmental science, the physics of gases, electromagnetic radiation, and all the remaining sciences our flights involve. These thoughts, questions and concerns come to the surface and then drift quietly away ..., unless those of us with the opportunity take responsibility to bring science right up to their noses.

Scientists of the 21st Century
Where are they going to come from?

We have all developed concerns about the economic priorities of the 21st century. Where is science going to fit in to what appears to be an era of dwindling choices? How are we going to ignite, in a few of our current primary and secondary students, the personal drive toward scientific education and achievement which will be necessary for them to hurtle the inevitable obstacles that we have built?

One way is to do our part to grab their attention now. The educational hooks built into our balloon missions can be applied to elementary science instruction in grades 4-6, to physical science as taught in grades 7-9, as well as high school and undergraduate courses. Support of the primary and physical science programs will be the most productive toward helping students consider careers in science. Support of the high school and undergraduate programs, where students have already established their educational and career direction, might be 'preaching to the choir'.

The Scientific Learning Hooks of High Altitude Ballooning

"What is this stuff we are breathing? How come my birthday balloon 'flew' away when I accidentally let it go? Why is the sky blue? Where does wind come from?"

"Wait a minute ... are you telling me that MTV is flowing through my body right now? And, get this, the signals from my favorite top-40 station, the colors I can see, the heat I can feel, the cause of my sun tan and sun burn, and the x-ray picture of my broken arm are all made of the same stuff? Cool."

Our high altitude balloon experiments are rich in the topics that answer these questions and many more. We are involved in the environmental science of our atmosphere and weather, the physics of gases, and the understanding and application of electromagnetic radiation. All of these topics can be encapsulated and brought to primary and physical science educators as focal points for classroom study.

But is is not nearly enough just to make flights happen. We have to go out of our way to support education before, during and after our missions. We need to make and live up to long term flight commitments. We need to pay the expenses.

Take it to the Educators' Doorstep

Support should be provided in several ways, before, during and after missions. All support costs should be borne by the project group. Ascensions should be scheduled for the normal school day.

Science educators are looking for interesting and well supported projects for their students' benefit. They will welcome the possibility of hooking required topics of established curriculum to high altitude balloon experiments. They will go to a great deal of effort to allow students to participate in interesting projects, but only after they are convinced that these projects are dependable and worth while.

Groups supporting high altitude balloon missions need to commit as much, if not more, time and money to communicate with and support educators as they spend on their payloads and mission logistics. Volunteer educators and publicists should be added to project teams to publish mission specific lesson plans and periodic newsletters timed to capture the attention of educators as they plan for future terms.

Project educators will know what primary and physical science teachers need for support. They will know how to form a successful focal point with lesson plans and teaching aids. They can communicate with educators in their professional language and, because they know the secret handshakes, their support will be accepted.

Project publicists will know how to put together a continuing project newsletter which will capture the attention of busy educators. They will know, or be interested to learn, how to use desk-top publishing software. They will know how to ferret out the real and important stories and to write appropriate copy.

Communicating with Educators

A mailing list can be started by contacting a local science teacher and asking about regional associations. Those associations should be interested in either providing a mailing list of their members or including a short article in their newsletter asking for participation. State departments of education should be able to provide mailing lists of school districts and possibly individual science teachers.

A project newsletter should be published and distributed to teachers on the growing mailing list. These periodic newsletters should contain advance notice of features and dates of future missions, scientific and logistical results from past missions, suggestions for reception and interpretation of telemetry, technical articles on payloads, and submitted articles and pictures from participating schools. Newsletters to educators should be published dependably and timed to their decision cycles. Many public school science educators will not receive mail at their schools during the summer so home addresses should be considered. (See Sample Newsletter following article)

Participation of Amateur Radio operators should be solicited to provide local support. Lists of ARRL members and member organizations are available through ARRL Section Managers. Local hams can lend equipment to schools as required for receiving telemetry, helping with antennas, providing information broadcasts on HF nets, and perhaps helping to explain the whole process to interested students.

Educators are going to need last minute mission information and will probably not have funding for long distance telephone expenses. Project teams should obtain inexpensive 800-number services for voice announcements of last minute information such as launch dates and times and final payload configurations.

Project team educators should produce lesson plans which match specific payload features to scientific topics. These plans will give classroom educators a direction to follow before, during and after missions. Lesson plans should include teaching objectives, classroom activities, quantitative problems, qualitative problems, library research suggestions, words for vocabulary building, and reference materials. Lesson plans should be discussed in newsletters and made available to educators as requested. (See Sample Lesson Plan following article)

Flights should be scheduled for the normal school day, that is, Monday-Friday while schools are in session. It would be unreasonable to expect participating teachers and students to be available on weekends but adjustments to student class schedules can be made.

Education topics:
Where is the balloon?
The release site?
The landing site?

Concepts of latitude and longitude coordinates.
Putting altitude into perspective.
Positioning systems - Dead reckoning.
- Celestial navigation.
- LORAN and OMEGA.
- GPS.

What is moving the balloon horizontally?
Surface wind and winds aloft.
Wind direction and speed at given altitudes.
Observed weather versus forecast weather.

What is causing the balloon to rise?
The physics of lighter-than-air craft.
Balloon types: hot air, unpressurized and superpressure gas.

What are the weather conditions aloft?
Temperatures.
Pressures.
Humidity.
U.S. Standard Atmosphere (See attachment following article)

When can we receive from the balloon transmitter?
Spherical tangent range versus altitude.
Line of sight versus radio reception.

What is telemetry?
Telemetry sensors/processing/transmitting/interpreting.

Where is the money going to come from?

We could argue all day about the causes of our economic downward spiral but the fact is, today, right now, our primary and secondary schools are cutting programs, staff and support which might have had the potential of igniting scientific curiosity.

Ultimately we are all going to bear the expense of these program cuts. We can currently bear the expense of supporting part of their replacement. We have the resources to make these missions happen. We can enhance these resources to communicate with and support the educational community.

For further discussion contact:
Ralph Wallio, W0RPK
[redacted]

High
Altitude
Balloon
Experiments
in
Technology

Supported by:

Middle River Valley
Radio Observatory

Indianola Community
Schools

Simpson College

Contact:
Ralph Wallio
[redacted]

[redacted]

THE HABET DOWNLINK

MAY 19, 1993

EOSS To Host National Balloon Symposium

The Colorado based Edge of Space Sciences (EOSS) group is complementing their very active and successful high altitude balloon experiment schedule by hosting the first (and, hopefully) annual National Balloon Symposium. This meeting, during the weekend of August 20-22, 1993 in Denver, will bring together participants of many nation wide amateur high altitude balloon projects.

Symposium attendees will share information through presentations of submitted papers and informal discussions of a wide range of topics including the history of high altitude ballooning, payload design, flight systems, launch processing, regulatory issues, flight tracking and recovery, high altitude physics, elementary and secondary educational support and tall tales of past flights. A symposium proceedings will be available to attendees and to others after the big weekend.

EOSS has organized as a 501(c)(3) non-profit corporation. They are affiliated with Colorado high schools and universities toward promotion of science and education through amateur radio and high altitude balloons. They have conducted more than ten balloon missions, meet

Continued, "EOSS", Page 2

LEFT:
Bryce Gilbert, N0UOX, and Nick Middleton, N0VAF, both freshmen at Indianola High School, discuss details of a recent project.
Story on Page 2.

Sample Lesson Plan

GEOGRAPHIC LATITUDE AND LONGITUDE

GOAL: The purpose for this lesson is for students to understand the concept of global coordinates (Latitude and Longitude).

OBJECTIVES:
(1) Students will draw 30-degree latitude and longitude lines on blank practice globes.
(2) Students will find and designate specific coordinate locations on practice globes.
(3) Students will draw degree, minute and second lines on blank practice maps.
(4) Students will find and designate specific coordinate locations on practice maps.
(5) Students will find and designate specific coordinate locations on real globes and maps.

ADVANCED PREPARATION:
(1) Review concept of latitude and longitude coordinates (Longitude divides sphere into 360 degrees; Latitude divides north and south hemispheres into 90 degrees).
(2) Review mathematical relationships of degrees, minutes and seconds (60 seconds = 1 minute; 60 minutes = 1 degree).
(3) Review application of latitude and longitude to find specific locations on globes and maps.

Materials and Equipment: Students and teacher.
Projected or drawn aids.
Blank practice globes and maps.
Markers and pencils.
Real globes and maps.

PROCEDURE AND METHODOLOGY:
(Day-one)
Introduction: Discuss applications of locating coordinates.
Introduce concepts of latitude and longitude.
Body: Assist students with drawing 30-degree latitude and longitude lines on blank globes.
Closure: Students should be able to find specific coordinate locations on blank globe.

(Day-two)
Introduction: Discuss further division of globe into smaller coordinate units.
Introduce concepts of degrees, minutes and seconds.
Body: Assist students with drawing lines on blank maps representing latitude and longitude in degrees, minutes and seconds.
Closure: Students should be able to find specific coordinate locations on blank map.

(Day-three)

Introduction: Discuss application of latitude and longitude coordinates to find specific locations on real globes and maps.
Introduce coordinate designations on real globes and maps.

Body: Assist students with estimating coordinates of selected locations on globes and maps and with finding specific locations with selected coordinates.

Closure: Students should be able to describe specific locations with coordinates and find specific locations with coordinates.

EVALUATION:

Students: Did students comprehend the necessity for coordinate systems?
Did students comprehend and correctly apply the concept of latitude and longitude?
Did students comprehend the concept of degrees, minutes and seconds?
Could students correctly apply these concepts by describing specific locations in terms of latitude and longitude and find specific locations when given specific latitude and longitude coordinates?

Teacher: Was the teacher motivational?
Did the teacher understand the concepts and information discussed?
Did the teacher monitor and correct student progress?

U.S. STANDARD ATMOSPHERE

1976 National Aeronautics and Space Administration (227-pages)

Available from the National Technical Information Service 703-487-4650 (Regular service) 800-553-6847 (Rush service - surcharge)

Part 1	Defining Constants and Equations
Part 2	Atmospheric Model
Part 3	Trace Constituents
Part 4	Main Tables
Table I	Temperature, pressure, and density for geopotential and geometric altitudes in metric units.
Table II	Acceleration due to gravity, pressure scale height, number density, mean particle speed, mean collision frequency, mean free path, and mean molecular weight for geopotential and geometric altitudes in metric units.
Table III	Sound speed, dynamic viscosity, kinematic viscosity, and thermal conductivity for geopotential and geometric altitudes in metric units.
Table IV	Same as Table I except altitudes in feet. Table V (Same as Table II except altitudes in feet.)
Table VI	Geopotential altitude in meters as a function of pressure in millibars.
Table VII	Same as Table VI except altitudes in feet.
Table VIII	Atmospheric composition in terms of number density for nitrogen, atomic oxygen, molecular oxygen, argon, helium, and atomic hydrogen.

EOSS Commitment to Education

by Tom Isenberg, N0KSR

The success or failure of a society depends on the transfer of knowledge to the young. Edge of Space Science's (EOSS) commitment to education grew from the interest in teaching youth the skills so in later life they have the skills to succeed and lead.

Our first balloon flight was done for fun. We then realized the educational potential of ballooning and formed Edge of Space Sciences. Our vision was to supplement what teachers have started in the classroom and let the students use what they learned. Due to the strong desire to be a part of an educational group, EOSS adult membership has grown rapidly. Every member agrees educating the students is the group's top priority.

REAL TIME EDUCATION

We like to think that our direct, hands-on approach to the learning process is closing the learning loop. Where else do students really get a chance to test the knowledge they learn in class?

The EOSS approach to education is a fun way for young adults to experience what they learn, and it motivates them to apply that knowledge. Each mission is a team effort. Students learn that their contribution is important to the success of the mission; this drives participation and education. The value of what a student has learned becomes evident after the successful completion of the project. Many parents comment that they wish they had a similar opportunity for real time education when they were in school.

Knowledge flows down. What one learns and knows, one can teach to others. Many schools are already using this concept. Older students tutoring younger ones gives both students benefits. Likewise, adults have a wealth of information to pass along to students, and to each other.

EOSS students get a feel for what the job market will hold for them in a few years. Many companies are reducing their workforce to stay competitive. As a result, engineers must take on the added responsibilities of writing proposals, making presentations, selling ideas to customers, and other customer-related activities. EOSS stresses the importance of writing, speaking, public relations, and other non-technical aspects of learning in order to emphasise these skills that are important in the real working world.

EOSS projects teach team building. We believe everyone has ideas to offer. Each member learns they can freely express themselves, and that every idea has some merit. Allowing equal input raises students' self esteem. Also, EOSS has learned from the students, and has used many of their suggestions.

FROM IDEAS TO LAUNCHES

Earth's lower atmosphere is perhaps the least studied part of our planet's environment. This has not been due to the lack of desire to explore this area, but the barrier has been the cost of the exploration. Helium-filled balloons provide a relatively inexpensive, reusable platform to explore the atmosphere. Amateur radio, with its variety of communication methods, provides an inexpensive, convenient way to communicate with the experimental payloads. With balloons and amateur radio, EOSS provides the tools to to allow further study of the lower atmosphere.

Each experiment starts with an idea. EOSS emulates the organizational process that companies use to complete a project. For example: Cherry Creek High School was demonstrating a homemade Geiger counter. One student mentioned that it would be neat to measure the radiation above 50,000 feet. We suggested that the student write a proposal explaining his experiment and present it to the club at our next meeting. After hearing the proposal, the members approved the project. The student then made sure the electronics would properly interface with the EOSS shuttle computer. A design review was scheduled where a check list of testing and compatibility was reviewed. The experiment was ready. The launch date was set and the students were able to plot radiation versus altitude during the flight.

CURRICULUM

Although EOSS has not developed its own curriculum, we are quick to suggest subject areas a school can explore during a balloon flight. Some schools use our projects toward a student's semester grade. Other schools give students extra credit for working on our projects. EOSS strongly recommends a direct grade-related incentive for the students.

During an EOSS project basic subjects became interrelated. Rather than going into a description of each subject area, here is a list of ideas to feed your imagination:

- Mathematics:
  - Basic math skills
  - Algebra
  - Trigonometry
  - Geometry
- Sciences:
  - Physics
  - Earth Sciences
  - Computer Science
  - Electronic Technology
  - Meteorology
  - Space Science
- Language Arts:
  - Writing
  - Speaking
  - Journalism
- Communications:
  - Photography
  - Video tape
  - Public Speaking
- Community Awareness:
  - Parental Involvement
  - Community Service
  - Public Relations

PUBLIC RELATIONS

EOSS has a complete team for public relations. Our PR has three distinct divisions.

The first, and most important division, is our PR for the schools and other student clubs. How EOSS presents itself to these groups has a great bearing on the groups' future involvement. We learned that to get to the students, we need to get the interest of the teachers. Initial contact with a school includes an explanation of who we are and what we have to offer. This educational presentation to the teachers includes a video of a past project, that highlights student participation. Usually, this leads to a date to meet with the students. The students' best respose has been to the launch. For the students' interest, EOSS throws in the spectacular and the education comes naturally. The education comes naturally. Once interested the students and EOSS plan a launch.

The second PR division works toward community awareness: "Look what we are doing!". For each launch, we send out press releases to all media. EOSS sets up booths where we can reach the public. We have information packets to send in the mail. EOSS strongly encourages students to prepare their own PR for their launch. A small area of this is information for parents. EOSS tells the parents what their child is doing and tries to interest the parent in working with EOSS.

In the third PR division, EOSS has a presentation to encourage businesses to make donations to our non-profit corporation.

PROJECTS BETWEEN FLIGHTS

EOSS needed a way to help maintain interest during the time between launches and to engage those students who were not actively working on an experiment. "TWEENER" projects offer the best way to give several groups of students a way to work on similar projects between our launches. "TWEENERS" are beneficial to EOSS because the projects are designed to solve identified real problems.

An example: Our beacon payload's landings kept breaking its antenna or burying it in the dirt. This jeopardized our ability to find the payload and was a major concern. EOSS asked several schools to review the payload's design and invent a package that could absorb the shock of landing and keep the beacon antenna upright and vertical. EOSS provided the students a list of specifications, such as weight and strength. The student designs were tested by dropping them from a tethered balloon. The project that best met the test criteria was declared the winner. We have utilized several of the designs from this TWEENER project.

Another TWEENER project involved antenna building and fox hunting techniques. The students were asked to build a yagi, quad, or loop antenna. Then they learned transmitter hunting skills, and used compasses and maps to plot the location of a radio beacon hidden within their city. The student team that had the best accuracy was declared the winner.

LOOKING TO THE FUTURE

Looking ahead, EOSS plans a continued effort to encourage schools and universities to use ballooning as a means to study the lower atmosphere. We also want to help amateurs and universities in other parts of the country to start their own balloon groups. EOSS believes the educational potential we offer to schools to be far better than some other projects because of our hands-on education. Our yearly goals are for each EOSS member to mentor to one student, and to increase our student membership.

EOSS has a diverse offering of balloon curriculum, and so our education team has a great challenge. We will continue to share our ideas and programs with the community as a proven means of supporting education.

"What I Know, I Can Teach"

Edge of Space Sciences, Inc.

Support Education, Amateur Radio and High Altitude Ballooning,
join EOSS!!!

Edge of Space Sciences is exploring frontiers in amateur radio and high altitude ballooning in an effort to further the scientific education of students and Hams.

Membership contributions and donations are used to finance balloon flights, and design and build inovative payload systems.

Membership entitles you to a copy of our newsletter.

EOSS
Edge of Space Sciences, Inc.

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376 W. Caley Circle
Littleton, CO 80120

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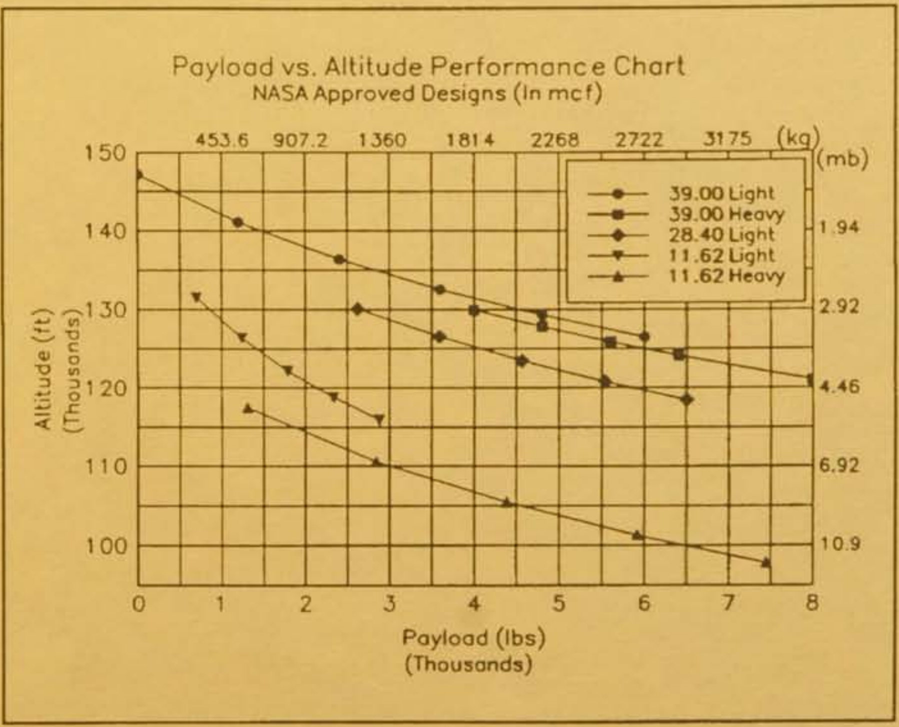
NATURAL SHAPED SCIENTIFIC BALLOONS

Shown at the right are payload vs. altitude curves for the five standard balloon designs now in use by NASA and flown by the NSBF.

We have the experience proven track record to manufacture virtually any size and configuration of balloon to meet your scientific or research needs. The largest successful balloon built to date is a 3-capped 39.95 mcf balloon.

The use of **Astrofilm E** since 1985 has allowed us to build balloons that have had no failures attributed to deficient balloon materials.


Payload vs. Altitude Performance Chart
NASA Approved Designs (In mcf)

Sounding Balloons

Thousands of balloons in the 7,000 ft^3 to 500,000 ft^3 volume range have been manufactured from 0.25 mil and 0.35 mil **Astrofilm D** balloon film. These balloons have been successfully used to perform atmospheric soundings by numerous customers that require a low cost, high probability of success sounding balloon.

Space Training Articles

Several specially shaped training articles have been made for use at the Johnson Space Center-Houston. These articles are used to instruct personnel in the use of the Space Shuttle manipulator arm. Different shapes constructed include replicas of the Space Telescope and the Long Duration Exposure Facility.

LSSL Balloon Systems

We have developed several LSSL (Limited Space Self-Launching) balloon systems for individual applications. One application required the deployment in mid-air of both the main balloon and a 10,000 foot long antenna. The largest successful system to date delivered a 3,000 pound payload to 80,000 feet altitude. That system utilized a 55,000 ft^3 fabric/poly launch balloon and an air deployed 1.5 mcf main balloon.

Aerodynamically Shaped Balloons

We manufacture stock sizes of tethered balloons that vary from 110 ft^3 to 9,000 ft^3. Stable flight of blimps in winds up to 60 mph have been reported by users. Payload capability ranges up to 300 pounds and altitudes up to 10,000 feet are attainable.

Spherical Balloons

Over the years, Raven has built spherical balloons ranging in size from 2 feet to 200 feet in diameter. 70 ft diameter spheres built for NASA have attained flight durations of 103 days with payloads of 125 lbs to altitudes of 84,000 feet. Balloons have been built using polyester films, reenforced films, and coated fabrics. Payload capabilities of up to 500 pounds are easily attainable. Unattended flight durations of certain smaller balloons have been over 400 days.

If you have a unique inflatable application, let us help you design a system, to fulfill your particular requirement.