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September 2014

Near Space FPV Glider

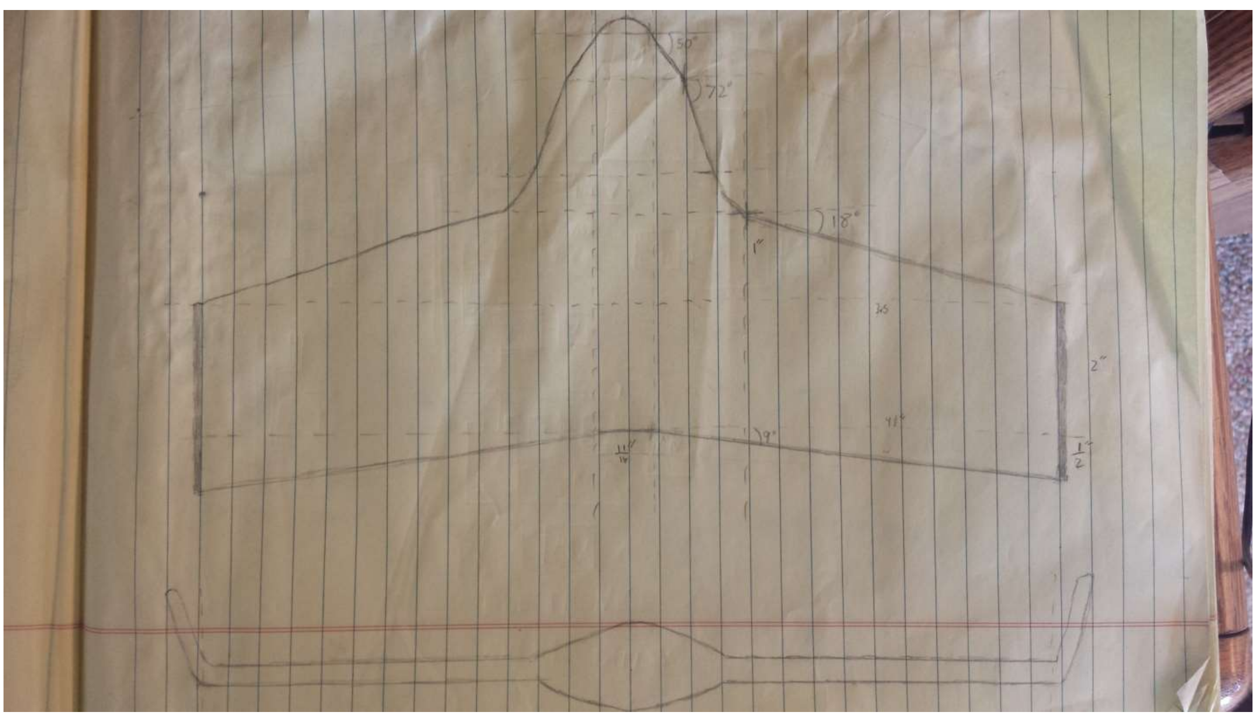
Roughly a year ago I received the inspiration to build a high altitude FPV (First Person View) glider from David Windestål at Flite Test. He posted a video on YouTube of his near space adventure and decided I wanted to give it a shot myself. I thought there was something truly amazing about designing, building, and piloting a craft that could fly at such extreme heights and farther than 99% of all other remote control vehicles. The goal of this project was to build a glider equipped with long range pilot control and video transmission apparatus. Then attach the glider to a weather balloon which would tow it to 90,000 feet where the glider would jettison the balloon and I would pilot the glider back to the launch site through the live video feed and an autopilot system.

If you take a look at David Windestål's article about his high altitude glider (here) you will notice I used many of the same parts as his project. Why try to reinvent the wheel? However, I did make a few changes to avoid issues he encountered.

Airframe

To begin I needed to pick an airframe that would be stable at high speeds, have a decent glide ratio, and plenty of room for avionics. I decided scratch build a flying wing out of foam insulation and carbon fiber reinforcement. Using Excel I calculated the best dimensions based on the desired wing loading and airfoil.

First Sketch of glider design



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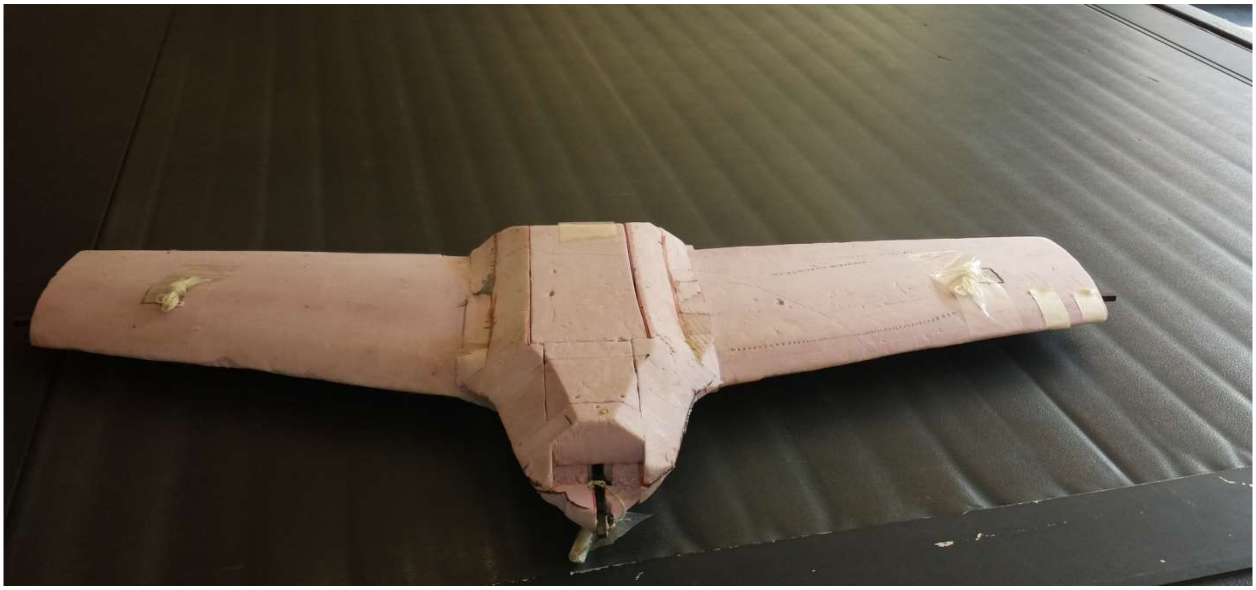
After a few days of building, the prototype was finished. It turned out very solid and ridged but unfortunately was unstable on the pitch axis.



As you can see in the picture above I had a some hard landings during the test flights. I spent a few days trying to get the bugs worked out but it was taking up all of my limited build time. I decided the best course of action would was to purchase a pre-built plane and focus more effort on the avionics. This proved to be a good call and actually helped save the glider during the actual mission.

I decided to use the Multiplex FunJet because it met my previously stated requirements and was proven to work on these types of missions. I did add quarter inch carbon fiber square tube reinforcement along the fuselage, wingspan and control surfaces to prevent flexing and fluttering at high speeds. Additionally the carbon fiber provided the needed anchor points to attach the balloon.

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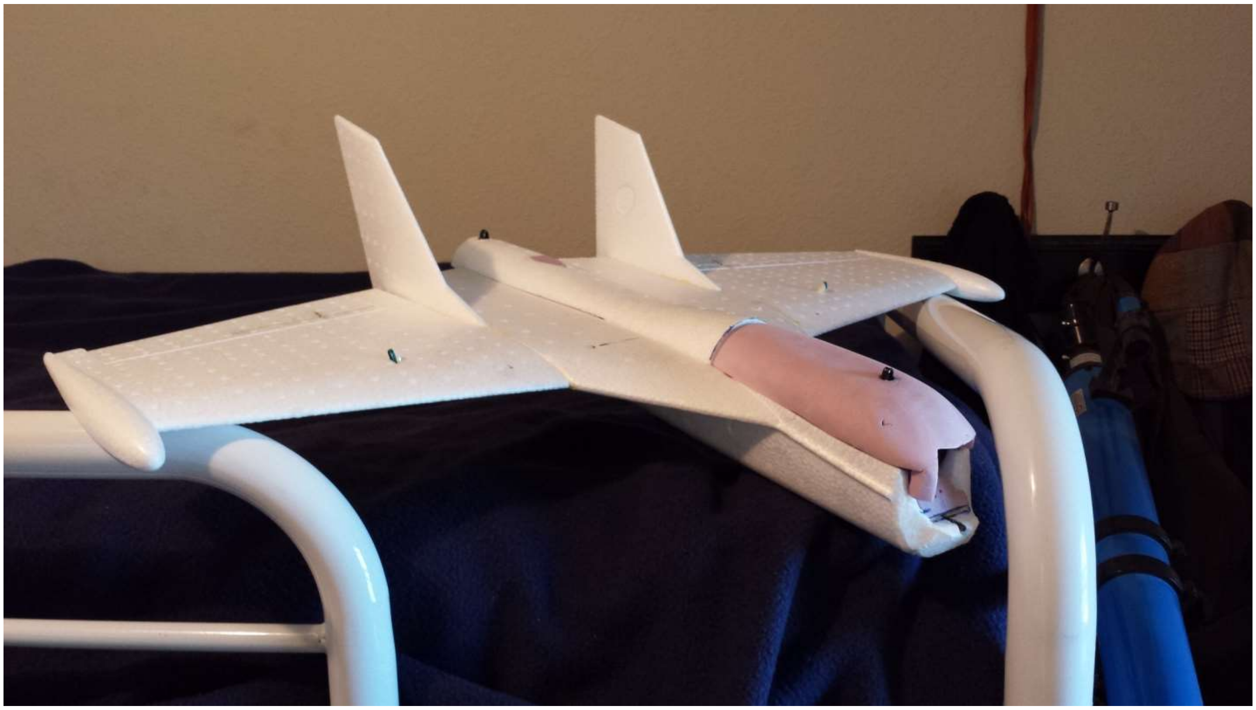
Stock Multiplex Funjet.

I gave the Fun Jet a "nose job" to allow for maximum visibility while flying FPV and built a custom hatch out of insulation foam.



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Next step was to give the glider a blaze orange color to aid in recovery if I was unable to pilot the glider back to the launch site.

I then added some aluminum tape to help reflect radar which also gave it a cool "spacey" look.

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Servos

The servos are the small motors that move the control surfaces. I used two 9g metal gear servos from Hobby King and mounted them in the pre-cut slots in each wing. Additionally, I disassembled both servos and cleaned off the lubricant which would have slowed the servo at low temperatures.

Video Transmission

From research and past high altitude experiments, I felt that the GoPro Hero 3 White edition would be the best video capture device on the glider. It is capable of recording HD video onto a micro SD card while simultaneously outputting video to the transmitter. I made a custom GoPro video out cable using a 10 pin mini USB plug and servo wire. The build tutorial can be found here. However I found for the price and build time, it's cheaper to purchase a quality cable online.

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GoPro Hero 3 White with video out cable

I did a few tests on the battery life of the stock GoPro and it lasted a maximum of 2.25 hours while recording in 720p at 60fps, which is the recommended setting for the video cable I was using. I wanted around five hours of battery life so I soldered a single cell 2200 mAh lithium polymer battery to the terminals inside the GoPro and was able to power the camera for roughly seven hours. I actually ran out of space on my 32GB memory card before the battery died.

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GoPro external battery connection

GoPro mounted in glider with video out cable

GoPro's external battery mounted in glider

The video transmitter and receiver I used were both manufactured by Ready Made RC. I decided to use a 1.5w 1.2 GHz transmitter with a 1.2 GHz receiver and SAW filter to reduce interference. If you are located in the United States, you are required to possess an amateur radio technicians license to operate radio equipment at this power and frequency.

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1.2 GHz video receiver

To save on weight, I removed the receiver from the gold heat sync and used aluminum tape to attach it to the GoPro's external lipo battery. Lithium polymer batteries do not operate well below 32°F and the video transmitter can easily overheat; a "two birds with one stone" situation.

1.5w 1.2 GHz video transmitter

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To make the range testing much easier I used 30dB attenuator. It essentially drops the range of a radio system by a factor of 32. Because I wanted a maximum range of 20 miles, I only needed the system to work at a distance of 0.625 miles with the attenuator in line with the transmission antenna.

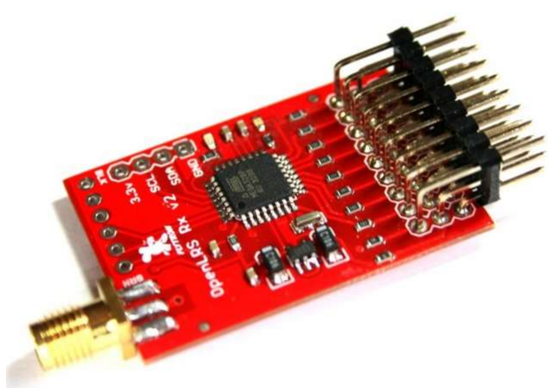
30dB attenuator

Long Range Pilot Control System (LRS)

The long range pilot control system is what allows the pilot to fly the plane while on the ground. It is the main method of giving commands to the glider and autopilot. For amateur pilots in the United States the only legal radio system readily available is a 433 MHz transmitter and receiver. Just like the video system, an amateur radio technician's license is required to operate at this frequency.

Judging on performance and price I decided to use Flytron's OpenLRS transmitter and receiver. It performed best during range testing and was open source so I could customize the code to my specific needs.

Open LRS 433 MHz receiver



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Open LRS 1w 433 MHz transmitter

The firmware I used on both the receiver and transmitter was OpenLRSng. I found it easiest to use the OpenLRSng configurator which can be found here. It is much simpler than wading through lines of C+ code trying to find where you accidentally deleted a semicolon.

To flash the boards I used a FTDI cable. I learned the hard way both the receiver and transmitter absolutely cannot be powered by the 5v from the computer while flashing. The cable I used was advertised as a 3.3v cable but when put to a voltmeter, it read 5v. This caused my receiver's radio chip to burn out and needed to be replaced. Because Flytron was out of stock, I used a Hobby Kings 433 MHz Orange OpenLRS receiver. It is essentially a clone of the Flytron version but is $15 cheaper. To avoid this error again I soldered a toggle switch to the 5v power on the FTDI cable so I could use it with boards that require the 5v supply.

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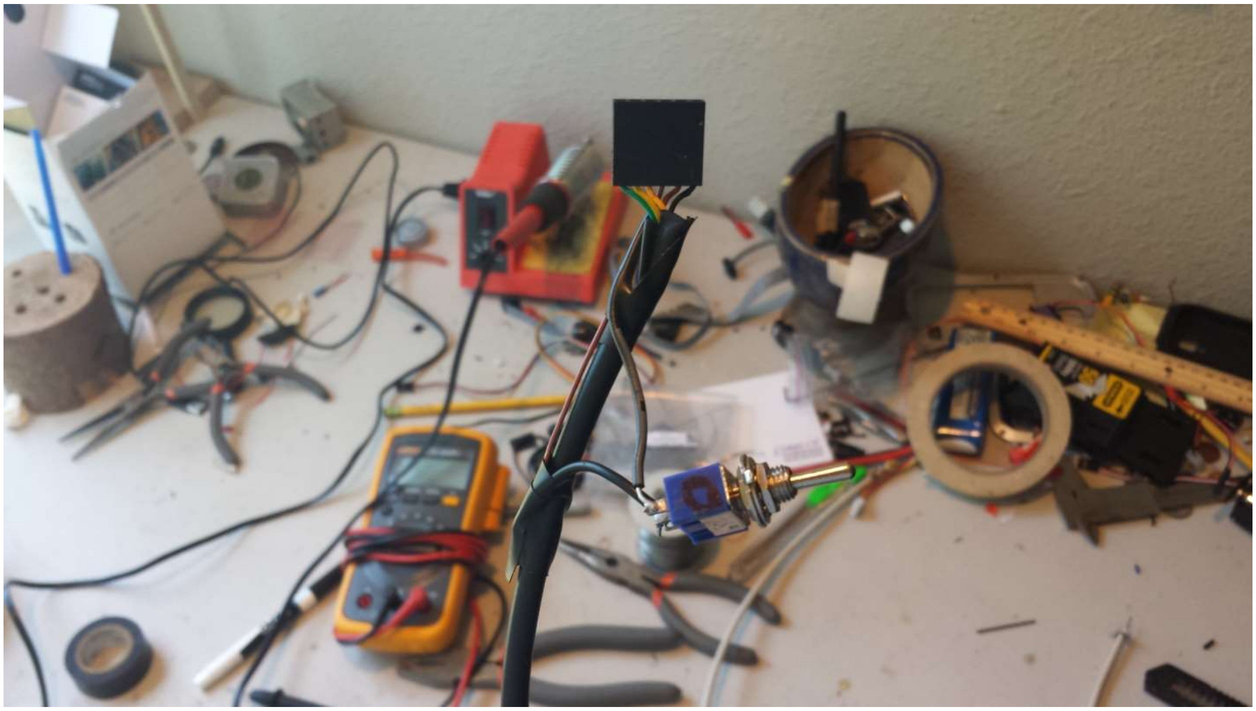

In range testing I had a solid connection for 8 miles before I lost signal but I needed around 20 miles. I added Flytron's 7w amplifier in line with the transmitter and was able to boost the maximum range to 21 miles.

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Flytron's Open LRS 7w booster

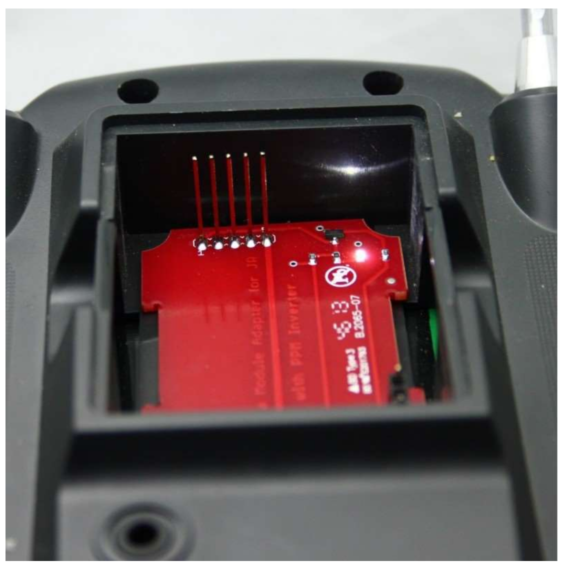
When using the booster you cannot supply it with more than 50mw RF power. If you are using a system with over 50mw you need to reduce it with an attenuator or change the transmitter code to only allow 50mw to the booster. I accidentally ran the full 1w from my transmitter to the booster while testing and fried the amplification chip and had to replace it.

To power the booster I used two double cell 4,000mAh lipos in parallel for longer life. The maximum voltage for the booster is 9v and I ran it at about 7v for most of the flight.

The actual pilot controller I used was a Turnigy 9X. It was equipped with plenty of channels and I already had one lying around. Unfortunately the OpenLRS transmitter is not stock compatible with the 9X so I bought an adapter.

Turnigy 9X transmitter

Open LRS transmitter to 9X adapter



Video Antennas

Through much testing and late nights reading about antenna theory, I decided to use IBCrazy's 1.2dBiC circular polarized Clover leaf antenna on the video transmitter. On the reciever I used Ready Made RC's 16dBiC Gatling antenna. It is is essentially a quad-crosshair circular polarized antenna. Circular polarization has numerous benefits over linear polarization for FPV flying. It eliminates multipath interference and orientation of the antennas does not affect transmission quality. The build instructions for the Clover antenna can be found here. Unfortunately there is no tutorial on the Gatling so it was purchased.

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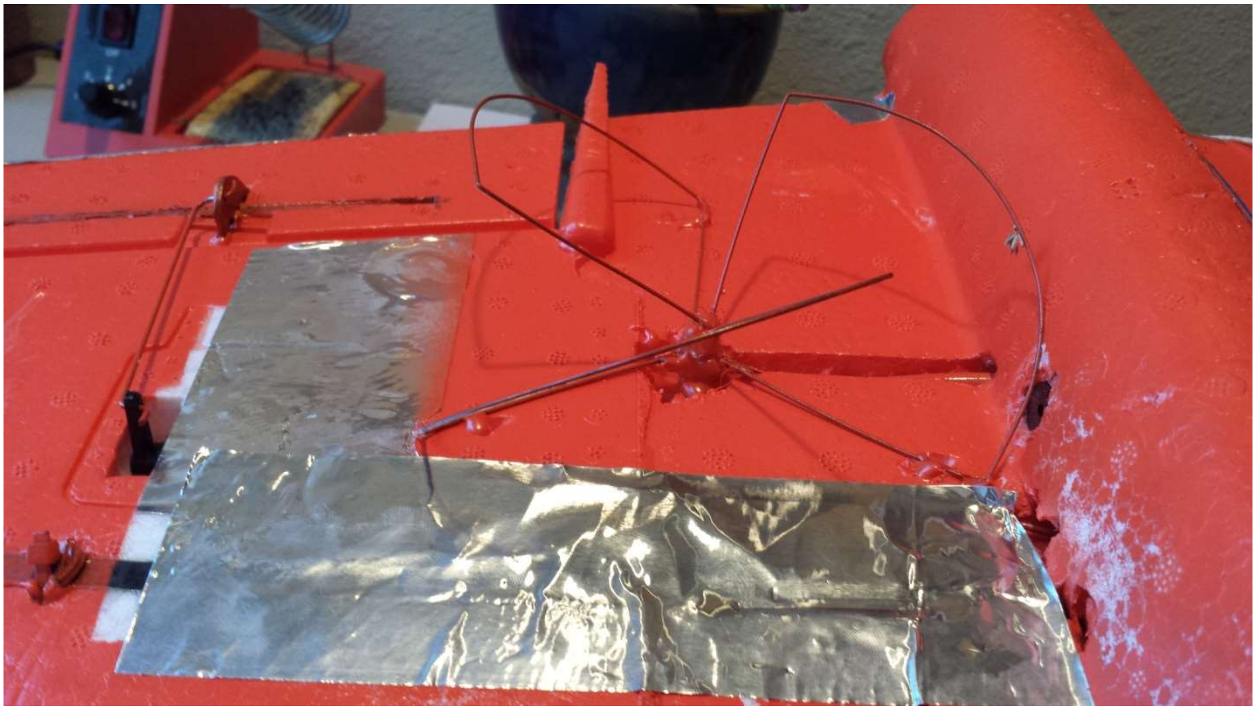
1.2 GHz Clover Leaf antenna



I noticed the servo nearest the video antenna was fluttering around when the video transmitter was powered on. After a bit of experimentation I found a piece of aluminum tape over the servo provided enough shielding from the RF and the fluttering stopped.

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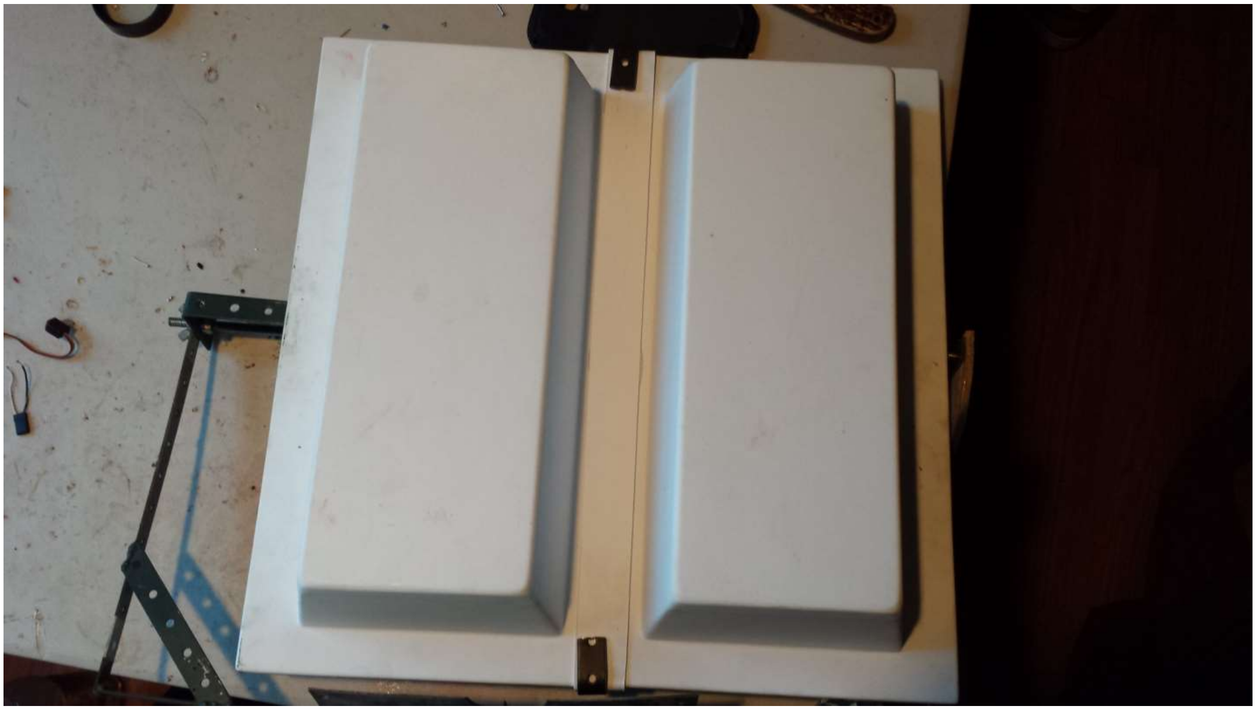
1.2 GHz 16dBiC Gatling antenna



Pilot Control Antennas

For the pilot control antennas I found the best range I could achieve was using a four element 9dBi Yagi transmitter antenna and a 2.2dBi Turnstile antenna. It is a similar idea as the video antennas, a highly directional antenna on the ground with a omni-directional antenna on the glider. The build instructions for the Yagi antenna can be found here and the instructions for the turnstile can be found here.

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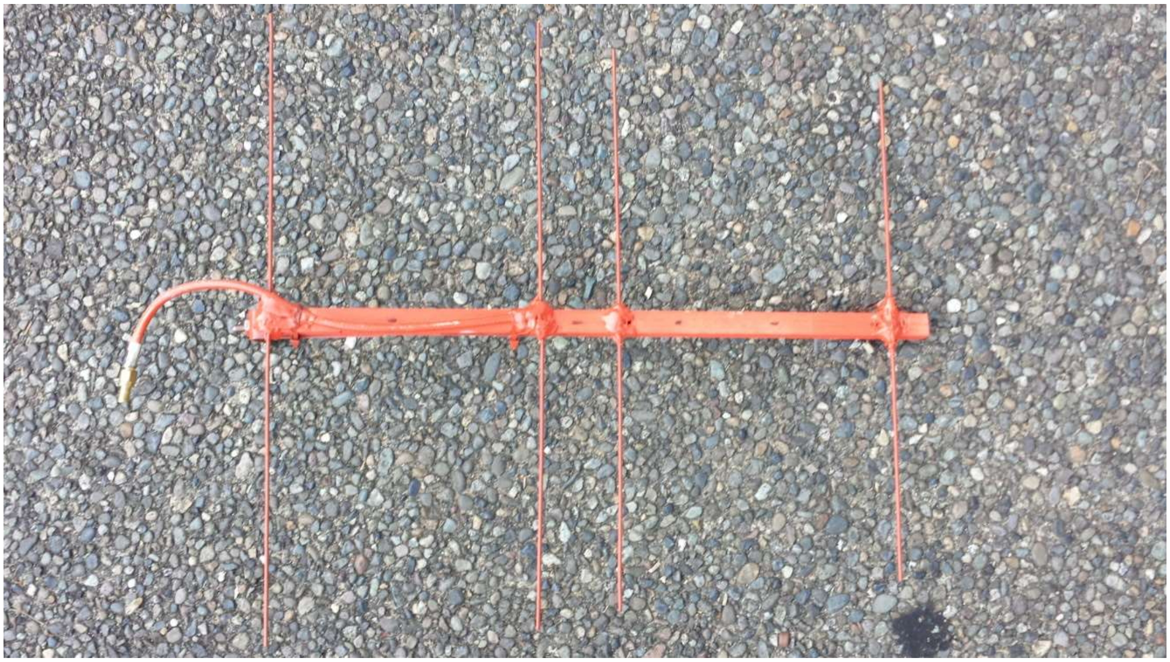
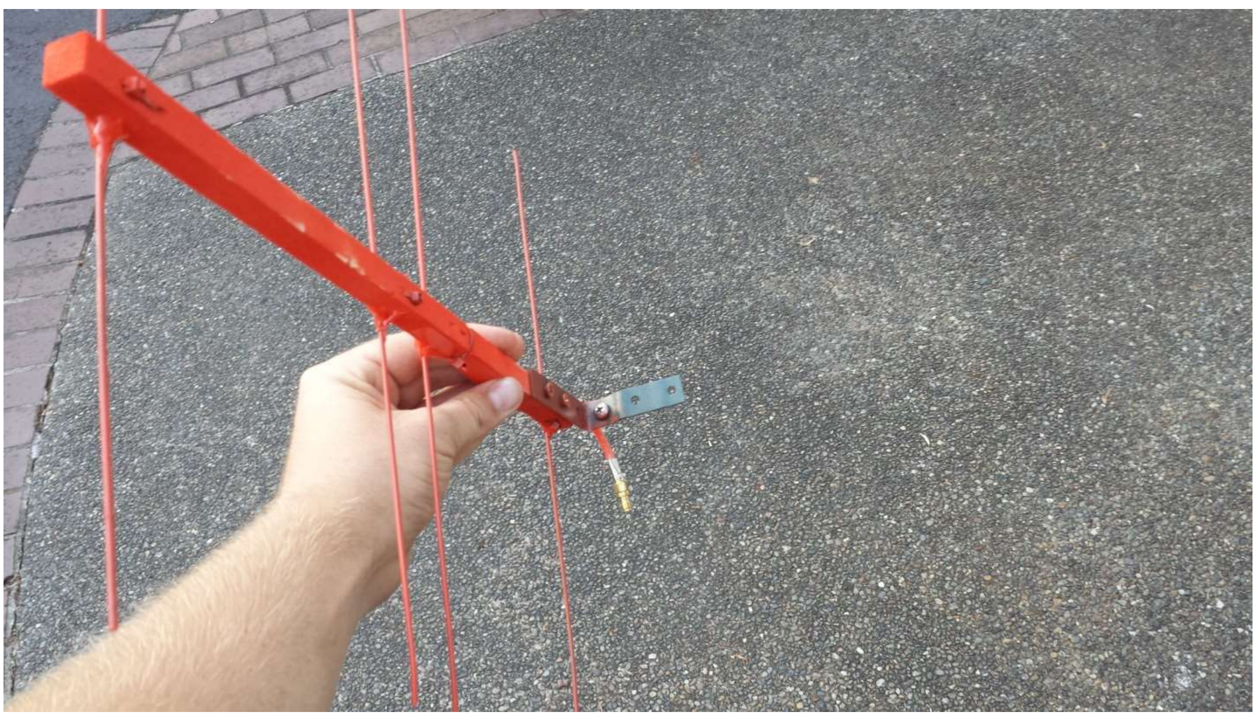
9 dBi four element Yagi antenna





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Turnstile antenna mounted on the glider

Antenna Stand

My initial plan was to use an automatic antenna tracker. It would use servos to point the directional antennas at the plane and ensure best signal but I did not have time to design it. However, I still needed method of pointing the antennas in the correct direction, so I welded a simple manual antenna tracker that would rest on a 7ft tripod.

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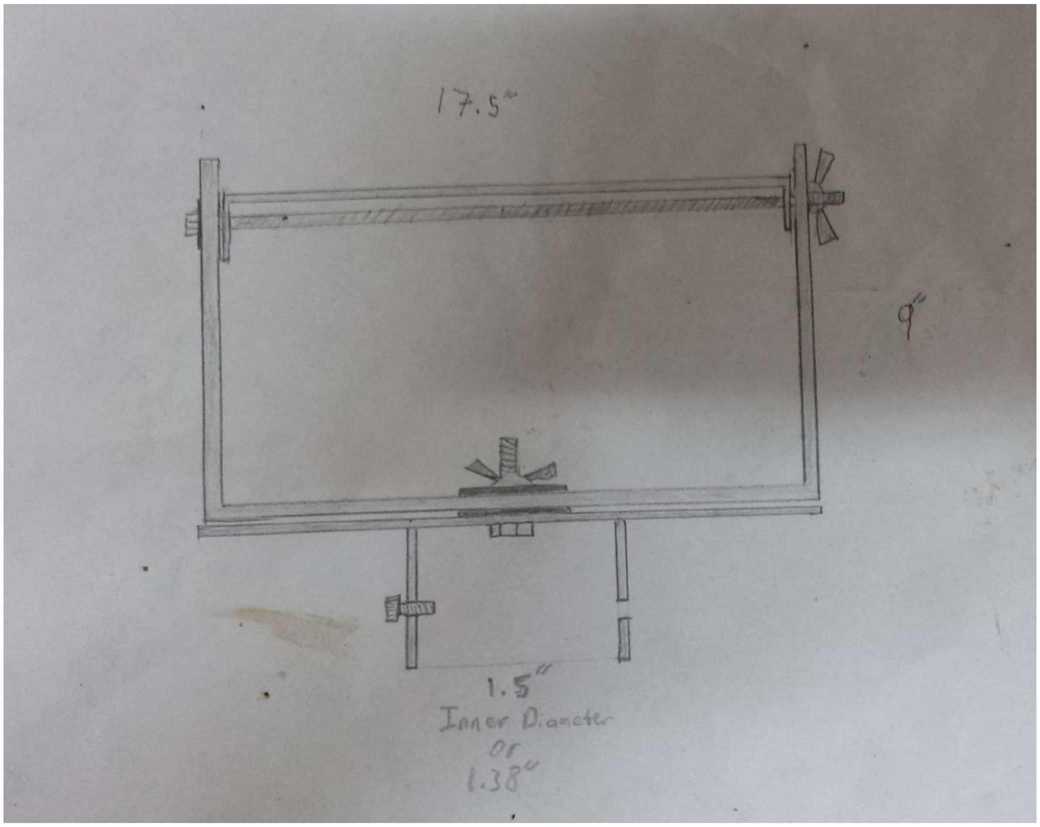
Manual antenna tracker design



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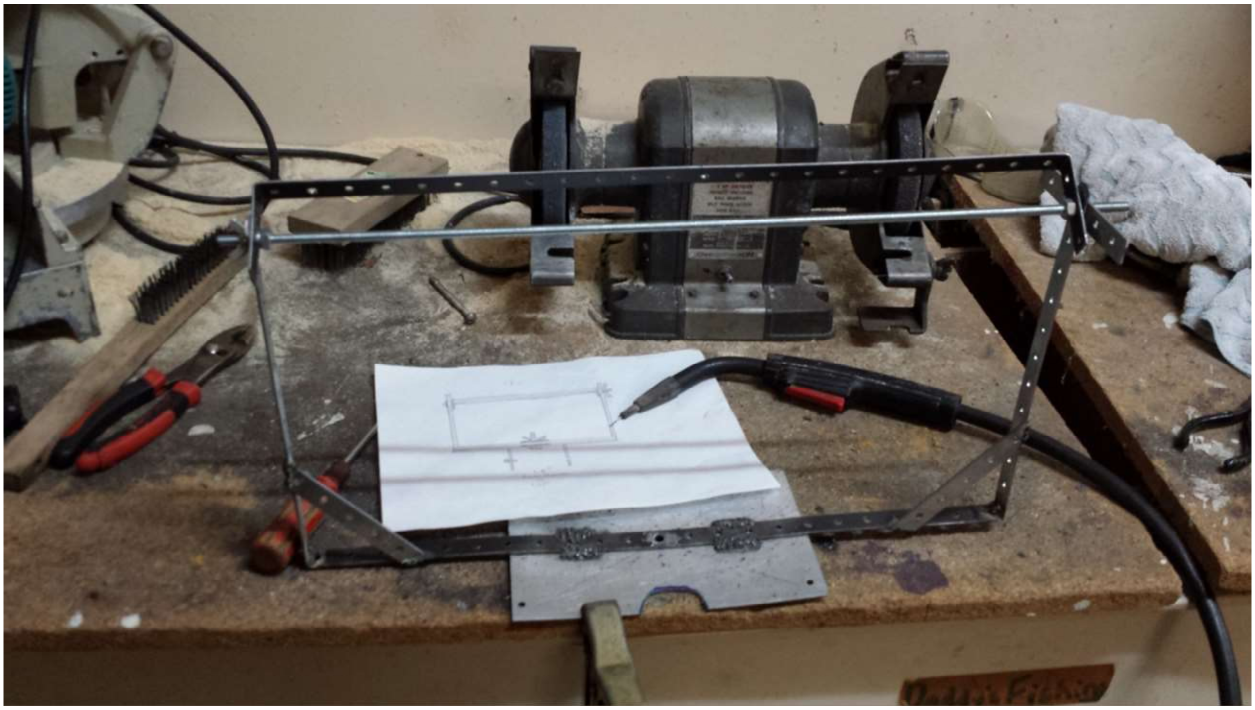
Midway through building the tracker



The adapter that allowed the tracker to swivel while being secured to the tripod

On top of the adapter I glued a 360° compass to measure the horizontal bearing

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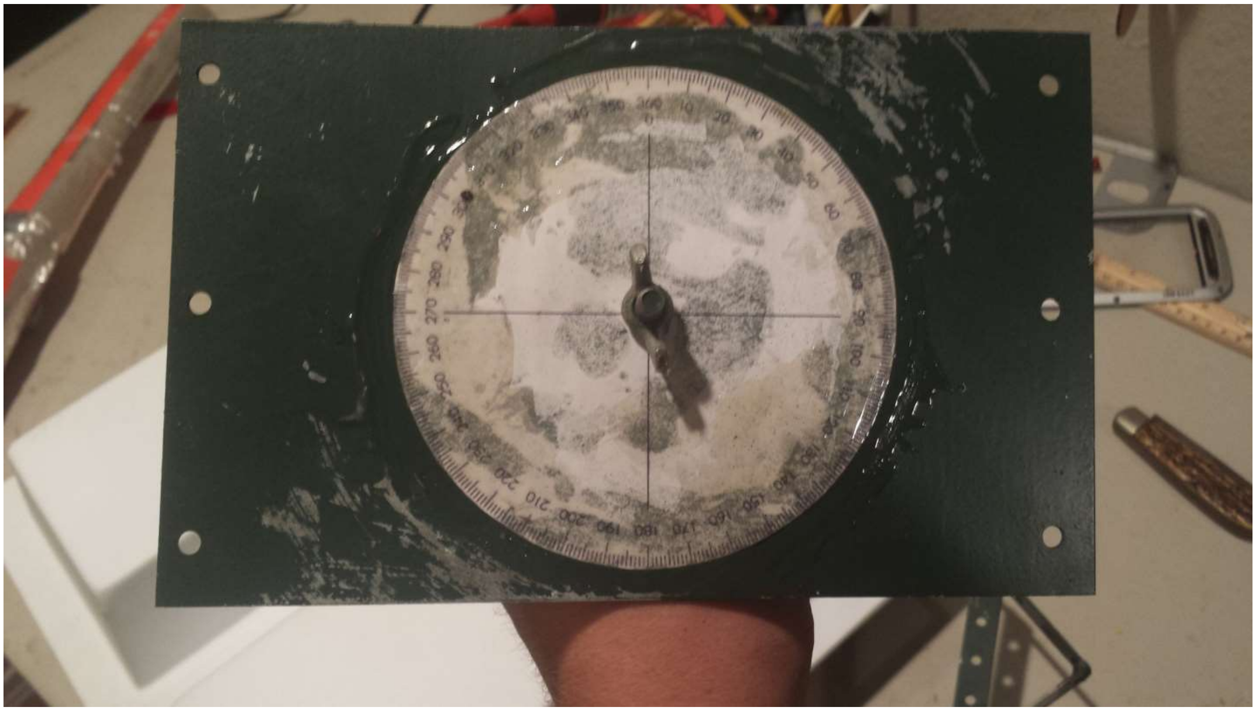
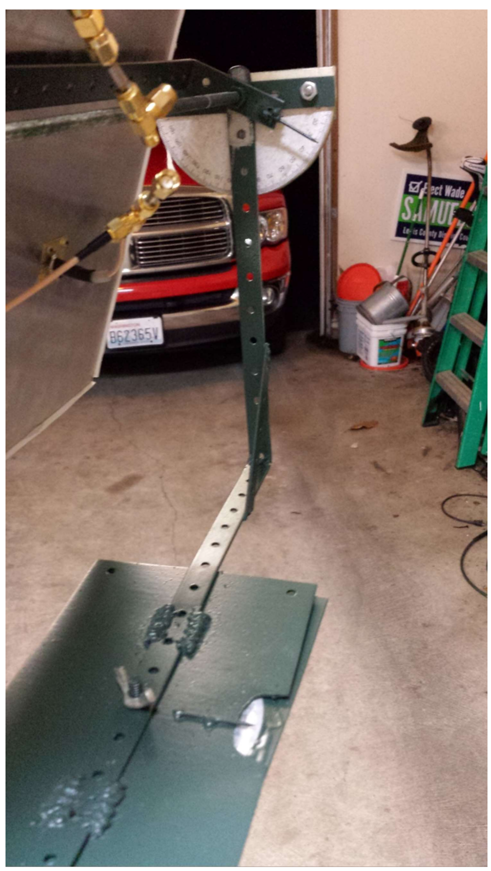


I screwed a protractor on the frame of the tracker to measure the elevation bearing.



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Finished manual antenna tracker

Using the tracker was a two person job. After orienting the tracker to North, one person would enter the glider's GPS coordinates and altitude into an Excel spreadsheet which converted that information in to vertical and horizontal bearings. Another person would then manually turn the tracker to the found bearings and tighten the wing nuts to hold the antennas in place. Overall it worked great but the constant adjusting of the tracker became a bit tedious.

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Autopilot

I believe the most important piece of equipment on the glider was the autopilot system. It is essentially a secondary pilot that will take over if problems arise. Hands down the best autopilot system at this time is the ArduPilot Mega(APM) from 3D Robotics. It is an open source, Arduino based system that is capable of piloting almost any remote control vehicle.

ArduPilot Mega 2.6 with GPS and power module

It has countless features that aid the pilot in flying a craft. I used it specifically for the "return to launch" feature. In the event of pilot control or video transmission is lost the, autopilot will fly the plane back to the launch site and land. It can also perform pre-programmed missions or accept commands through a telemetry link on a laptop but I did not use these options. It is flashed and configured through the ArduPilot Mission planner which can be found here.

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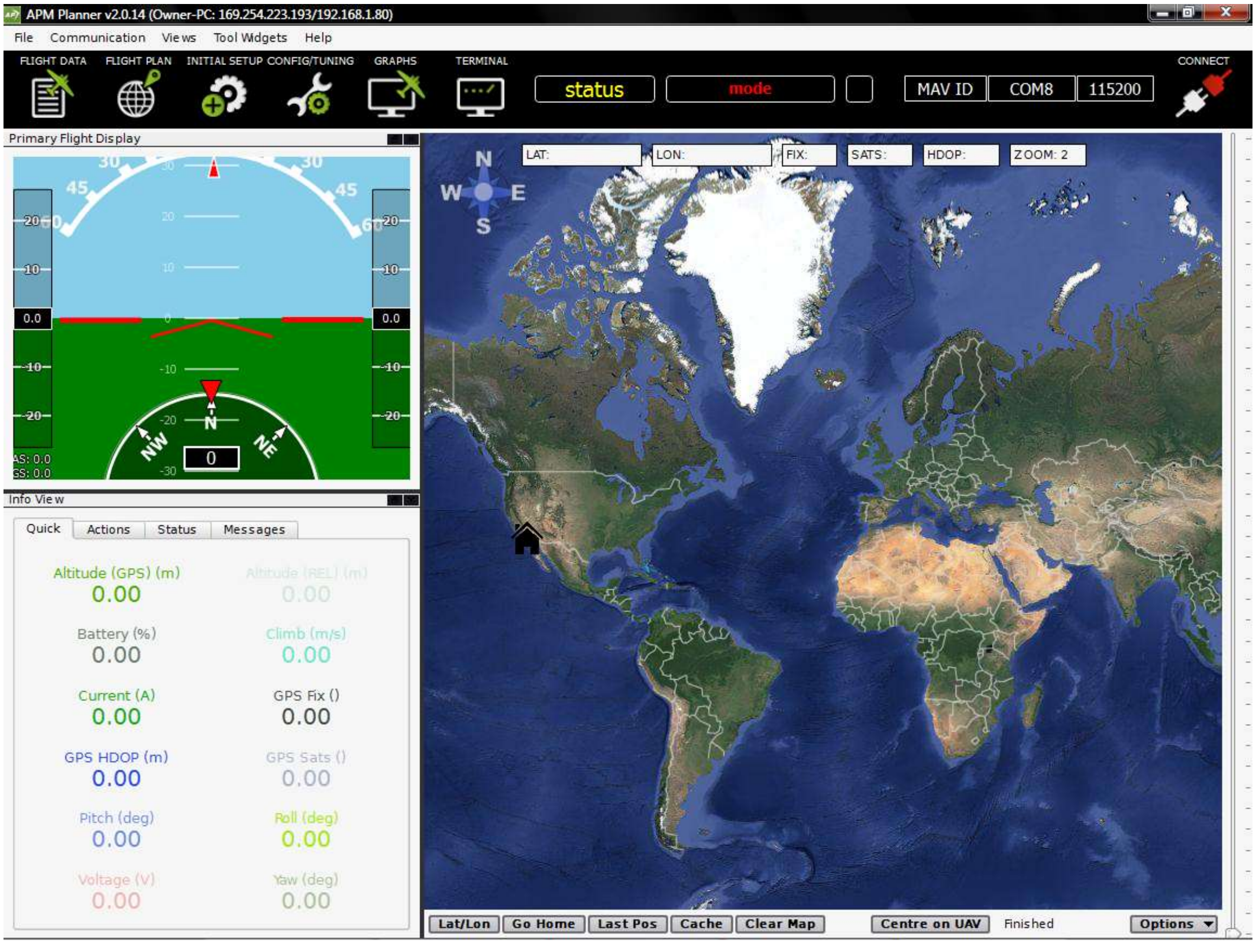
ArduPilot Mission Planner 2.0



Unfortunately when testing, the first APM I used stopped working. I tried to find a problem with my wiring or a low battery but nothing was out of place. When powered on through the power module a small green LED would light up but nothing else. The same happened when powering through the USB port on my computer. I tried re-flashing the board but my computer couldn't recognize it. Fortunately, one of the guys helping me build the glider owned an APM and let me use his.

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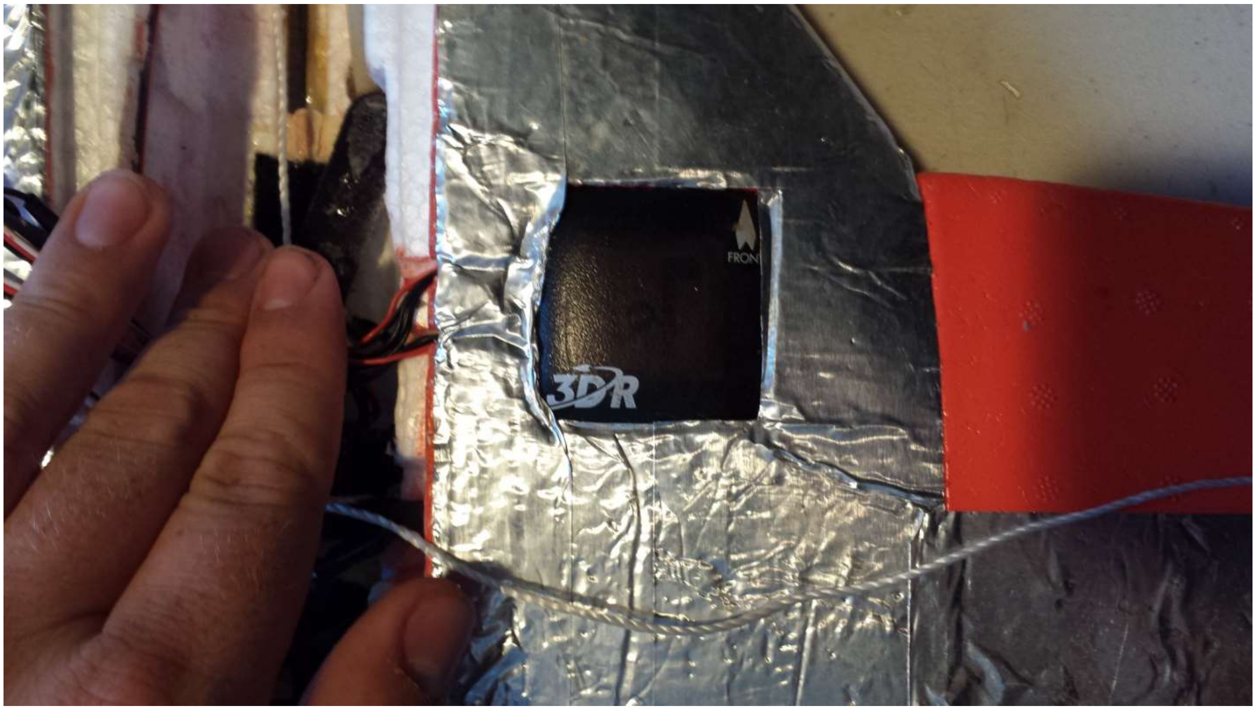
APM GPS mounted in the glider



On Screen Display (OSD)

Another cool feature of the APM is the capability of adding an on screen display which is a valuable tool when flying FPV. It can overlay information about the craft onto the video transmission and help the pilot fly with more confidence. The only compatible OSD with the APM is the MinimOSD. Just like the APM it is open source and Arduino based. It plugs directly into the telemetry port on the APM and converts the information the autopilot is using into information the pilot can use on the ground.

MinimOSD 1.1

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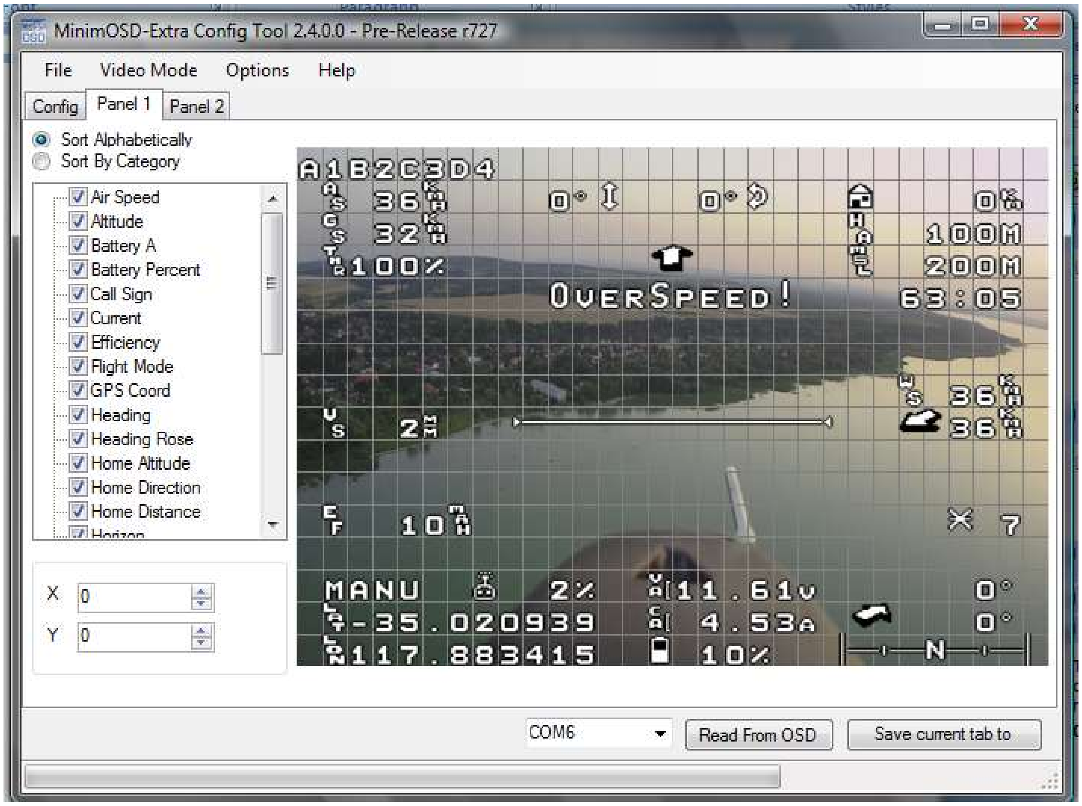
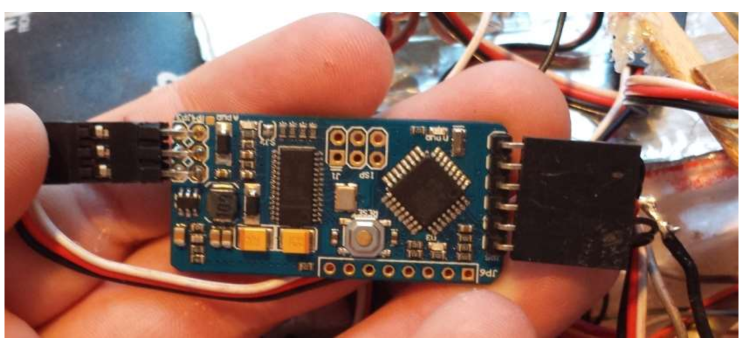
To flash the OSD I used the MinimOSd Extra Configuration Tool



When the first APM crashed, it also ruined the OSD that was currently plugged into it. I was beginning to run low on cash so I replaced it with a clone from Ebay. It was $40 cheaper and worked exactly the same.

MinimOSD 1.1 clone



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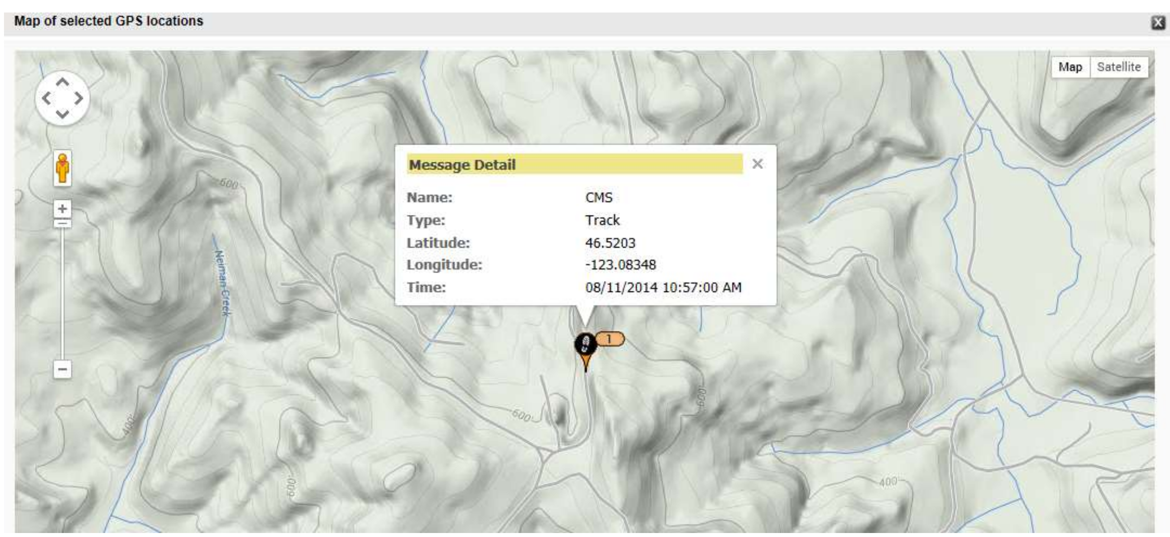
GPS Locator

To improve the odds of recovering the glider, I installed a SPOT GPS tracker. It is advertised as safety device for outdoorsmen that gives the exact GPS coordinates of an individual if they get in trouble. I have tested these trackers before on past ballooning projects and they worked flawlessly.

SPOT GPS tracker

Example information shown from the SPOT locator



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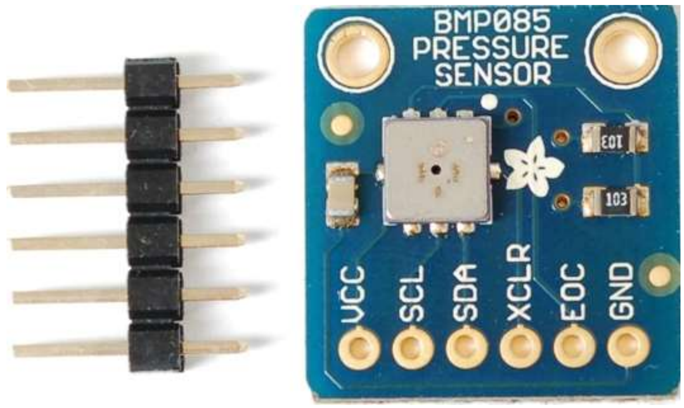
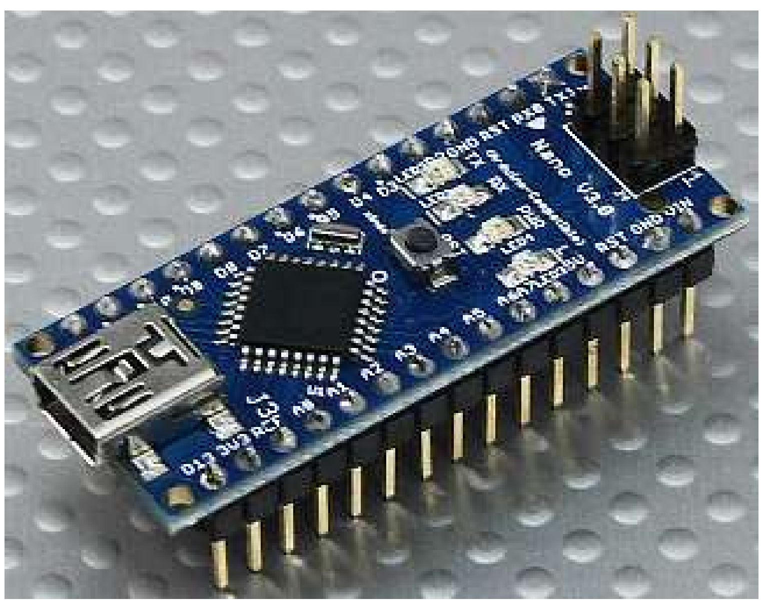
Data Logging

I wanted to record the altitude temperature and pressure during the flight and already had the parts from a previous project. I used an Arduino Nano as the main computer, a Micro SD breakout board to record the data and a BMP085 sensor.

BMP085 sensor



Arduino Nano



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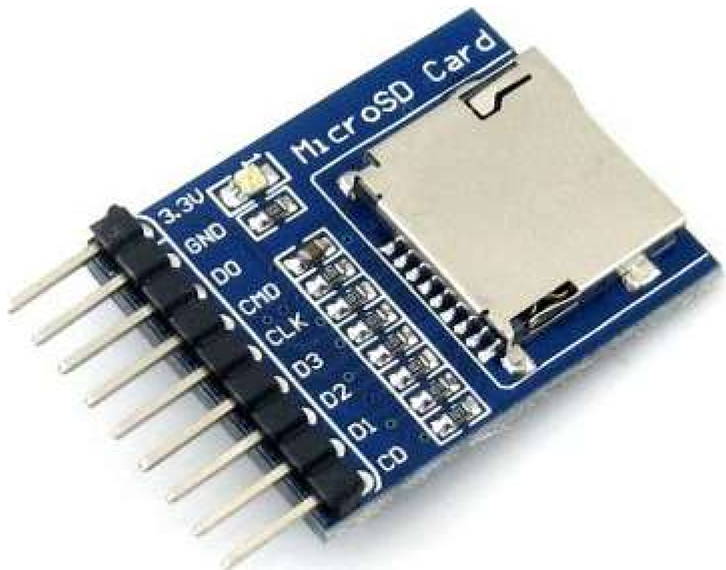
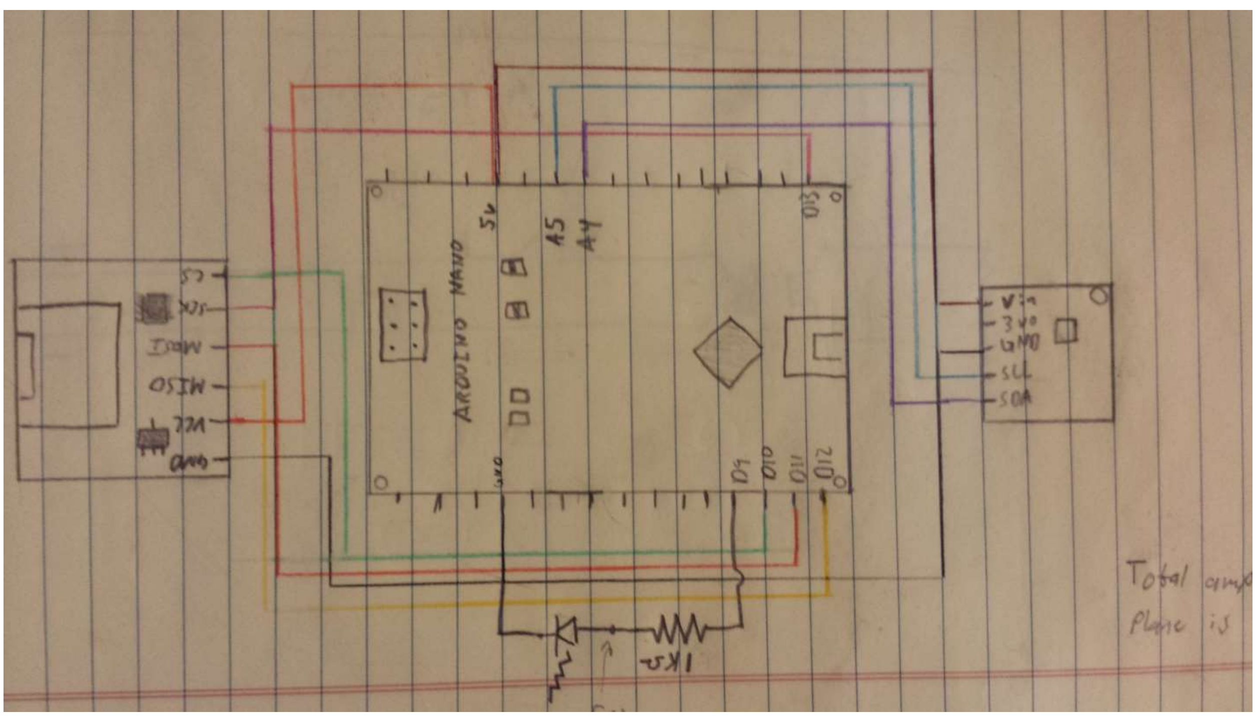
Micro SD Card breakout board



To wire them all together I used this schematic.



If you can't read the picture here it is again.

SD Breakout

Vin → 5v

Gnd →Gnd

SCL→A5

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SDA→A4

BMP085 Sensor

GND→GND

VCC→5v

MISO→D12

MOSI→D11

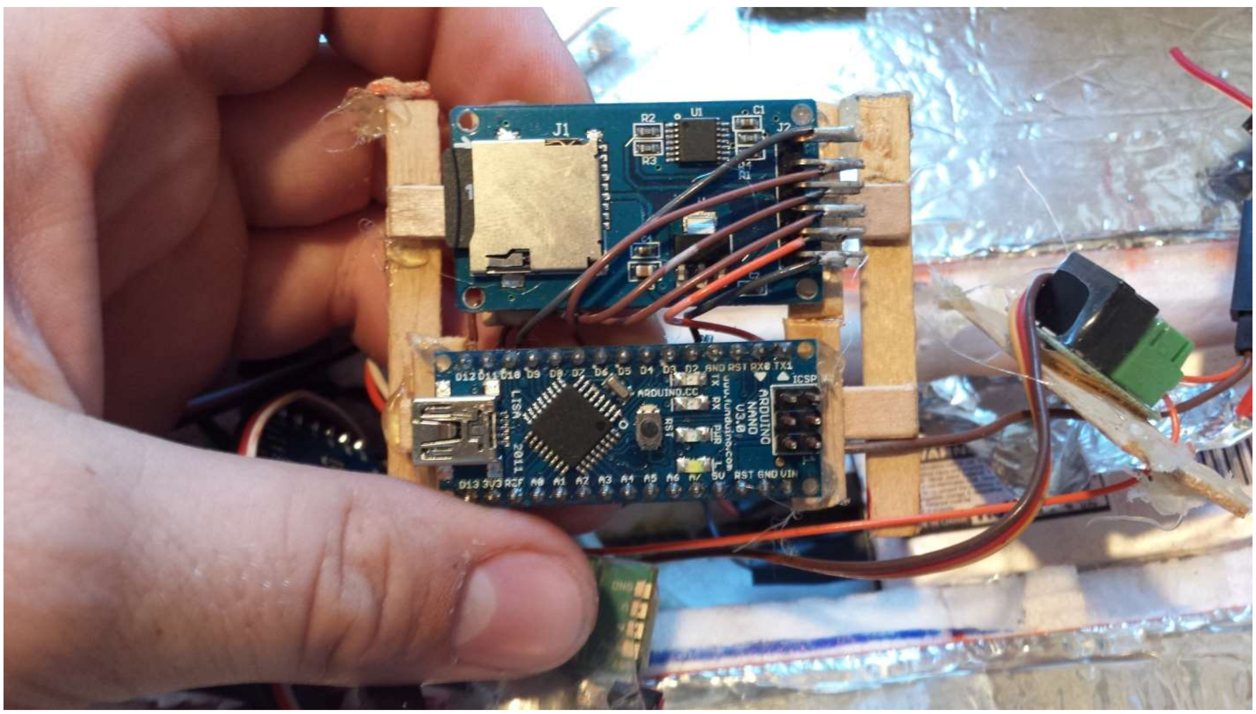
SCK→D13

CS→D10

LED

D9→1KΩ Resistor→LED→GND

The sketch I used was adapted from a few different example codes online and can be found here. Just click the "download" button in the top left corner and copy the contents of the .txt file into the Arduino IDE. When powered on, the LED will flash and take a data reading every second and store the information on the SD card in a .txt file named "TEST".



I mounted the sensor on the outside of the plane but it is light sensitive so I covered it with a cotton ball and duct tape.

Batteries

To power the plane, I needed a 12v source that would last longer than three hours. The best batteries I found were Energizer Lithium Ultimate AAs. They are extremely light weight, last nine times longer than the average AA and are rated to work a -40°F making them perfect for this mission. Additionally I have tested these exact batteries on a past near space project and they performed perfectly.

Eight Lithium Ultimate AAs in series providing the required 12v.

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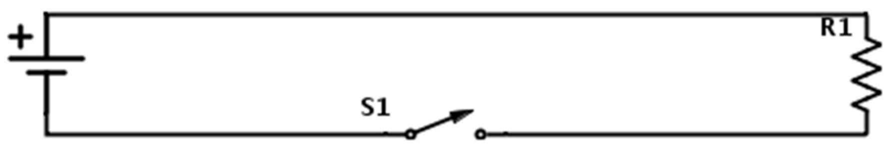
Balloon Cutoff

One of the most crucial aspects of the flight was the balloon jettison. I needed a reliable, simple method to detach from the balloon when maximum range was reached. I decided to improve on David Windestål's idea of using a 10Ω 1/4w resistor and match head to melt the nylon twine connecting the plane and balloon. Through experimentation I found that the match head was rather bulky and did not have enough contact area with the twine to have an effect. I rather used a short piece of safety fuse wrapped around the resistor and twine. Only a small piece of the fuse touched the resistor and the rest was wrapped around the twine. I did notice the resistor usually melted the twine on its own before the fuse had enough time to light but I still kept it as a failsafe.

To activate the cutoff I used a small radio controlled relay which plugs into a channel on the LRS receiver. When the switch was closed the circuit between the 12v battery and resistor would be completed and cause the resistor to heat up. I programmed the receiver to automatically activate the cutoff and switch the APM into "return to launch" mode if I lost radio contact for more than thirty seconds.

This is a schematic of the cutoff circuit. R1 is the 10Ω 1/4w resistor and S1 is the radio controlled relay.



10Ω 1/4w resistor and fuse cutoff

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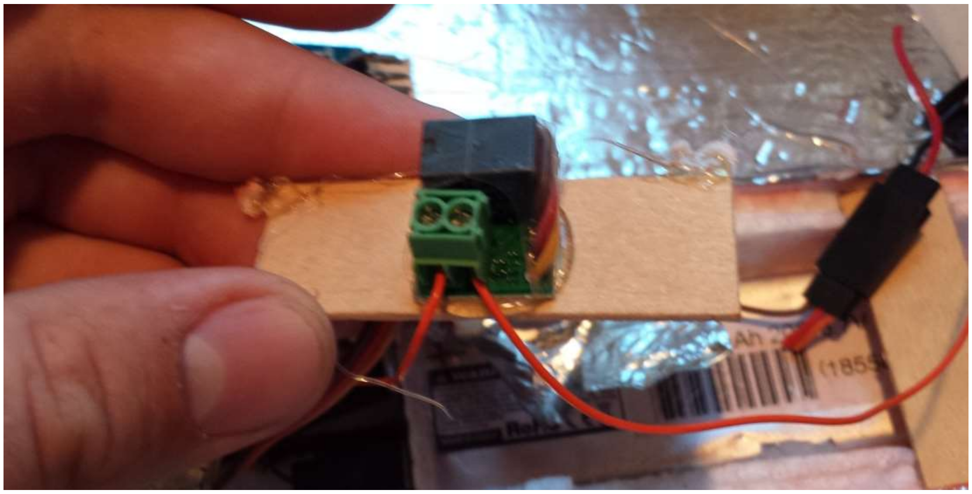
Radio controlled relay cutoff switch



Ground Station

I observed from David Windestål's project that much of the trouble he encountered during his flight was caused by cables breaking on his radio gear. I wanted to avoid this during my mission and decided building a solid ground station would be the best course of action. If I encased all wiring in a box I would eliminate numerous problems that could arise.

Ground station box

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First time laying all the parts together

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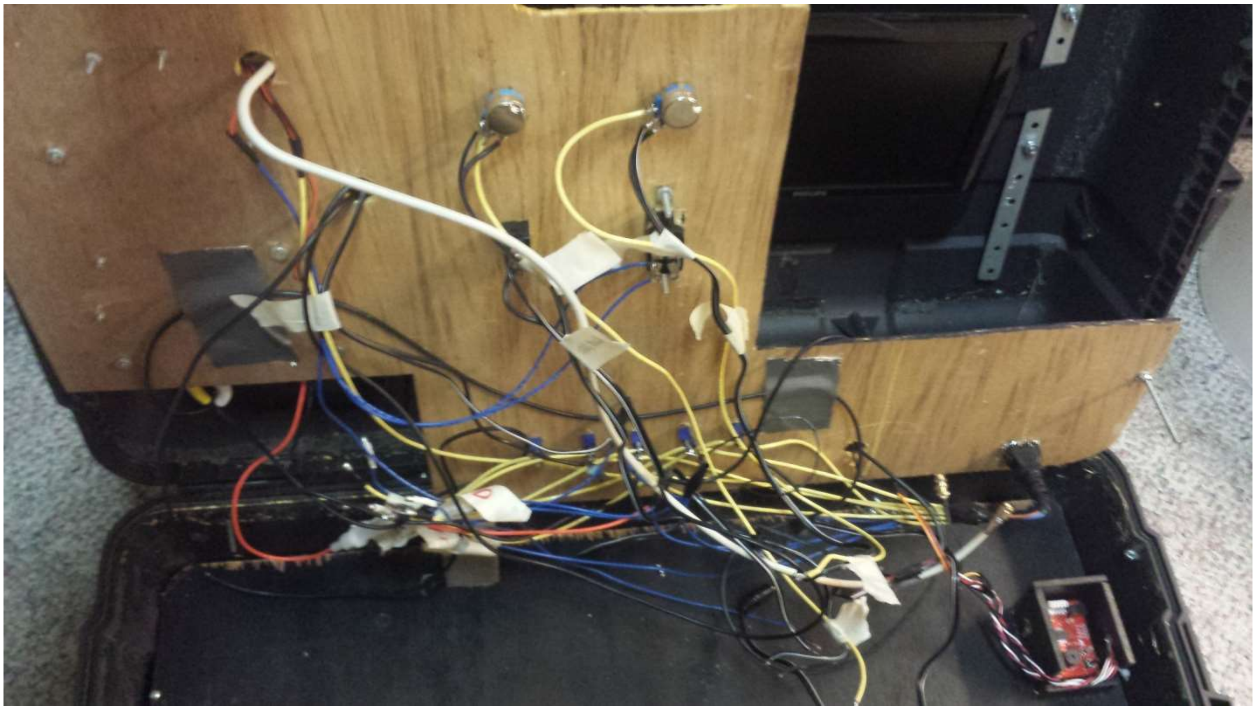
I know the wiring looks messy but I ran out of zip ties. If you look at the bottom right of the picture you will notice I mounted the LRS transmitter and adapter in the box and not in the 9x transmitter. I felt this was much more secure and there would be less chance of a wire coming unplugged.



Finished ground station

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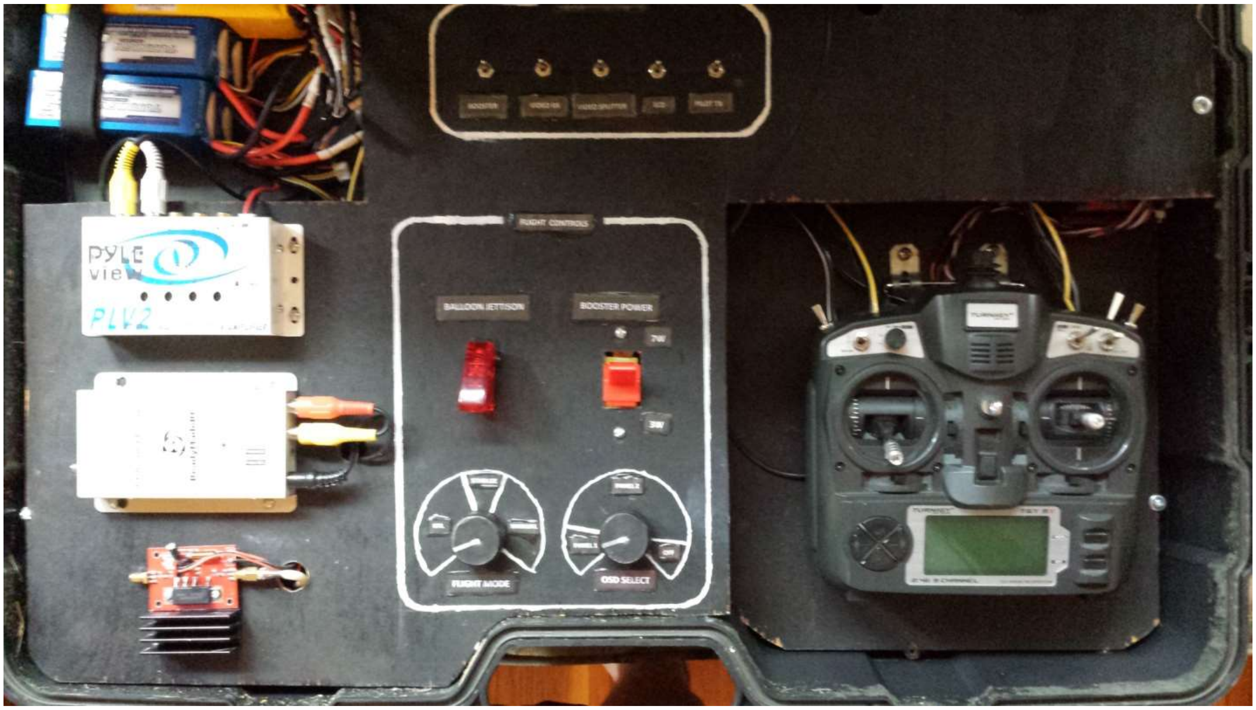
I added a 12v video splitter to the box which enabled me to record the video on the ground station monitor



I hardwired the flight control switches to the 9X transmitter. I figured it would be much easier than trying to remember what each switch did and what position the knobs were for each flight mode. I replaced the small potentiometers from the transmitter with larger 5kΩ linear potentiometers to make installation easier and the small toggle switch with the awesome red toggle switch.

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Flight control switches

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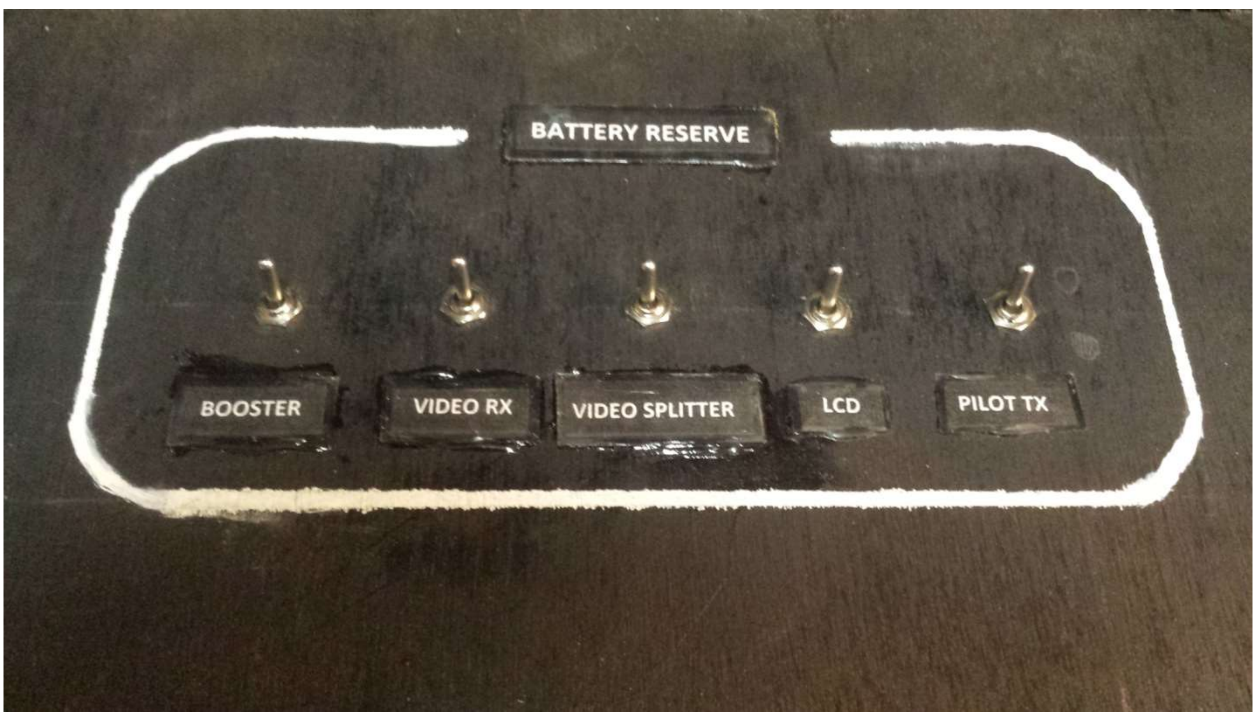
This is the 12v power port for all the electronics in the box. I ran an extension cord from the battery of my truck which powered the whole system.

I wanted a backup power supply in event my truck stopped working or someone tripped on the cable, so I wired in four lipo batteries. I kept them on during the whole flight along with the truck battery to ensure uninterrupted power.



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The Balloon

The balloon I used was a 1200g latex weather balloon. It can carry a payload of about 5lbs. The plane weighed in at exactly 2lbs so it was perfect for the job.

1200g weather balloon

One of the trickest parts of filling the balloon is deciding how much helium to blow into it. From past experience I found the easiest method is to find the total weight of the balloon and payload and fill the balloon until it pulls 1.5lbs more than the total weight. For example, if the balloon weights 2lbs and the payload weighs 3lbs fill the balloon until it pulls upward with a force of 7.5lbs.

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The Launch

The initial plan was to launch in Eastern Washington but due to wildfires, we decided to launch a bit closer to home in Winlock Washington. I used a balloon path predictor (which can be found here) to help estimate the direction the balloon would travel and was surprisingly accurate. The actual path was almost identical to the estimated one.

Mission Control

To record the flight video I used a RCA to USB converter which was plugged into a laptop and saved directly to the hard drive. The second laptop was used to quickly calculate the headings for the antenna tracker.

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Filling the balloon

Filling the balloon proved to be a little tricky. Although we had past experience filling large balloons, the wind blew very hard causing the it to flop around. However we were able to fill without incident.

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Attaching the glider to the balloon

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Releasing the glider

After a systems check and countdown I released the glider. If you look closely you can see the orange wires connected to the cutoff resistor.

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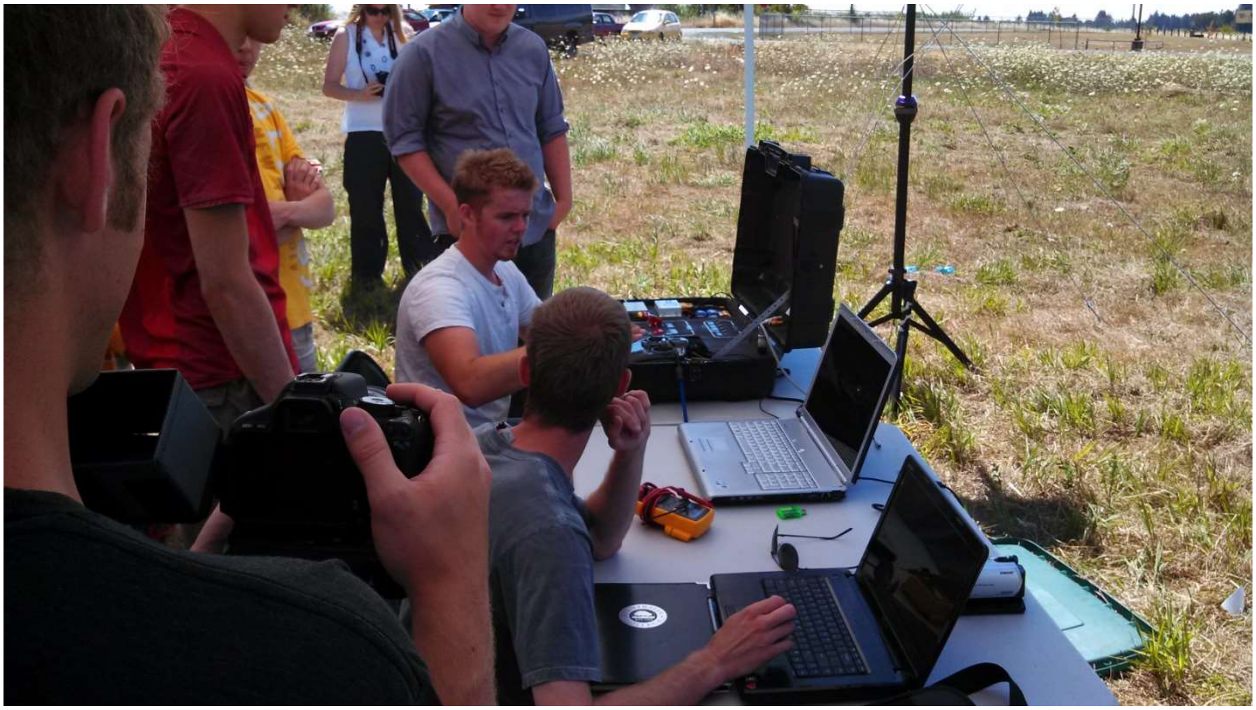
Mission Control after launch



Watching the live video from the glider

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The Flight

Watching the balloon ascend was one of the highlights of the flight. The video was fairly smooth and the view was breathtaking! Although it was slightly tedious, every three minutes we would adjust the antenna tracker for the new location of the glider. Because of a strong south-west, wind we reached our maximum radio range of 20 miles at an altitude of 60,000 feet. This was a little lower than planned, but I did not want to risk losing control of the craft. When the glider first disconnected from the balloon it actually free fell for about fifteen thousand feet. We predicted this might happen due to the low air density at that altitude.

I flew the glider for the first few minutes but the wind blew the glider out of our pilot control range. However, ArduPilot failsafe kicked on and piloted the glider without a hitch. I was thoroughly surprised how well the autopilot system performed! At peak altitude it had ten satellite locks and accurate compass readings. I quickly noticed the autopilot was doing a better job correcting for wind gusts than me, so I switched it to Return To Launch mode for the rest of the flight.

Because the headwind was so strong, I was unable to pilot the glider back to the original launch site. We lost all radio connection to the glider about twelve miles away from our launch site because of hills blocking the line of site communication. The autopilot was still in control but did not have enough altitude to reach home, so it landed in a forest about nine miles away. Fortunately, we prepared for this exact scenario with the SPOT GPS. It sent us the location of the landing site but it was a five mile hike so we waited to retrieve the craft until the next day.

Hiking in the woods to retrieve the glider

The SPOT was accurate to about fifteen feet so it took us a while to comb the briers and trees to finally locate the glider.

Exactly how we found the glider

The glider was in amazing shape! There was a slight dent in the wing from hitting a little tree but not bad for an autopilot landing! The plane batteries continued for another two hours after landing and the GoPro battery lasted for another four.

Summary

I am ecstatic with how this project turned out! All the systems worked perfectly and we successfully recovered the glider. I was a little disappointed the glider did not land a closer to the launch site but the heavy winds were out of my hands. The footage is a blast to watch and inspires me to continue flying!