LESSONS LEARNED FROM REXUS12'S SUAINEADH EXPERIMENT: SPINNING DEPLOYMENT OF A SPACE WEB IN MILLI GRAVITY

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ABSTRACT

On the 19th of March 2012, the Suaineadh experiment was launched onboard the sounding rocket REXUS 12 (Rocket Experiments for University Students) from the Swedish launch base ESRANGE in Kiruna. The Suaineadh experiment served as a technology demonstrator for a space web deployed by a spinning assembly. Following launch, the experiment was ejected from the ejection barrel located within the nosecone of the rocket. Centrifugal forces acting upon the space web spinning assembly were used to stabilise the experiment's platform. A specifically designed spinning reaction wheel, with an active control method, was used. Once the experiment's motion was controlled, a 2 m by 2 m space web is released. Four daughter sections situated in the corners of the square web served as masses to stabilise the web due to the centrifugal forces acting on them. The four daughter sections contained inertial measurement units (IMUs). After the launch of REXUS12, the recovery helicopter was unable to locate the ejected experiment, but 22 pictures were received over the wireless connection between the experiment and the rocket. The last received picture was taken at the commencement of web deployment. Inspection of these pictures allowed the assumption that the experiment was fully functional after ejection, but probably through tumbling of either the experiment or the rocket, the wireless connection was interrupted. A recovery mission in the middle of August was only able to find the REXUS12 motor and the payload impact location.

1 INTRODUCTION

Continuous exploration of our solar system and beyond requires ever larger structures in space. The biggest problem nowadays is the transport of these structures into space due to launch vehicle payload volume constrains. By making the space structures deployable with minimum storage properties, this constraint may be bypassed. Deployable concepts range from inflatables, foldables, electrostatic to spinning web deployment. The advantage of the web deployment is the very low storage volume and the simple deployment mechanism. The concept of a space-web, such as the Japanese 'Furoshiki' satellite [1,2,3], depicts a large net held in tension using radial thrusters or through the centrifugal forces experienced by spinning the assembly [4]. These webs can act as lightweight platforms for the construction of large structures in space without the huge expense of launching heavy structures from Earth. Utilising miniature robots that build as they crawl along the web, huge satellites to harness the Sun's energy or antennas for further exploration of the universe may become viable when implementing space webs technology. There have been several experiments conducted on the deployment of the space webs. In 2006 the deployment of a Furoshiki web by the Japanese ended in a chaotic deployment sequence due to misalignment of the radial thrusters as a result of out of plane forces. The Russian Znamya-2 [5] experiment was the first that successfully deployed and spin stabilised large space structure. More recently, in 2010, the Japanese solar sail Ikaros [6] was successfully deployed using thrusters to introduce spinning. The Ikaros square solar sail had a 20 m diagonal and used solar pressure for acceleration, solar cells on the membrane for power generation and the attitude control using the sail.

2 EXPERIMENT DESCRIPTION

2.1 Overview

The Suaineadh experiment [7] consisted of two distinct sections, the ejected part Central Hub and Daughters (CHAD) and the Data Storage Module (DSM) which remained on the REXUS rocket. The ejected part undertook all mission operations once separation with REXUS had been achieved (Fig. 1). It consisted of the central hub, the web and four daughter sections. Ejection of the experiment from REXUS occurred at an altitude of approximately 70 km and followed a pre-determined automated deployment sequence, which allowed for a safe separation distance to be achieved. The apogee of the experiment was at 86 km altitude at approximately 140 seconds into the flight.

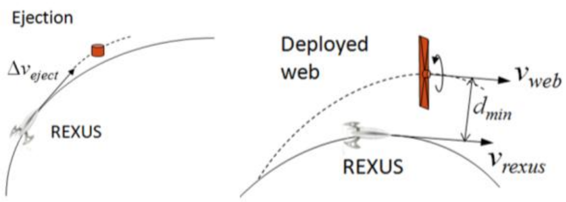

Figure 1: Schematic of Suaineadh ejection and deployment.

CHAD carried all subsystems required to achieve the mission objectives and provides stowage for the web and daughters prior to deployment. The web had the dimensions of 2 m by 2 m (Fig. 2) and was composed of ultralight and flexible braided Spectra fishing lines. Images of the deployment and stabilisation phases were accumulated by cameras located within the central hub. Data was gathered by inertial measurement units (IMUs), one IMU was located inside each of the daughter sections and another one was located inside the central hub itself. Image and data collection began two seconds before the web deployment sequence starts. The data was stored on CHAD as well as being transmitted via a wireless link to the DSM and stored there until recovery after landing. After ejection and prior to deployment, a reaction wheel was used to accelerate the central hub to a sufficient angular velocity for deployment. The daughter sections were released to initiate web deployment. Centrifugal forces acting on the released daughter sections fully deployed the web. As the deployment neared completion the reaction wheel again rotated the central hub to a sufficient velocity to reduce recoiling effects and to achieve web stabilisation. A RF-beacon was placed on CHAD to locate and recover the experiment after the mission in order to collect data.

Figure 2: Deployed Suaineadh web on ground.

2.2 Mechanical

The available volume permitted by the nosecone adapter position of Suaineadh within REXUS 12 demanded that the structural design be as simplistic and efficient as possible. The maximum footprint of the experiment was 0.33m in diameter by 0.40m in height, with a mass of approximately 12kg. For the majority of the structure Aluminium 6082 was used in an effort to reduce the mass as far as much as the mechanical loads would permit with a degree of safety factored in. The exception was the DSM top plate where sensitive flight recorded data was stored. A steel plate was used to protect this section from additional impact loads during touchdown of the recovery module. The expected mechanical and environmental loads expected to be encountered through each mission phase can be summarised as:

- 20-g maximum acceleration.
- 290 kN/m^2 maximum dynamic pressure.
- 4 Hz spin rate during launch.
- -30°C to $+200^{\circ}$C temperature range.

The modular design of CHAD (Fig. 3) allowed quick access to all the essential internal subsystems of the experiment, separable by three tubular sections; the Lower Chamber, Central Chamber, and Upper Chamber. The reaction wheel, modem and ejected section data storage facilities were housed within the Lower Chamber, with the reaction wheel mounted as closely the plane of the deployable space web as possible to position the centre of gravity as closely to this plane. Where possible, PC-104 architectures were used, and orientated vertically such that they encompassed the reaction wheel motor. This proved the most economical use of the available volume.

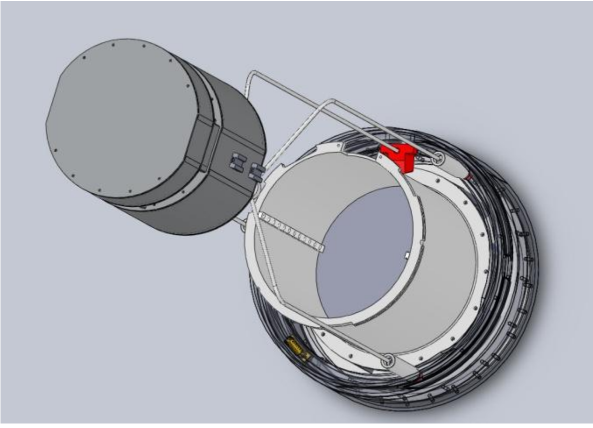

Figure 3: CAD of CHAD ejection from Magic Hat on DSM.

The Central Chamber functioned as a services pass-through between the Upper and Lower Chambers. It was also about the Central Chamber that the space web was wrapped and stowed prior to deployment. All Saft power systems were stored in the Upper Chamber, along with four cameras positioned radial to capture images of the space web deployment. The Daughter Release Spine was also mounted within the Upper Chamber, which was responsible for the simultaneous release of the corner mass Daughter Sections attached to the web. The Release Spine was actuated by stored strain contained within a compressed spring that itself was release upon command by a Cypress pyrotechnic cutter shearing a tensioned steel wire.

Transmitting antennas were appropriately positioned on the outward facing surfaces of the top and bottom plate on the Upper and Lower Chambers respectively. This provided as closely as possible full spherical coverage back to the DSM where the receiving antennas were positioned. Due to limitations imposed by REXUS 12, the antennas position on the DSM were only able to provide a half-spherical field of view, which unfortunately would result in communication breaks were the REXUS 12 rocket to begin tumbling motion.

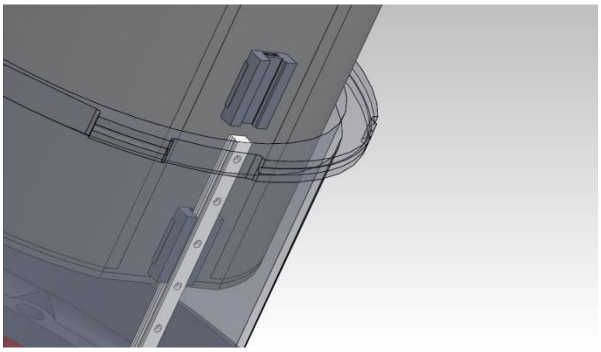

Figure 4: Guiderails inside Magic Hat and carriages on CHAD.

The ejectable CHAD module was stowed within the ejection chamber, commonly referred to as the Magic Hat, against a compressed wave spring. This allowed a Cypress pyrotechnic cutter to activate the release of CHAD once REXUS 12 reached apogee. Linear guide rails (Fig. 4) were used to prevent tumbling motion of CHAD upon release. The Magic Hat was mounted directly on top of the steel top plate of the DSM, which in turn was mounted upon radially space pillars fixed to the bulkhead plate of the Nosecone Adapter. This provided a readily accessible volume between the top plate of the DSM and the bulkhead in which the DSM subsystems were housed.

2.3 Electronics and Software

The electronics used were a mix of Commercially Off The Shelf (COTS) components and custom-made boards when COTS board were not available. This approach reduced design and production time of the electronics subsystem. The electronics and software for control and data acquisition was separated to allow for a more reliable failsafe system [8]. The main control of the experiment was undertaken by a small microprocessor (PIC (Programmable Interrupt Controller)) placed on a custom made PCB in CHAD, while the data acquisition, which required more computing power, was done by more advanced CPUs and an FPGA (Field-Programmable Gate Array).

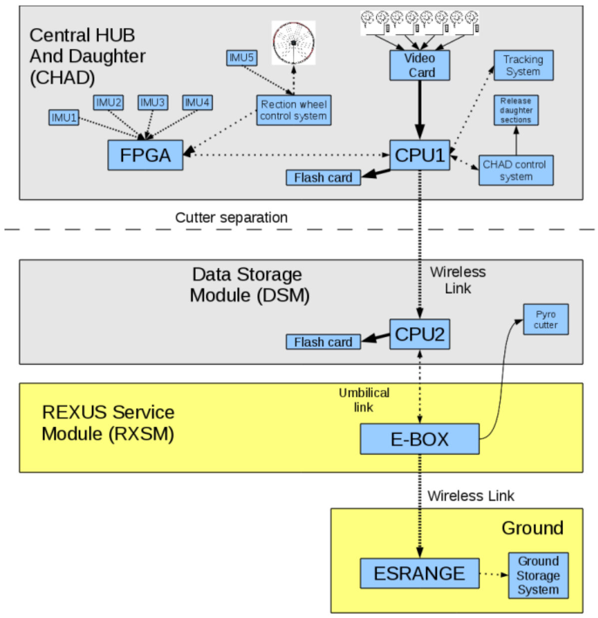

Figure 5: Schematic of electronics.

To provide data acquisition from multiple sensors, i.e. IMUs, an FPGA is used. The FPGA (Cyclone IV) was placed on the DE0-Nano board. The main purpose of the FPGA was to gather the sensor data, packet, serialize and sent it to the CHAD CPU. Data was gathered at a rate of 50 Hz from the four daughter sections as well as from the Reaction Wheel Controller (RWC). To reduce the data that was needed to be sent over the wireless link, the unnecessary information sent from the IMUs are filtered out in the FPGA before the data was packaged according to reference 8. The data streams from the IMUs were then combined into one stream and sent to CHAD CPU.

The RWC consisted of an FPGA, IMU and motor driver mounted on a custom-made board controlling the reaction wheel. Two VSX-104+ boards were used in the experiment. Each board contained one SoC chip with one CPU, compatible with 486SX instruction set, using a 300 MHz system clock. Both CPUs used GNU/Linux as an operating system with custom written software.

One CPU parallel with a custom made board was placed in CHAD, which was responsible for capturing images from four cameras on CHAD, storing these images on two internal flash cards and sent them through a wireless link to DSM. A second CPU was placed on the DSM which was similar to the one on CHAD without the custom made board. The second CPU stored all incoming data from the wireless link on the two flash cards.

Both CPUs included the functionality to report its route status packets received from other modules. Three different types of data were expected from the experiment. First, most important for post-flight data analysis were readings from the sensors, IMUs and RWC. As a secondary verification method, pictures from the four cameras on board CHAD were recorded. The last type of data contained status information about each component. All these types of data were stored on DSM's and CHAD's flash cards.

Communication

Four 915 MHz antennas were used for the telecommunication. CHAD had one on the top and one on the bottom. Two receiving antennas on the REXUS rocket were placed symmetrically on the outer rim of the magic hat ejection barrel. The size of the antenna was 31 mm × 31 mm. For a continuous communication between CHAD and DSM it was of great importance to account for possible tumbling of the rocket and of CHAD. Therefore, the antennas had to cover most of the sphere around CHAD.

All antennas were designed as printed rectangular spiral antennas. The reflection coefficient and the far-field polar plots of the antennas can be seen in Fig. 6. The realized gain is −6 dBi and the bandwidth is 12 MHz. When testing the communication between two Nano IPn920 platforms (separated by 100 m) using the antennas in open space, the data rate can reach 100 kB/s. Using 900 MHz frequency requires special permission from the Swedish telecom authorities, even when transmission was to be at an altitude of several km and below one minute.

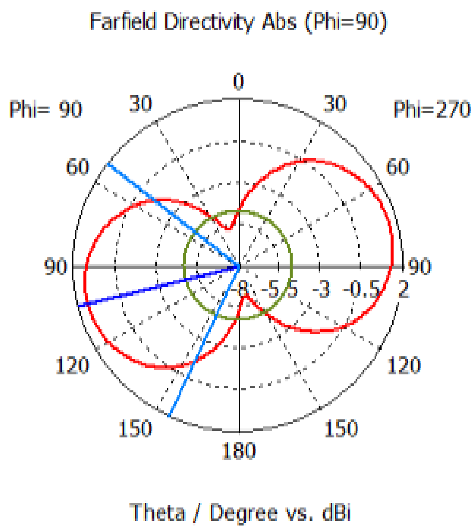

Figure 6: Polar plot of 915MHz antenna.

3 LAUNCH

3.1 Launch Campaign

The REXUS 11/12 launch campaign took place at SCC's (Swedish Space Corporation) ESRANGE close to Kiruna in Northern Sweden from the 12th until the 23rd of March 2012. During the first week the Suaineadh experiment was prepared to be integrated with the other experiments and the service module from DLR MORABA (Mobile Rocket Base). After various bench-tests and a flight simulation the Suaineadh experiment was ready for the first hot countdown on the 19th of March 2012.

3.2 Launch and Mission

On the launch day, the weather added no constrains to launch. The hot countdown of T−2 hours began at 1300 local time. The Countdown proceeded without any major delays. All experiments were powered up at T−600 s, At T−565 s Suaineadh's ground support software received the first telemetry that all systems were up and running. At T−240 s the SODS (Start Of Data Storage) signal was given and received. The switch of REXUS rocket from external power to internal batteries, which are placed in service module, was performed at T−120 s. At T−0 s REXUS 12 launched and the Suaineadh ground support successfully received notification about the LO (Lift-Off) signal. SOE (Start of Experiment) signal was given at T+26 s. Suaineadh was ejected from the nosecone position of the REXUS 12 rocket at T+80 s, the ground support software indicated successful ejection, further corroborated by post mission analysis of recovered pictures. After ejection, the amount of available memory onboard the rocket should decrease with data rate of wireless link (up to 100 kB/s), which would indicate that a wireless connection between CHAD and the DSM was established. Only minor changes of free space were observed. 420 s into the flight, the Suaineadh ground support software and all the other ground stations ceased to receive further telemetry from REXUS 12. Approximately 30 minutes after lift-off, the recovery helicopter team began its search for the REXUS 12 payload and Suaineadh's CHAD. After a two hour search, only the REXUS 12 payload could be recovered. Investigations into the lost signal showed that the parachute of the REXUS 12 payload had malfunctioned and therefore the radio beacon was unable to function. The non-parachuted REXUS 12 payload hit the ground at terminal velocity.

3.3 Post Flight

After the recovery of the REXUS 12 payload, the Suaineadh team disassembled the DSM. Unfortunately, the helicopter team was unable to detect the radio beacon from CHAD and therefore did not recover the ejected section. Due to the REXUS 12 parachute malfunction, the REXUS 11 launch was postponed and successfully launched in November 2012.

4 RECOVERY MISSION

4.1 Overview

The Suaineadh team embarked on a recovery mission from the 17th until 26th of August 2012 in order to search for the missing CHAD section. Shortly after the launch campaign, the experts from all organisations involved in REXUS/BEXUS provided the Suaineadh team with the GPS ground track of the REXUS 12 rocket, the GPS coordinates of the impact zone from the helicopter team that recovered the payload, rocket motor and nose cone. The Suaineadh team was also provided with the acceleration profile of the REXUS 12 rocket during the mission and the recovery video from the payload prior to impact.

With this data it was possible to estimate the approximate impact location of CHAD. The recovery expedition consisted of Suaineadh launch campaign team members and new partners from across Europe. The search began at the impact location of the REXUS payload employing a spiral search pattern. Due to the fact that the parachute of the REXUS 12 payload did not deploy, it could be assumed that CHAD may be located within close proximity to the impact site of REXUS 12. Fig. 7 shows the location of the rocket motor (68.341017N, 20.979600E), the REXUS12 payload (68.336983N, 20.990333E) and the nosecone (68.320267N, 20.986750E).

The ground track of REXUS12 runs along 51 km from Esrange to the impact zone (red line in Fig. 7). The selection of the separation spring and bench tests on the ground indicated a velocity differential between Suaineadh and the rocket of approximately 1 m/s at Suaineadh separation. Due to the fact that the parachute of the REXUS rocket malfunctioned, the Suaineadh experiment and the REXUS payload should have followed a similar ground plane trajectory up until impact. The nose cone and the rocket motor where ejected in opposite directions. It cannot be predicted if the impact location of the Suaineadh experiment lies between the REXUS payload and the nose cone or the payload and the motor. It was decided to establish a base camp at the impact location of the REXUS 12 payload.

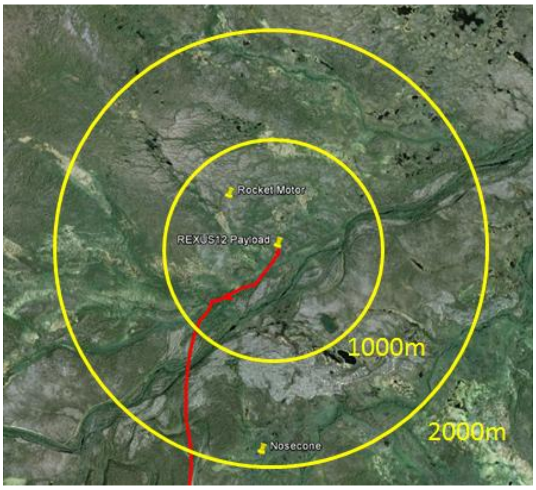

Figure 7: Landing position of REXUS12 payload, nosecone and rocket motor (source Google Earth).

Fig. 7 shows that the payload impact position in between the nose cone and the rocket motor location. The rocket motor impacted in a north-ward distance of 631 m with respect to the REXUS 12 payload and the nose cone impact position is within a south-ward distance of 1880 m. The base camp was used as an origin point for daily missions to various location of interest.

4.2 Mission

The recovery crew parked at Järämä, the Sami settlement north of the suspected impact zone. The 5 km walk to the base camp already showed the high density of swamp land. On the way to the base camp the REXUS 12 rocket motor was found. The base camp was set up around 400 m north of the original set up place because of swamp around the payload impact zone. In the following six days the recovery team tried to cover as much area as possible through swamps, forests, bushes and rivers. At the end of the week the only piece of Suaineadh that was found was a bracket which was mounted to the magic hat onboard the rocket (Fig. 8).

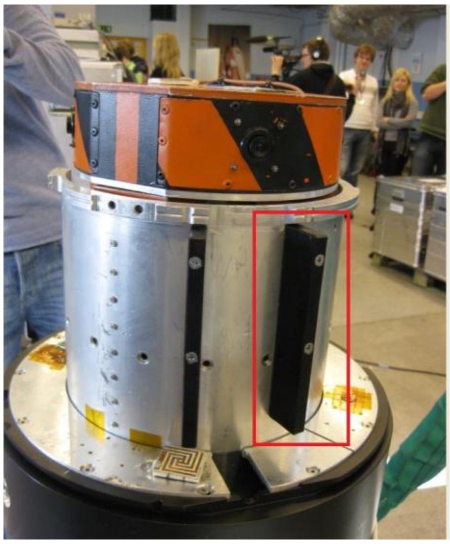

Figure 8: Only Suaineadh part found during recovery mission: bracket from magic hat.

5 RESULTS

After the recovery of the rocket on the 19th of March, 22 pictures were recovered from the internal storage module on the DSM. These 22 received pictures were recorded by the four cameras on the ejected section CHAD. These four cameras were separated by 90 degrees and therefore observed in full 360 degrees.

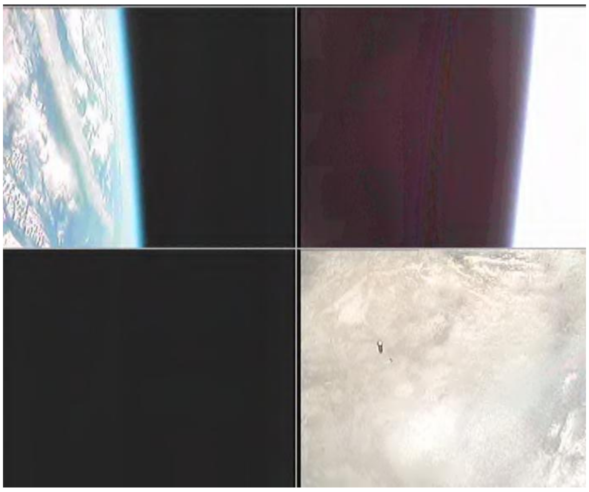

Figure 9: Picture recorded from ejected section shortly after ejection (cameras 90° apart).

Fig. 9 shows one of the first pictures received after separation. The curvature of the Earth can be seen in two frames and the Earth and the blackness of space in the other two. The recording of the images started in between 15 to 20 s after the ejection from the rocket, depending on how long the reaction wheel took to spin up CHAD to the required spin rate. By sequencing the received images, it was possible to conclude that CHAD was indeed spinning and therefore it is concluded that the reaction wheel was operational.

In the last two frames of the received images the successful release of the daughter sections can also be seen, but that it is at this point that the images cease. The reason of the data loss was likely a result tumbling of either the ejected experiment or the REXUS12 rocket after separation. Based on the information received over the wireless link it can be said that all the systems worked nominally at least up to the point of transmission loss and that it is suspected that a more complete data set could be stored on the CHAD data storage.

6 LESSONS LEARNED

The following subchapters will give an overview on the main lessons learned during the two year project. These lessons learned should help future teams to design, build and fly their experiments. A more detailed list can be found in reference [9].

6.1 Experiment Design & Requirements

- It is important to establish and document a comprehensive list of requirements during the initiation of the project, and that these should be continuously updated where necessary
- Requirements should always be achievable within the scope of the project. If they are not, then this can lead to unnecessary diversions of resources which in turn may compromise progress.
- A regimented system for logging requirements should be established from the beginning of the project and properly managed throughout. A numbering system is advantageous here, provided that team members are careful not to renumber requirements without consent.
- If using a wireless communication between ejectable experimental hardware and the REXUS rocket, then full spherical fields of view are essential so that communication is not lost during tumbling motion of either body. The REXUS rockets have since been shown to begin tumbling prior to experiment ejection, and is the likely cause of lost in data transmission between CHAD and the DSM in the Suaineadh experiment.
- Recovery measures should be applied to any ejectable experiments where data recovery is required. This should include a parachute system and tracking facilities so that the recovery crew can locate the experiment in quick time.

- Proposed projects must be realisable within the campaign duration provided by REXUS. Proper scheduling, including key milestones, should be used to track progress and that any deviations are highlighted as early as possible. It should be the responsibility of participating universities to observe this and to supply additional resources if necessary.

6.2 Mechanical (Design & Fabrication)

- It must be realised from the beginning of the project that when designing systems with extremely limited volumetric envelopes, with no scope for increasing, then the mechanical and electronic system will intrinsically influence the design of each other. This means that every effort should be made to freeze the conceptual design of these components as early as possible, so that the impact of any future modifications is minimised as far as possible.
- Any necessary changes to design features must be identified and logged with all team members as early as possible, with actions only taken once the required modifications have been discussed and agreed with those team members that will be affected. Ultimately, severe changes must be approved by the project manager.
- Where possible, a particular screw standard should be adopted and documented. A useful approach is to compile a list of screws, and indeed all fastener types, with their location in the experiment and number required noted. This method makes it simpler to track supplies and to ensure all necessary tools are available at all times.
- Where possible, established standards should be adopted, such as PC-104 architectures, which will allow for multiple components to be stacked and subsequently mounted together. The advantage to this is that should access to these components be required, then the entire assembly may be removed together more easily.
- Manufacturing standards should be considered and applied at all points during the design process. Careful consideration must be given to this when designing with CAD software and that manufacturing tolerances are given in all technical drawings given to manufacturers.
- In a scenario where mass and volume are paramount, effort should be given to verifying the mechanical design to ensure that over-engineering is minimized. FEA (Finite Element Analysis) is a useful resource in this respect, but in the least manual calculations of simplified structures should be made.
- Prototyping can be a useful resource for verification. Rapid prototyping is recommend for form and fit testing, whereas simplified engineering models can be used to verify mechanically loaded features.
- Where possible, design should attempt to include COTS so reduce lead times in manufacturing. It can also be prudent to simplify designs such that the student s themselves can fabricate many of the parts. This will reduce mechanical workshop costs and lead-times.
- Account for significant manufacturing delays of the university workshop and make sure to order parts from workshops outside university before summer to be able to have the parts in the early autumn. University workshop lead-times can often fluctuate throughout the academic year, and that every effort should be given to track this and account for it during project scheduling.
- If possible, it is recommended that particular technicians be assigned to the project so that liaising becomes more transparent.
- A thorough understanding of the mechanical and environmental loading conditions should be obtained, and that all material and parts selections are considerate of these.
- Attempt to where possible to follow ESA ECSS-Q-ST-60C guidelines for parts selection. This will improve the knowledge and understanding of the student teams, but do take care to consider the project budget when following this advice as these components will typically be more expensive.

6.3 Electrical

- Specify rough PCB dimensions and numbers early in the project for the mechanical team for the structural design.
- Try to use designs that have been flown before and thus proved themselves.

- Use components that are easily available almost everywhere. Use COTS components when possible to save time.
- If radio beacon is used to find the ejectables: design receiver to properly receive sent data. At the launch campaign everyone is rather busy and especially if problems occur it is difficult to get a hold of the person responsible for the receiver.
- Make sure that there is a connector outside the experiment to directly reprogram the microcontroller inside the experiment.
- Use LEDs visible from the outside to show that critical functions are working (e.g. LO given, microcontroller powered up, radio beacon transmitting, camera recording, etc.)
- Separate experiment's control functionality (LO, SOE, SODS and activation of actuators) from data management. In the best case implement experiment's control in simple microcontroller.
- When removing isolation from cables it is very easy to damage the wires. Consider buying rotary wire stripper.
- Buy crimping tools for Dsub connectors, it is much faster and more secure than soldering.
- Use PTFE cables which are resistant to soldering temperatures.
- Use separate fuses for each component (camera, CPU and sensors) on power distribution boards.
- Order professional PCB's for custom boards for final version.
- When buying anything advert yourself as a university representative, many times companies donate or give discounts for their products (experience shown that it easier to get such a discounts from smaller retailers/companies).
- Design and order/create prototype hardware (PCBs and components) early.
- Design the prototype with as much functionality as possible, even things that might not be needed later on (it is easier to remove components than add).
- While waiting for PCB orders, test components on breadboards or similar (if possible), read their data sheets thoroughly.
- Stick with components where information on the usage can be found on online, it makes designing/debugging of electronics much easier.
- Be realistic and do not overdo the component choice, e.g., do not put in the fastest, most complex CPU if a small 8-bit will do the job just as good.

6.4 Software (Design, Implementation, Testing)

- When using an online compiler, be aware that you will not have access to the Internet all the time, especially during tests or even reviews.
- Use an explanation for each function so that other team members can help while fixing bugs.
- Keep software simple, use modular design, for more powerful CPUs use Linux, there is lot of ready to use software for it.
- Implement ground support software early and make it solid, it will benefit later.
- Implement remote clearing flash memories of experiment.

6.5 Testing & Validation

- A useful alternative to testing the mission timeline which includes pyrotechnic cutting to use an LED in place of the pyrotechnic cutters for repeated tests. However, care must be given to ensure that no power spikes are observed when integrating actual pyrotechnic cutters as this can lead to premature deployment. It is recommended that at least three deployment tests include actual pyrotechnic cutters to ensure safe operation.
- Any changes to system designs post testing and validation must be followed by repeated tests to ensure that modifications have not compromised the operation of the experiment.
- Where possible, identify, assign and commence component testing as early as possible to allow time for required modifications.
- If tests can be performed prior to the CDR, this will allow for additional support from the REXUS team should complications be encountered.
- Produce simple flight simulator (electronics in parallel with all other design).
- Produce a "fuse box" which is useful during first connection of experiment to simulator or REXUS control module.

6.6 Workshops & Launch Campaign

- The REXUS reviews (PDR (Preliminary Design Review), CDR (Critical Design Review), etc.) sometimes collide with exam periods so careful planning of the students' studies is vital to avoid that the REXUS project

work is affecting the other courses or vice versa.
- When travelling to the launch campaign, it is a good idea if not everyone arrives at the same time, so team members that come later can bring missing components or tools.
- Make sure that there are always at least two team members that know the electronics/software at each review and official test (integration and bench test).
- Bring red tape for RBF (Remove Before Flight) items.
- When getting closer to delivery time, set a time when experiment should be good enough to fly, after that only perform timeline tests and fix bugs. The last tested timeline before a big test should always be without any problems.
- If the team is a multi-location team similar to Suaineadh, it is recommended to make the most use of the time at the workshops, possibly stay a few days longer to work as a team.
- When possible, bring hardware to the workshops, experts can give advice directly.
- The soldering course offered by ESA is a valuable workshop to learn how to manufacture space certified electronics.
- Find dedicated transport boxes for experiment early.

6.7 Project Management

- Try to work only with students that geographically are studying in the same campus. Communication and resolving of problems will be much easier if students from the same campus are involved in the experiment. Having meetings with all members present in the same room can't be replaced. Video- and teleconferencing are not very effective when it comes to resolving problems.
- Be aware of different time zones and clock chances, always schedule meetings in UTC but also write in brackets the time of each participating country to reduce confusion.
- Find a good project management tool and let all the communication go through this tool to keep track of the discussion on particular topics. (Skype is recommended to use for telecons, Dropbox and Google docs are useful to share documents, Doodle.com is a great tool to schedule meetings, facebook groups is a good tool for online communication/discussion and file sharing but everyone needs to be signed up on facebook. Basecamp has been used by the KTH REXUS projects SQUID, RAIN and MUSCAT.)
- When working on a big document together, it is recommended to inform the other team members of the document usage time and renaming the document with date and initials (check out a document).
- A good GANTT chart enables the project to meet all necessary deadlines. The more detailed an estimate can be made for each task, the more precise and reliable GANTT chart can be created.
- Weekly meetings are obligatory to keep status updated within team.
- If students work on experiment as part of their coursework, make sure that student is also available during summer.
- Have a dedicated room where experiment can be assembled and kept without disturbance.
- Most students have not worked in such large teams and together with students from other disciplines before, so an introduction to group dynamics would be advisable to avoid future problems related to, e.g. different expectations, priorities and levels of commitment within the team.
- Many students are getting course credits for their work, but it is important that both the requirements for the course and the requirements from the REXUS team are met. The team members and their supervisors need to understand that the deliverables for the project and the deliverables for the course can be two separate things. Technical reports are of courses necessary for the documentation, but more important is to build and test as quickly as possible. The report can be produced later.
- Assign a person responsible for the outreach activities. This person shall be involved with the design of the experiment, but shall not be overloaded with work. Otherwise, the outreach production and quality will suffer.
- Have dedicated supervisors that are willing to spend parts of weekends and long days to perform important tests and tasks.
- Open-minded, skilled and good team workers on both supervisor and student levels is what the REXUS/BEXUS projects need. Both supervisors and students must be prepared to work in unexpected directions not thought of from the beginning when they joined the project and be willing to quickly gain new knowledge in fields that are further away from the main studies and knowledge.

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8 CONCLUSIONS

On the 19th of March 2012 the Suaineadh experiment was launched into space onboard REXUS 12. The Suaineadh experiment had the purpose of deploying a web in space. The team was comprised of students from the University of Strathclyde (Glasgow, UK), the University of Glasgow (Glasgow, UK) and the Royal Institute of Technology (Stockholm, Sweden), designing, manufacturing and testing of the experiment.

Unfortunately, the ejected section could not been recovered by the recovery helicopter team. 22 pictures were received over the wireless link between the experiment and the REXUS rocket confirming that the experiment was fully functional with initiated spinning up after ejection. In the last two frames that were received, it could be seen that the daughters were successfully released. The wireless connection was interrupted before web deployment, likely caused by tumbling of the experiment or the rocket.

A recovery mission in mid August 2012 at the landing site was not able to recover the ejected section on which it is hoped that more data should still be stored. There remains one last hope of recovering Suaineadh during to the start of the hunting season within the impact area.

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