9) The weight set, with desired lift weight in step 4, is to be connected to the injection mechanism. Helium container valve is then carefully opened to begin the inflation.

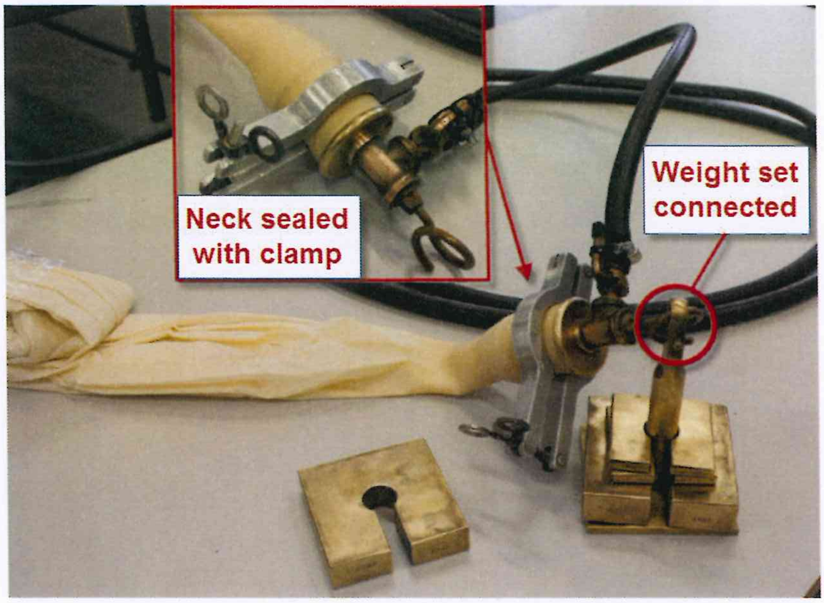


Figure 21: Balloon neck sealed to injection nozzle

10) The inflation continues until the weight set is free floating at neutral state, helium tank valve is then immediately closed.

11) Using suitable string, the balloon neck is tied off tightly twice above the injection nozzle, tying an extra string at the balloon neck to heavy weight on the ground to prevent the balloon from escaping.

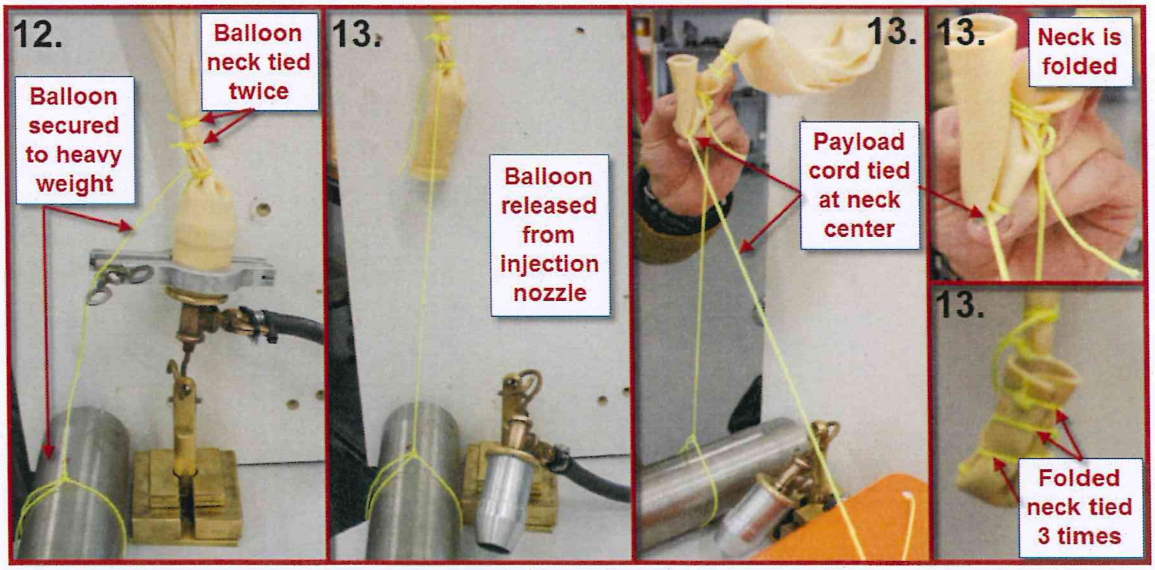


Figure 22: Balloon neck tied

12) The injection mechanism then is removed and the payload cord is tied to the neck center. The balloon neck is folded over the payload cord, making it double and tied again three times. The balloon neck should now be bent over double with the payload suspension cord nestled in the bottom of the bend and the whole thing securely tied three times.

13) The balloon then should be ready for release. The balloon itself is sensitive against fat from human hands so using disposable latex gloves at all times is important while handling the balloon.

3.15 Parachute

The altitude that we were aiming for was about 30-35 km. Because of the low air pressure at this altitude the balloon will expand and finally burst and begin to fall down to earth. The speed that the balloon will fall at is rather high and therefore a parachute was added below the balloon to reduce the fall speed. To decide the size of the parachute the team considered the drift of the balloon. If the parachute would be too big then the speed down would have been too slow and the equipment would drift a lot.
The team decided to contact the Reykjavík Airbourne Rescue Team. Davíð Þór Bragason was our specialist at the rescue service, he is a member of the parachute rescue team. Davíð was really helpful and was excited about the Skyward Sphere project. We told him what we were planning to do and told him the weight of the payload. He showed us a 3 foot drag chute that skydivers pull out and drags out the main parachute.
This parachute was then tested in the main hall in RU, the „Sun". A load was attached to the parachute and dropped from the 3rd floor down to ground floor. The weight of the payload was the same as was planned for the launch. The parachute reduced the speed sufficiently for our purposes so the team decided to use this parachute in our test flight.

Since we were not able to recover the test flight the parachute was lost and we had to buy another for next flight. Based on calculations made on how fast the equipment was falling during the test it was clear we needed a bigger parachute. The rescue service did not have parachute that would meet these requirements. While we were working on this project we were in contact with members of a retired local HAB project. They had a parachute that was 4 feet in diameter and were willing to sell it. To get a rough idea how fast the equipment would fall after the burst we used a calculator that was found on the Internet [5]. By using this 4 foot parachute the average descent speed was about 25 m/s which was acceptable. This speed is the average speed so when the balloon burst the speed is more than 25 m/s because of less drag due to lower atmospheric pressure but when the equipment gets closer to the ground the speed reduces and therefore is lower than the average speed.

3.16 Spaceship model

CCP contacted a local prop maker to make a model of a spaceship that would be possible to send to near space with a latex balloon. The prop maker's name is Þorfinnur Karl Karlsson (Tobbi). The initial idea was to rotocast the model but after the artist told us about the thickness of the shell the team was very concerned about how heavy the finished model would be. The team then got an example of the plastic Tobbi was going to use for the model. With a small experiment, the team calculated the density of the material and found the volume of the finished model by making a model in Solidworks. The estimated weight of the model was calculated and found to be roughly 6 Kg.

It was clear to all involved that this weight was way too much, so the artist had to resort to another, more time consuming method of hand casting the model in two shells. This process made the model very fragile, but the weight was a promising 2367 grams. It was then painted and some led lights put on it to make it look more realistic.

The model is based on a spaceship in the Eve Online universe, see Figure 23.

Figure 23: CCP space ship model

3.17 Data logger and cutdown

Data logger

We used an Arduino microcontroller connected to a data logger shield to save data during the flight. A temperature and pressure sensor were mounted on the shield. The data is then saved to an SD card every second. A real time clock was used to timestamp the data. Data could be saved for approximately 5 hours before the 9 V battery ran out of power [8]. (Format of data?)(Example?)

Cutdown

Our first balloon landed halfway to the Faroe Islands and it was not possible to retrieve it. Since we did not want to this to happen again we decided to use a time controlled cut down mechanism as a safety backup. Using the same Arduino as for the data logger, a simple code was written to switch on the cut down after a certain time. This time was set to 2 hours and 20 minutes. According to wind speeds this flight time would still let us land close enough to Reykjavík so that the helicopter could retrieve it. The cut down used a low resistance MOSFET transistor as a switch, a 9 V battery for power and a high resistance nichrome wire as a cutting device. The cut down mechanism worked well during the tests. The second flight worked as expected and the balloon popped before the cutdown turned on.

(Model #?) (Circuit diagram?)

4 Logistics

4.1 Síminn

The live streaming from the flights would have been impossible without the help of Síminn's cellular technical department and 3G antenna setup. Síminn holds three 5Ghz wide bands of the 2100 Mhz 3G spectrum, only 2 of those bands are in use. Síminn set the phone provided to us to operate on the free band. Because of this, Síminn had to install a cell specifically for the purpose of the flights.

4.1.1 Flight 1

For flight 1, Síminn installed a cell in a cell tower in Öskjuhlíð in Reykjavík, see Figure 24. The cell has an internal mechanism to allow the operators to adjust the angle of the antenna. The antenna was installed upside down and then the antenna was tilted upward as much as possible. The antenna was aimed at the balloons predicted trajectory.

where is the antenna?

Figure 24: Öskjuhlíð cell tower

Síminn calculated the probable signal distribution and plotted it using Google Earth, see Figure 25.

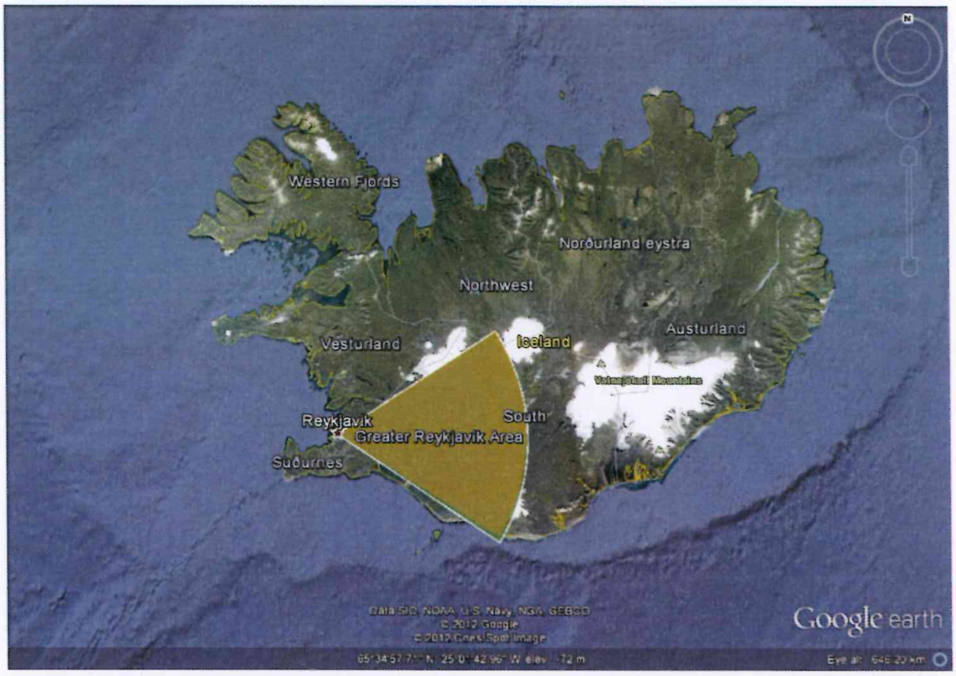


Figure 25: 3G signal distribution from Öskjuhlíð cell tower

4.1.2 Flight 2

In the second flight we used the same setup as we used for the first flight. The second flight was considered a success from the 3G connection standpoint. See Figure 26 for an overlay of the track onto the signal distribution.

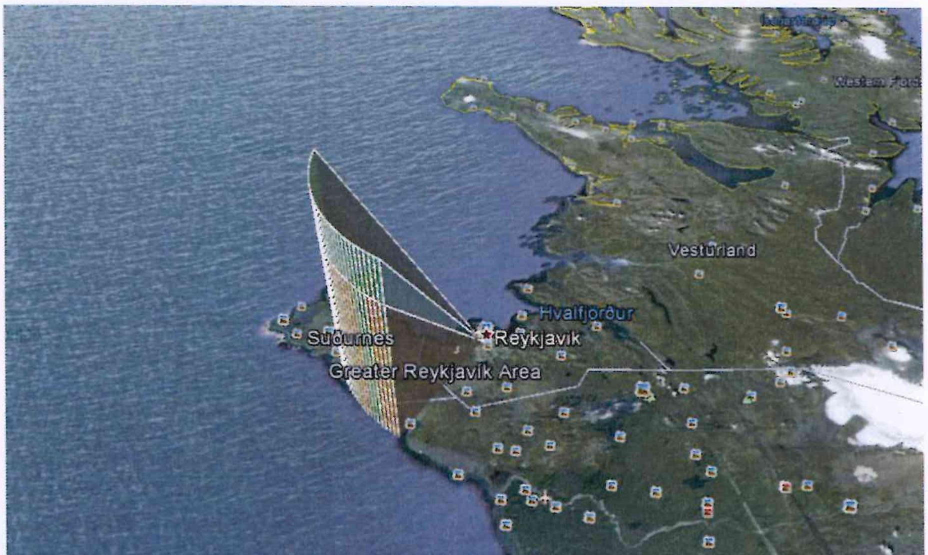
Figure 26: 3G signal distribution with flight 2 track

4.1.3 Flight 3

The winds shifted a couple of weeks before flight number 3. The high altitude winds shifted from an eastward heading to a due south heading. Because of this we wouldn't be able to use the cell already set up on Síminn's Öskjuhlíð cell tower. Síminn brought in a mobile 3G antenna and set it up specifically for the third flight. The antenna was rigged at a 45° angle, See Figure 28.

Figure 27: Mobile cell being set up

The distribution for the new setup up looked quite different because of the greater inclination of the cell. See Figure



(Very nice)

Figure 28: 3G signal distribution from the mobile cell

4.2 Icelandic Association of Radio Amateurs (IRA)

After the first test flight the team realized that more reliable and higher resolution in flight tracking was needed. Then the Trackuino community project was discovered. The Trackuino sends out APRS data packets on HAM radio frequencies. Because of this it's necessary to have a HAM radio call sign to legally operate the Trackuino. For assistance in using the APRS system and with acquiring the necessary permissions from the Post and Telecom Administration of Iceland, the Icelandic Association of Radio

(Put this first)

Amateurs (ÍRA) were contacted. Two members of the ÍRA and avid APRS enthusiasts Jón Þ. Jónsson and Samúel Guðjónsson were brought into the loop and they were eager to help. Other members of the ÍRA fast-tracked their APRS infrastructure implementation and the ÍRA's main APRS antenna was angled to maximize it's effectiveness along the balloons projected flight path. The involvement of Jón and Samúel were instrumental to the operation of the Trackuino and successful in flight tracking.

4.3 Authorization

Unmanned balloon flight, as in our case, is governed by local law. It's necessary to obtain permission for each individual flight from the Civil Aviation Authority (CAA). Each application is reviewed by the CAA and Isavia.

for the flight permission it's necessary to provide the following information:

- Balloon or project identifier
- Categorization of balloon and physical description
- Transponder codes if applicable
- Name, ID number and telephone of responsible party
- Launch location
- Estimated time of launch
- Number of balloons and time between launches (if more than one balloon)
- Projected ascent vector
- Projected flight height
- Estimated flying time through 60k ft
- Estimated time and location of landing

Unmanned balloons are classified in 3 categories according to payload weight:

Light (< 4kg)

An unmanned balloon is classified as light if the total weight of the payload is less than 4kg.

Medium (4-6kg)

An unmanned balloon is classified medium if if the total weight of the payload is between 4 and 6kg.

Heavy (> 6kg)

An unmanned balloon is classified as heavy if:

The total weight of the payload is more than 6kg.

The weight of any individual package of the payload is more than 3kg.

The weight of any individual package of the payload is more than 2kg and it weight to unit area ratio is greater than 13 g/cm2.

It was clear from the beginning that we would have to be in the light or medium category, not only because of the lift capacity of our balloon but also because of the additional safety requirements necessitated by the law when flying a heavy balloon. The additional safety requirements are:

- Clouds or cloud formations reduce visibility or cover more than half of the sky
- Horizontal visibility is less than 8 km

- A heavy or medium heavy balloon may not be released in a manner such that the balloon flies over urban areas or gatherings unless directly connected with the flight
- A heavy balloon must have two independent means of stopping the flight
- A heavy balloon must have radar reflective material that echoes ground radar (200-2700mhz) or have other means of tracking
- In areas utilizing SSR radar transponders the balloon must have an SSR transponder that automatically reports altitude with a pre-defined code
- In areas utilizing ADS-B ground stations the balloon must have an ADS-B transmitter that automatically reports altitude
- A heavy balloon cannot be flown between sunset and sunrise (corrected for altitude) unless the balloon, connectors and payload, whether connected or disconnected during flight, are illuminated
- A heavy balloon cannot be flown between sunset and sunrise under 60k ft. unless the payload is painted/equipped with flyers in bright colors

4.3.1 Application process

The permission for the first flight was the most difficult to obtain. The first application was incomplete and had to be resent with additional information. The application was reviewed by experts at the CAA and Isavia. This process took several days and was only completed just prior to the test launch with the help of Þorsteinn Pálsson who is a lecturer at Reykjavík University and a former director general of the Icelandic Civil Aviation Administration.

Consecutive permissions were based upon the first and were processed much faster.

4.4 Communication with the Coast Guard.

The team realized that at the altitude that was aimed for the balloon and equipment would pass through very strong jet streams. The team had to deal with the fact that the balloon might land on sea. Because of that, there had to be some plan that could be relied on to get the balloon. It was discussed to rent a boat but that was quickly written off due to cost. The next idea was to contact the coast guard and ask them if they could get the equipment for us, if it will land on sea or just if it will land somewhere in the highlands.

They were excited and ready to talk to the group about the next steps. Before we had a further talk to the coast guard we needed to contact all of the helicopter service companies in Iceland and get it confirmed from them that they could not perform the recovery. Since this project is for a private company, the coast guard could not perform this task without getting confirmation from the other private helicopter companies that they did not have the equipment to perform the recovery or are just not interested. Since the balloon might land on sea, none of the private helicopter companies could get the balloon due to lack of equipment. A proposal was created and sent to the private helicopter companies and there they confirmed that they could not get the balloon. It was very important to be ready when the landing coordinates of the equipment were clear and therefore the recovery team had to be ready whether the balloon lands on sea or inland. Because of that, the proposal that was made had to contain both of the conditions, the helicopter had to be able to retrieve it if it would land on sea or inland.

After the second balloon was launched and the landing coordinates were known, the coast guard were contacted. The coordinates were in the range that the guard defined as the outer range, 50 nautical miles so they accepted to try to recover our equipment.
The coordinates came from a service website for one of our tracking device, Spot. That website gave the coordinates in a decimal format. Decimal format gives degrees and part of degrees, f.e. 41.878 where the 41 is the 41 degree and .878 is a part of one degree. The coordinates that the website gave were sent to the coast guard.
After the coast guard crew had searched for an hour in the highland at the given coordinates without seeing the balloon/equipment the helicopter had to head back to Reykjavík since the time that was

planned for the recovery was limited.
After the helicopter arrived in Reykjavík the team started to think what could have went wrong. It was rather weird that the crew didn't find the equipment because the Spot is supposed to be very precise. Later the group found out what had gone wrong, and that was the format of the coordinates. The Spot website gave the coordinates in decimal but the coast guard uses degrees, minutes; second. That was the reason why the crew didn't find the equipment.

4.5 The visit to Keflavík weather station

No one in the Skyward Sphere team had any experience of weather balloons, so the team started to think if there would be anyone that had some experience. After some research, the team found out that the weather station at Keflavík airport releases 350 gr balloon carrying a radiosonde every 12 hours for meteorological purposes.

The team contacted Torfi Karl Antonsson, the head of the National Weather service (NWS) station at Keflavik airport, three members of the team went to Keflavik airport to meet him. In this visit, Torfi showed how they released the 350 gr balloon. This is accomplished with an automatic system. In this visit the team got a rough idea how it would be best to launch the balloon. Torfi also talked about their high altitude ozone measuring. That test is conducted upon request from an unknown institution in Germany. The balloon that is used to conduct the ozone tests is released manually and filled with helium.

On Thursday the 16th of February the same small team went on a second visit to Keflavik airport. Jens E. Kristinnsson was on duty that day. The reason for this visit was that the weather station was launching a 1200 gr balloon for ozone measurements. The team watched the filling of the balloon and the actual launch. Jens demonstrated how it would be best to fill the balloon and he recommended that the filling process should be performed inside. On departing, Jens donated two 350 gr latex balloons, a filling mechanism and weights that are used to calibrate the balloon during filling and to set the lift capacity. This equipment is exactly what was needed to fill the balloon. The load is hooked on the filling mechanism and the filling process begins. The helium flows easily into the balloon. When the load begins to lift, and the balloon is neutrally buoyant, the filling process ends (see Section 3.14).

4.6 Check lists

For the first flight, a check list was made for how the launch should be performed. Every step was described precisely. During our initial test launch there were some things missing so the team decided to make a check list for all the equipment needed for a full flight. This resulted in 4 check lists:

- How to fill the balloon.
- The structure.
- The electronics devices and launch procedure.
- All the equipment need for the flight.

When a flight is being prepared and launched, one person is in charge of the check lists and makes sure everything listed on the checklist is brought, all the tasks listed are done, and in the right order.

4.7 Fanfest.

Fanfest is a conference where the players of Eve Online gather to meet each other in real life. It was held at Harpa music hall in Iceland 22-24 of March 2012. Fanfest is focused on the games CCP is working on and currently available. There are numerous lectures about gaming, player versus player tournaments, parties and a lot of other activities.

At first the goal was to launch the main flight from the Fanfest venue, but due to poor weather conditions we decided to have an indoor demonstration to show off the equipment that had been used on previous flights. We decided to have it on the last day of Fanfest on the 24th of March.
The rig was put together and included 3 GoPro camera boxes, the boom, spaceship model, box with

phone, parachute and 350g latex balloon. The rig was assembled at RU except for the model and the balloon. In the entrance of Harpa the balloon was filled up with helium until it lifted more than the weight of the rig. Then the model was fastened to the boom and the box and then everything attached to the balloon. The rig was tied between two hallways in middle of Harpa where it hooverd all Saturday. From the phone there was live video stream while it was in the air in Harpa which could be watched on the Internet. Hilmar Veigar Pétursson, CCP Games CEO gave a presentation about this near space project and presented an online event for the third flight.

4.8 The University Day

The University Day was held on the 18th of February. On this day all people interested in the work done at universities around Iceland are invited to visit them. The universities use this opportunity to introduce their departments and what people can study.

For the university day, the school of science and engineering at RU asked the team to set up a prototype of the equipment in the main hall of Reykjavík University and present the project.
The prototype contained following equipment:

- 350 gr balloon donated by the Icelandic Met Office
- Samsung Galaxy Note
- Parachute (4 ft)
- Styrofoam box
- Spot

The balloon with the suspended payload hovered in the Sun, Reykjavík University's atrium, over the guests attending the University Day. A live video was streamed from the phone to a computer and on the screen the guests could see the video. This project intrigued a big part of the visitors, specially the younger ones. For the box display setup see Figure 29.

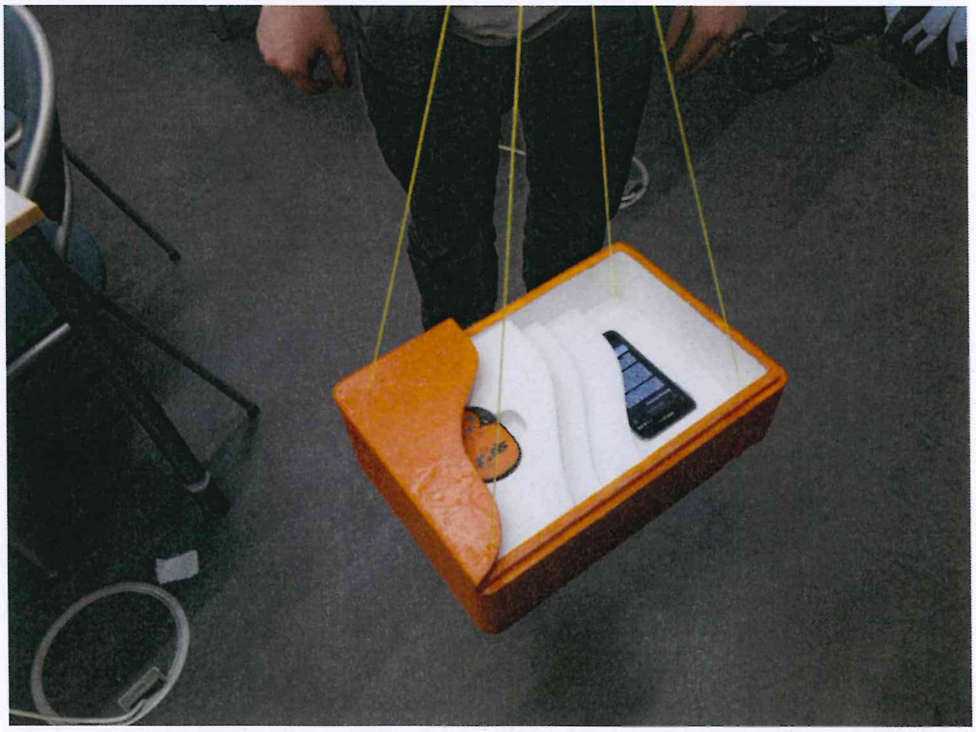


Figure 29: Box setup for the University Day

5 Process

5.1 Flight 1

The first flight was a test flight performed at 22.02.2012. The weather conditions were very good, calm winds with temperature around 0°C. In this flight we used a 3000 gr. Kaymont balloon filled with helium with a free lift of 200 gr, parachute, styrofoam box and ballast to simulate the weight of the pod and other equipment that was missing, the ballast consisted of a 10 liter container filled with dry sand until it weighed around 3 kg. We decided to include a minimal amount of electronic equipment in the styrofoam container. We used a phone to stream video, Spot for tracking and a temperature logger to log the inside temperature of the equipment box (see figures 30 and 29).

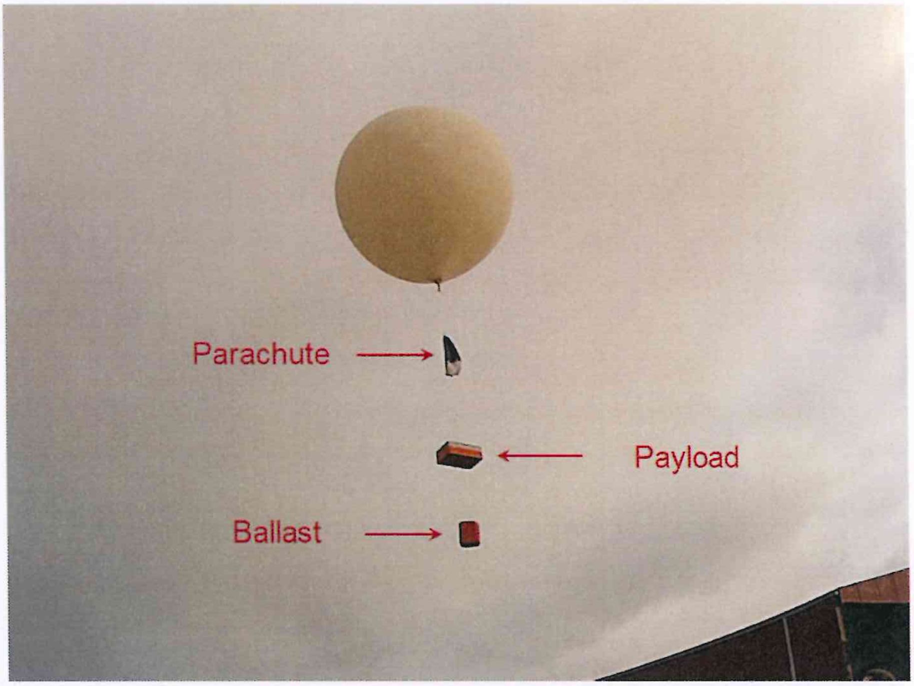


Figure 30: The test launch setup

5.1.1 Launch

In the beginning all the material was moved to the hangar and we started to get everything ready so the team could start filling the balloon when permission for the flight was granted. When the authorization from CAA came the filling procedure started, following the filling procedure check list (see section 3.14) The parachute was fixed to the tether below the balloon, then the styrofoam box attached to the parachute and then the ballast weight. When the final clearance came from air traffic control to launch and everything was ready we took it out the main hangar door and released it.

5.1.2 Post launch

After launching, the team watched the live stream from the phone and watched the track from the phone and the Spot. When it was at an altitude of about 11 km, after one and half hour flight time, the Spot stopped sending a signal and after two hours the phone stopped sending a signal. At an altitude of 18 km, all contact with the balloon was effectively lost. At this point the balloon was over middle of Iceland on the outskirts of Vatnajökull glacier. The team calculated an average ascent rate of about 2 m/s. After around six hours from the launch just as the team was about the write the test equipment off as lost, the Spot finally gave a coordinate. Shortly after, the payload fell at around 33 m/s into the Atlantic ocean, 175 km of the south-east coast of Iceland, between Iceland and the Faeroe Island (see figure 31). At that moment we realized that recovery would not be possible.

5.1.3 Results

What went well in this test flight was the GPS tracking from the phone, which ended at an altitude of 18 km when the phone lost the GPS signal. The stream stopped when it first lost the 3G connection for a short time and that made it clear it would need another application to run the stream. The application would have to be able to restart the stream server on the phone as soon it regained the data connection. Now we also knew that the Spot gave coordinates up to an altitude of 11km. It was clear that the free lift would have to be a lot more than 200 grams, about 2200 gr would have been more accurate and then the ascent rate would had been about 5,5 m/s. If the free lift is this much (2200 gr) it would call for more helium in the balloon and it would burst at around 34.000 meters. In this test flight the balloon too slowly and also went too high. The total height is unknown but the team estimated that it went roughly 40.000 meters. Because of this the equipment went too far from point of origin. To prevent this from happening again the team thought of a safety cut down that would cut the balloon free from the equipment after a certain time had elapsed. For more technical information about the cut down see section 3.17.

Figure 31: The test launch landing site

5.2 Flight 2

The Main Flight was launched on March 17 2012 at 11:23. The date was chosen because forecasts indicated that it was the best weather that we would get for a while. The weather conditions were fair in the morning, −3°C and moderate winds. As the launch preparations progressed the wind increased considerably.

5.2.1 Trajectory

For our previous flight we'd used the University of Wyoming Balloon Trajectory Forecast [15]. After meeting with one of the team members from from the HABIceland balloon team we switched over to the HABHUB trajectory forecast [6]. HABHUB's interface is much more user friendly than that of the

University of Wyoming's model. Another feature is that you can adapt the model to incorporate different ascent and descent speeds.

5.2.2 Authorization

Because of our experience with the approval process of our application for authorization for the test flight we applied well in advance for authorization for the main flight. The review process this time around was much shorter and we had the authorization letter in hand well before the actual launch date. As before the terms of the permit were to abide by the local flight regulation and call up the air traffic control tower for final clearance before the launch.

5.2.3 Payload

As this was a full scale launch, it had all the equipment and the model on board. As in the test flight a styrofoam box was used to house the delicate electronics (Trackuino, Samsung Galaxy Note and Arduino board for cut-down and logging). A boom was constructed from CNC milled styrofoam and fiber reinforced plastic rods to carry the GoPro cameras in the desired locations. The cameras were angled to view the model laterally from the front, angled down on the model from the top and one camera capturing the balloon itself in an upward direction. Due to the Spot interfering with the Trackuino, the Spot was moved to a location on the camera boom. transmitter

Figure 32: The structure and payload

5.2.4 Launch preperation

To reduce ~~Due to~~ confusion and errors in the test flight's preparation, check lists were made for all steps in the procedure. From what equipment to bring to the hangar to how the balloon was filled and the payload attached. This time around, filling and payload assembly went smoother than in the previous launch.

Reference to appendix.

5.2.5 Launch

When the balloon and payload were ready and we had been cleared with air traffic control at Reykjavík Airport, the balloon was released from its tether to the filling table, the hangar doors were opened and the balloon was brought outside. At this point the wind had increased considerably and upon exiting the hangar, the balloon was pushed to the ground. As we needed to take the slack off the line tethering the equipment to the balloon we were forced to run with the balloon across rough ground. At the point of release, the balloons altitude was insufficient to properly suspend the payload and it hit the ground, snapping the camera boom, banging the cameras off axis and tangling the lines suspending the model. The balloon and payload took off, but it was obvious that there was considerable damage to the payload and we might not get useful video from the flight. Another consequence of the crash is that the Samsung Galaxy Note was banged loose of its milled seat and the live stream showed only the inside of the styrofoam box. The crash also disconnected the phone from its external antenna. Despite of this the phone stayed in coverage for the whole duration of the flight to an altitude of almost 34km.

(photos?)

Figure 33: Strong winds when launched

5.2.6 Tracking

With three trackers on board we were sure that we would be able to track the balloon, and in fact we sure were able to in spite of the crash during the launch. The Samsung Galaxy Note, the Spot and the Trackuino all performed as planned, and in the case of the Samsung and the Trackuino, well beyond expectation. The Samsung Galaxy Note transmitted location data for almost the entire trip. It only stopped shortly before impact, when it lost the line of sight to the cell tower. The Spot performed similarly to the previous flight. It cut out at an altitude of around 11 km and re-appeared once it was on the ground. It, however, performed the task of providing the retrieval coordinates well. The Trackuino was a total surprise. It performed admirably ~~with almost zero drop out.~~ A lot of time was spent on the Trackuino build, but none of it was wasted. The aprs.fi website provides you with a live updated Google Earth .kml file that is very exciting to watch. The balloon burst at 12:55 at an altitude of around 33.300 m.

only losing communication at an expected 3000 meters altitude.

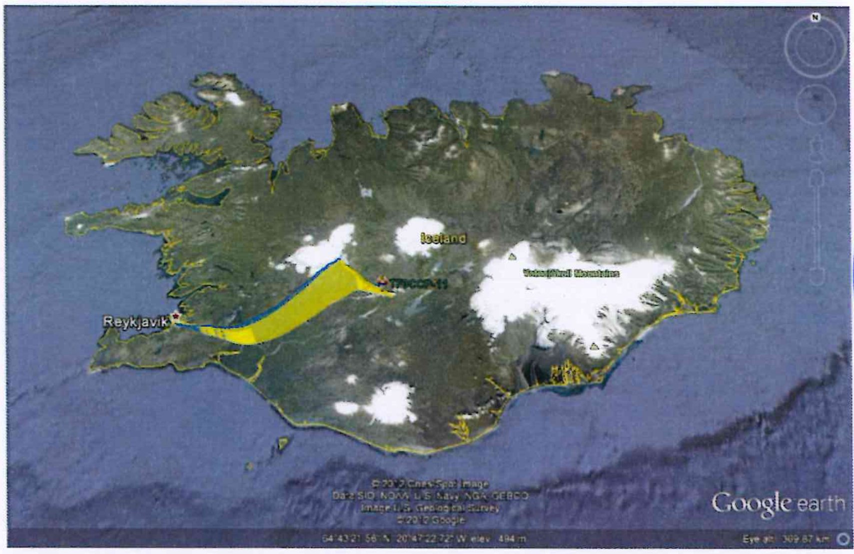


Figure 34: Second flight; predicted and actual trajectories

5.2.7 Recovery

The payload landed at 13:17 in the Icelandic highlands, near the Sultartangi hydroelectric power station. As agreed upon, a helicopter from the Icelandic Coast Guard was spooling up for a combined search and rescue exercise and retrieval mission, along for the ride was team member Þórður Sigurbjartsson and a CCP camera crew. The helicopter and its crew never found the payload in spite of accurate location data. Later we discovered that we experienced similar problems as our space faring collegues at NASA, the data from the Spot was in the decimal coordinate system but unfortunately the Coast Guard crew mistook this for conventional deg-min-sec coordinates and ended up searching in the wrong location for over an hour.

Once it became clear that the helicopter mission was a failure, groundwork was laid for a 2 car retrieval mission by 4x4 superjeeps. A member of the team and a member of the support crew had a superjeep (see Figure 35a) each. The mission was planned and provisioned during the remainder of the day and early next morning 8 people in two cars headed out for the Icelandic highlands. At this time of year there is quite a lot of snow in the highlands so the trip lasted 14 hours but only covered a distance of around 350 km for the round trip. As with most highland trips in the winter there was some excitement and brake downs. Mid-trip a drive shaft in one of the vehicles had to be fixed. The mission was a success, the entire payload was retrieved, during the landing the space ship model cracked open, besides that there was no additional damage sustained by the payload, all the electronics survived and was eventually flown again on the final flight.

(a) A superjeep during the recovery mission (b) Everything recovered

Figure 35: Payload recovery

5.3 Flight 3

CCP were eager to try another lunch and have the launch placed were they could take out their staff and form a large CCP logo. However, wind direction on the launch day made this impossible. The launch took place on Wednesday May 10 at 12:27. The weather conditions were ideal that day for a launch with less than 3 m/s winds and clear skies.

5.3.1 Launch preparation

The team was provided with a place near CCP, owned by the Icelandic Marine Research Institute. On the day before the launch, the team transported all the equipment to the this location and started the prepirations for the launch. The payload was assembled and all devices were charged. In the following morning, the team assembled at CCP main office for breakfast and then headed out to the launch site. Final preperations were made, the balloon was filled, all the electronic equipment was put in place, switched on and tested.

5.3.2 Authorization

The authorization for the flight was attained well in advance and without any problems. A slight change to the procedure where the final approval from air traffic control tower was attained was encountered. The tower requested the flights trajectory forecast and the estimated total flight time, and the estimated time for the balloon to clear 30.000 feet.

5.3.3 Launch

The launch itself went as well as could have been hoped for. No problems arose and the balloon ascended beautifully.

Figure 36: Successful launch

5.3.4 Tracking

To estimate the flight length and time we used the HabHub trajectory model. In this flight the balloon exploded earlier than expected. When it exploded there was a lot of wind and most likely some part of the rig was thrown around and hit the balloon because the balloon did not explode in many pieces, it split along the entire length of the balloon. This occurred at a height of around 20km. The pod did not go as far up as hoped. The launch itself was successful, and some beautiful pictures were recorded. All the rig apart from the pod was retrieved.

Figure 37: Third flight; predicted and actual trajectories

5.3.5 Flight

The flight of the balloon was not as straightforward as in flight 2. At a point when the balloon was well clear of Reykjavík the lines tethering the model spaceship to the camera boom and and the equipment box broke. Afterwards when we inspected the payload it appears that the quick release connectors, connecting

(Picture?)

the fishing lines to their respective tie points, in conjunction with the violent shaking experienced during the flight may have been the cause. Shortly after the the loss of the model the thrashing of the payload amplified and may have hit the balloon itself causing it to puncture and tear, resulting in a premature descent. The flight reached an altitude of around 20km.

5.3.6 Landing

The Trackuino transmitted a signal up until the very end of the flight, the final location from the Trackuino was at an altitude of 717m. Using this information the team had an approximate landing site, which appeared to be in the middle of lake Kleifarvatn. The phone also a sent signal for the duration of the flight and kept streaming almost all the time. It stopped streaming just 2 minutes before landing due to lack of coverage from the cell tower at the landing site.

5.3.7 Recovery

A member of Iceland's Radio Amateur Association, Ari Jóhannesson (TF3ARI) was the first one to arrive at the landing site. He had been tracking the flight via its APRS signal from his car. Shortly afterwards team members arrived by vehicles and then a CCP camera crew flew in on a helicopter to film the recovery. Although it landed in water, none of the equipment was damaged. The styrofoam box sealed everything inside from water and floated the payload. The GoPro's attached to the camera boom were submerged at landing, they are however contained in a waterproof housing.

Figure 38: A part of the Skyward Sphere team and the helicopter used for the recovery

6 Conclusion

A project like this is inherently labour intensive. There is a lot of research to be done, not only into equipment and methods but also what others have achieved with similar projects. Logged man hours are over 2500, unlogged work would probably add around 20% and bring the total to around 3000 man hours. This project was worked on along side numerous other courses at the University of Reykjavík.

The Hönnun course did not however consist entirely of work on this project alone.

Besides the amount of work called for, the project also called for knowledge the team didn't possess. In many cases the team adapted and was able to gain the knowledge necessary to accomplish the required tasks, in other cases, expertise was recruited from those who had the required skills. We are very grateful to all of those who lent a hand. (What skills?)

Although we tried to anticipate problems and take steps to prevent them or have ready countermeasures should they arise, there were a lot of unexpected problems. These problems we dealt with to the best of our abilities. The nature of some problems made them entirely impossible to deal with except with time. This includes the notorious Icelandic winter weather. The second flight, although partially successful was affected by the weather at launch. High winds blew the balloon laterally for a few dozen meters resulting in the payload colliding with the ground, knocking cameras out of alignment, ~~braking~~ breaking the camera boom and tangling the model tethers. Even the third flight, which took place on a beautiful day with prime weather conditions was affected by it. Strange jet winds or some form of updraft shook the payload so intensely that it appears to have impacted with the balloon and may have contributed to its premature descent.

On the equipment side, some things performed well and others didn't live up to expectations. Initially we had high hopes for the Spot tracking device, this was mainly because the device is extensively used by amateur HAB enthusiasts in the United States. In our experience the platform is not entirely reliable in Iceland. We believe that this is due to Iceland's northerly location. This creates problems for the Spot when relaying it's position over the Globalstar satellite communication system. (cite?) The Trackuino is an example of a very reliable piece of equipment. It's reliability is excellent when paired with the ÍRA members enthusiasm on the receiving end. In our opinion the Trackiuno has a bright future. It's basic design can be expanded and built upon to accomplish other tasks. There are already ideas at Reykjavík University to use it as a platform for further study. The HabHub balloon trajectory forecasting model is another example of performance beyond expectations. The accuracy of the model is exemplary. (how good?)

It is our hope that this project can be used as a starting point for further steps into scientific projects based upon high altitude ballooning. We are already looking forward to phone calls from students working on similar projects sometime in the future.

Conclusion? Did you meet customer requirements or not. Needs to be stated here.

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Reykjavík University
Hagnýtt verkefni
Hönnun

Spring semester, 2012
Submitted: May 11

Skyward Sphere
CCP Space Program

Project report

Nice job with citations

Needs more details and quantitative data.

Needs appendix with CAD models, simulations, circuit diagrams, BOM

Report by:
Students of Hönnun 2012

Contents

List of Figures

1 Introduction

Skyward Sphere is a high altitude balloon project. The project's primary goal is to send a high altitude balloon with video cameras to record video of a model, provided by the project's main sponsor, in the stratosphere and then retrieve the model along with the equipment. The secondary goal is to maintain a 3G connection and stream video from a smartphone during the majority of the flight. Third goal was for more academic purposes, measuring pressure and temperature at high altitudes. The project was done in cooperation with CCP Games and Síminn. Work started on the Skyward Sphere project at Reykjavík University (RU) in mid-January 2012.

2 Background and context

2.1 Partners

There were two sponsoring partners involved in this project:

- **CCP Games:**
  CCP is this project's biggest sponsor. CCP Games is a gaming company in Iceland that develops the massive multiplayer online game EVE Online. The Eve Online universe is a virtual reality. *"Virtual reality is about true human interaction and true human emotions in a living and evolving world"*[4]. EVE Online is set in space and the players venture on adventures to secure resources. The game is a science fiction world with a big focus on economy.[4]

  CCP's goal with this project is to do something interesting for the community of EVE players.

- **Síminn:**
  Síminn is Iceland's biggest telecommunications company. They supplied us with the infrastructure and expertise that made a 3G data connection at this altitude possible. Síminn also provided us with Samsung Galaxy Note smartphones for the flights.

  Síminn's goal for project is of marketing value and also to test 3G capabilities of their systems.

2.2 Technical problems

The problems faced in the beginning were varied and many. A model of a spaceship had to go up to a minimum of 30.000 meters. It had to be possible to record video of the model with the curvature of the earth as background. There had to be tracking equipment for recovery. The temperature can go down to -55 °C at 10 km up to 16 km height[14].

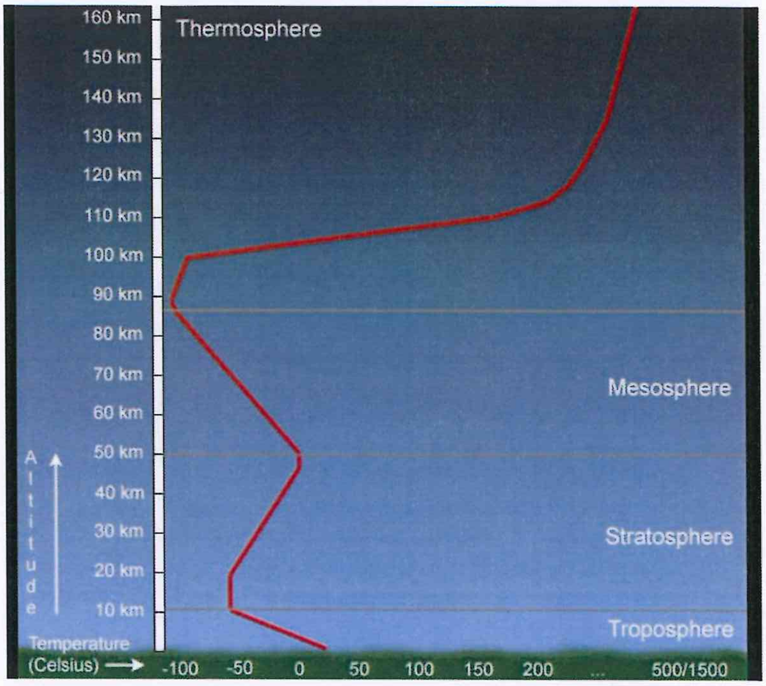


Figure 1: Temperature change with height. [16]

At a height of around 5 to 12.5 km there are strong winds called jet winds [14]. The design of the structure had to withstand these high altitude weather conditions. The electronics had to be protected from the cold, had to be waterproof and handle the impact of landing without loss of data. Because of the small size of Iceland and strong winds, it's necessary to choose the launch site carefully ~~so the payload doesn't~~ to avoid landing in the ocean. To lift up the heavy load, estimated at 3-5 kilograms, to such a high altitude, a large and strong balloon was needed.

2.3 Resources

To solve this task, the following resources were required. A more detailed description of the resources and equipment used can be found in the subsections in chapters 3 and 4.

Material:	**See Sections:**
Tracking equipment	3.1 & 3.2 & 3.3
Smartphone	3.4
Electronics box	3.5
Release mechanism	3.8 & 3.9
Cameras	3.11
Latex weather balloon	3.12
Gas lighter than air	3.13
Parachute	3.15
Spaceship model	3.16

Table 1: Resources

(Nice, though isn't this a repeat of the table of contents?)

3 Technical information

3.1 Spot

For tracking the balloon's path we looked into numerous devices. The tracker had to meet the following requirements:

Waterproof
: If the payload landed in water. Also if there was heavy rain,

Light weight
: Because of weight limitations imposed by regulations and cost considerations, the team had to minimize the weight of the equipment. The weight of the payload could not exceed 8 kg, because that would call for extra tracking systems, light system and radar transponders as described in section 4.3. Also the balloon can't lift more than ca. 5 kg to reach 33 km height with an acceptable ascent rate.

Low energy usage
: To minimize the battery weight we had to choose a tracker that used as little energy as possible.

After surfing the internet looking for good solutions to this problem, we ended with two main options. On one hand there was a tracker called „Yellowbrick "[17] and on the other hand there was tracker called „Spot"[12].
The main specifications for these devices can be seen in Table 2.

Device		
Specifications	**Yellowbrick**	**Spot**
Battery	5,3 Ah LiPo	3 AAA batteries
Transmissions time	ca. 10 days	limited to 1 day
Operating temp	-30°C to 60°C	-30°C to 60°C
Waterproof	yes (1m/30min)	yes (1m/30min)
Weight	305 grams	147,4 grams
Price	81.000.- ISK	32.000.- ISK

Table 2: Information for tracker devices

As can be seen in Table 2 these devices have almost the same specifications apart from weight and transmission time. The transmission time on the Spot is limited to 24 hours, that is enough for our purpose because the plan is to recover within a day from launch. That leaves two deciding factors, the weight and the price. The Spot is less than half the weight and price of the Yellowbrick so it was decided to choose the Spot device (see Figure 2) for this system.

Figure 2: Spot tracker device

3.2 Trackuino

The team stumbled onto the Trackuino project [13] when doing a Google search for tracking options for the project. The Trackuino project is an open source project maintained by high altitude ballooning enthusiasts who need a simple platform for tracking their balloons. The Trackuino is based upon 3 main components. At its core is an Atmega328p processor running the Arduino bootloader, making it compatible with the Arduino IDE. The Atmega receives serial GPS data from a Venus 634FLPx GPS receiver. The Trackuino's program integrates the GPS data into APRS (Automatic Packet Reporting System) [2] packets and transmits them via a Radiometrix HX1 transmitter. The APRS system receives these packets and displays them online.

(Need a system diagram)

3.2.1 Making printed circuit board (PCB)

The base of the Trackuino is a dual layer printed circuit board (PCB). Being dual layered it has traces on both sides of the PCB. The board was handmade in Reykjavík University's electronics lab with photoresistive etching. A prototype PCB was made which was unusable due to spotty transfer of the photoresistive agent onto the blank PCB. This resulted in blotchy traces on the PCB. A second PCB was made after adjustments were made to the printing and etching processes. By printing at a higher resolution and exposing, developing and etching for a slightly longer duration, the resulting PCB looked excellent. The PCB was drilled for 0,7 mm and 0,5 mm holes, see Figure 3. Later, a second PCB was made due to failure in assembly and soldering of the first board.

with the same process

(ok. how long? what resolution?)

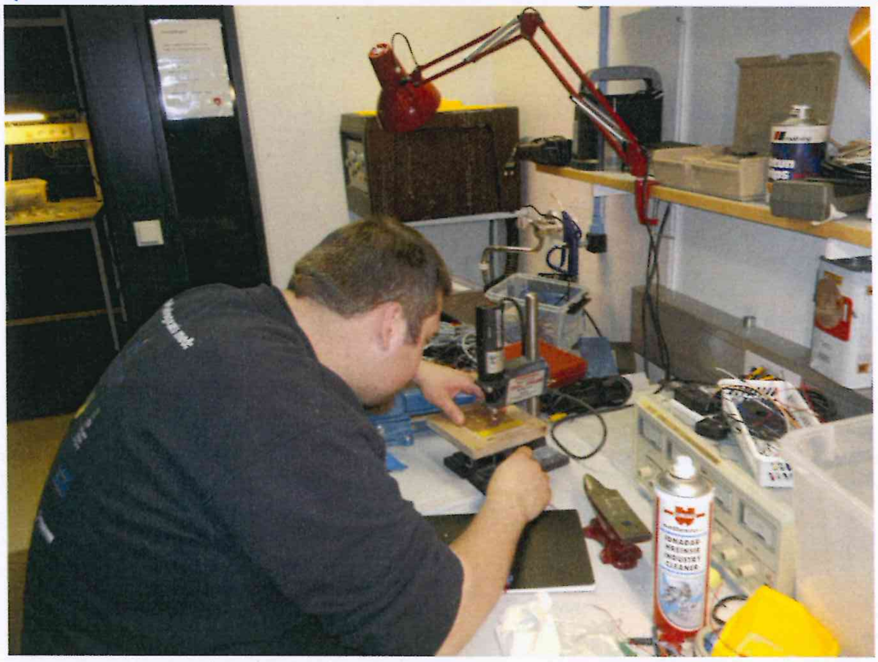


Figure 3: Trackuino PCB being drilled for components

3.2.2 Populating PCB

The Trackuino PCB (see Figure 5) was populated in accordance to the bill of materials (BOM) provided by the Trackuino project. Major components are the Atmega microcontroller, the Venus GPS receiver and the Radiometrix transmitter. Other notable components are 3.3V and 5V voltage regulators, screw connectors for connecting power and external components and a MOSFET for enabling the Trackuino's cut-down feature. Miscellaneous minor components are on the board including capacitors, resistors, diodes pinheaders, LEDs and a crystal oscillator.

Need to put circuit diagram + BOM in appendix. Put reference.

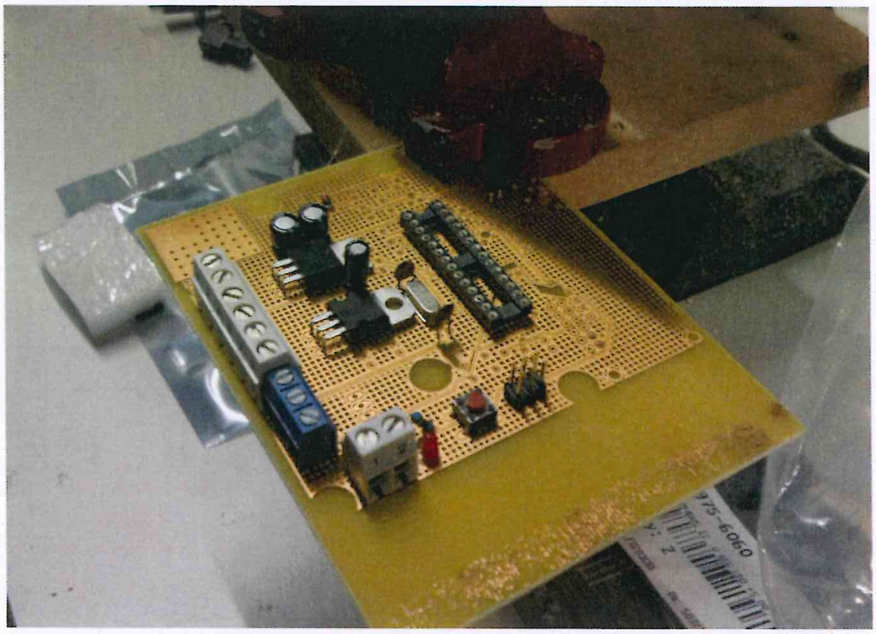


Figure 4: Trackuino PCB being populated with components

The first attempt at populating the PCB failed. This was due to the PCB not being cleaned of the remainder of the photoresistive material from the photoresistive etching process, lack of connections on both sides of the PCB and ~~simply sloppy~~ errors in soldering. A second PCB was made and the RU's electronics lab technician Hrannar Trauston was drafted for soldering.

3.2.3 Programming the Atmega 328P

The Atmega chip that the team procured was a standard version, i.e. it did not contain the Arduino boot loader that enables it to recieve Arduino coded sketches. After initial problems due to the first Atmega chip being defective the team managed to burn the Arduino bootloader onto the Atmega chip. The bootloader was burned onto the Atmega chip with an Atmel STK500 development system and firmware downloaded from ....

3.2.4 Trackuino antennas

Due to limited knowledge on the subject of antennas we decided to seek out help on this subject from members of the Association of Icelandic Radio Amateurs (ÍRA). For the GPS receiver, a basic off the shelf active button antenna was used. It was necessary to shorten the cable running from the antenna to reduce weight. The initial design ideas were to make a basic dipole antenna by using coaxial cable. According to calculations by the ÍRA expert Jon or Sam? the length of each pole of the dipole antenna would have to be 500mm.

3.2.5 Testing the Trackuino

A first test of the Trackuino was unsuccessful. No telemetry was received from the Trackuino, neither via the online APRS.fi tracking system nor with a handheld radio in the vicinity of the Trackuino set to receive APRS packets. After careful measuring it was revealed that the Trackuino had a few traces interconnected. This was fixed and the Trackuino was tested again, this time performing as expected.

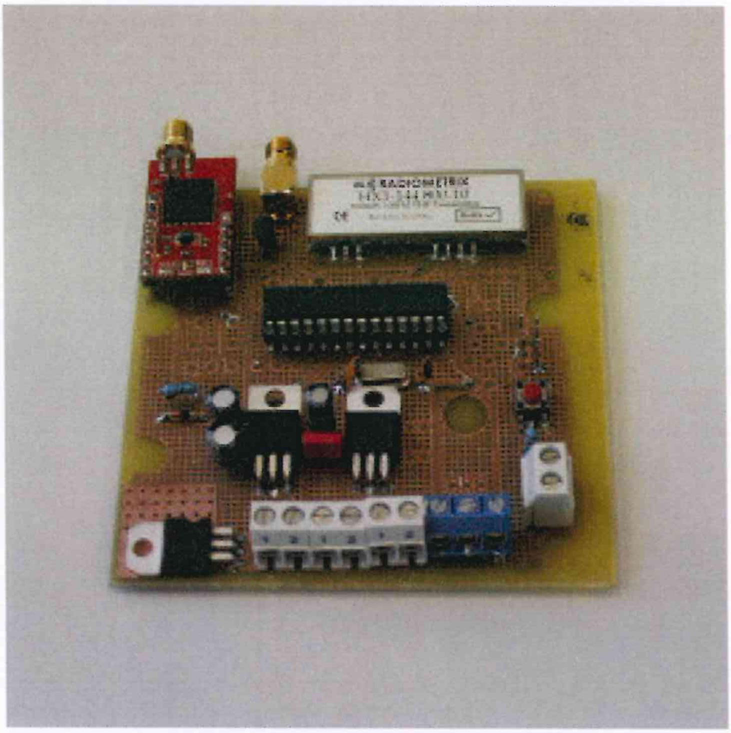


Figure 5: Finished Trackuino

3.3 Antenna ← Need to combine with 3.2.4

After we finished building the Trackuino, two antennas were needed. One for the GPS module and another for the VHF transmitter used to transmit the APRS data. The antenna for the GPS module was standard off the shelf active GPS button antenna. The team had to design and build the antenna used by the VHF transmitter. The VHF transmitter transmits on frequency of 144,8 MHz. Based upon advice from Samúel Guðjónsson and Jón Þ. Jónsson the team decided to use a dipole antenna with both poles made from a piece of wire. The alternative solution was to make a dipole from a wire and a plate of sheet metal. The plate was supposed to be under the foam box, but that would have caused too many problems, e.g. covering the phone lens, reducing phone reception and the wire would be directly in one of the GoPro's views, not to mention the added weight of the plate.
The antenna was made with $0,75\ \text{mm}^2$ wire. To calculate the length of the antenna we used the following formula provided by the radio amateurs $l = \frac{143}{f}$, where f is the frequency of the signal, which gives us the total length of the antenna (length of both poles). The length is approximately $0,988$ m.
When the team had designed and built the antenna, the next problem was to find a good place for it. The first idea was to put it on or inside the camera boom. However after attaching the antenna to the boom the team discovered a problem when measuring the standing wave ratio (SWR). It was found that almost all the transmission power was reflecting back to the Radiometrix transmitter, that meant that no power was going into sending the APRS package down to earth. Obviously this wasn't going to work and another solution was needed. The next idea was to move the antenna up into the tether between the parachute and the equipment box. Again the team measured the standing wave and it looked better. However wire for the cut down as well as the coaxial cable connecting the antenna to the transmitter contributed to an increased standing wave. The final solution was to have the antenna there, and simply fasten the coax cable from the antenna and the cut down wire to the upper end of the boom moving them away from the antenna itself. → (Need diagram, otherwise this does not make sense)

(What SWR values?)

3.4 3G phone

To be able to stream video through Síminn's 3G network a smart phone was needed. The things the team had ~~to have~~ in mind when choosing a device for the project where the following:

- ~~Withstand~~ operate under the extreme conditions, mainly the cold (?c)

- External antenna connector
- Good battery life
- Good range of applications available

Síminn provided two smartphones for testing, a Samsung Galaxy Note and a Motorola RaZr. Both of these phones seemed to meet the above requirements. The team however had no idea if the battery life would be sufficient, given the extreme temperatures the device was likely to encounter during the flight. To determine this, the phones were tested using a -80°C freezer to evaluate low temperature performance. The test was done by turnin all required applications on in the background and setting up a GoPro camera to record the time when the phone shut off. After 30 minutes the phones where extracted from the freezer. Both seemed to not be working. It was noted after looking at the video from the camera that the Motorola RaZr lasted 11 minutes and the Samsung Galaxy Note lasted for 27 minutes. Thus the device that was chosen was the Samsung Galaxy Note (for freezer test see section 3.7). The Samsung Galaxy Note (see figure 6) is a high end mobile device. Some of its features are:

- 5,3" WXGA HD super AMOLED screen
- 1.4GHz dual core processor
- Full HD video recording 1080P@24 - 30 fps
- 8MP rear camera
- 2MP front camera
- Standard battery, Li-Ion 2,500 mAh

Figure 6: Samsung Galaxy Note smartphone

3.5 Equipment Box

The equipment box is the smallest styrofoam fish box available, 3-5 kg and the outer dimensions including the lid are: 400x266x130 (LxWxH) mm and it weighed in around 194 grams. (why did you pick?)

The smartphone needed to be fastened inside the styrofoam box that stored our electronic equipment. The idea for the test flight was to make it as simple as possible so the team thought of fastening the phone down with wire or plastic cable tie. This was tried out by doing a small experiment by hitting the box with the phone inside to the floor, over and over again. The styrofoam in these boxes is not very stiff, the density is around 15 $\frac{kg}{m^3}$, and when the test was executed the fasteners ripped the box open.

It became clear that this solution was not an option. The team had to come up with a better solution, and it would be best to find a solution that would work for all of the flights. After rethinking the way to do this, we decided to mill out foam plates that fit inside the box and had seats for all the equipment e.g. phone, Spot and Trackuino. The plates were designed as layers, and one device put in each layer. ← diagram!

First the team had to design the foam plates and the seats for the equipment, this was done in Solidworks 2010. The plates were then milled out in a CNC mill.

The foam came in big blocks of 500 x 1000 x 50 mm. The CNC machine can take limited volume so it was necessary to find a way to slice these blocks into smaller pieces that would fit into the CNC mill.

For this project the team made a small foam cutter, it is made from two wire holders, held down with two clamps, that a special resistance wire is strung between. To adjust the cutting thickness we simply slide the wire up or down the wire holders. A power supply was connected to the two different sides of the wire, when power is applied, the wire heats up.

what resistance? what size of wire? what settings on the power supply?

Figure 7: Foam cutter

2

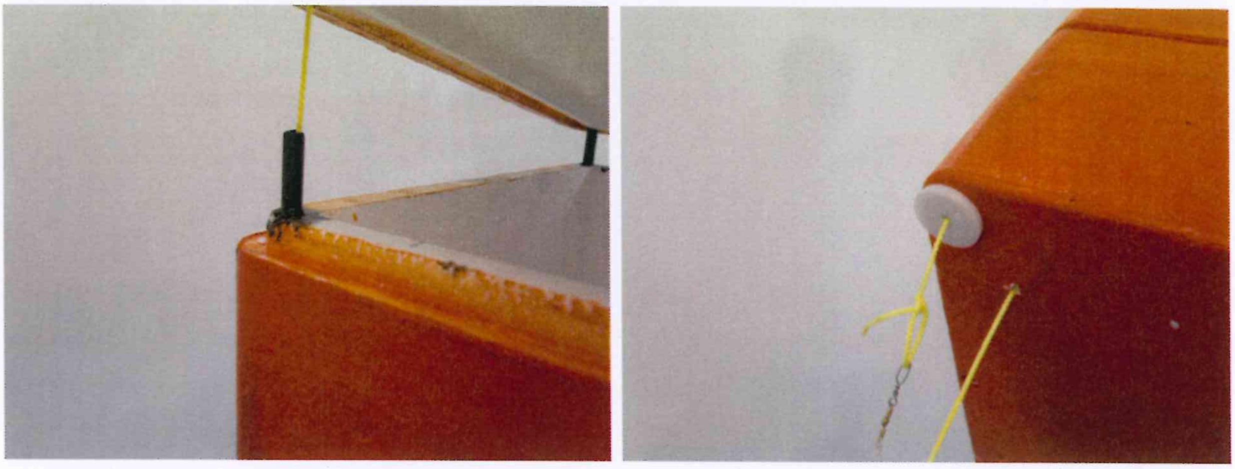
3.6 Box test

After deciding to use a styrofoam box for the electric equipment, some tests were required to find out the reliability of how the box was attached to the balloon. To fasten the box to the balloon we simply drilled holes in the four corners of the box and glued thin carbon pipes in to the holes (Figure 8a). Strings were threaded through the pipes and tied to plastic washers at the bottom of the box (Figure 8b). When the fastening mechanism was fully designed it had to be reliability tested. This was done at RU by filling up four half litres bottles with water, putting them in the box. Then on the third floor one end of the string was tied to the railing and then the box was thrown down (Figure 9). This design withstood the test ~~perfectly~~, so we decided to use it.

diameter?

with no visible damage

Good, but picture of test?



(a) carbon pipe glued into corner of box

(b) plastic washer that the string was attached to

Figure 8: Balloon attached to the equipment box

Figure 9: „Earth“ corridor test

3.7 Freezer test

The balloon was estimated to burst at a height of approximately 34.000 meters, this is in the mid stratosphere. On its way it will encounter extreme cold[3]. There were some ideas in the group about the extreme weather conditions and how to counter the extreme cold. The team decided that various components needed to be tested.
The crucial components to test were:

- Cameras : Go Pro (model?)
- Phones: Samsung Galaxy Note versus Motorolla RaZr
- Carbon fiber rods
- Tape: Tape on styrofoam and tape wrapped onto itself
- String
- Styrofoam

It was not easy to get a place to test these components in extreme cold. The companies that have freezers below -50°C are mostly in the food industry and there are very strict regulations on what can go in these freezers. After consulting with Joe Foley we decided to try the Icelandic Innovation Center (Nýsköpunnarmiðstöð). Markéta Foley, a researcher at the Icelandic Innovation Center informed us that they do not have freezers operating in this temperature range. Markéta pointed us toward the Agricultural University of Iceland (LBHÍ), as it turned out, they have freezers working in that range. The freezer test was performed in the following fashion.

A GoPro camera was set up looking at the phones. It would record when the phones would stop functioning. The test lasted for 30 minutes and had the following results:

Camera The camera stayed functional for the duration of the test, it appeared to have suffered no ill effects from the test. The test drained the cameras battery by about half it's capacity.

Motorola RaZr The Motorola RaZr remained powered on for approximately 11 minutes.

Carbon fiber rods The Carbon fiber rods had no visible changes. Approximately the same force was required the break a frozen rod compared to one at room temperature.

Duct tape The duct tape appeared to have the same holding strength at the testing temperature as it did at room temperature. The duct tape performs much better when taped onto itself compared with when it's taped onto other materials e.g. styrofoam and plastics.

String The string had no visible changes, approximately the same force was required to break a room temperature string compared to the frozen one.

Styrofoam The styrofoam had no visible changes, it did not become more brittle at the test temperature as we had feared.

These things were all used in our flight, only one was added later, fishing line.
Fishing line was added so we could reduce visibility of the strings attached to the spaceship model, also it's worth noting that a string can absorb water during it's ascent, this water could freeze and lead to degraded strength.

3.8 Release mechanism

We were thinking of a way to release the balloon and the equipment out on an open field. To do that there would have to be no wind on the balloon or something to hold the balloon in place. After some search on the internet we found an interesting project, the Samsung Space Project [11]. There the Samsung team used some sort of a tent to fill the balloon under while it's made ready for launch. When everything is ready, the top strip of the tent is pulled off and the sides of the tent are pulled away from the balloon and it is free to rise to the sky.

Our mechanism was made from three sections of plastic tarp with grommets, pegs and strings. One tarp was fastened down with pegs to cover the ground. The roof was made out of the remaining two tarps that were fastened together. This was done by tying a fixed loop to the grommets on one side of the first tarp and pull it through the grommets on the second tarp and then thread a string through the loops (see Figure 10). Then these two tarps were fastened down on the same pegs as the floor. When the balloon and equipment is ready, someone will pull the string threaded through the loops to loosen the two tarps. This would open the roof and free the balloon to rise to the sky (see Figure 11.

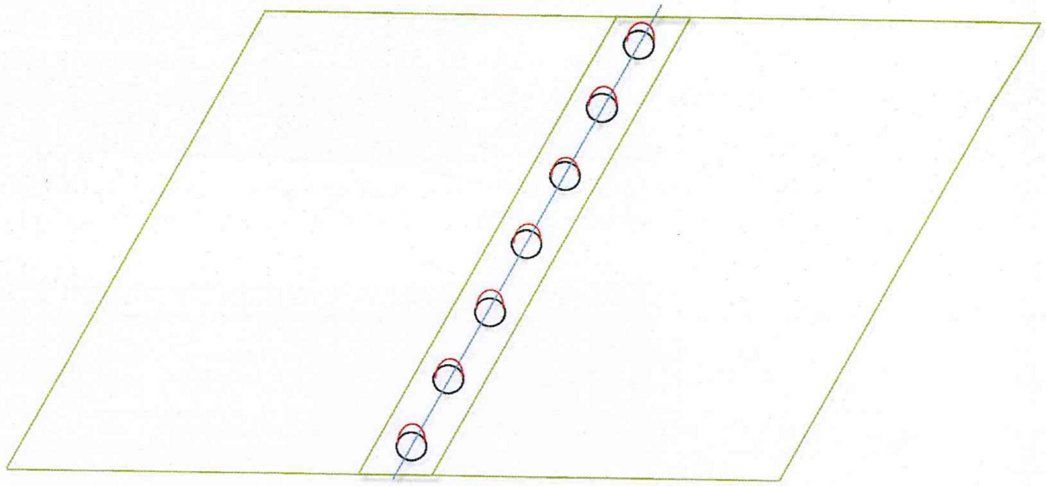


Figure 10: Isometric view of the release mechanism

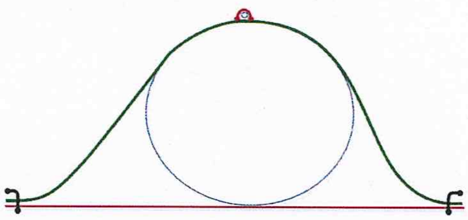


Figure 11: Sideview of the release mechanism

The plastic tarp was picked because it did not damage the balloon easily, was cheap and lightweight.

The balloon is pretty delicate once inflated so we did some tests to see if the tarp could damage the balloon. Normal party balloon was filled up and roughly rubbed against the tarp, this lead us to notice that the grommets on the tarp were too sharp. To fix this problem we applied duct tape to the grommets on the same side that could touch the balloon.

3.8.1 Release Mechanism Test.

The release mechanism was tested outside on the grounds of the RU campus. The wind was around 10 m/s and temperature 0°C, in these weather conditions it was hard to handle the size of the tarps. To begin with the bottom tarp is spread out and pegged down. On top there were two tarps zipped together with string in the middle and tied down with pegs on two sides. The other two sides were supposed to be open so the team could go under the tarp and fill up the balloon.

The result of this test was that it is not as easy as it supposed to be to go under the tarp and work with the balloon. The tarp beat around a lot in the wind and it is not comfortable to be under it doing the work, even when the wind speed was lower.
The best way to fill and prepare the balloon is to be inside in totally still weather so we decided to find a better solution. See section 3.9

3.9 The old hangar

When it was clear that our cunning release mechanism would not work in Icelandic weather conditions we decided to try to find a place where the team could prepare and release the balloon. There is an old and partly broken airplane hangar (see Figure 12) between Reykjavík University and Reykjavík domestic airport. The hangar is not in use so it is ideal to use it as a staging area for a launch. Inside, there is enough space, the vertical clearance inside is six meters and the door opening is five meters high and 10 meters wide. This is enough because when the balloon is launch ready it is about 3,5 m in diameter. The size of the hangar and location, near the school, make it an ideal place to launch from during the stormy winter in Iceland.

Figure 12: The old airplane hangar

For convenience the team built a table 2,4x2,4x0,9 m (LxWxH). The sides were made out of industrial wooden pallets with tarp stretched over to form the table surface (see Figure 13). The tarp used for the table was the same as was intended for the release mechanism. This table allowed the team to have a safe place to lay the balloon while filling without damaging it.

Figure 13: The table with the 3000 gr balloon on it

3.10 Boom

The requirement for the boom is to have it as light as possible and stiff enough to not bend due to the weight of the GoPro cameras.

Boom design
Top things to have in mind when boom was designed:

- Strong
- Light
- Long enough
- Attachable
- Stable

The first idea was to use carbon fiber bars or balsa wood. Balsa wood would have been much cheaper than buying carbon fiber. Carbon fiber is expensive, but by using used/damaged carbon fiber hockey sticks it was free.

By making the boom out of the damaged hockey sticks the boom would have weighed in around 600 grams. the carbon fiber sticks would make a very stiff boom, but it was hard to attach. The sticks are very brittle so it's hard to modify them.

The artist making the pod gave us some very thin carbon fiber rods early on. The team did not see any use for them at first but we came up with a clever idea on how to make the boom stiff and light with help from these thin rods. The rods came in 2 different thickness:

- Thin version 4 mm in diameter
- Thicker version 6 mm in diameter

The lenght of the rods was 1 m. The boom had to be longer than that so the rods were fastened together, the thinner rod was machined so it would fit inside the thicker rod, then two 6 mm rods were joined. With everything glued together, forming a 2 meter rod. The boom then consisted of 3 x 6 mm rods and triangle shaped foam spacers (see Figure 14).

Figure 14: Triangular foam spacers for the boom

Boom
The boom which is below the styrofoam box has the GoPro cameras on each end. One camera on the upper end and two on the lower end (see Figure 15). The camera on the upper end had top view on the spaceship model, one camera on the lower end had side view on the spaceship model and the third was

facing upwards toward the balloon and the rest of the equipment.

Figure 15: The setup of the equipment.

3.11 Cameras

The team used 3 GoPro HD Hero2 (see Figure 16) video cameras for this project. They are known for good reliability in extreme conditions. They also have a very wide angle of view. The view gets narrower the higher resolution you use. To record full-HD video (1920x1080) the highest resolution is needed with a viewing angle of 127°. Everyone wanted the best video quality possible so all cameras recorded full-HD video.

The cameras came with original GoPro cases (see Figure 16, the case has basic fasteners. These fasteners were used to fasten the camera to the boom. The team designed a special camera box for the camera that would hit the ground first, this proved not only to be very useful for the impact but also for thermal isolation, as it turned out during the second flight the cameras that were not in a styrofoam box died, but the one in the styrofoam box survived the whole flight and recorded video until it landed. The other cameras were not isolated and appear to have run out of batteries a lot sooner than the isolated one, or after 1h and 45 min. That time was too short to record the whole flight. Though only 5 more minutes would have done the job.

Figure 16: GoPro Hero 2 video cameras

3.12 Balloon selection

There are several types of HAB (High Altitude Balloons) available on the market and are, among other things, being used for projects like high altitude scientific or meteorological research and photography. Most commonly there are three types used for these purposes;

1) **Latex meteorological weather balloons** are categorized into grams which indicate the weight of the balloon itself. These balloons vary in sizes between 150-3000 grams and have a flight time of 2-4 hours, which mainly depends on filling volume and therefore payload weight. The filling volume of the gas injected into the balloon is determined by the weight it will carry, along with necessary free lift, giving the balloon constant ascent rate for the climb. Those balloons will constantly expand due to decreasing atmospheric pressure at higher altitude and finally explode when maximum elasticity in the latex material is reached and fall down.

2) **Zero pressure envelopes or balloons** are often made of thin, but rather durable polyester film which allows the gas inside the envelope to expand due to constantly reducing atmospheric pressure. But only so much that it fills up the entire envelope containing a constant volume of gas inside while excess gas expands throughout an open intake nozzle on the envelope bottom. This feature enables the gas pressure to equalize inside the envelope to a certain outer atmospheric pressure, making the zero pressure balloon able to float at constant altitude for days.

3) **Super pressure envelopes or balloons** are made of thin, but extremely durable and elastic polyester film which enables large pressure to build up inside the envelope while the balloon gains altitude. One way pressure regulator valves hold a constant pressure inside the envelope causing the envelope material to expand and equalize to a certain floating altitude. Super pressure balloons have floating capabilities upto weeks or months and are mostly used for high altitude scientific research on a larger scale.

Balloon selection generally is dependent on project size, budget and the objectives of the project. To optimize the selection, certain questions needed to be answered. For the Skyward Sphere project, the balloon selection was affected by following concerns;

a) **Altitude** required for this mission to succeed was estimated to be anything over 30.000 m for sufficient high altitude photography.

b) **Payload weight** was estimated to reach up to 5000 gr including all electronics, cameras, parachute, model and all payload structures.

c) **Flight time** needed to successfully complete the mission objectives would not have to be long so 1-2 hours of successful video recording including a view at peak altitude would be considered successful.

d) **Travelling distance** had to be minimum, or in a range of 100 km into land to make recovery possible. Travelling distance depends on ascent rate of the balloon (gas volume) and high altitude winds.

e) **Cost or budget** was a very important factor and played the biggest role in balloon selection. For this project, the budget was rather low which set a rather restricted boundaries to the balloon selection.

f) **Regulations** were one of the important aspects as a larger balloons like zero or super pressure envelopes are especially made for heavier payloads and therefore has to meet stronger regulations of the CAA.

Based on the considerations listed above, the most economical solution for this project was to select a 3000 gr latex meteorological weather balloon from the supplier Kaymont Consolidated Industries. This supplier is by far the most known on the meteorological weather balloon market. Boundaries of the payload were set by the largest available latex balloon available from the Kaymont supplier with respect to the desired altitude.

3.13 Gas selection and lifting properties

For this project, three types of gases were available and considered as a realistic option as balloon inflation gases that gave proper lifting capabilities.

a) Hydrogen, H

b) Helium, He

c) Methane, CH_4

To estimate potential lifting capabilities of the balloon for each gas type, basic buoyancy calculations were made. Equation 1 shows potential buoyancy of each gas listed above where F_{gross} is the force produced by total weight of all equipment plus the balloon it self, ρ is the density of air and the lifting gasses at sea level, g is the acceleration caused by gravity and finally $V_{balloon}$ is the filling volume of the balloon.

$$F_{buoyancy} = V_{balloon} \cdot (\rho_{gas} - \rho_{air}) \cdot g - F_{gross} \tag{1}$$

Because buoyancy depends on the difference of the air and gas densities, it is sufficient at this stage, to examine difference in buoyancy between gases for only $1m^3$ of volume and skip the gross weight of the system to obtain only effective buoyant mass by dividing Equation 1 by earth's gravitational force, g. The equation is reduced to:

$$m_{buoyancy} = V_{balloon} \cdot (\rho_{gas} - \rho_{air}) \tag{2}$$

By replacing $V_{balloon}$ with $1\frac{kg}{m^3}$ and with little bit of algebra the buoyancy estimation formula finally becomes:

$$m_{buoyancy} = \rho_{gas}(1 - \frac{\rho_{air}}{\rho_{gas}}) \tag{3}$$

With, $\rho_{air} = 1.292\frac{kg}{m^3}$, Table ?? shows calculations of the effective buoyancy mass for each of the three available lifting gases mentioned above.

Gas	Density, $\rho_{gas}\left[\frac{kg}{m^3}\right]$	Buoyancy mass, $m_{buoyancy}[kg]$	Cost [ISK]
Hydrogen, H	0.090	-1.202	31.016
Helium, He	0.178	-1.114	53.280
Methane, CH_4	0.6556	-0.6364	

Table 3: Effective buoyancy unity mass of gases

As seen in Table ??, hydrogen has the most lifting capabilities and methane the worst. Table ?? shows advance of lifting capabilities between available gases in percentage.

	H	He	CH_4
H	1	7.9%	88.9%
He		1	75%
CH_4			1

Table 4: Comparison of lifting capabilities between gases

As seen from Tables ?? and ??, hydrogen has the most lifting capacity based on the effective buoyancy mass but methane the least.

Another concern that had to be accounted for, besides lifting capabilities, is the cost of each gas type and possible fire hazard. For this project, helium was chosen as inflation gas for the balloon. Helium is a more expensive choice than the other gases but is much safer during the inflation process compared to hydrogen or methane which are highly flammable [1], also helium has only 7.9 % less buoyancy in air than hydrogen [9].

The team's gas supplier was Ísaga. Ísaga is a known gas supplier in Iceland. Ísaga also recommended helium for this project because safety should always be a top priority when dealing with gases. (Ha!)

3.14 Inflation process

Volume of the lifting gas used to inflate the balloon depends on several factors;

1) Ascent rate

2) Burst altitude

3) Gross lift

Some explanations are needed to understand the basics of lifting capability phrases in high altitude ballooning. The equation below shows how free lift or buoyancy of a balloon is calculated. Often, the earth's gravitational force is excluded from every the lifting capabilities and therefore described only by mass.

$$m_{buoyancy} = m_{net} - m_{gross}$$

or in more common way;

$$Freelift = Netlift - Grosslift$$

(Need to fix formatting)

where;

- **Free lift** is the buoyancy of the balloon after including all attached payloads and the balloon itself. Buoyancy gives the balloon a certain ascent rate for the climb.
- **Net lift** is the force necessary to lift the mass of all attached payloads and balloon itself.
- **Gross lift** is the force necessary to lift the mass of all attached payloads excluding the balloon.

To estimate the filling volume, dominant factors regarding the ascent rate and gross weight were decided in advance.
Ascent rate should be at least 6 m/s.
These pre decided factors directly affect the burst altitude, buoyancy force or free lift and filling volume. A burst calculator [6] was used to estimate the filling volume based on these predetermined factors, giving the volume of 11.7 m^3 along with free lift of 4 kg. However one must remember that the filling volume for desired ascent rate and gross weight does not have linear relation with variations of balloon type and size. (Cite?)
Several steps were followed in a special made filling and handling procedure for this project. Shown in Fig 17

1) With figure 17 let's start by introducing the equipment used for inflating the balloon.

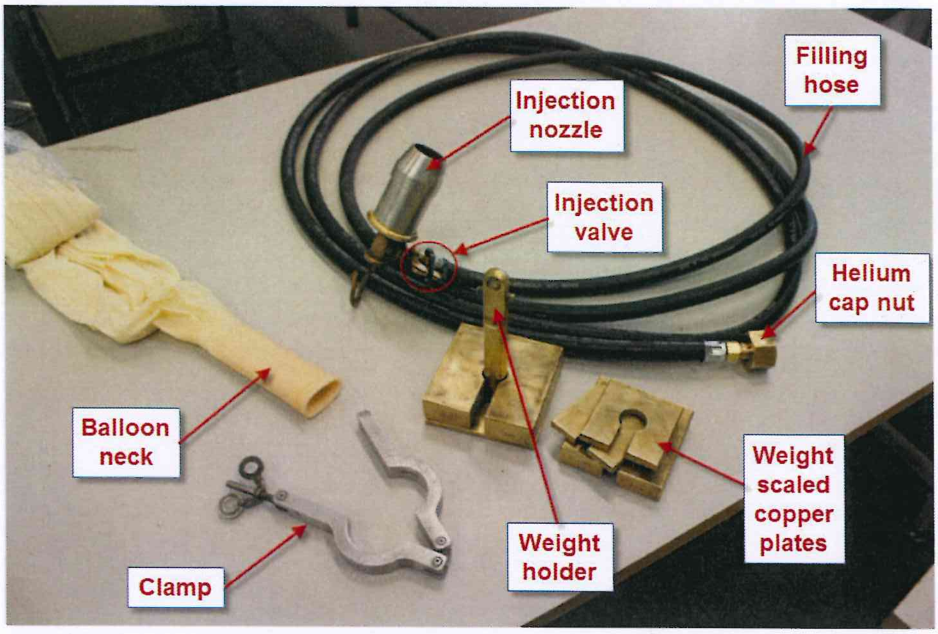


Figure 17: The filling equipment

2) The entire payload, including parachute, strings and other additional objects, is weighed using a ~~fairly accurate~~ scale.

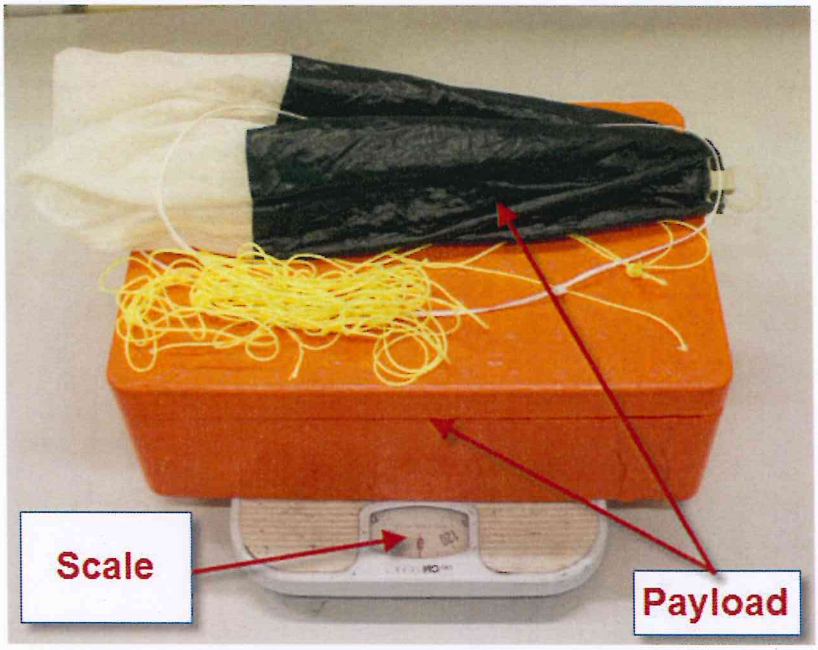
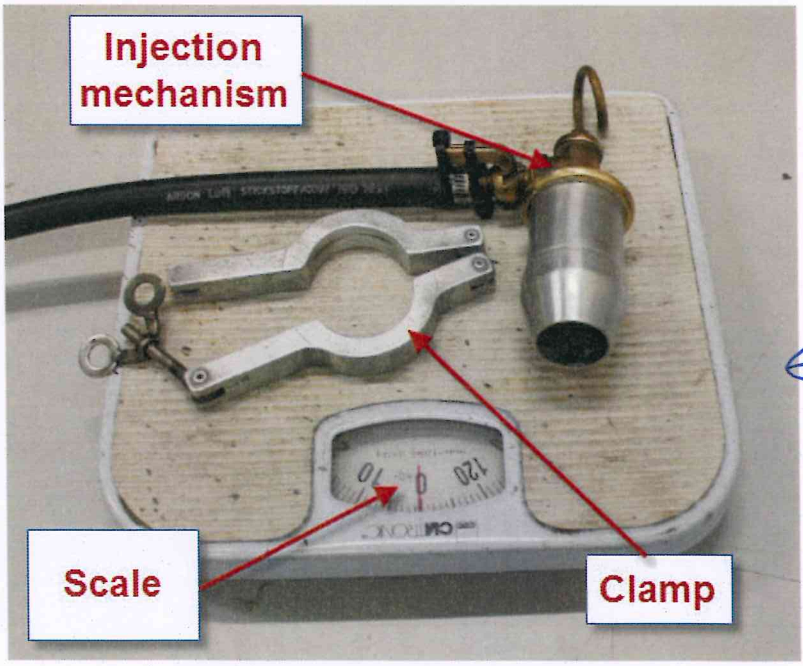


Figure 18: The entire payload weigh tent

3) The injection mechanism is then weighed and subtracted from the payload weight from step 2. This gives the actual gross lift of the balloon. The reason for this step is to exclude the filling equipment which stays behind from the payload weight. (Need to connect this with the variables in equations)



← Not very accurate...

Figure 19: Injection mechanism weigh tent

4) The equivalent weight obtained from step 3 then is added, plus the calculated buoyancy mass for desired ascent rate using scaled copper plates and weight holder borrowed from the Keflavík weather station for this project.

5) Before inflation begins, the balloon has to be spread onto a smooth surface like tarp or construction plastic.

6) Connection of the filling hose to the helium container valve is next, making sure the injection valve on the balloon injection mechanism (nozzle) is fully open at all times.

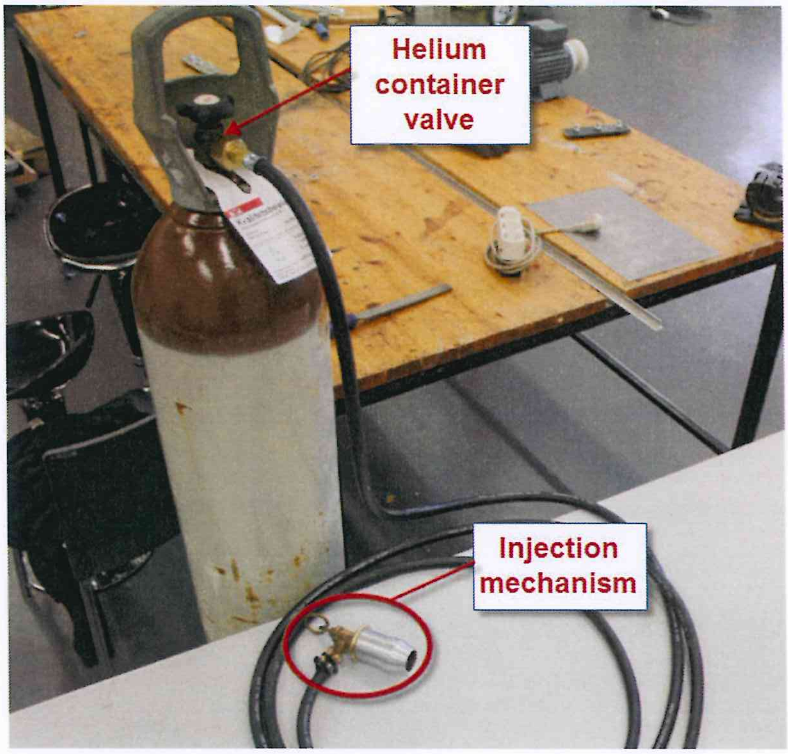


Figure 20: Connection of filling hose to helium container

7) Before inflation, cracking the helium container valve slightly is important to blow out any dust before the injection nozzle is fitted to the balloon neck.

8) The injection nozzle is connected properly to the balloon neck and thoroughly sealed by using the aluminium clamp from the set.