OPERATION HELIOS

Stratosphere Imagery

Liam McBride-Kelly
&
Riccardo Miceli McMillan

Contents

Introduction

This project, known as Operation Helios, was aimed at capturing video of the curvature of the earth from 35km altitude using a high altitude weather balloon and a multitude of electronic equipment. The project spanned over two years, from May 2010 to April 2012. On the 14 April 2012 the Brisbane based team travelled to Tamworth, NSW and Helios 1 was launched, reaching a maximum altitude of 32.28km above sea level. The raw footage can be viewed at www.operationhelios.com/r or a montage can be viewed at www.operationhelios.com/m.

Operation Helios arose out of our interest in aeronautics, electronics and film making. Throughout the span of the project many challenges were encountered including technical obstacles, physical constraints, financial limitations and legal requirements connected with government bodies such as the *Civil Aviation Safety Authority*.

Overall Diagram

See below an overall diagram of Helios 1.

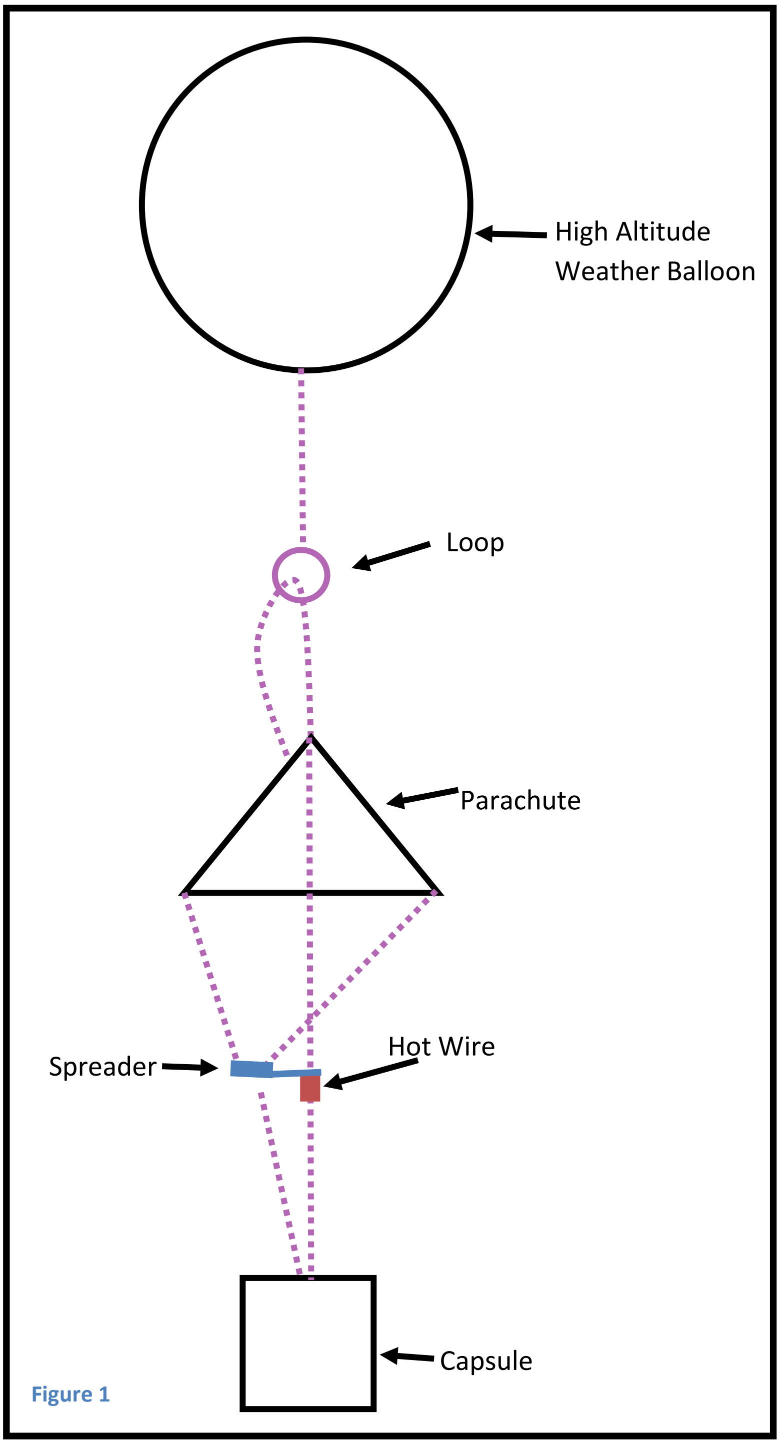
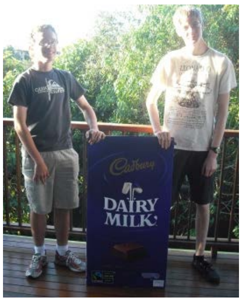


Figure 1

Project Stages

This project involved four main stages. The initial stage, research, development, required us to design a craft incorporating a high altitude weather balloon and a multitude of electronic equipment. The second stage was the fabrication of major components. The third stage entailed the acquisition of government approvals and subsequent launch. The final stage of this project was the retrieval of Helios 1 and analysis of the gathered data.



Throughout the project we needed to manage financial resources, executing constant fundraising. Initially we gained sponsorship by promoting the project via our website. Midway through the project it became obvious that we did not have the finances to continue. Using the $170 that we had left we bought a 10Kg chocolate bar and raffled it at school. We made $600 profit from this venture and used these funds to complete the project.

Stage 1 – Research and development

We researched similar projects based both internationally and locally. However the principal source of information was Western Australian group, "Project Horus". This group has launched 20 balloons meaning they have a wealth of information around this type of project. For every launch they publish a full report describing the issues they encountered. In addition we initiated email contact with the group to further clarify certain issues. We also discussed several ideas with Ashley Anderson of the Tamworth Amateur Radio Club. By combining ideas from both groups with ideas of our own we were able to develop a unique and robust design for Helios 1. For example Horus has never incorporated a cutdown system, but after reading about a launch that flew over three states we decided to incorporate one! Perhaps one of the most interesting applications of existing technology is the use of a CB Radio to activate the cutdown system from high altitudes; CB Radio is traditionally used for voice communications or short range RC. Another unique aspect of our design is the balsa assembly on the side of the capsule for stabilisation; this was added after viewing very unstable footage from other balloon launches.

Stage 2 – Major Components of Helios 1

Helios 1 has four main elements; the capsule, a parachute, a High Altitude Balloon and a variety of ground equipment used for launch, support and recovery.

Capsule

The capsule is a box constructed of 20mm depth polystyrene *(see figure 2, page 10)*. Polystyrene is used as it offers excellent insulation. There are two layers inside the capsule, allowing for maximum space efficiency. A balsa wood assembly is attached to one side of the capsule. The capsule contains all the sensitive electronics which make the project possible. This includes an APRS tracking system, a SPOT Personal Tracker, a LIPD for RDF, an emergency cutdown, a Gopro HD Camera and a power supply *(see figure 4, page 11)*.

Balsa Assembly

A balsa assembly is attached to one side of the capsule. This assembly serves multiple purposes. Firstly, it holds the antenna in place. Secondly, it moves the centre of gravity to the side of the capsule, improving stabilisation. Thirdly, it acts as a rudder, again improving stabilisation. Finally, the balsa assembly extends inside the capsule, providing support for the upper layer.

Power Supply

The capsule is powered by 16 AA lithium batteries. These batteries are arranged in two packs. Each pack consists of 8 batteries wired in series, producing a total of 12 volts. These packs are wired together in parallel, doubling the effective peak current and battery life. Lithium batteries were selected as they are extremely light, have a high battery life and are not seriously affected by low temperatures. The batteries are connected to a switch mode voltage regulator set to supply 6.5 volts. This 6.5 volt supply is connected to both a 5 volt linear regulator and a 3.3 volt linear regulator.

APRS Tracking System

APRS (Automatic Packet Reporting System) is an amateur radio protocol used to relay packets of information, in this case, packets advising the GPS location of the capsule. APRS is very well supported in Australia with hundreds of "i-gates" – receivers which pass packets received to websites such as aprs.fi. It is also possible to setup a mobile receiving station which decodes packets offline. Both the website aprs.fi and a mobile receiver were used for the project, this will be discussed further later. The APRS tracking system consists of three components; GT-320FW GPS receiver, an opentracker+ APRS modem and a FDC150 VHF radio transceiver *(see figure 3, page 10)*. Like the other tracking systems it is affixed to the upper layer.

GT-320FW GPS receiver

The GT-320FW GPS receiver was selected as it interprets the Cocom regulations in a way which is usable for high altitude tracking. The Cocom regulations stipulate that GPS receivers should shutdown when traveling at speeds faster than 1,900km/h **AND** altitudes greater than 18km. Unfortunately many GPS receivers interpret the limits incorrectly as an **OR** statement, meaning that as soon as the GPS is above 18km it shuts down. The GT-320FW interprets the limitations correctly as an **AND** statement – meaning it can be used for high altitude tracking. The GPS receiver outputs NEMA gps data which is fed directly into the opentracker+ APRS modem.

Opentracker+ APRS modem

The opentracker APRS modem takes NEMA GPS data from the GT-320FW GPS receiver and outputs APRS packets. The modem also handles the keying of the APRS radio and has an onboard temperature sensor and voltage metre. The Opentracker+ is programed to transmit the capsules GPS location, callsign, altitude, internal temperature and operating voltage every minute. The Opentracker+ is powered by the 12 volt rail of the capsule.

FDC150 VHF Radio Transceiver

The FDC150 is tuned to 145.175MHz, the Australian APRS frequency. Its internal battery has been bypassed and is instead powered by the 12volt rail of the capsule. The radio's audio output, input and PTT key are connected to the Opentracker+. The radio is set to transmit at 2.5 watts which is plenty when operating line of sight.

Antenna

The antenna is a ¼ whip antenna turned on its side and is constructed from a BNC cable. The cable's shield is removed and short wires are attached in its place, serving as a ground plane. The antenna has a very low gain; a quality that is useful in an application such as this one where the signal needs to be radiated in all directions. The antenna is far from perfect, but suffices for the purpose.

SPOT Personal Tracker

The SPOT is a tracking device designed for people who participate in wilderness recreation. Like the other tracking systems it is affixed to the upper layer *(see figure 3, page 10).* Using a commercial satellite network it uploads its GPS position to the SPOT website every 10 minutes. It was borrowed from Project Horus and served as a backup in case APRS failed. It was the only device on board which was powered completely independently from the main power supply– this choice was made to ensure it would still function even in the instance of a massive critical failure . It was not relied upon in recovery as APRS served its purpose but it was still good to have a backup system.

LIPD

A low interference potential device (LIPD) is a small radio transmitter which operates in the licence free ISM (industrial scientific and medical) band. The LIPD used in this project was extracted from an old wireless temperature probe. Like the other tracking systems it is affixed to the upper layer *(see figure 3, page 10).* The LIPD served as a last resort method of tracking the location of the capsule. If the SPOT and the APRS failed then the LIPD could be found with the use of an RDF (Radio direction finder). Essentially an RDF is an antenna which is made in such a way as that it only receives signals from one direction. By sweeping the horizon with such an antenna the approximate direction of an LIPD can be found. The LIPD is connected to the 3.3 volt rail of the capsule.

Go Pro HD Hero

The Go Pro HD Hero is a camera which is commonly used for action sports. It was selected as it consumes little power, has a small form factor and records in 1080p video. The Go Pro is affixed to the lower layer of the capsule *(see figure 4, page 11)* and is powered by both its internal battery and the 5 volt rail of the capsule. This duel power supply system ensured that even if a massive critical failure occurs in the main power supply, video will still be recorded.

Emergency Cutdown

The emergency cutdown system is designed to listen for a secret series of DTMF tones on CB radio and respond by activating a hotwire which cuts away the balloon in the case of an emergency. The system has five parts; a CB radio, a DTMF decoder, an Arduino Uno, a single transistor as a relay and a small length of nichrome wire. All the cutdown electronics, bar the nichrome wire itself, are affixed to the lower layer of the capsule *(see figure 4, page 11).*

CB Radio

The CB radio is tuned to channel 23 (a telemetry only channel). Its audio output is connected directly to the DTMF decoder. The radio is powered by the 5 volt rail.

DTMF Decoder

DTMF (Dual-tone multi-frequency) is a 16 digit signalling system which is designed for use on low quality connections. The DTMF decoder board consists of a MT8870 DTMF Receiver and the external components which it requires to run (resistors, ocilator, capacitors, etc). The DTMF decoder has an audio input, a 4 bit output and a 1 bit output. When a DTMF tone is heard the corresponding digit is output via the 4 bit output and the 1bit output goes high. This 1bit “tone heard” output makes it extremely easy to interface to the DTMF decoder. The DTMF decoder is powered by the arduinos 5 volt rail. The 4bit and 1bit outputs are connected to the arduinos digital input pins (2-6)

Arduino Uno

The Arduino Uno processes the output of the DTMF decoder. It searches for a specific set of digits and it they are received it pulls digital pin 13 high. The Arduino code was outsourced to a friend (YHLS) as there was little time till launch and far too much work for just two people to do. The Arduino is powered by the 12 volt rail of the capsule.

Transistor

A TIP122 transistor is used to activate the cutdown as the arduino is not able to supply the high current required to drive the nichrome wire.

Nichrome Wire

The nichrome wire is wrapped around one side of the loop as shown in figure 1 (page 3). When a current is supplied it becomes extremely hot extremely quickly. It easily cuts through the builders twine used in the loop. The Nichrome wire is powered off the 12 volt rail.

Parachute

A fluoro coloured 1.5m diameter “spherachutes” parachute is used *(see figure 6, page 11)*. This parachute was selected as it is lightweight, high visibility and has the ability to slow the capsule to an impact speed of 5m/s. At the base of the parachute a spreader is attached. This device keeps the parachute partially open so that it inflates reliably during decent. Affixed to the spreader is a small balsa wood strut which holds the nichrome wire away from the parachute lines. This strut ensures that when the nichrome wire is engaged only the cutdown line is melted.

High Altitude Balloon

A 1000g Hawoyee High Altitude Balloon was used for the flight. It was filled with 3.5m^3 of helium. This balloon was selected as it is low cost and has a reasonably high volume, allowing it to reach extremely high altitudes. As the balloon rises the pressure outside the balloon decreases (atmospheric pressure decreases with altitude) causing the balloon to expand. Eventually the balloon expands to its burst volume and ruptures.

Ground Equipment

There was a variety of ground equipment used in the launch and recovery.

Online APRS Reception

A laptop is connected to a mobile internet dongle. The laptop then accesses the aprs.fi website. When an i-gate, an APRS station which uploads packets received to the internet, uploads a packet the aprs.fi website automatically updates to reflect the last known position of the capsule. The balloon was launched near Tamwoth, NSW, an area which has many APRS i-gates installed. This made tracking the balloon via aprs.fi extremely practical.

Offline APRS Reception and Decoding

The offline APRS reception and decoding system was put in place in case the capsule flew into an area which was not covered by i-gates or aprs.fi went offline *(see figure 7, page 12)*.

Antenna

An antenna is mounted on the roof of the car using a magnetic base plate.

Radio Scanner

A radio scanner is connected to the antenna on the roof and tuned to 145.175mhz, the Australian APRS frequency. The scanners output is connected to a TNC (APRS modem).

TNC (APRS Modem)

The TNC is connected to the radio scanner’s audio output. The TNC is configured to decode APRS packets. The TNC’s RS232 output was connected to the laptop’s RS232 input.

Laptop

The laptop has UI-View installed, a free program which is designed to interpret the RS232 data which the TNC outputs. UI-View displays the current altitude, latitude, longitude, speed and heading of the capsule.

Inflation Adaptor

A series of pieces of PVC pipe were assembled to convert the small outlet of the helium tank up to the larger diameter inlet of the balloon *(see figure 5, page 11)*. The Inflation adaptor worked exceptionally well – allowing us to fill the balloon in 15 minutes.

Communications

Inside of the Helios team, communication was achieved via 5W handheld CB radios *(see figure 8, page 12)*. For communications with the local amateur radio club, 2 metre amateur radio was used.

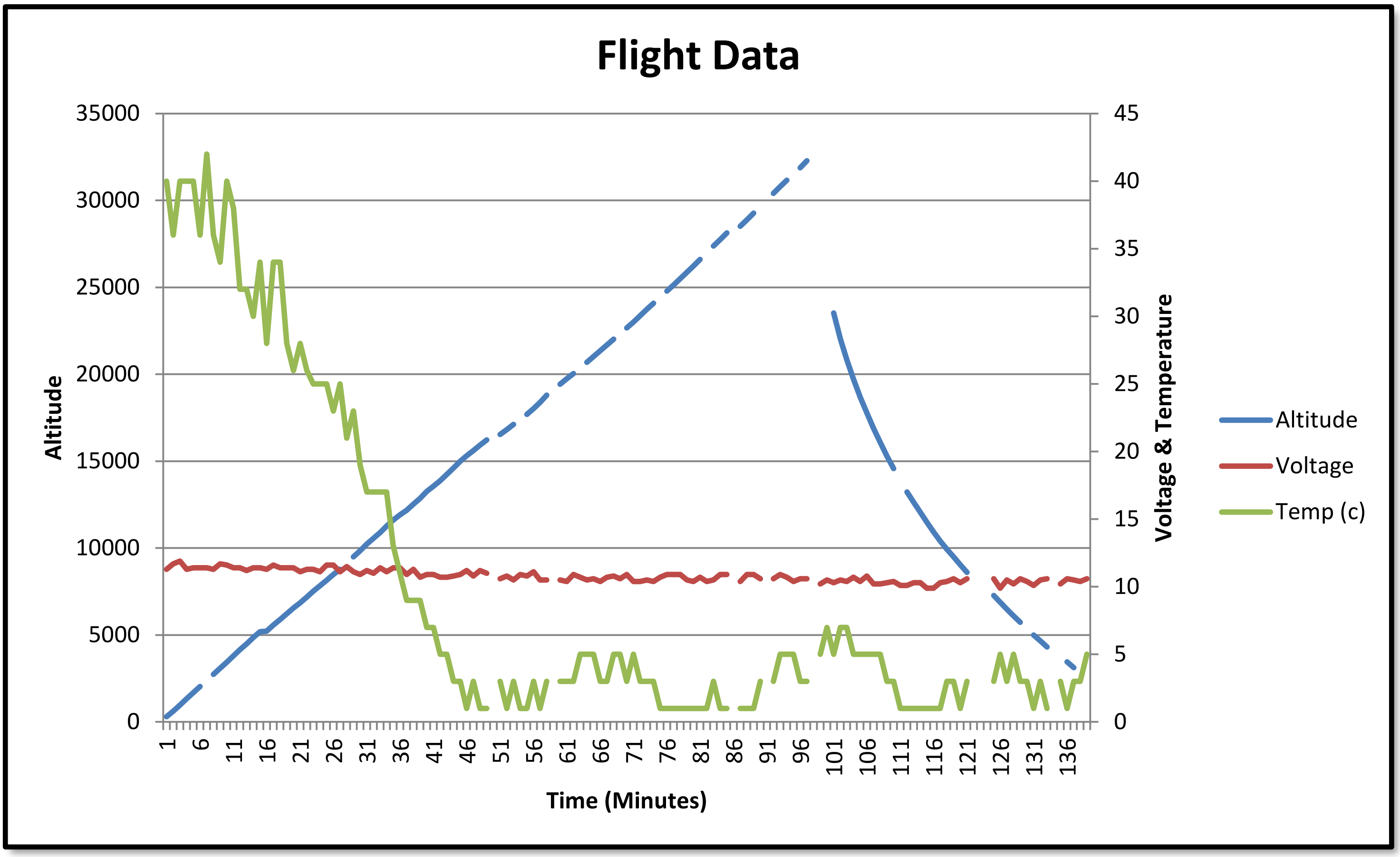
Stage 3 –Legalities and Launch

Obtaining the correct permits to launch a High Altitude Balloon is quite complex. We had conversations with others who had launched balloons and they said that they had been charged from $500 to $1000 for official permission to launch. We inquired with the *Civil Aviation Safety Authority* (CASA) in late 2010 and mid-2011. Unfortunately at these points the project was still in an evolving stage so it was not possible to provide CASA with the information they required to start processing permits. Coincidently, in December 2010, we started communicating via the internet with a member of the Tamworth Amateur radio club, Ashley Anderson. The Tamworth Amateur Radio Club was embarking on their own balloon project at the time. Anderson was extremely helpful, giving us advice about the complex electronic systems involved. In November 2011, we met with Anderson at the Gold Coast Hamfest. Here we talked at great length about the legality, and the idea of launching near Tamworth was formed. One of the members of the Tamworth Amateur radio club, John P, is an aeronautical engineer, so knows how to deal with CASA. Acting in the mutual interests of the Helios team and the The Tamworth Amateur Radio Club, John instigated discussion with CASA. After much discussion between John and CASA we finally got approval for two launches just one week before launch day, at no charge. On launch day, a NOTAM (Notices To Airmen) was broadcast requesting that all air traffic redirect to avoid an area of 60km radius around the launch site for one hour. In this hour window we launched both our balloon and the balloon of the Tamworth Amateur Radio Club.

Stage 4 - Assessment of Launch, Flight and Recovery

Operation Helios was a complete success; it was tracked effectively throughout its flight via APRS and SPOT and captured amazing imagery. The launch was very swift. We arrived on location, prepared the capsule, inflated the balloon with our adaptor, rigged the parachute and cutdown and then simply released the capsule. There was tension during the wait for the first packet to be received but soon the packets started coming in on the minute. The insulation worked extremely effectively – with the internal temperature never falling below zero degrees Celsius. Some packet data was not successfully received, leaving holes in the flight data recorded, as can be seen below, but overall the tracking systems worked extremely well. The last APRS packet received was while the capsule was still falling so SPOT data had to be used to find the final landing location.

Recovery was a challenge, the capsule landed in the middle of a farmer's property at the top of a thirty metre tree. We had to leave the capsule overnight and recover it in the morning. After seeking the permission of the land owner, the tree was cut down and the capsule recovered. Major damage was done to the capsule and DTMF cutdown circuitry but all the expensive equipment survived unscratched. The footage captured was simply amazing *(see page 13)*, but unfortunately the landing was not recorded as the SD card filled to capacity more quickly than expected. Overall the launch, flight and recovery went very well with an excellent end result.



Conclusion

Throughout the project many things were learnt, such as basic electronic skills and design, designing for redundancy, basic programing, radio based electronics, effective information gathering, financial management, fundraising, managing human resources, networking, negotiation and developing partnerships.

If we were to launch another balloon two major modifications would be made. Firstly, a second cutdown would be incorporated which has the ability to cutdown the parachute as well as the balloon. In the existing system only the balloon can be cutdown. We overlooked the fact that the parachute has a tendency to get stuck in trees. If we had been able to cutdown the parachute then we would have been able to retrieve the capsule from the tree without having to cut the tree down. Secondly, a larger SD card would be used. The camera ran out of memory while falling. It would have been interesting to see the landing. A 32gb SD card would suffice.

Overall the project was a great success and an excellent experience for all involved.

Appendix - Photographic Documentation

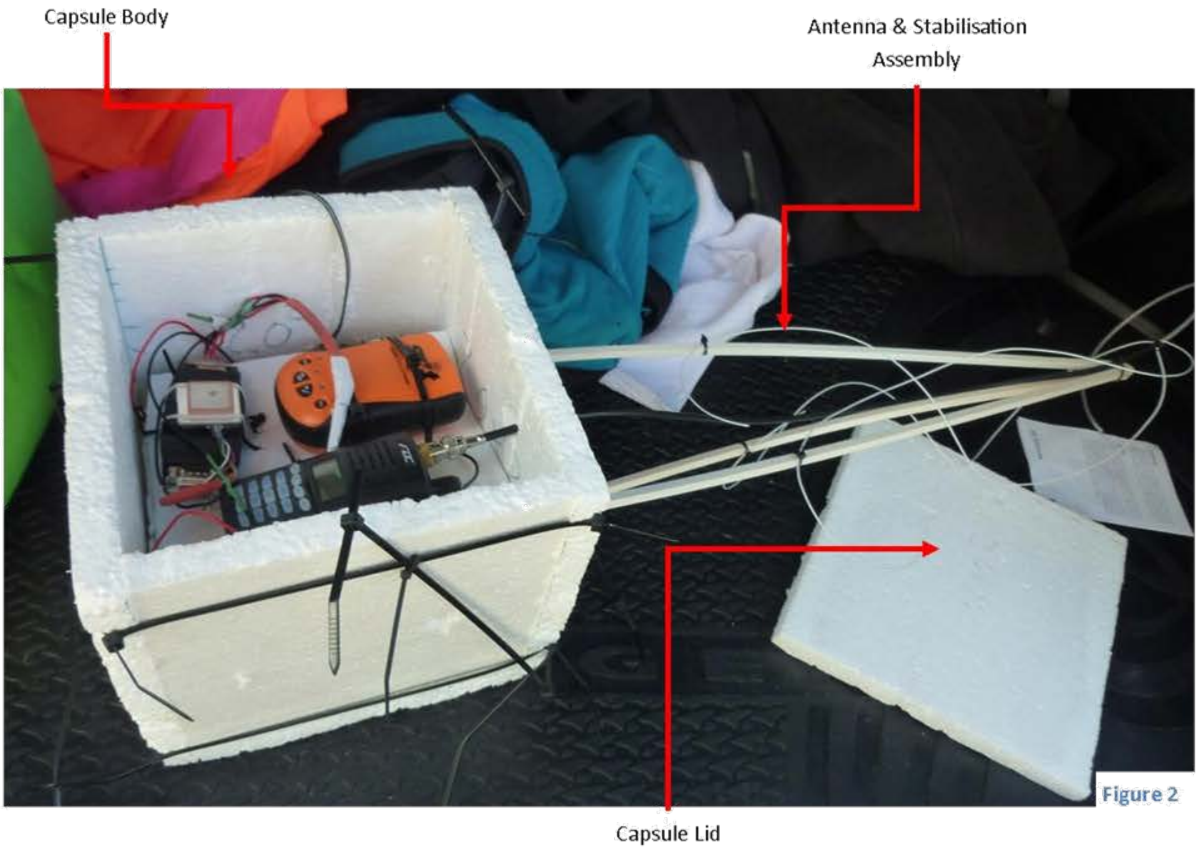


Figure 2

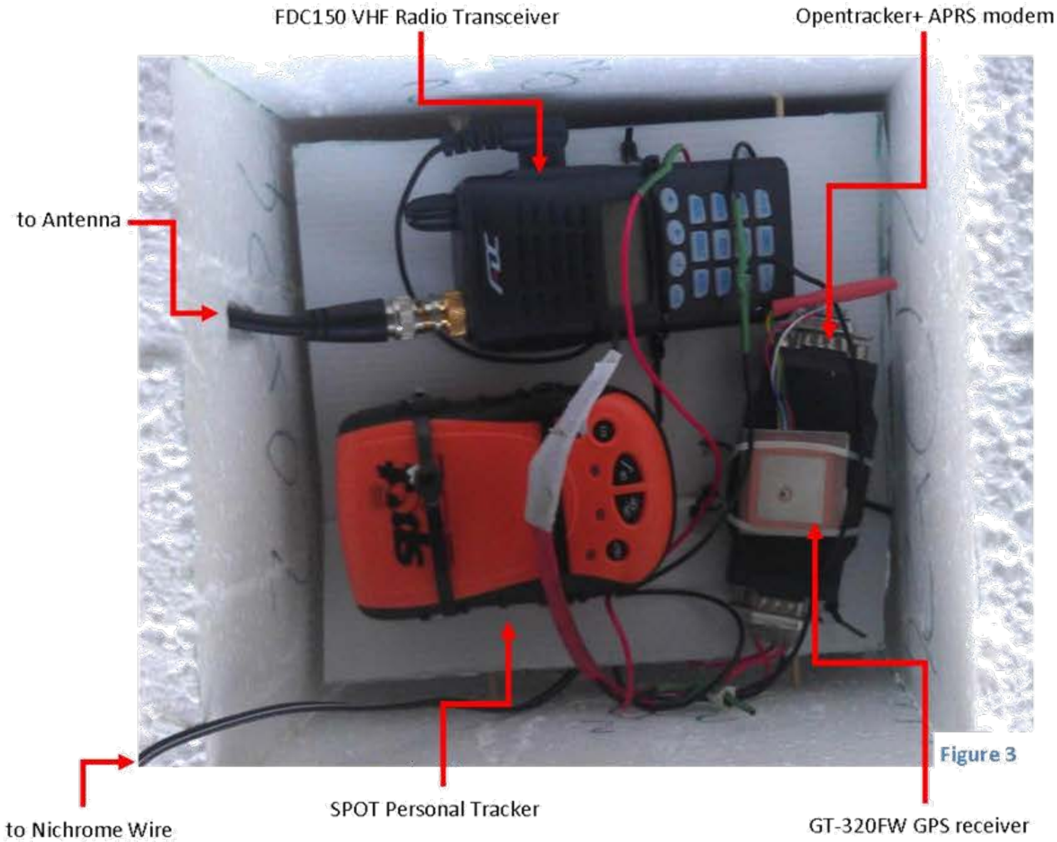


Figure 3

N.B. In figure 4, skewers are used to support the upper layer. This was our initial design; the balsa assembly was only added the day before launch.

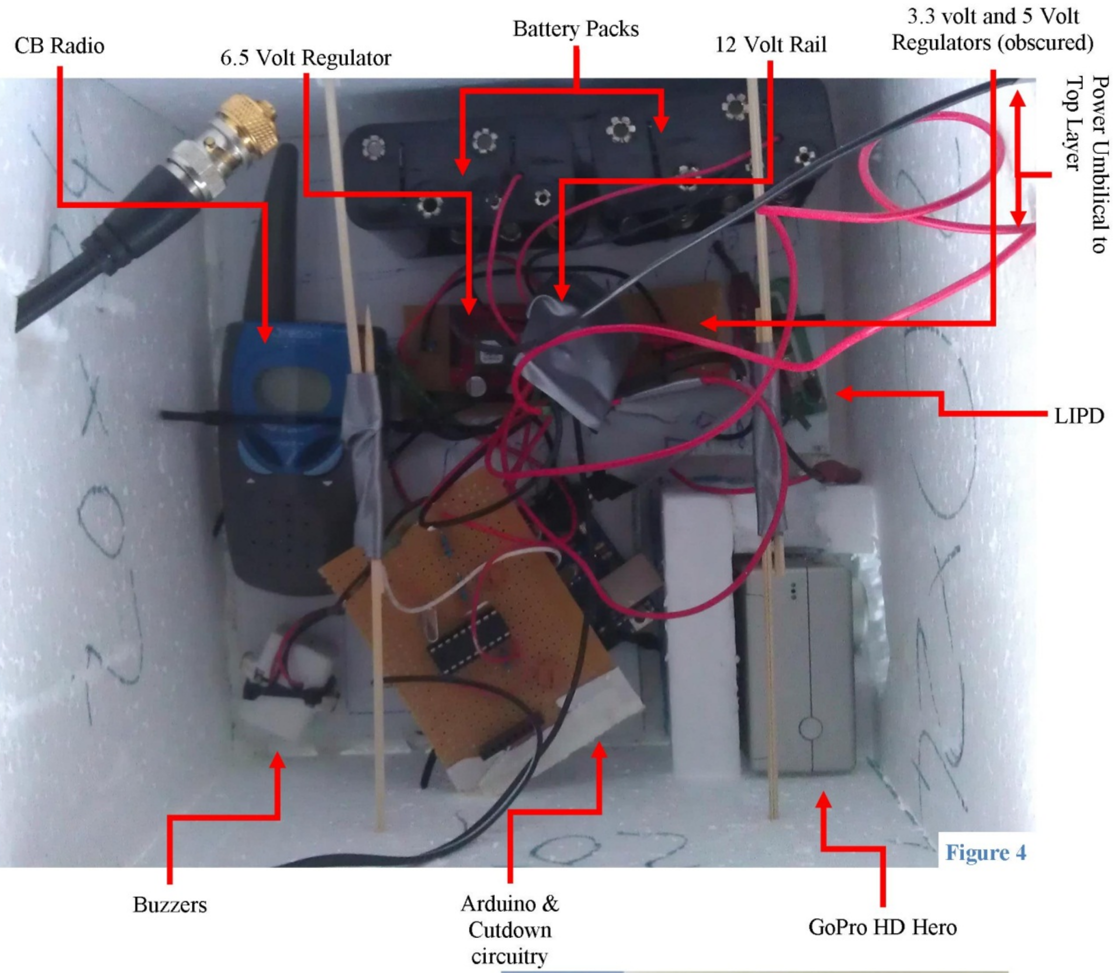


Figure 4

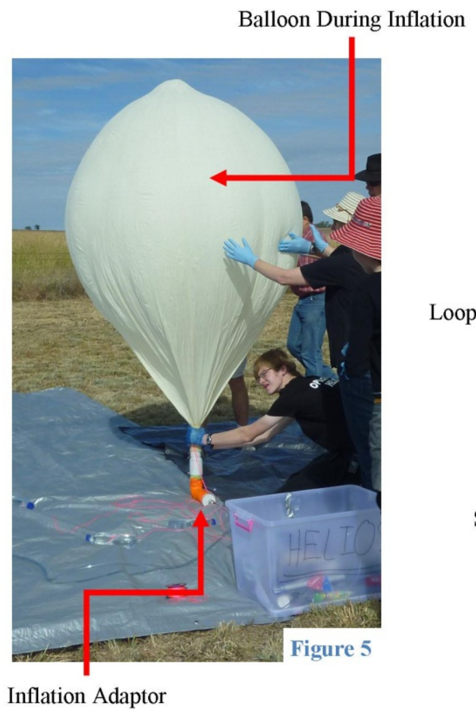


Figure 5

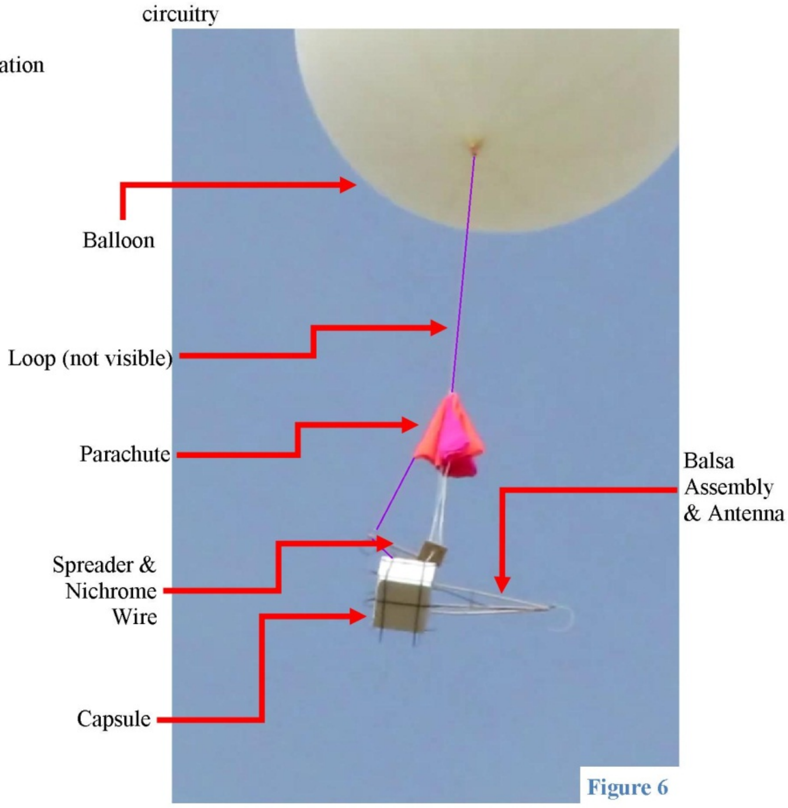


Figure 6

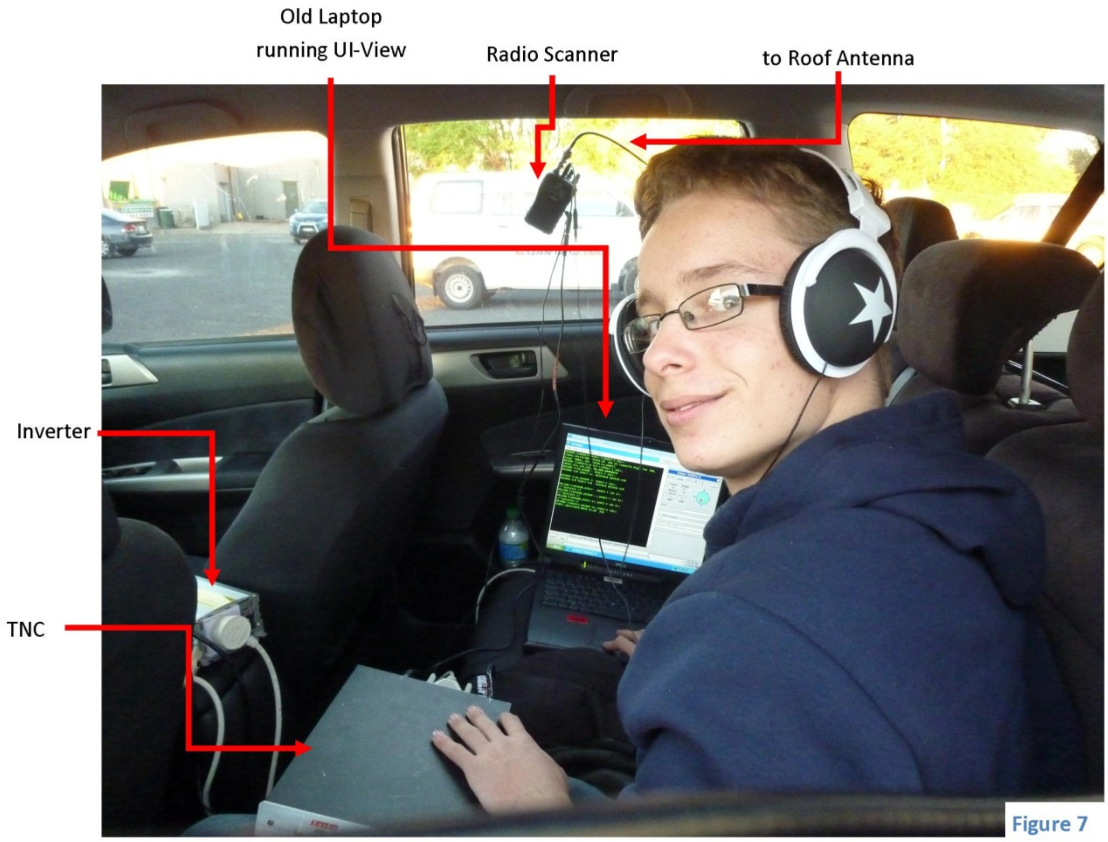


Figure 7

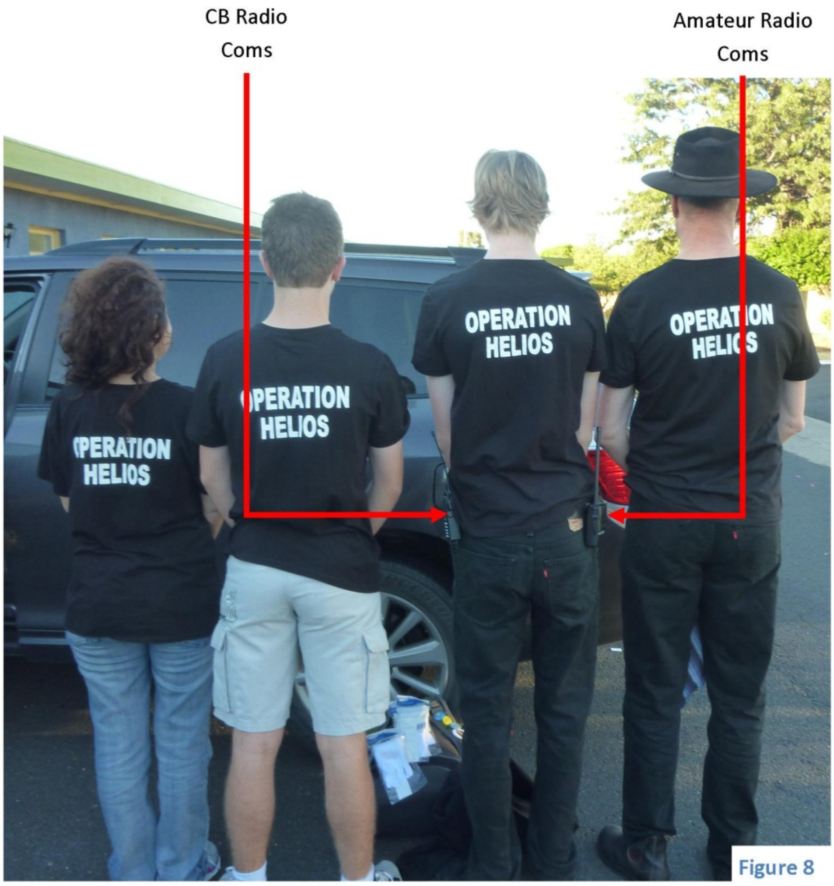


Figure 8

Ascent

Figure 9

32 KM Altitude

Figure 10

Burst

Figure 11

Appendix – Flight Information

Launch Location	-31.24617, 150.461 http://goo.gl/maps/sZEZ	Approximate Launch Time (UTC)	13/04/2012 @ 23:52
Landing Location	-31.61816, 151.31551 http://goo.gl/maps/Smd8	Approximate Landing Time (UTC)	14/04/2012 @ 02:10
Maximum altitude	32,277 metres	Approximate flight time	138 minutes
Horizontal Displacement	91,118 metres	Approximate Launch Time (UTC)	13/04/2012 @ 23:52

Credits

- ***Ashley Anderson*** – for his invaluable assistance with all the electrical aspects of the project
- ***John P*** – for his amazing ability to liaise with CASA
- ***Tamworth Radio Club*** – for their valuable assistance on the launch day
- ***Friends, Family & Sponsors*** – for their continued support
- ***Terry B of Project Horus*** – for the valuable insight he provided us with
- ***Leon S*** –for his last minute assistance in the programing of the cutdown (a friend from school)
- ***Amanda MacKinnell*** – for her recommendations around tracking solutions
- ***Mr Hodges*** – for his assistance in the editing of this report
- ***Brisbane State High School Staff and Students*** – for their support and facilitation of our fundraising efforts