SED

Student Experiment Documentation

Document ID: BX16_iSEDE_SEDv5-1-31JAN14

Mission: BEXUS 16

Team Name: iSEDE

Experiment Title: Inflatable Satellite Encompassing Disaggregated Electronics

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Version:	Issue Date:	Document Type:	Valid from:
5.1	**31 January 2014**	**Spec**	**31 January 2014**

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Thomas Sinn, Project Manager & Scientific Advisor

Change Record

Version	Date	Changed chapters	Remarks
0	2008-12-18	New Version	Blank Book 2010
1.0	2013-01-18	All	PDR
1.1	2013-01-25 (pre-PDR)	1.1 + references 4.1 2 & 5 4.3 3.1 3.3.2 5.1 Appendix C	Background on inflatables Illumination Added requirements PE13+14 Table of Components Improved task allocation Included known costs Updated test matrix Battery Data Sheets
2.0	2013-05-13 (CDR)	1.2 1.3 1.5.2 2.1, 2.2, 2.3 & 2.4 3.1 3.2 3.3.1 3.3.2 3.4 3.5 4.1 4.2 4.4.1.2 4.4 4.5 4.5.1 4.5.2 4.5.3 4.5.4 4.7 4.8 5 5.3	Consolidated Added softrobotics to Exp. Objt. New team members: Software Added: DE_50, DE_51, DE_52, DE_53 & OP_16, Changed: DE_06, DE_08, DE_12, DE_21 & OP_08, Deleted: FU_01 & FU_02 Added softrobotics to WBS Updated Schedule Updated manpower Updated budget Updated Outreach Added risk for soft robotics Updated Update experiment description Including interfaces Softrobotic actuation Mechanical section inc. Deployment & camera mount Restructured Electronics Design section Updated Electronics block diagram. Added Section 4.5.5 Restructured. Added detail & schematics Restructure. New headings Changed the RF module choice and details New Power Budget Updated Power Components, Updated Power system design, New Power Distribution Updated T&V updated and test 0.13 added (low temp critical comp) Test results

		6.1.1 6.3 Appendix A	Dimensions & Mass Updated Mission Timeline Added PDR Report
3.0	2013-06-24 (pre-IPR)	- 2.4 3.2 3.3 3.4 4.1 4.3 4.4.1.2 4.4.3 4.4.5 4.4.6 4.6.2 4.6.3 4.6.4 4.6.8 4.5.2 4.5.3, 4.5.4 4.9 5 5.1.1 6 Appendix A Appendix B Appendix D	Added missing Eurolaunch logo Added new OP requirements Updated Schedule Updated Budget Updated Outreach Updated Experiment Setup Updated Experiment Components Added Inflatable Displacement Updated Hub Material Added Folding Technique Added Thermal Design for Deployment Mechanism Added Thermal Design for Inflatable Structure Added Thermal Design for Mechanical Structure Updated software description and changed from Arduino Ethernet to Raspberry Pi Updated Hub controller, Raspberry Pi as Hub. Updated to PanStamp added Connectors Updated Ground Support Software T&V chapter updated Added EMC (0.14) and Conductance test (0.15) Added RBF, Updated necessary preparations and countdown Added, CDR report Newsletters, posters and press releases Added datasheet actuation fluid (Glysantin G30) Added Technical Drawings
3.1	2013-07-07 (IPR)	2 3.1 3.2 3.3.2 3.3.1 3.4 3.5	Deleted in flight charging req., added clearance req. Updated task allocation(tab3.1) Revised schedule Revised budget Added summer internship Updated outreach (working link) Updated risk register Added fixed spots on

		4.1 4.3 4.4.1.2 4.4.1.3 4.4.2 4.4.3 4.4.4 4.5.1 4.5.2.3.1 4.6.5 4.7.3 4.9.1 6 6.3 Appendix A	deployables Experiment component status table added Clearance requirement PCB-Inflatable Mounting Updated Solenoid Description Updated Hub Design Updated Camera Housing Wiring schematic added Bright white LED lights added Added Thermal Design for Hub Deleted the charging section, as well as other references to this. Added ‘Are you sure’ pop up to ground support software Added clearance req. Updated timeline Added SEDv3.0 review
3.2	2013-07-11 (post IPR)	1.5.1 2.4 3.2 4.1 6.1.5 6.3	New Contact Point ER_OP_18 altitude req. Schedule: IPR to Campaign Mounting: Top of BEXUS rails ER_OP_18 altitude req. Updated timeline
3.3	2013-08-12	2.4 3.3 3.4 4 4.7 4.7.5 5 6 6.1.3 6.2.1 Appendix A	Deleted battery requirements Updated risks Updated outreach Deleted battery references Changed schematic Updated Power Budget Updated T&V Updated timeline Removed Batteries RBF pin description Added IPR report
3.4	2013-08-28 (EAR)	All 4.3 4.5.5 5	Correction in wording Experiment components Cable pin allocation Updated T&V
4	2013-09-16 (Pre-Campaign)	2.3 2.4 4 4.4.5 4.4.7 5 5.1.1 5.1.2 5.2.1	Changed Requirement: DE_19 Changed Requirement: OP_16 Overhaul, present tense Added Mobius Camera Added folding picture Updated Verification Matrix Updated Test Schedule Updated Test Matrix Updated Test Results

		6.1.1 6.1.3 6.1.4.1 6.1.4.3 6.2 6.3 6.4	Breakdown Updated Dimensions & Mass Updated Electrical Interfaces Updated General Requirements Updated Electrical Requirements Updated Pre Flight Procedures Table Updated timeline Added Post Flight Procedures Table
4.1	2013-09-23 (Revised Pre-Campaign)	4.3 4.4.5 5..2.1 5.3 6.2	Updated Experiment Description Table Updated Mobius Camera Updated Test Schedule Updated Test Results Updated Pre Flight Procedures Table
5.0	2014-01-13 (Final Report)	1.5.3 7.2 7.3 7.4 7.5	Team Evaluation Launch Campaign Description Results Discussion and Conclusions Lessons Learned
5.1	2014-01-31	All	Updated tense

Abstract: The goal of this project from students of the University of Strathclyde is to design and build an initial prototype of an all-inflatable satellite with disaggregated electronics for deployment on-board a BEXUS balloon as proof of concept. The idea is to use cellular structures as support for all the subsystems composing a typical nano-satellite. Each subsystem and component is mounted on a different cell. Cells are both individually inflated and individually controlled. The aim is to design and build a prototype for this new type of satellite, demonstrating the deployment and wireless communication among components. Furthermore, the inflatable satellites have the ability to change their shape to prove a smart structure concept from the bio-inspired mechanism that plants are using to follow the sun.

Keywords: Inflatable, Disaggregated Electronics, Satellite, Gossamer Structure, Residual Air Inflation, Passive Deployment, Shape Change, Smart Structure, BEXUS

CONTENTS

ABSTRACT 1

1 INTRODUCTION 2
1.1 Scientific/Technical Background 2
1.2 Mission Statement 5
1.3 Experiment Objectives 5
1.4 Experiment Concept 6
1.5 Team Details 7
1.5.1 Contact Point 7
1.5.2 Team Members 7
1.5.3 iSEDE Team Member Evaluation 9
1.5.4 Conclusions 13

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS 16
2.1 Functional Requirements 16
2.2 Performance requirements 16
2.3 Design Requirements 17
2.4 Operational Requirements 20
2.5 Constraints 21

3 PROJECT PLANNING 24
3.1 Work Breakdown Structure (WBS) 24
3.2 Schedule 26
3.3 Resources 27
3.3.1 Manpower 27
3.3.2 Budget 28
3.3.3 External Support 32
3.4 Outreach Approach 33
3.5 Risk Register 39

4 EXPERIMENT DESCRIPTION 47
4.1 Experiment Setup 47
4.2 Experiment Interfaces 51
4.2.1 Mechanical 51
4.2.2 Electrical 53
4.2.3 Radio Frequencies (optional) 55
4.3 Experiment Components 56
4.4 Mechanical Design 58
4.4.1 Payload - iSEDE satellite 59
4.4.2 Deployment Modules 64
4.4.3 Hub 69
4.4.4 Camera Housing 71

4.4.5 Mobius Camera 73
4.4.6 Support structures 73
4.4.7 Folding Technique 78
4.5 Electronics Design 79
4.5.1 Electronics Overview 79
4.5.2 Hub 81
4.5.3 Satellites 87
4.5.4 Wireless Communication 93
4.5.5 Cabling Pin Allocation 93
4.6 Thermal Design 94
4.6.1 Thermal Design for Deployment Mechanism 95
4.6.2 Thermal Design for Inflatable Structure 95
4.6.3 Thermal Design for Mechanical Structure 95
4.6.4 Thermal Design for Hub 95
4.7 Power System 97
4.7.1 Power Sources 97
4.7.2 Power Circuitry 97
~~4.7.3 Charging the Satellite Batteries~~ 98
4.7.4 Power Distribution 99
4.7.5 Power Budget Breakdown 99
4.7.6 Power Distribution Diagram & Schematics 100
4.8 Software Design 101
4.8.1 Software Overview 101
4.8.2 Hub 101
4.8.3 Satellite(s) 102
4.8.4 Software Implementation 102
4.8.5 Data Flow 108
4.8.6 Implementation 109
4.9 Ground Support Equipment 110
4.9.1 Ground Support Software 110

5 EXPERIMENT VERIFICATION AND TESTING 114
5.1 Verification Matrix 114
5.2 Test Plan 120
5.2.1 Test Schedule 120
5.2.2 Test Matrix 132
5.3 Test Results 133
5.3.1 Test Results Breakdown 133

6 LAUNCH CAMPAIGN PREPARATION 139
6.1 Input for the Campaign / Flight Requirement Plans 139
6.1.1 Dimensions and mass 139
6.1.2 Safety risks 139

6.1.3 Electrical interfaces 140
6.1.4 Launch Site Requirements 141
6.1.5 Balloon Mounting & Mission Requirements 141
6.2 Preparation and Test Activities at Esrange 142
6.2.1 Remove Before Flight (RBF) pin 145
6.3 Timeline for countdown and flight 146
o Both Hack-HD recording off (safe data) 148
6.4 Post Flight Activities 148

7 DATA ANALYSIS PLAN 151
7.1 Data Analysis Plan 151
7.2 Launch Campaign 151
7.2.1 Day 1: 4th October 151
7.2.2 Day 2: 5th October 151
7.2.3 Day 3: 6th October 154
7.2.4 Day 4: 7th October 157
7.2.5 Day 5: 8th October 158
7.2.6 Day 6: 9th October 165
7.2.7 Day 7: 10th October 165
7.2.8 Day 8: 11th October 166
7.2.9 Day 9: 12th October 166
7.2.10 Day 10: 13th October 166
7.3 Results 166
7.4 Discussion and Conclusions 167
7.5 Lessons Learned 167
7.5.1 Experiment Design & Requirements 168
7.5.2 Mechanical (Design & Fabrication) 168
7.5.3 Electrical (Design, component selection, fabrication, testing) 169
7.5.4 Software (Design, Implementation, Testing) 170
7.5.5 Testing & Validation (Suggested tests, problems, time allocation) 170
7.5.6 Workshops & Launch Campaign (Who should attend, travel suggestions, preparation) 171
7.5.7 Project Management (+ software tools, outreach and risk assessment) 171
7.5.8 Miscellaneous 171

8 ABBREVIATIONS AND REFERENCES 173
8.1 Abbreviations 173
8.2 References 175

ABSTRACT

The goal of this project from students of the University of Strathclyde is to design and build an initial prototype of an all-inflatable satellite with disaggregated electronics for deployment on-board a BEXUS balloon. The idea is to use inflatable, cellular structures as support for all the subsystems composing a typical nano-satellite. Each subsystem and component is mounted on a different cell. Cells are both individually inflated and individually controlled. The aim is to design and build a prototype for this new type of satellite, demonstrating the deployment and communication among components.

Traditional satellites have a rigid structure defining the basic configuration of the satellite and holding in place all the subsystems. A variation of the shape or configuration of the satellite is normally achieved through the use of deployable structures or appendices (antennas, solar arrays, booms, etc.). Although modern structural solutions are modular and multifunctional, still the structure of a satellite represents a significant portion of its mass and a limitation on the achievable configuration, extension of deployable components and packing efficiency during launch. The idea of this project is to replace classical structures with cellular ones. Cellular structures are made of a number of light weight cells individually inflated. When deflated, cellular structures can be packed to occupy a very small volume. Once the structure is deployed in space, it can extend to a large area with a small mass. In order to allow high packing efficiency during launch, subsystems like computer, cameras, gyroscopes, accelerometer, etc. need to be miniaturized and distributed across the cells. The required level of miniaturization is already available in smart phones. Mobile phones are de facto, complete satellites that could be potentially deployed in space. The idea is to explode (disaggregate) a smart phone, place its components on the cells and make all the components communicate. The unique architecture of the inflatable structure opens the possibility of changing its shape to be adapted to various space mission stages or environmental conditions [9]. Cells can then be individually controlled to change the overall shape of the satellite. The experiment follows up on experiment to REXUS13's StrathSat-R [8] which has the purpose of deploying inflatable structures from cube satellites.

1 INTRODUCTION

1.1 Scientific/Technical Background

Space vehicle size is nowadays mainly governed by launch vehicle dimensions. The use of deployable structures became necessary due to their low stowage and high in-orbit volume. For the success of future space missions involving large space structure, the development of new deployable structures and the improvement of current designs are of great importance. Applications can be easily envisioned through truss structures, masts, crew quarters, transport tunnels, large solar arrays, solar concentrators, solar sails or antennas. A valuable option for these large ultra-light structures is the exploitation of inflatables. Reasons for the use of inflatable structures range from their low cost over exceptional packaging efficiency, deployment reliability and low stowage volume to low weight. Over the last few decades, inflatable structures became an emerging field to overcome launch vehicle payload size restrictions [13]. Research in inflatable structures can be dated back to the 1950s. The first major developments during this time showing the potential of these novel structural concepts were the Goodyear antennas in the early 1960s and the Echo Balloon series from the late 1950s to the early 1960s. The Contraves antennas/sunshades and the L'Garde, Inc., inflatable decoys followed in the 1970s and mid-1980s [14]. The biggest achievement up to date is the Inflatable Antenna Experiment (IAE) of L'Garde which was launched from a Space Shuttle in May 1996 [15].

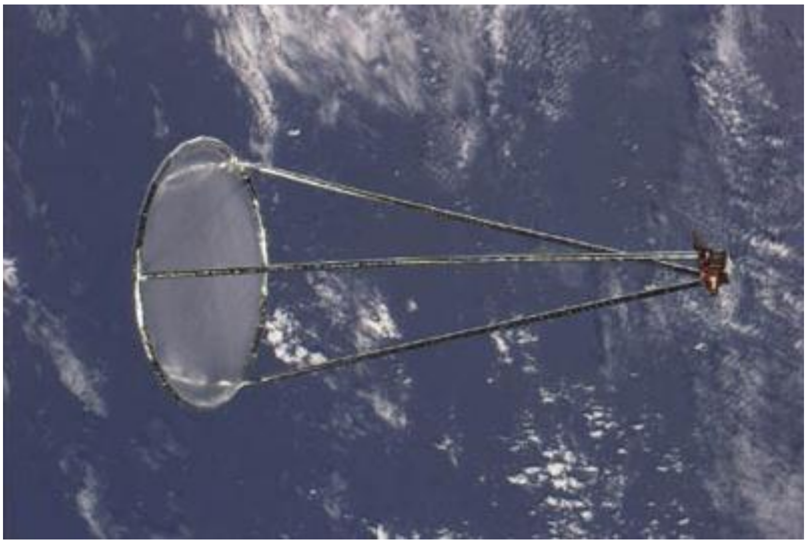


Figure 1-1: Inflatable Antenna Experiment (IAE) deployed in 1996 (source NASA)

Research has been undertaken in various institutions all over the world in the field of inflatable structures;[16-18] new membrane materials have been discovered that can withstand the space environment, advanced simulation tools were developed that capture the highly non-linear behavior of the inflation process and rigidization techniques have been investigated making the structure non-reliant on the inflation gas after deployment [19-21]. The industry is focusing on a variety of applications of inflatable structures to enable future space flight at present. After 1996, inflatables were used as protection devices for planetary rovers. The inflatable balloons were used to soften the landings of the Mars rovers Pathfinder in 1996 and Spirit and Opportunity in 2003.

Figure 1-2: Deployment test of inflatable airbags of Mars Pathfinder mission in 1996 (source NASA)

Various companies are working on the use of inflatable antennas, reflectors, booms and solar arrays as satellite components. Just recently the company Space Ground Amalgam working on these inflatable satellite structures won a 100k prize in the Space Frontier Foundation's NewSpace business plan competition [22]. Other research is carried out in inflatable boom experiments like the CFRP Booms from the German Aerospace Center (DLR) [23]. Also NASA is working on a couple of inflation based structures which led to a successful test of the Inflatable Reentry Vehicle Experiment (IRVE-3) in July 2012. The most ambitious plan comes from Bigelow Aerospace which has the target of building a Commercial Space Station consisting of inflatable modules. In January 2013, Bigelow Aerospace was contracted by NASA to build an inflatable module called BEAM to be tested on the International Space Station during 2015 to 2017 [24].

Figure 1-3: Artist view of Bigelow module attached to ISS (source Bigelow)

Various space structures are serving just one specific purpose in space systems nowadays. By developing a structure that can adapt itself to various mission stages, the flexibility of the entire mission can be enhanced. With applying smart structures, the spacecraft can easily adjust itself to the space environment and expensive on-ground simulation to verify the accuracy of the structure when subjected to the harsh space environment will become no longer necessary. These kind of smart structures have various applications in space systems. Examples of these structures range from telecommunication over earth observation to human space missions. For example, these structures can form antennas or concentrators which are able to adjust their focal point autonomously depending on their orientation towards the sun or their position in orbit. By using a smart membrane as a substructure for a solar sail, attitude control of the solar sail can be achieved by changing the shape of the structure and therefore varying the area subjected to the solar wind. This area change will result in an attitude change of the space craft.

By distributing the electronics now over the surface of the inflatable smart structure a very lightweight giant structure in space can be created without having the need for any rigid heavy substructures which would be dead weight. These satellites with a high area to mass ratio would be a great way to ensure that the satellite will reenter the Earth's atmosphere in the recommended 25 years to mitigate space debris.

The iSEDE project follows up on the research of PhD student Thomas Sinn of the Advanced Space Concepts Laboratory on "Smart Space Structures" [9, 10]. The undertaken research developed a bio-inspired method to deploy and change the shape of structures in space facilitating residual air inflation and adapting nature's heliotropism concept [13] to a mechanical system consisting of inflated cells with interconnected micro pumps. This led to the REXUS 13 experiment StrathSat-R [8] with its ejected cube satellite SAM (Self-inflating Adaptive Membrane). SAM will deploy an inflating membrane consisting of 36 cells with two actuator cells connected by micropumps in order to change its shape. Due to some problems with the pyrocutters, Strathsat-R will be re-launched upon REXUS15/16.

1.2 Mission Statement

"The iSEDE team shall disaggregate the electronics of a nano-satellite across an adaptable, all-inflatable structure to be deployed into a high altitude environment."

The iSEDE project will demonstrate the disaggregated electronics and autonomous behaviour required to successfully develop an adaptable, lightweight, inflatable space structure designed for short mission earth observation purposes. This design will enhance the new concept of nano-satellite, further developing the University of Strathclyde's work on inflatable structures. The project is focusing on disaggregating the electronics, removing the need for a rigid structure containing the basic satellite subsystems. The design will demonstrate feasibility for space applications, and be deployed in a high-altitude environment to prove this.

1.3 Experiment Objectives

1. Deployment of Satellites
    - Observe deployment of the satellites
    - Verify existing LS-DYNA simulations
2. Demonstrate Disaggregated Electronics
    - Wirelessly communicate between Satellite & Hub
    - Take sensor readings, transmit & store data
3. Demonstrate Autonomous Behaviour
    - Generate reports depending on sensed values
4. Alternate shape of satellites
    - Deform cells via integrated soft robotic elements actuated via micro pumps [9, 10]

- Measure displacement
- Control displacement

1.4 Experiment Concept

The concept of this experiment is to have a minimum of 2 satellites on board the BEXUS gondola and a central controller, the hub. One satellite should be deployed before launch and the other deployed when the balloon reaches float altitude. When all satellites are deployed, there is communication between the satellites and the hub. The hub communicates with the ground station through the BEXUS E-Link. The ground station is able to receive reports and give commands. For example, a command to cause the satellites to change their shape though the pumping of antifreeze between cells on the satellites.

1.5 Team Details

The team is made up of 7 members from different departments and at different stages in education. The tasks have been distributed between the members.

1.5.1 Contact Point

Thomas Sinn - PhD researcher at the Advanced Space Concepts Laboratory

Thomas Sinn
Team e-mail: isede2013@gmail.com
Personal e-mail: Thomas.sinn@strath.ac.uk

Department:
Advanced Space Concepts Laboratory
Department of Mechanical and Aerospace Engineering
James Weir Building
75 Montrose Street
Glasgow, G1 1XJ, UK

1.5.2 Team Members

The team composition and organisation is given in the table below.

team member	*background, interest*	*project area*	*academic credit*
Thomas Sinn MSc, PhD-Cand., Dept. of Mechanical & Aerospace Engineering, University of Strathclyde	Aerospace engineering, deployable space structures, inflatable structures, smart structures	Project Manager Payload Advisor Deployable Structure, Smart Structure Outreach	Related to PhD-Thesis of Deployable Smart Space Structures
Tiago de França Queiroz , BEng, Computer Science, University of Strathclyde	Linux, Servers, Embedded Programming	Software, Embedded Systems, Electronic Lead	Summer internship (Science Without Borders)
Frazer Brownlie BEng Mechanical Engineering, University of Strathclyde	Mechanical systems	Mechanical Lead, Testing & Validation	Summer internship Strathclyde, Honours thesis project

team member	*background, interest*	*project area*	*academic credit*
Larissa Batista Leite , BEng, Computer Science, University of Strathclyde	Java, GUI Design	Ground Support Software	Summer internship (Science Without Borders)
Adam Rowan MEng Electrical and Mechanical Engineering, University of Strathclyde	Power systems engineering; Space technologies; Mechatronics	Software; Electronics; Outreach	Master's thesis project
Jonathan Gillespie MEng Electrical and Mechanical Engineering, University of Strathclyde	Control & Automation; Power systems	Power systems; Outreach	Master's thesis project
Andrew Allan MEng Electrical and Mechanical Engineering, University of Strathclyde	Autonomous systems; Adaptable space structures	Mechanical Design; Outreach	Master's thesis project

1.5.3 iSEDE Team Member Evaluation

Evaluations from **Tiago, Frazer, Andrew, Larissa, Craig, Darryl and Jonathan**

Evaluation forms analysed and plotted by **Thomas**

Text compiled with comments from **Tiago, Frazer, Andrew, Thomas, Larissa, Craig and Jonathan**

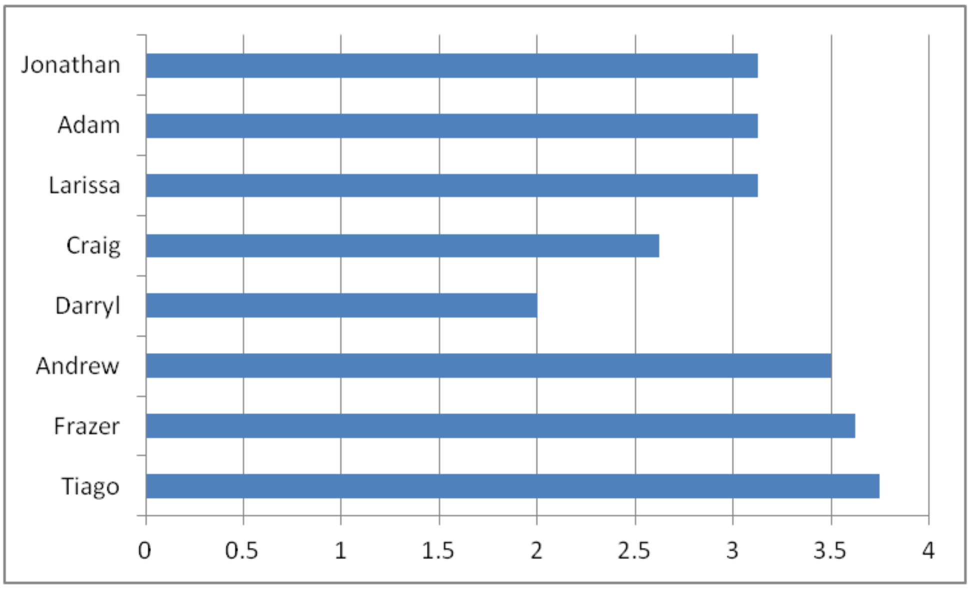
Date: **26/10/2013**

The following evaluation was undertaken for all members of the team except for Thomas. This was necessary to keep the anonymous nature of the team member evaluation which was compiled and analysed by Thomas. The team members were also allowed to give additional comments which are summarized below some of the graphs and the conclusion chapter.

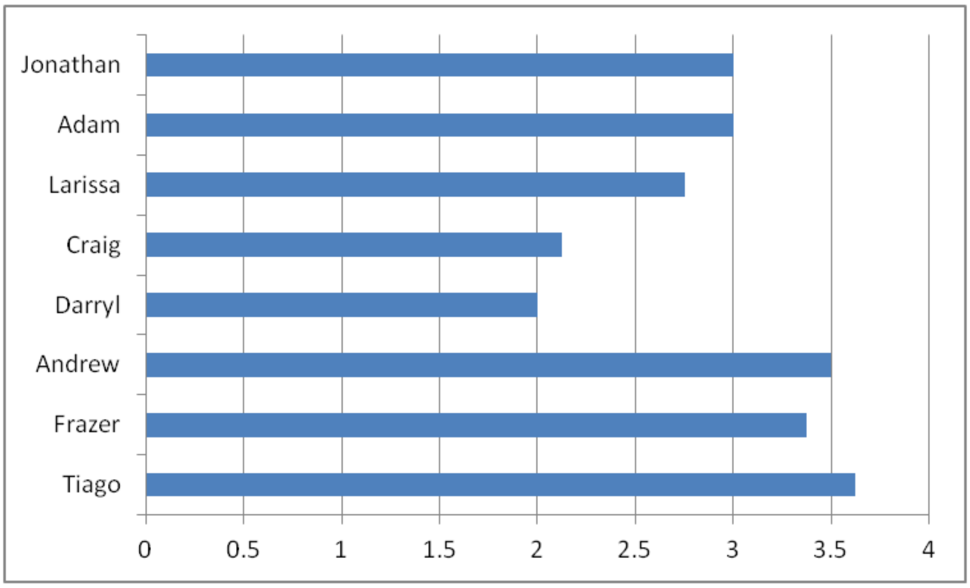
Each team member evaluated all the others with the following scale: 0 = Non-existent/never, 1= Poor, 2 = Average, 3 = Good, 4=Excellent. The following graphs are the average of the sum of all the team member inputs.

1.5.3.1 Team Behaviour / Reliability:

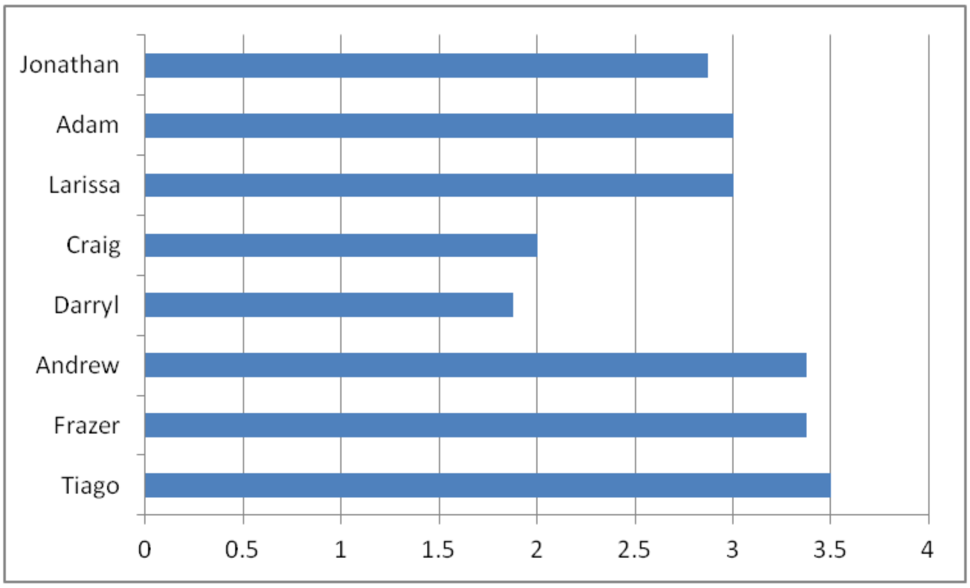
1) Attended Team Meetings and Responded Promptly to Team e-mails.



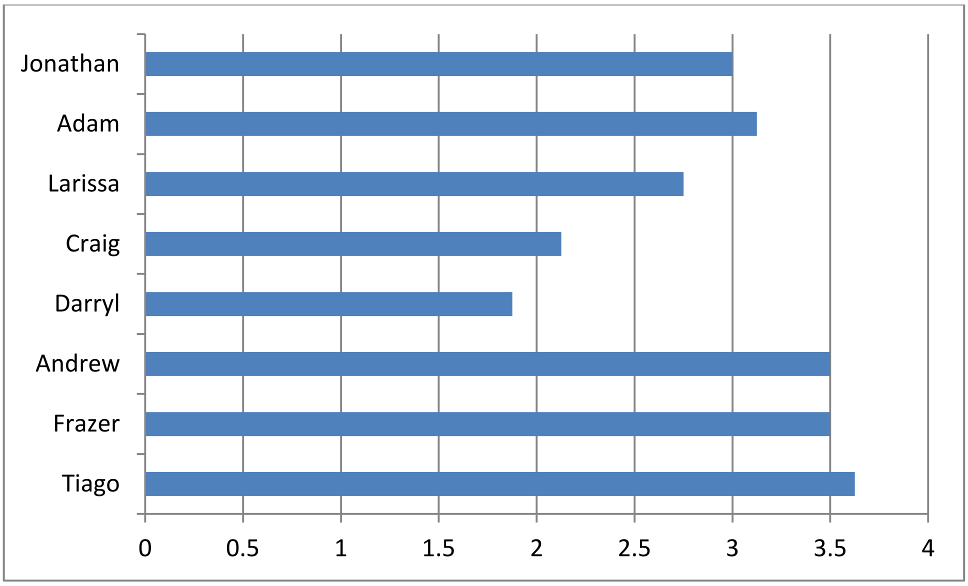
2) Helped Move the Team's Decisions Along.



3) Skilled in Analyzing What to Do.

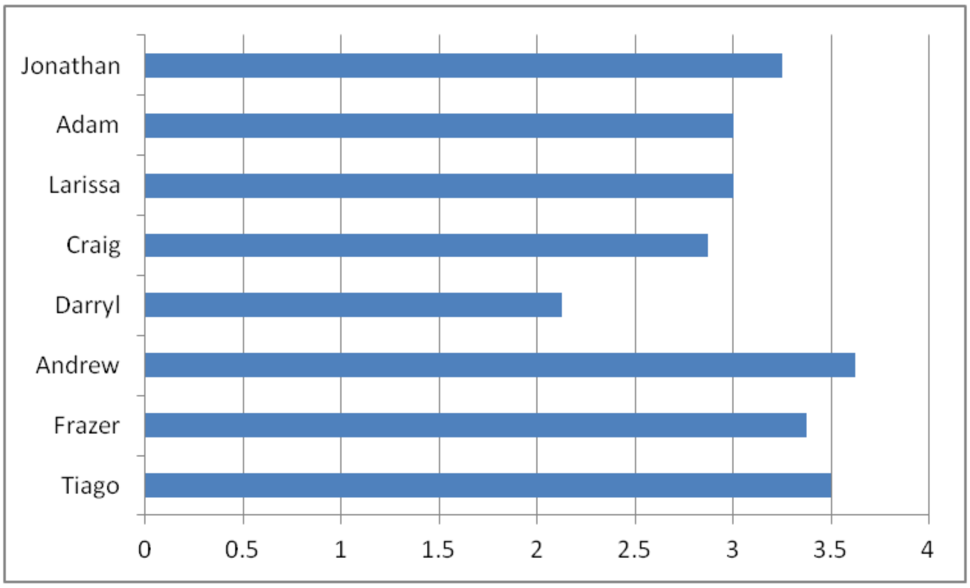


4) Calibre of Contribution to Team Decisions.

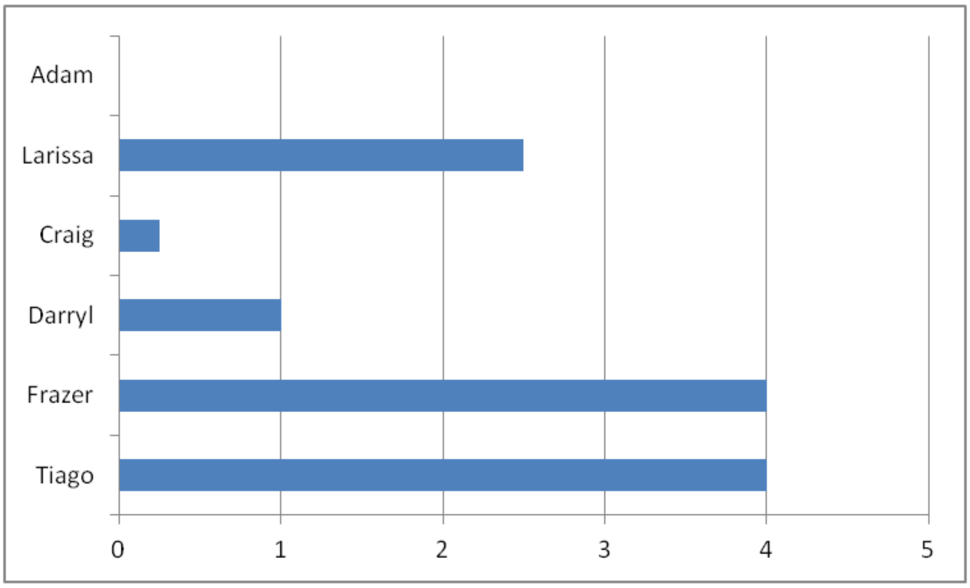


1.5.3.2 Fair share of work:

5) Completed His/Her Fair Share of the Work: **October 2012 – May 2013**

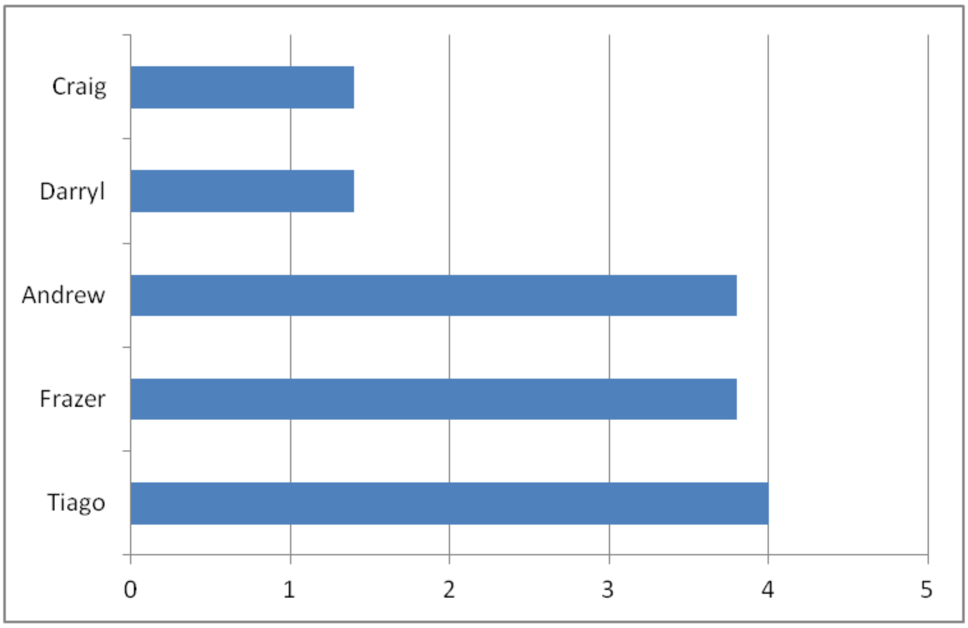


6) Completed His/Her Fair Share of the Work: **June 2013 – September 2013**



Over the summer, Tiago and Larissa worked on the project as part of their exchange program internship, Frazer and Darryl were on a paid Strathclyde internship and Adam and Craig promised to work on the experiment over the summer. Andrew and Jonathan already said early in the project that they would not be able to work on it over the summer. From the evaluation it can be clearly seen that the bulk of work was undertaken by Tiago and Frazer, spending also most of their free time on the experiment. Larissa did all the required work and responded quickly with results on new tasks. On the other hand, the work of Craig and Adam was non-existent during the summer. Also Darryl's work ethics over the summer was poor even though he was on a paid internship.

7) Completed His/Her Fair Share of the Work: **CAMPAIGN**



Tiago, Frazer, Andrew, Darryl and Craig where sent to the launch campaign in Kiruna. Frazer and Andrew were responsible for the mechanical structure and the inflatables, Tiago was responsible for electronics and software, Craig was in charge of documentation (which he failed to deliver) and Darryl was responsible for support, documentation and the external camera (failed to deliver functional system for balloon flight duration, Darryl was just doing work when he was told to do so).

1.5.4 Conclusions

In summary, it can be said that Tiago and Frazer did the bulk of the work, spending endless hours on the experiment throughout the entire project duration and at the launch campaign. Tiago started off as the head of software but then also took over the electronic design over the summer. Frazer worked first on testing and validation but then took over the mechanical lead in summer. Without Tiago and Frazer's dedication especially over the summer, there would have been no iSEDE at the launch campaign. Also Andrew did great work for the experiment during his MEng project and the launch campaign. He was the mechanical lead first and then supported Frazer on the mechanical side during the launch campaign. Also during summer, he responded to requests quickly and helped Frazer to understand the mechanical design. Jonathan did great work during his MEng time on his area on power systems even though the design kept on changing frequently. Larissa did a great job working on the ground support software and responded quickly if a task needed completion. Larissa delivered a working ground support software for the launch campaign. Her not being physically in Glasgow over the summer might resulted in some minor difficulties. Adam did a great amount of work during his MEng time until May but then disappeared for the summer, even though he promised to work on the experiment. Craig was the project manager first and did his fair share of work during his MEng time. Craig disappeared completely over the summer even though he promised to work on the project; as a result he lost the team leader role. He resurfaced shortly before the launch campaign. To be allowed to go to the launch campaign, he promised to write and send a daily detailed report to Thomas (project manager, not at the launch campaign). Craig failed to write the daily updates and final report. The issue with the fragile solenoid connection could have been discovered before the flight with proper documentation and communication. Darryl's performance during the whole project was well below average. During his BEng time, he was working on the wireless communication which had to be taken over by Tiago due to poor work ethics and bad research. Over the summer, Darryl was on a paid Strathclyde internship where he worked on the power systems for the experiment. Half of the time he did not show up and came to the lab late and left early, he also failed to deliver a report and poster at the end. His work on the power system also had to be taken over and finished by Tiago. Nevertheless, the team decided to send Darryl to the launch campaign where he also did just work when he was told to do so, he and Craig spent the rest of the time on their personal computer.

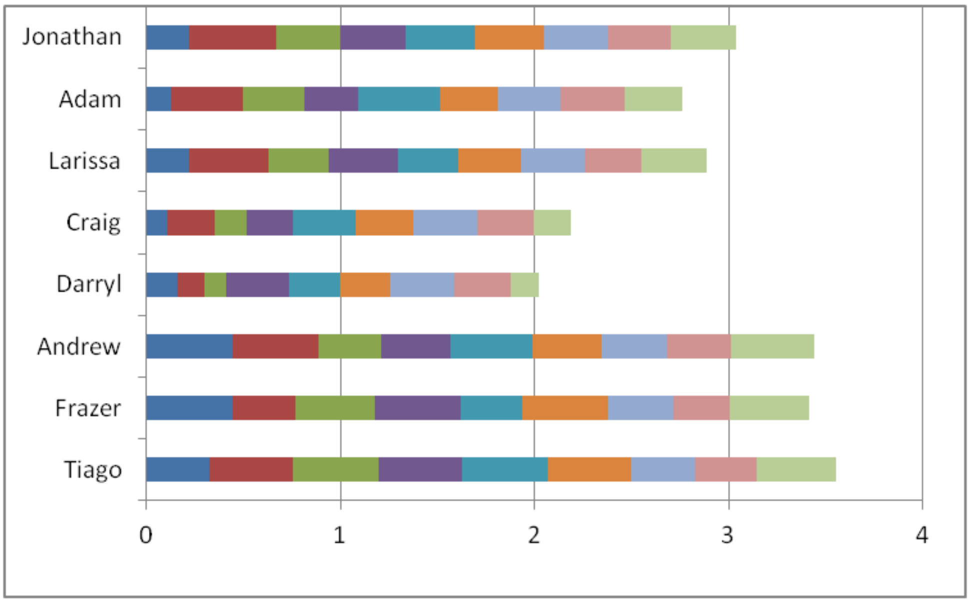


Figure 4: Overall performance of team members

Due to the poor performance of Craig and Darryl coupled with their unfulfilled promises during the summer and the campaign, it was decided by the team and the supervisor to remove Craig and Darryl from

the team in October 2013. The delays and problems before and at the launch campaign were a result of the manpower lost during the summer.

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Functional Requirements

ID	Description
~~ER_FU_01~~	~~There shall be a minimum of two deployable satellites~~ (Design requirement ER_DE_50)
~~ER_FU_02~~	~~One satellite should be deployed prior to launch~~ (Operational requirement ER_OP_01)
ER_FU_03	The electronics of each satellite shall be disaggregated across its inflatable structure
ER_FU_04	Cameras shall capture the deployment and performance of the satellites during the mission
ER_FU_05	Passive inflation shall be demonstrated by each satellite
ER_FU_06	Wireless communication shall be established between the satellites and hub
ER_FU_07	Each satellite should measure the ambient temperature and pressure
~~ER_FU_08~~	~~Charging of each satellites' batteries shall be demonstrated~~ (Decision (June 13): charging during mission unnecessary)
ER_FU_09	Each satellite shall demonstrate an alteration of its shape
ER_FU_10	Control of any shape alteration shall be demonstrated

2.2 Performance requirements

ID	Description
ER_PE_01	Resolution of images captured by the camera(s) shall be at least 800x600 pixels
ER_PE_02	Images captured shall have at least 16 bit colour
ER_PE_03	Temperature measurements of critical components shall take place at a frequency of at least 0.2Hz
ER_PE_04	Ambient temperature measurements shall take place at a frequency of 0.2 Hz
ER_PE_05	All temperature measurements shall have a minimum sensitivity

	of ±5 °C
ER_PE_06	Differential pressure measurements shall be taken at a frequency of 0.1 Hz during adaptive phase
ER_PE_07	Differential pressure measurements shall have a minimum sensitivity of ± 20 Pa
ER_PE_08	Any shape alteration shall be within ±5 cm of desired position
ER_PE_09	During shape alteration the bottom cell should not be displaced by more than 20 cm.
ER_PE_10	The wireless link between the hub and each satellite shall be able to communicate with a bandwidth of at least 75 kbps
ER_PE_11	All shape alterations should be completed in under 20 minutes
~~ER_PE_12~~	~~Batteries should display a measurable increase in SOC during the 30 minutes charging phase~~ (Decision (June 13): charging during mission unnecessary)
ER_PE_13	Differential pressure sensors must be capable of measuring between (-250) – 250 Pa
ER_PE_14	Component temperature measurement must be capable between (-30) – 40 °C

2.3 Design Requirements

ID	Description
ER_DE_01	The experiment shall be designed to work within the temperature profile of the BEXUS balloon
ER_DE_02	The experiment shall be designed to operate in the vibration profile of the BEXUS balloon with special consideration given to the launch and landing stages
ER_DE_03	The experiment shall be designed in such a way that it shall not disturb or harm the gondola or any other experiment
~~ER_DE_04~~	~~The experiment batteries shall be qualified for use on a BEXUS balloon~~ (Decision (July 13): batteries unnecessary)
~~ER_DE_05~~	~~The experiment batteries shall either be rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight~~ (Decision (July 13): batteries unnecessary)
~~ER_DE_06~~	~~The connector for the batteries in the gondola mounted~~

	~~experiment shall be accessible from the outside within 1 minute~~ (Decision (July 13): batteries unnecessary)
ER_DE_07	The deployment box for each satellite shall be no larger than 1U (10x10x10cm)
ER_DE_08	Each satellite shall consist of ten interconnected inflatable cells
ER_DE_09	One central control unit (the Hub) shall be located inside the gondola to control the experiment timeline and relay data up and down the BEXUS E-Link
ER_DE_10	Component circuitry shall be laid out in such a way to allow each satellite to be folded down into their deployment box before the experiment commences
ER_DE_11	COTS components shall be used where applicable and affordable
ER_DE_12	The experiment shall be mounted on the inside of the BEXUS gondola
ER_DE_13	No components or parts shall become detached from the experiment at any point during the BEXUS flight
ER_DE_14	The peak current draw from the BEXUS umbilical shall not exceed 1A at 28V
~~ER_DE_15~~	~~Power shall be distributed across each satellite~~ (Decision (July 13): batteries unnecessary)
ER_DE_16	Each satellite shall have a redundant, hard-wired data connection to the Hub
ER_DE_17	Communication between the satellites and the hub shall be wireless
ER_DE_18	The hub shall have a communications link with the BEXUS E-Link
ER_DE_19	Communication up down the BEXUS E-Link shall not exceed 300 Kbps (13.09.2013 changed from 100kb to 300kbps after adding live webcam downlink)
ER_DE_20	The wireless communication system shall have a bandwidth capable of transmitting all data defined within the data budget
ER_DE_21	The deployment box of the satellite deploying at float altitude shall remain sealed until deployment command is given
ER_DE_22	The deployment boxes shall not cause any damage to the deployable structure

ER_DE_23	The hatch on each deployment box shall remain attached after deployment of the inflatable structure
ER_DE_24	The inflatable cells shall not burst when subjected to vacuum pressure
ER_DE_25	Pressure shall be measured inside at least 2 adjacent cells in each satellite
ER_DE_26	Critical components shall have the embedded capability of measuring their temperature
ER_DE_27	All PCB’s shall be resin-coated to be prevent arcing in vacuum pressures
ER_DE_28	All tracks and wires should withstand environmental conditions
ER_DE_29	Tracks and components mounted on each satellite shall withstand the strain exerted during folding
ER_DE_30	All interfaces shall be secured tight to prevent loosening due to any vibrations during flight
ER_DE_31	Solid state, non-volatile data storage shall be used
ER_DE_32	Capacity of storage memory shall be sufficient to store all measurement and status data
ER_DE_33	Cameras shall be positioned suitably to capture deployment of all satellites
ER_DE_34	Cameras shall carry out all image processing and store images locally
ER_DE_35	A redundant power line shall be provided from the BEXUS module to the satellites
ER_DE_36	The hub shall be powered by the BEXUS link
ER_DE_37	Status updates shall be generated and sent down the E-Link to the ground station regularly for each critical component
ER_DE_38	A control algorithm shall control the shape alterations of each satellite
ER_DE_39	All data shall be communicated back to the hub for storage in its SD card
ER_DE_40	Each satellite shall store all its data on an SD card locally
ER_DE_41	The ground station shall be capable of sending commands to each satellite and receiving data through the BEXUS E-Link
ER_DE_42	Feedback data shall be sent down the BEXUS E-Link to the

	ground station
ER_DE_43	The hub shall be insulated to provide thermal protection
ER_DE_44	The hub shall have an Ethernet port for connection to the BEXUS E-Link
ER_DE_45	Any change in shape shall not interfere with electronics or external structures
ER_DE_46	The wireless communications shall not use any BEXUS prohibited frequency bands
ER_DE_47	Each satellite shall be securely fastened to the gondola
ER_DE_48	The hub shall be securely fastened to the gondola
ER_DE_49	The experiment structure should be no longer than 650 mm
ER_DE_50	There shall be a minimum of two deployable satellites
ER_DE_51	A light source shall be mounted inside the gondola to illuminate the experiment
ER_DE_52	The soft robotic actuator element shall not leak fluid into the environment
ER_DE_53	The fluid in the soft robotic actuator element shall not freeze at the temperatures to be expected during the balloon flight
ER_DE_54	A switch shall be mounted on the outside of the experiment to switch in-between flight and test mode
ER_DE_55	A clearance (nothing mounted on the bottom) of 25cm in actuation direction on the bottom of each satellite is required.

2.4 Operational Requirements

ID	Description
ER_OP_01	One satellite shall be pre-deployed before launch
ER_OP_02	The hub shall accept commands from the ground station at any time
ER_OP_03	The Hub shall be active from launch command given through the E-Link from the ground support station
ER_OP_04	At float altitude all systems shall become active
ER_OP_05	Data storage shall begin as systems are online
ER_OP_06	Any adverse behaviour identified through housekeeping should

	be reported down the E-Link to the ground station
ER_OP_07	Status of critical components shall be reported to the ground station
ER_OP_08	One satellite shall be deployed at float altitude
ER_OP_09	Wireless communication between the hub and satellites should be established after deployment
ER_OP_10	Shape change shall begin upon receipt of command from ground station
ER_OP_11	Electronic systems shall operate autonomously
ER_OP_12	The satellites shall conduct measurements autonomously
ER_OP_13	The experiment shall accept a request for radio silence at any time while on the launch pad
ER_OP_14	All data shall be relayed back to the hub SD card for storage
~~ER_OP_15~~	~~The charging phase shall be initialised only after shape change has been completed~~ (Decision (June 13): charging during mission unnecessary)
ER_OP_16	The experiment light inside the gondola shall be able to be switched on
ER_OP_17	The float phase of the balloon shall be at least two hours to run through experiment cycle twice
ER_OP_18	The flight altitude shall be at least 25km (low pressure required for cell inflation)
ER_OP_19	During the actuation phase of iSEDE, other experiments on the gondola shall not introduce any movement to the gondola
ER_OP_20	The side walls of the gondola shall be attached during the flight
ER_OP_21	(Remove Before Flight pins shall be attached to the satellite boxes to ensure safe handing)

2.5 Constraints

There are a number of constraints, both technical and managerial, that must be applied to the experiment in order to be compliant with BEXUS requirements, academic needs and experimental requirements.

All constraints are listed below:

1) **Schedule**[1]
    a) The project team shall all receive academic credit for the work carried out with iSEDE. Therefore, a considerable amount of the work must be carried out within the academic year in order to show sufficient evidence that will warrant academic credit.
    b) In addition, the project must run alongside the BEXUS 16 timeline in order to meet design reviews, integration, launch and reporting deadlines.
2) **Cost**
    a) The project is running on a tight budget with set funds being allocated to each academic project involved in iSEDE by the engineering faculty. The only additional support being received is through provision of passive components by sponsor, Coilcraft, and an undisclosed quantity of funds from the experiments academic sponsor. Therefore, it is important that the budget outlined in section 3.3.2 is strictly adhered to.
3) **Manpower**
    a) The iSEDE project team currently consists of 9 members. It is endeavoured that this shall increase through our current recruitment drive; however, it is important that the scope of the project remains relatively constant throughout. Any significant scope creep could lead to substantial increases in the already tight schedule, and could put the project at risk of failing to meet deadlines.
4) **Technical**
    a) BEXUS Compliance
        i) The experiment cannot operate any wireless communications on the 2.4 GHz, 1000 MHz or 400 MHz frequency bands
        ii) Power drawn from the BEXUS module cannot exceed 28 V at a peak current no greater than 1 A
        iii) Power must be received through interfacing with a MIL – C-26482P series 1 connector with an 8-4 insert arrangement (MS3112E8-4P)
        iv) The electrical interface between the BEXUS E-Link and the experiment must use the standard Ethernet 10/100 Base-T protocol
        v) Data transmission up and down the BEXUS E-Link must be kept to a minimum
        vi) The experiment must be able to withstand the accelerations stated within the BEXUS user manual throughout the flight
        vii) The experiment must be able to withstand the harsh temperature profile experienced throughout the flight
        viii) Experiment mass and volume must be kept to a minimum in order to allow for the other student experiments to be accommodated comfortably within the gondola

[1] Schedule constraints can be seen in more detail within the Gantt chart

b) Experimental
   i) The design must incorporate a number of inter-connected inflatable cells
   ii) The electronics must demonstrate disaggregation across the full inflatable structure
   iii) Each satellite must be capable of being folded into a ≤ 1U deployment box
   iv) All data must be stored in the hub in addition to aboard each satellite in case any satellite appendages external to the gondola are damaged upon landing
   v) Any shape change must be completed within the experiments half hour long operational phase.
   vi) Electronics must have the capability to operate autonomously in the case that a communications link is lost with the ground station
   vii) Electronics must not damage the surface of the inflatable material so as not to risk failure

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

The work breakdown structure in Figure 3-1 shows the main breakdown of tasks for the project.

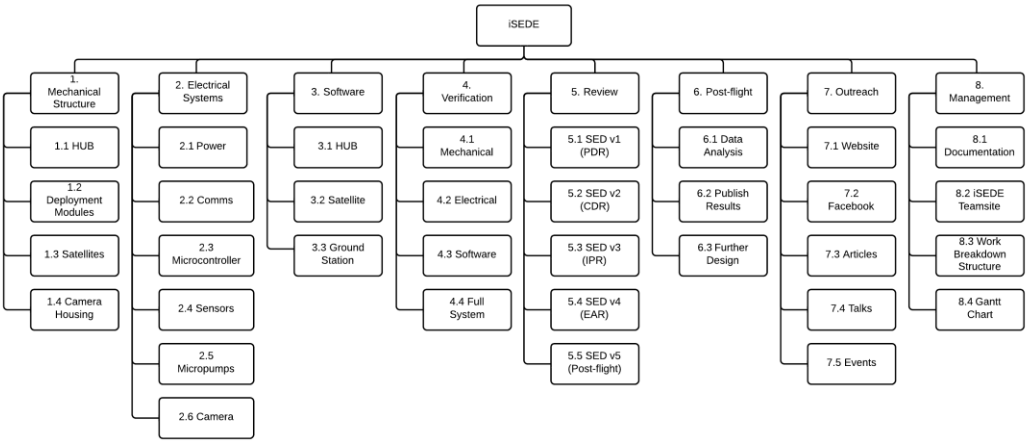


Figure 3-1: Work Breakdown Structure

Figure 3-2 shows a further breakdown of tasks for each mechanical area of the project.

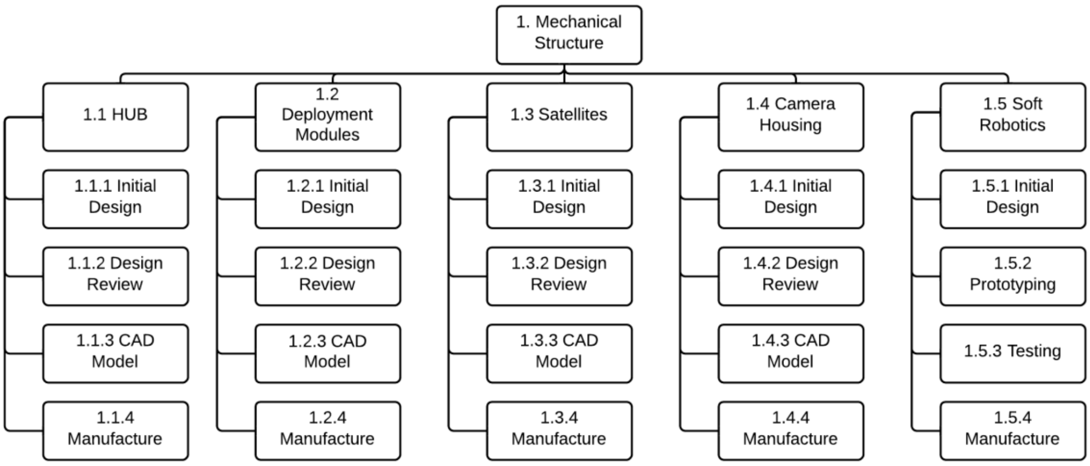


Figure 3-2: Mechanical WBS

Figure 3-3 shows a further breakdown of tasks for each electrical area of the project.

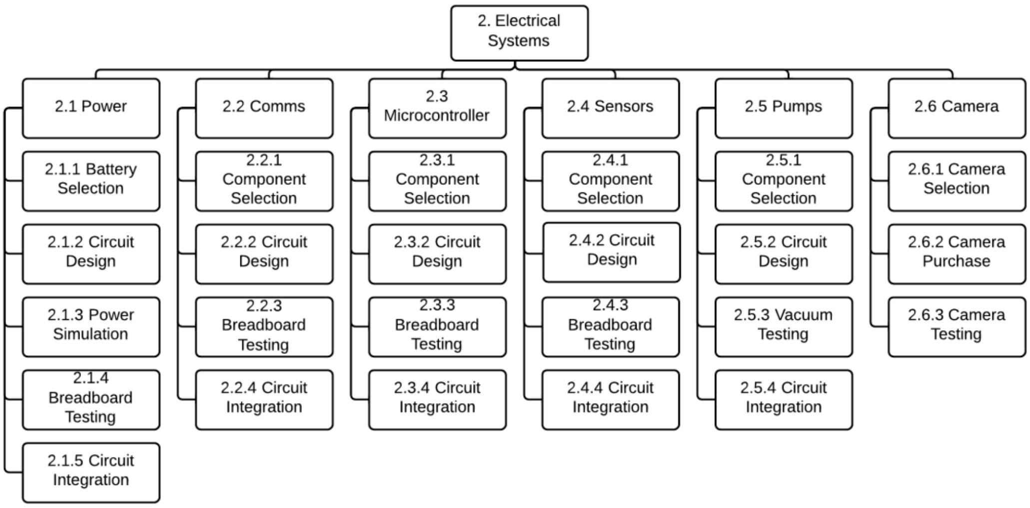


Figure 3-3: Electrical WBS

Figure 3-4 shows a further breakdown of tasks for each software area of the project.

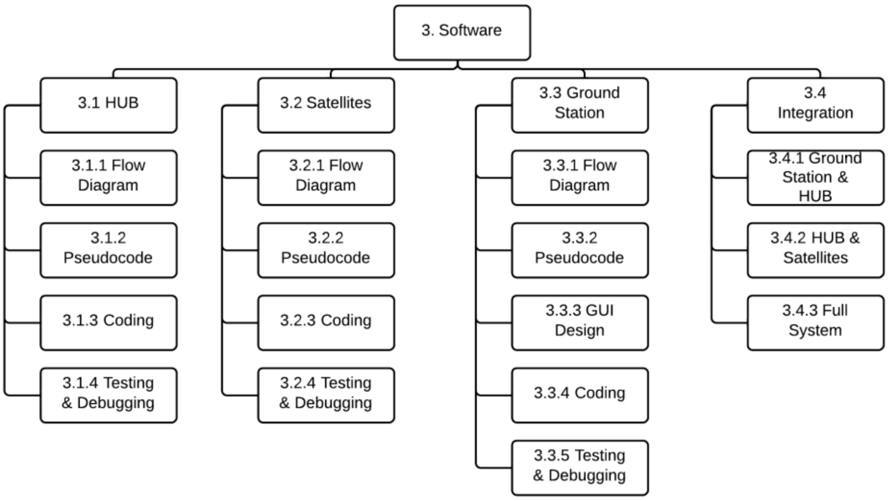


Figure 3-4: Software WBS

Following from the WBS, each team member was allocated tasks which reflected their specialisations and interests.

Table 3-1: Allocated Tasks

Task Number	Task	Lead Engineer	Additional Engineer
1	Mechanical Structure	Frazer Brownlie	Thomas Sinn, Andrew Allan
2.1	Power	Tiago Queiroz	Jonathan Gillespie
2.2	Comms	Tiago Queiroz	Adam Rowan
2.3	Microcontroller	Tiago Queiroz	Adam Rowan
2.4	Sensors	Tiago Queiroz	Adam Rowan
2.5	Micropumps	Tiago Queiroz	Adam Rowan
2.6	Camera	Tiago Queiroz	Adam Rowan
3	Software	Tiago Queiroz	Larissa Leite
4	Verification	Thomas Sinn	Frazer Brownlie
5	Review	All	
6	Post Flight	Thomas Sinn	Tiago Queiroz, Larissa Leite,Frazer Brownlie
7	Outreach	All	
8	Management	Thomas Sinn	

3.2 Schedule

The GANTT chart below summarizes all the tasks that need to be performed from the IPR onwards. This GANTT chart updates the full GANTT chart (BX16_iSEDE_GANNTv1_13MAY13) on the teamsite.

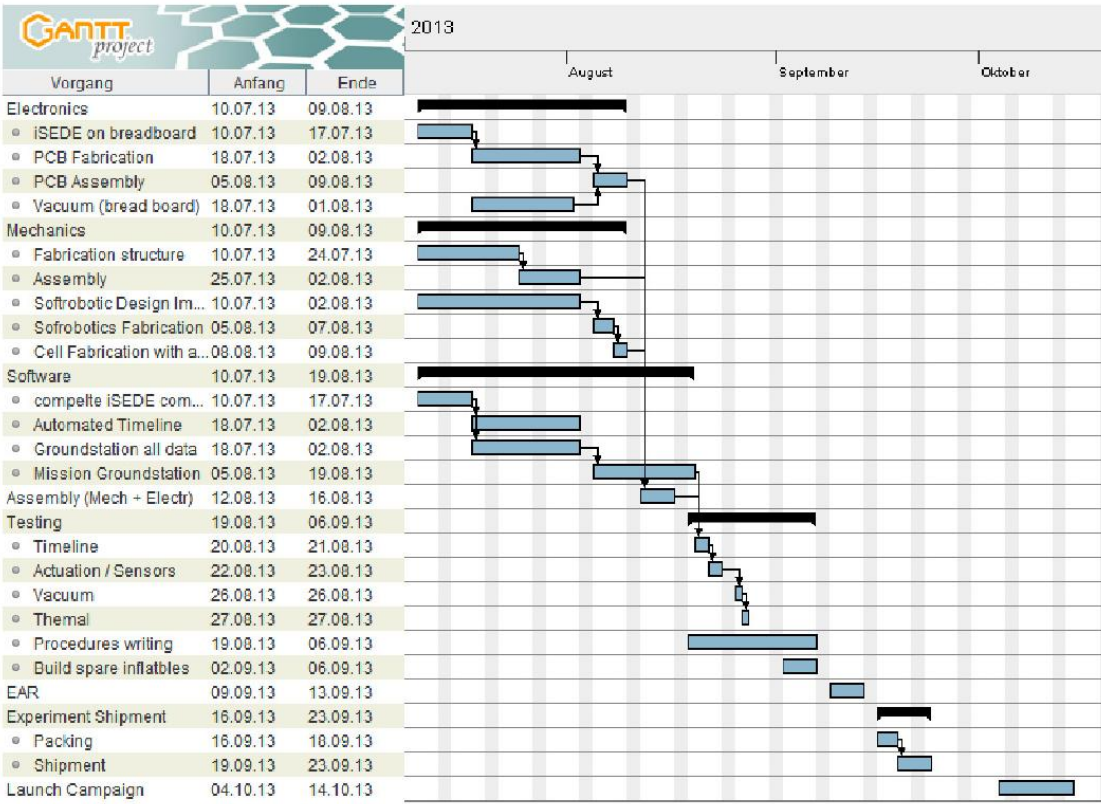


Figure 3-5: GANTT chart after IPR

After the IPR the team is focusing on getting all the subsystems ready and tested in the vacuum chamber before ordering PCBs. In the first week of August the electronics and the mechanical structure was assembled and thoroughly tested (timeline, actuation, vacuum, thermal). The week before the EAR (week 37) was used to write up all the procedures for the launch campaign. After the EAR, the experiment was prepared for shipping on the 20th of September. The launch campaign was from the 4th to 14th of October.

3.3 Resources

3.3.1 Manpower

A core team of seven students are completing most of the work on the project. Thomas Sinn was work 10 hours per week on the project. Every other team member has worked at least 15 hours per week on the project, as per the academic requirements. Two computer science students (Tiago Quieroz and Larissa Leite) have been recruited to work on the embedded programming and ground support software. They shall also provide support with electronics as they have some experience in this area. They were working on the project on a full-time basis throughout the summer months as part of a Science Without Borders internship.

Andrew Allan and Jonathan Gillespie stepped down from their roles after bringing their areas of the design up to CDR level. This was managed by a controlled hand over of their work to other members of the team. They were still be available for consultation should the need arise. Andrew handed over his design and responsibilities to Frazer Brownlie, and Jonathan to Darryl Black. Frazer Brownlie and Darryl Black are working on iSEDE full time over the summer as a paid internship of the Department of Mechanical and Aerospace Engineering / University of Strathclyde. Therefore, during summer Frazer, Darryl, Tiago and Larissa are working full time with the support of Thomas over the summer on fabrication, assembly and testing of iSEDE. These five team members should be enough to finish the experiment in time for experiment submission in September 2013.

3.3.2 Budget

The budget of iSEDE is a sum of various dissertations, projects and funding of the Aerospace and Mechanical Engineering Department University of Strathclyde.

3.3.2.1 Component Budget

The current funding for the project is £2950. Expenses so far come to a total of £2720 (as of 07.07.2013). The spending on components, materials and tools is itemised in Table 3-2. The funding is made up with £400 from the 5th year EME project, £100 from 4th year EME project, £50 from 4th year MAE project, £400 department contribution and £2000 excess from a university project on inflatable structures.

Date	Component	Quantity	Supplier	Unit Cost	Cost
17-Dec-12	Arduino Nano 3.0	3	RS Components	£29.00	£87.00
17-Dec-12	Raspberry Pi type B	1	RS Components	£21.60	£21.60
17-Dec-12	Arduino Ethernet without PoE	1	RS Components	£34.40	£34.40
17-Dec-12	ACS712 Low Current Sensor Breakout	1	Active robotics	£10.91	£10.91
17-Dec-12	Digital Temperature Sensor Breakout	1	Active robotics	£8.10	£8.10
17-Dec-12	TEMT6000 Interface Board	1	Active robotics	£3.70	£3.70
26-Feb-13	Wood for test stand	1	Hardware Store	£31.50	£31.50
26-Feb-13	Cornerpieces	1	Hardware Store	£18.50	£18.50
26-Feb-13	FTDI Basic Breakout - 5V	1	Active Robotics	£11.83	£11.83
05-Mar-13	Zulu-868 Transeiver Module	1	Farnell	£37.00	£37.00
12-Mar-13	ADXL345 Accelerometer Breakout	3	Active Robotics	£19.04	£57.12
12-Mar-13	MOSFET N-Channel 50V 0.22A SOT23	1	RS Components	£0.18	£0.18
13-Mar-13	TMR 6-0510 Regulator	1	RS Components	£17.00	£17.00
13-Mar-13	TMR 3-1210WIE Regulator	1	RS Components	£11.40	£11.40

13-Mar-13	AAT3683 Charging IC	1	RS Components	£1.31	£1.31
15-Mar-13	HackHD Camera PCB	2	HackHD.com	£119.27	£238.54
15-Mar-13	GoPRO Skeleton Housing	2	gopro.com	£45.99	£91.98
17-Mar-13	868 MHz BEAD Antenna	3	RF Solutions	£17.70	£53.10
20-Mar-13	Socket Solder Tail Single Row	1	Digi-Key	£11.76	£11.76
20-Mar-13	Socket Solder Tail Single Row	1	Digi-Key	£1.23	£1.23
26-Mar-13	Micropumps + Controllers + Tubing	1	Bartels	£660.00	£660.00
26-Mar-13	LBA Pressure sensors	1	LBA	£478.64	£478.64
26-Mar-13	Soft Robotics Material	1	Curetime	£108.05	£108.05
26-Mar-13	Linear movement actuator,5.6V 15deg	2	RS Components	£21.78	£43.56
26-Mar-13	Tool steel semi flush cutter 110mm	1	RS Components	£6.87	£6.87
26-Mar-13	Anti static band cordset	2	RS Components	£17.59	£35.18
26-Mar-13	DIGITAL MULTIMETER 5XP-A	1	RS Components	£36.00	£36.00
26-Mar-13	0.5m black test lead,4mm plug	5	RS Components	£2.04	£10.20
26-Mar-13	0.5m red test lead,4mm plug	5	RS Components	£2.04	£10.20
26-Mar-13	HELPING-HAND	1	RS Components	£9.87	£9.87
26-Mar-13	AVR Atmega328P Microcontroller	5	RS Components	£1.90	£9.50
26-Mar-13	PROTOTYPINGBOARD 36	2	RS Components	£20.86	£41.72
26-Mar-13	Kapton Film 304x200x 0.025mm	1	RS Components	£30.00	£30.00
26-Mar-13	High temp masking tape	1	RS Components	£14.54	£14.54
26-Mar-13	Capacitor for linear actuator	2	RS Components	£8.00	£16.00
26-Mar-13	Foil Blanket Pk 6	2	RS Components	£10.58	£21.16
26-Mar-13	Pull action latching solenoid	1	RS Components	£6.27	£6.27
26-Mar-13	Clear heatshrink tube 3/1mm i/d	1	RS Components	£6.95	£6.95
26-Mar-13	Clear heatshrink tube 18/6mm i/d	1	RS Components	£7.26	£7.26
26-Mar-13	LI ION CHARGER 2241 LI 2 CELLS	1	RS Components	£35.00	£35.00
26-Mar-13	DSUB SOCKET WIRE SOLDER - 9 WAYS	10	RS Components	£0.86	£8.60
26-Mar-13	DSUB PLUG WIRE SOLDER - 9 WAYS	10	RS Components	£0.85	£8.50
26-Mar-13	7 piece mini electronics tool kit	1	RS Components	£20.24	£20.24
26-Mar-13	5 piece general purpose cutter set	1	RS Components	£26.37	£26.37
26-Mar-13	50 ties and fixing assemT18R MB2A	1	RS Components	£8.99	£8.99
26-Mar-13	Sub-1GHz RF Transceiver CC1101	3	RS Components	£3.84	£11.52
26-Mar-13	A55KJ Soldering Iron Tips	1	Maplin	£5.99	£5.99
20-Apr-13	5m 3/4inch 10swg Al T6 Tube	1	Richard Austin Alloys	£36.00	£36.00
07-Jun-13	5m 16mm 10swg Al T6 Angle	1	Richard Austin Alloys	£12.00	£12.00
07-Jun-13	5m 25mm 10swg Al T6 Angle	1	Richard Austin Alloys	£10.00	£10.00
07-Jun-13	2.4m 2mm 10swg Al T6 Sheet	1	Richard Austin Alloys	£47.00	£47.00
25-Jun-13	M4 (4mm), A2 COUNTERSUNK CSK SOCKET CAP ALLEN BOLT SCREWS STAINLESS STEEL	1	Falcon Workshop Supplies	£2.40	£2.40

	(FWS) (Artikel: 190726817504 Transaktio n: 838144932009)				
25-Jun-13	M4 (4mm), A2 COUNTERSUNK CSK SOCKET CAP ALLEN BOLT SCREWS STAINLESS STEEL (FWS) (Artikel: 190726817504 Transaktio n: 838144934009)	1	Falcon Workshop Supplies	£1.55	£1.55
25-Jun-13	A2 STAINLESS NYLOC INSERT NUTS, STANDARD PITCH, DIN985 NYLOC LOCK NUT TYPE T FWS (Artikel: 190762409167 Transaktion : 838144937009)	1	Falcon Workshop Supplies	£3.70	£3.70
25-Jun-13	A2 STAINLESS NYLOC INSERT NUTS, STANDARD PITCH, DIN985 NYLOC LOCK NUT TYPE T FWS (Artikel: 190762409167 Transaktion : 838144938009)	1	Falcon Workshop Supplies	£1.55	£1.55
25-Jun-13	A2 STAINLESS NYLOC INSERT NUTS, STANDARD PITCH, DIN985 NYLOC LOCK NUT TYPE T FWS (Artikel: 190762409167 Transaktion : 838144941009)	3	Falcon Workshop Supplies	£1.45	£4.35
25-Jun-13	M8 (8mm) A2 STAINLESS STEEL SOCKET CAP SCREWS, ALLEN KEY BOLTS HEX HEAD (FWS) (Artikel: 200831471285 Transaktio n: 906760784010)	1	Falcon Workshop Supplies	£5.60	£5.60
25-Jun-13	M8 (8mm) A2 STAINLESS STEEL SOCKET CAP SCREWS, ALLEN KEY BOLTS HEX HEAD (FWS) (Artikel: 200831471285 Transaktio n: 906760785010)	1	Falcon Workshop Supplies	£5.22	£5.22
25-Jun-13	M8 (8mm) A2 STAINLESS STEEL SOCKET CAP SCREWS, ALLEN KEY BOLTS HEX HEAD (FWS) (Artikel: 200831471285 Transaktio n: 906760786010)	1	Falcon Workshop Supplies	£6.45	£6.45
25-Jun-13	M3 (3mm) A2 Stainless Steel Socket Cap Screws, Allen Key Bolts Hex Head (FWS), 200832008647	3	Falcon Workshop Supplies	£2.25	£6.75
02-Jul-13	RESISTOR, 2512, 2W, 33K, 1%; Product Ran	5	Premier Farnell		
02-Jul-13	RESISTOR, 4.7K, 0.25W, 1%; Product Range	50	Premier Farnell		
02-Jul-13	RESISTOR, 2512, 2W, 5K1, 1%; Product Ran	5	Premier Farnell		
02-Jul-13	RESISTOR, 2512, 2W, 6K8, 1%; Product Ran	5	Premier Farnell		
02-Jul-13	RESISTOR, 2512, 2W, 7K5, 1%; Product Ran	5	Premier Farnell		
02-Jul-13	CAPACITOR, 4.7UF, 35V, SMD; Product Rang	10	Premier Farnell		

02-Jul-13	CAPACITOR, CASE B, 2.2UF, 50V; Product R	10	Premier Farnell		
02-Jul-13	INDUCTOR, 10UH, 10%, 3A, TH RADIAL; Prod	3	Premier Farnell		
02-Jul-13	INDUCTOR, 3.3UH, 20% 1.5A TH RADIAL; Pro	2	Premier Farnell		
02-Jul-13	TRANSISTOR, NPN, TO-92; Transistor Polar	10	Premier Farnell		
02-Jul-13	MOSFET, P, -200V, -11A, TO-220; Transist	4	Premier Farnell		
02-Jul-13	IC, 74HC CMOS LOGIC; Logic Device Type:B	9	Premier Farnell		
02-Jul-13	WIRE, WHT, 18AWG, 1/18AWG, 30.5M; Reel L	1	Premier Farnell		
02-Jul-13	RIBBON CABLE, 6WAY, PER M; No. of Condu	5	Premier Farnell		
02-Jul-13	RIBBON CABLE, HIGH FLEX, 6WAY, PER M; No	1	Premier Farnell		
02-Jul-13	HEADER, SHROUDED, R/A, 6WAY; Connector T	10	Premier Farnell		
02-Jul-13	HOUSING, CRIMP, RECEPTACLE, 2.54MM, 6WAY	10	Premier Farnell		
02-Jul-13	CONTACT, SOCKET, 26-22AWG, CRIMP; Series	40	Premier Farnell		
02-Jul-13	HEADER, R/A, 0.1", 12WAY; Connector Type	5	Premier Farnell		
02-Jul-13	HOUSING, 24AWG, 12WAY; Connector Type:Wi	5	Premier Farnell		
02-Jul-13	LED, HI BRIGHT, 5MM; Bulb Size:T-1 3/4 (	10	Premier Farnell		
02-Jul-13			Premier Farnell		£75.90
03-Jul-13	SENSOR, ABS PRESS 14.5PSI, 344B-4; Press	1	Premier Farnell		
03-Jul-13	CONVERTER, DC/DC, 2:1I/P, 1W, 12V; DC /	1	Premier Farnell		
03-Jul-13	HEATSHRINK, 4.8MM, CLEAR, 1.2M; I.D. Sup	1	Premier Farnell		
03-Jul-13	RESISTOR, 3.3K, 0.125W, 1%; Product Rang	10	Premier Farnell		
03-Jul-13	RESISTOR, 0.125W 1% 8K2; Product Range:M	10	Premier Farnell		
03-Jul-13	RESISTOR, 0.125W 1% 150R; Product Range:	30	Premier Farnell		
03-Jul-13	LED, 3MM, GREEN; Bulb Size:T-1 (3mm); LE	10	Premier Farnell		
03-Jul-13	LED, T-1 YELLOW; Bulb Size:T-1 (3mm); LE	10	Premier Farnell		
03-Jul-13	RESISTOR, 0.125W 1% 20K; Product Range:M	10	Premier Farnell		
03-Jul-13	RESISTOR, 10K, 0.125W, 1%; Product Range	10	Premier Farnell		

03-Jul-13	LED, 3MM, RED, 100MCD, 643NM; Bulb Size:	10	Premier Farnell		
03-Jul-13			Premier Farnell		£35.06
04-Jul-13	White PVC Equipment Wire 16/0.2mm 100m	1	RS-Components		
04-Jul-13	Clear heatshrink tubing, 3.2mm bore	2	RS-Components		
04-Jul-13			RS-Components		£12.95
				TOTAL	**£2,718.90**

Table 3-2: Itemised Budget

3.3.2.2 Travel Budget

Most of the students in the iSEDE team are eligible for the ESA funding to attend the workshops, reviews and launch campaign. Two of the team members are from Brazil which isn't an ESA member state, therefore additional funding is required to be found for Tiago and/or Larissa to attend the launch campaign. The Aerospace and Mechanical engineering department might offer support, but this needs to be negotiated by a case to case basis. So far, Tiago got sponsored by the department with £200 to attend the Soldering Course and the CDR at ESTEC in May. Further funding to attend the launch campaign is currently sought for through various applications for travel grants (IET, home institution, ...). It is estimated that another £1000/person are required to send Tiago and/or Larissa to the launch campaign (flights and hotel).

3.3.3 External Support

The Advanced Space Concepts Laboratory at the University of Strathclyde provides the team with the most support. The team's endorsing professor is Dr Massimiliano Vasile, who is an Associate Director of the Advanced Space Concepts Laboratory.

As the majority of students study a joint Masters Degree in Electrical and Mechanical Engineering, contacts within the EEE department are supporting on power, electronics and communications.

The large percentage of work being related to students' academic projects means that academic supervisors also provide support where required.

International magnetics manufacturer, Coilcraft, have offered their support to the iSEDE team in providing components and testing facilities where possible.

Dr Brian Stimpson, expert in mechatronic systems at the University of Strathclyde, has also offered support in design considerations.

3.4 Outreach Approach

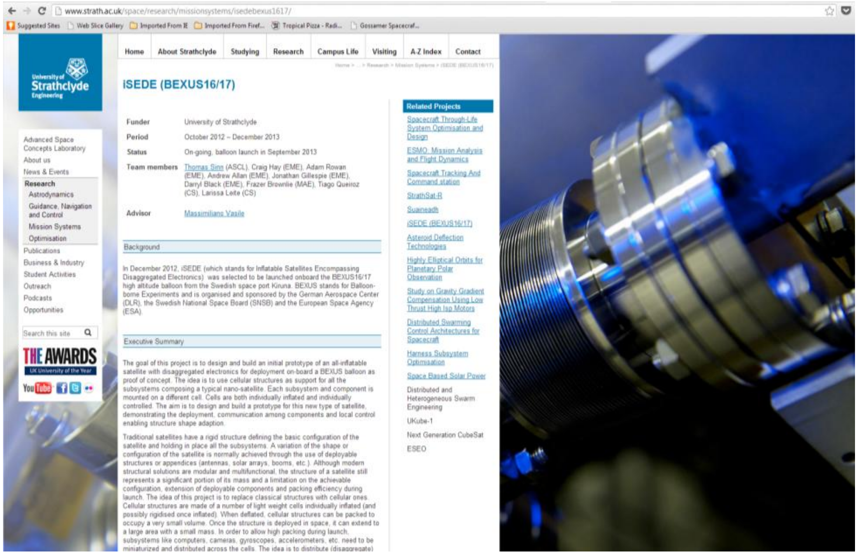
Each member of the iSEDE team is using their skills and their network of contacts to arrange outreach activities and raise the profile of the project and the BEXUS programme. This section details what has been done so far and how we plan to implement an outreach strategy. The following list should provide a comprehensive overview over the planned and undertaken outreach activities of the iSEDE team, more detailed press releases and articles can be found in Appendix B:

- Internet:
    - Facebook page: https://www.facebook.com/iSEDE.BEXUS
    - Regular photo updates and updates on experiment progress

Figure 3-6: iSEDE Facebook Page

- Project page on the webpage of the Advanced Space Concepts Laboratory / University of Strathclyde

  (http://www.strath.ac.uk/ascl/research/missionsystems/isedebexus1617/)



- iSEDE Blog: http://isede2013.wordpress.com

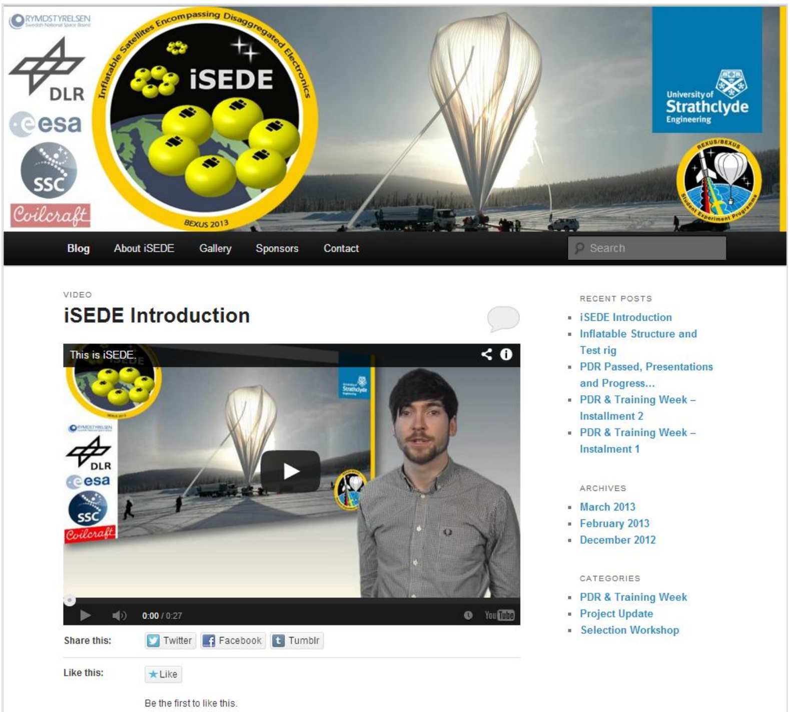


Figure 3-7: iSEDE Blog

- Any performed outreach actions, e.g. press releases published, journalists contacted, logos or information brochures designed
  - Team Branding

- Logo created

Figure 3-8: iSEDE logo

- Details of media coverage, e.g. newspaper articles, radio/TV interviews, internet news articles, etc
  - August 2013: Post on ESA Education facebook page on outreach activity of iSEDE team at UK Space Conference 2013, Glasgow, UK

esa education

ESA Education shared a link.
2 hours ago

20 university students from University of Strathclyde brought their enthusiasm to the 2013 UK Space Conference (15-17 July). Here they showed how exciting is to engage into ESA's education hands-on activities and presented to other students and a large public the experiments they built for launch on board the Rexus and Bexus educational sounding rockets and atmospheric balloons annual campaigns. One of the conference's special guests, ESA British astronaut Timothy Peak, visited their stand and wished the student good luck for the upcoming Bexus launch campaign (4-14 October 2013).

UK Space Conference 2013
www.flickr.com

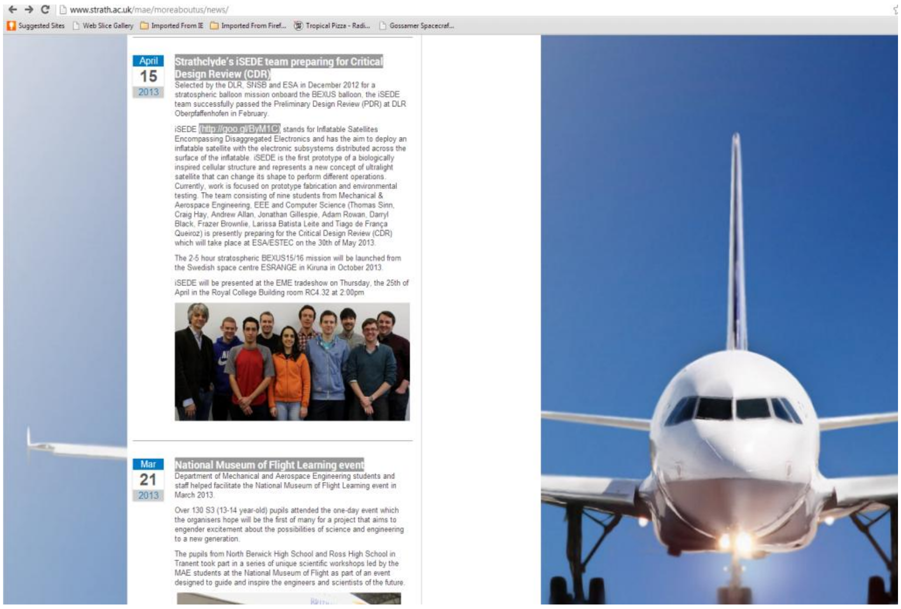
Sets let you organize your photos on Flickr. Explore the 7 photos in this set.

Like · Comment · Share 5

Figure 3-9:: ESA Education facebook post on 9th of August 2013

- June 2013: Newsletter article on iSEDE's CDR from Mechanical & Aerospace Engineering Department/University of Strathclyde (Article in appendix B)

- April 2013: News article on departmental homepage of Mechanical & Aerospace Engineering/University of Strathclyde (http://www.strath.ac.uk/mae/moreaboutus/news/)



www.strath.ac.uk/mae/moreaboutus/news/

April 15 2013

Strathclyde's iSEDE team preparing for Critical Design Review (CDR)

Selected by the DLR, SNSB and ESA in December 2012 for a stratospheric balloon mission onboard the BEXUS balloon, the iSEDE team successfully passed the Preliminary Design Review (PDR) at DLR Oberpfaffenhofen in February.

iSEDE (http://goo.gl/ByM1C) stands for Inflatable Satellites Encompassing Disaggregated Electronics and has the aim to deploy an inflatable satellite with the electronic subsystems distributed across the surface of the inflatable. iSEDE is the first prototype of a biologically inspired cellular structure and represents a new concept of ultralight satellite that can change its shape to perform different operations. Currently, work is focused on prototype fabrication and environmental testing. The team consisting of nine students from Mechanical & Aerospace Engineering, EEE and Computer Science (Thomas Sinn, Craig Hay, Andrew Allan, Jonathan Gillespie, Adam Rowan, Darryl Black, Frazer Brownlie, Larissa Batista Leite and Tiago de França Queiroz) is presently preparing for the Critical Design Review (CDR) which will take place at ESA/ESTEC on the 30th of May 2013.

The 2-5 hour stratospheric BEXUS15/16 mission will be launched from the Swedish space centre ESRANGE in Kiruna in October 2013.

iSEDE will be presented at the EME tradeshow on Thursday, the 25th of April in the Royal College Building room RC4.32 at 2:00pm

Mar 21 2013

National Museum of Flight Learning event

Department of Mechanical and Aerospace Engineering students and staff helped facilitate the National Museum of Flight Learning event in March 2013.

Over 130 S3 (13-14 year-old) pupils attended the one-day event which the organisers hope will be the first of many for a project that aims to engender excitement about the possibilities of science and engineering to a new generation.

The pupils from North Berwick High School and Ross High School in Tranent took part in a series of unique scientific workshops led by the MAE students at the National Museum of Flight as part of an event designed to guide and inspire the engineers and scientists of the future.

- Article in edition of Strathclyde Telegraph (university newspaper)

- Article in national newspaper – The Scotland on Sunday

- Presentations given by team members, e.g. at the university or a conference
    - September 2013, iSEDE presented at student team competition at International Astronautical Congress (IAC) in Beijing, China
    - August 2013, poster presentation on Smart Deployable Structures with iSEDE technology demonstrator at Alumni Conference of the International Space University, Strasbourg, France
    - June 2013, iSEDE presented as part of research on Smart Space Structures, Postgraduate Research Presentation Day / University of Strathclyde, Glasgow, UK
    - March 2013, SET fort Britain, iSEDE mentioned on poster on Smart Space Structures, House of Commons, Parliament, London, UK
    - December 2012, presentation of iSEDE concept to StrathSEDS (Strathclyde division of UKSEDS student space society)

- Exhibitions of the experiment, e.g. at a fair or university open day.
    - July 2013, Booth at the UK Space Agency presenting REXUS/BEXUS and the Strathclyde experiments. Teaching Scouts and general public the advantages of inflatable space structures.

Figure 3-10: Outreach booth at the UK Space Conference, Glasgow, UK

- April 2013, Stand at Electrical and Mechanical Engineering Tradeshow. Academic staff and representatives from industry viewed projects completed by students within the department.

Figure 3-11: Electrical Engineering University Tradeshow, April 2013

3.5 Risk Register

Each risk is scored with a Total Risk Index (TRI), which is the result of multiplying its severity and likelihood of occurrence scores. Severity is rated from 1 to 5 with 5 being most severe. Probability is rated A to E with E being the highest probability. The TRI is then classified in four groups: Green, Yellow, Orange and Red. Only Green risks are accepted by the EAR and Yellow risks are justified.

E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low
	1	2	3	4	5

Table 3-3: Risk Analysis

Risk ID
TC – technical/implementation
MS – mission (operational performance)
SF – safety
VE – vehicle
PE – personnel
EN – environmental

Probability (P)
A. Minimum – Almost impossible to occur
B. Low – Small chance to occur
C. Medium – Reasonable chance to occur
D. High – Quite likely to occur
E. Maximum – Certain to occur, maybe more than once

Severity (S)
1. Negligible – Minimal or no impact
2. Significant – Leads to reduced experiment performance
3. Major – Leads to failure of subsystem or loss of flight data
4. Critical – Leads to experiment failure or creates minor health hazards
5. Catastrophic – Leads to termination of the project, damage to the vehicle or injury to personnel

The rankings for probability (P) and severity (S) are combined to assess the overall risk classification, ranging from very low to very high.

ID	Risk	P	S	P x S	Action
TC10	Inflatable structure too large for deployment box	B	3	Low	Change dimensions of deployment box or inflatable structure.

TC20	Seals of inflatable burst under inflation pressure	B	3	Low	Alternative method of sealing and/or seal larger area.
TC30	Seals of inflatable leak under inflation pressure	B	2	Low	Refine design until reliable inflation in vacuum chamber tests.
TC40	Shape changing actuation cannot be fully tested in lab conditions	D	2	Low	Estimate difference between lab and mission conditions.
TC50	Cameras give poor image quality	B	4	Low	Purchase higher definition camera/more than one camera.
~~TC60~~	~~Reduction in battery capacity due to intensive testing~~ (deleted: no batteries required anymore)	~~A~~	~~4~~	~~Very Low~~	~~Buy spare batteries and use fresh batteries for mission.~~
TC70	Temperature testing damages components	B	3	Low	Have spare components.
TC80	Component failure during testing and integration	C	3	Low	Have spare components.
TC90	Not enough PCB space on inflatable structures	A	3	Very Low	Carefully review integration of inflatable structure and electronics throughout design.
TC100	PCBs mounted on inflatable tear inflatable structure	B	4	Low	Design PCBs without sharp edges or use flex PCBs.
TC110	Experiment does not fit together at integration	B	4	Low	Coordination between electronics and mechanics during design and during reviews.
TC120	Difficulty in accessing microprocessors for reprogramming	D	3	Medium	Create mechanical interface design and create access plan. Programme correctly first time.

TC121	Difficulty in accessing microprocessors for reprogramming	B	3	Low	Hub is easily accessible through side wall that is detachable
TC130	Failure of camera's SD Card	A	3	very low	Change the SD Card before mission.
MS10	Damage of mechanical structures during ascent	B	4	Low	FEA and testing before launch.
MS20	Deployment box does not release satellite	A	4	Low	Testing of release mechanism. More than one satellite for redundancy.
MS30	Movable parts damage experiment after deployment	A	4	Low	Ensure lid of deployment box opens in a controlled manner.
MS40	Battery charge too low	A	4	Very Low	Monitor battery charge and have spares.
MS41	Battery charge too low	A	1	Very Low	No more batteries on iSEDE experiment
MS50	Camera fails to capture deployment	B	3	Low	More than one camera. Design cameras as standalone system.
MS60	Bad lighting conditions during mission	B	3	Low	Consider installing artificial lighting.
MS70	Inflatable structure fails to inflate	A	4	Low	Design and test inflation for success in a one cell failure scenario.
MS80	Inflatable structure gets trapped while inflating	C	4	Medium	Simulate deployment and implement preventative measures where appropriate.

MS81	Inflatable structure gets trapped while inflating	B	3	Low	Structure is vertical, gravity helps force the inflatable structure to come out of the box.
MS90	Inflatable structure does not settle before shape changing phase	B	3	Low	Test inflation period and attempt to limit unwanted structure vibrations.
MS100	Temperature drops below operating range of components	C	4	Medium	Thermal analysis of components during design phase.
MS101	Temperature drops below operating range of components	B	4	Low	Components with wide temperature range were selected but thermal tests need to be performed -> possibly implement resistive heating
MS110	Cable connectors come unplugged	B	3	Low	Vibration testing.
MS120	Component failures due to vacuum	B	4	Low	Testing in vacuum chamber.
MS130	Component overheat in vacuum	C	3	Low	Extensive thermal tests of overheating components. Add heat sink to problem component.
MS140	Damage of SD cards/loss of data	A	4	Very Low	Specify high quality SD cards. Transmit data down E-Link where possible.
MS150	Damage from impact on gondola landing	C	2	Low	FEA and impact testing before launch.
MS160	Soft robotic actuators leak during mission	C	2	Low	Soft robotic element enclosed in inflatable cells, tubing to pump shall be inspected thoroughly.
MS170	Shock on launch damages experiment	B	4	Low	Finite element analysis and testing of mechanical structure

PE10	Software/electronics completion issues	C	4	Medium	Find new team members, keep track of progress and keep design simple while still achieving objectives.
PE11	Software/electronics completion issues	B	4	Low	Most of the electronics and software is implemented, now extensive testing is required
PE20	Masters student project group cannot finish manufacturing in time	E	1	Low	Hand over manufacturing to core team members.
PE30	Part-time students drop out	D	2	Low	Hand over work to additional team member.
PE40	PhD students complete their research	B	4	Low	New PhD students should replace them.
PE50	University work compromises ability to work on BEXUS	D	2	Low	Majority of team contributing as part of group project.
PE60	Shortage of team member for integration and testing of experiment after end of academic year	C	4	Medium	Recruit students and secure university internships to work on project over summer.
PE61	Shortage of team member for integration and testing of experiment after end of academic year	B	4	Low	Four students working on iSEDE full time over the summer (internship from home university and paid internship from Strathclyde)

PE70	Extracurricular students struggle with workload while carrying on studies	C	2	Low	Provide support and flexibility and revaluate project goals.
PE80	Software specialist unable to attend launch campaign	D	3	Medium	Ensure additional members know how to work with ground control system.
PE81	Software specialist unable to attend launch campaign	D	3	Medium	Applications sent for travel funding
PE82	Software specialist unable to attend launch campaign	A	3	Very Low	Travel funding received from department
SC10	Long delivery time for components	D	3	Medium	Order components at an early stage of the project.
SC11	Long delivery time for components	A	3	Very Low	All critical components are ordered. Only expendables (available in every electronic shop) need to be ordered
SC20	Workshop manufacturing delays	D	3	Medium	Early workshop submission. If necessary use a variety of university workshops.
SC21	Workshop manufacturing delays	B	3	Low	Drawings submitted and manufacturing started, constant updates from workshop and individual components can be collected once manufactured.
SC30	Lack of spare parts before mission	D	2	Low	Order sufficient number of spare parts.
SC40	Delay in PCBs manufactured by external company	C	3	Low	Design and order PCBs as early as possible.

SC50	Problems in electronic design stalling software development	D	2	Low	Purchase development boards for key components.
SC60	No additional funding made available	B	4	Low	Funds being made available by Department of Mechanical and Aerospace Engineering
SF10	Premature deployment may compromise other experiments	C	3	Low	Test release mechanism. Liaise with other experiment teams. RBF pin attachment
SF20	iSEDE wireless link may interfere with other experiments	B	4	Low	Collaborate with SSC/DLR and other teams.
SF30	Premature wireless transmissions may interfere with BEXUS or other experiments	B	4	Low	Experiment on standby until float altitude.
SF40	Failure or leak of batteries may cause damage during integration, transport or flight	B	4	Low	Ensure temperature range of batteries can handle expected temperature during all transport and mission phases. Test batteries in vacuum.
SF41	Failure or leak of batteries may cause damage during integration, transport or flight	A	1	Very Low	No more batteries in iSEDE experiment
SF50	Injury while manufacturing and integration	B	5	Medium	Consider safety before using tools or moving heavy objects.
SF51	Injury while manufacturing and integration	B	2	Low	Procedures documented and simulated by an assembly practise

SF60	Electrostatic Discharge	C	3	Low	Ground experiment and operator (electrostatic wrist band)

As safety percussion and to ensure a safe handling of the inflatable payloads, a Remove Before Flight (RBF) pin is placed in the closed deployment boxes during transport and preparation. This RBF shall be red and clearly visible.

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

iSEDE comprises of one experiment with five primary subsystems. The payload, the deployment modules, the central controller (the hub), the roof mounted support structure and distributed measurement devices.

There is direct communication with the experiment through the E-Link during the flight.

i. The payload of the iSEDE experiment is two inflatable structures with disaggregated electronics. These inflatable structures are suspended from the roof of the gondola and hang internally, as shown in Figure 4-1.

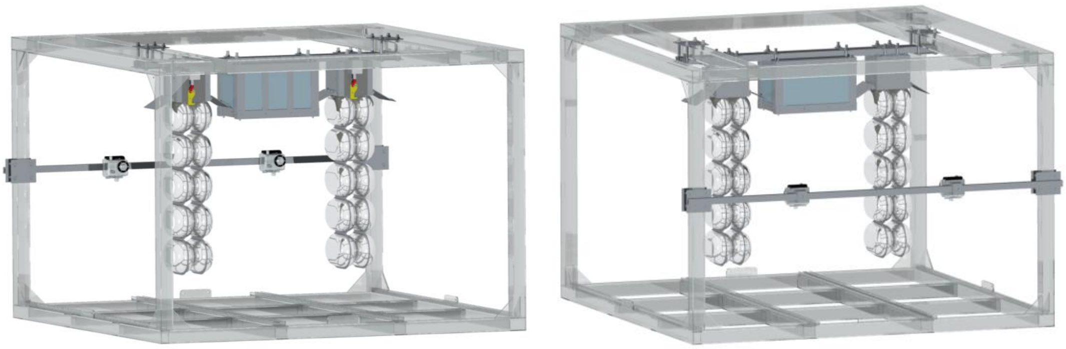


Figure 4-1: Gondola Layout

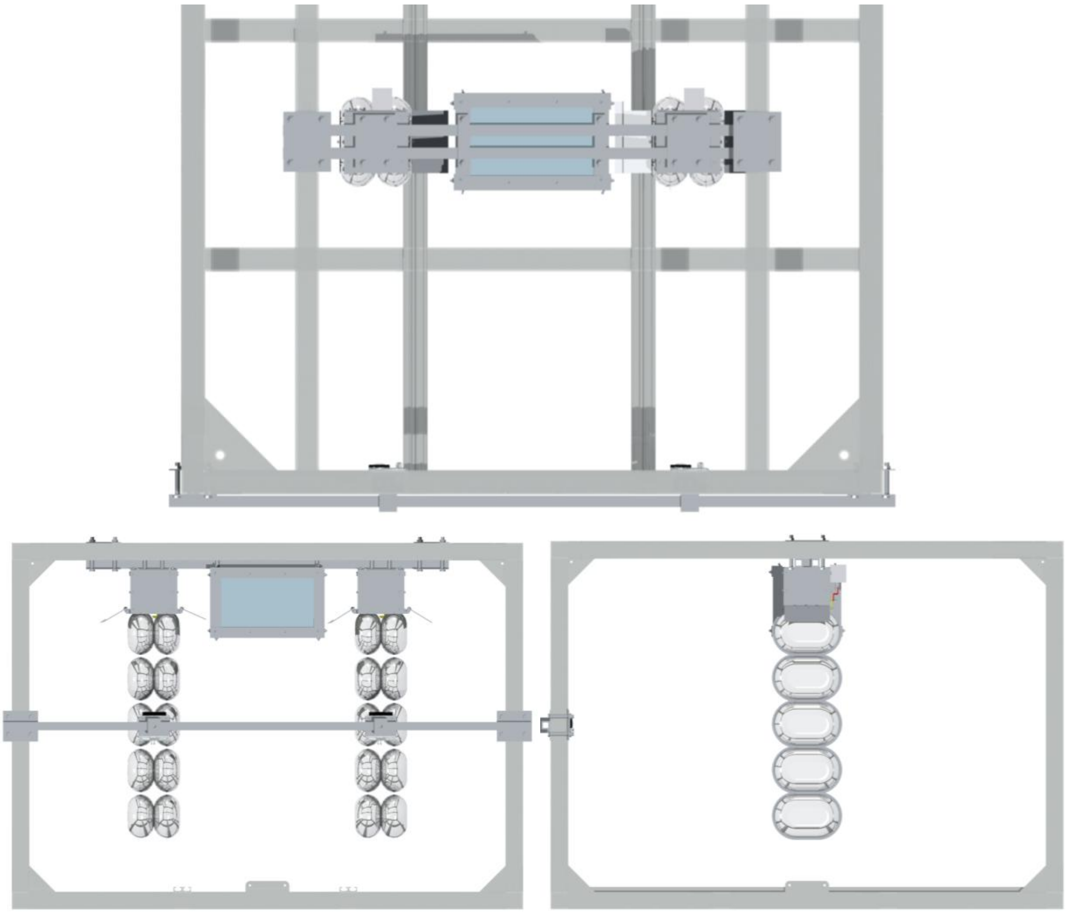


Figure 4-2: Gondola Plan & Elevation Views

Two inflatable structures are being deployed on the BEXUS campaign. Each inflatable structure is referred to as a satellite as it is a representative portion of a much larger inflatable structure. Each satellite is made up of 10 cells – 2 columns of 5 cells. One satellite is deployed prior to launch in order to observe the steady inflation on ascent and correlate this with recorded ambient pressure data. This also avoids the harsh deployment that was experienced when float altitude is reached, ensuring that if components or structure are adversely affected, one payload should be in perfect condition.

There are two primary mechanical interfaces to consider - the interface between the payload and the deployment module and the interface between the deployment module and the gondola. The payloads are also hardwired for power and communications for redundancy.

There is sufficient space around the structure to enable the demonstration of structure shape adaptation.

Figure 4-3 details the electrical architecture of one satellite. Considering all the electronics mounted on one side of the structure, there is a micropump controller pressure assembly on cell 1, 2 and 4 (counted from the top). The central cell also has a transceiver to communicate with the other satellite and the hub. An accelerometer is mounted on the bottom cell (cell 5).

The satellites have all components and circuitry hardwired for power and data, with a backup hardwired data line from the hub in the event that wireless communications shall fail.

The inflatable structure also has imbedded actuation elements in the form of soft robotics. These are present in the three cells as shown in section 4.4.1.2.

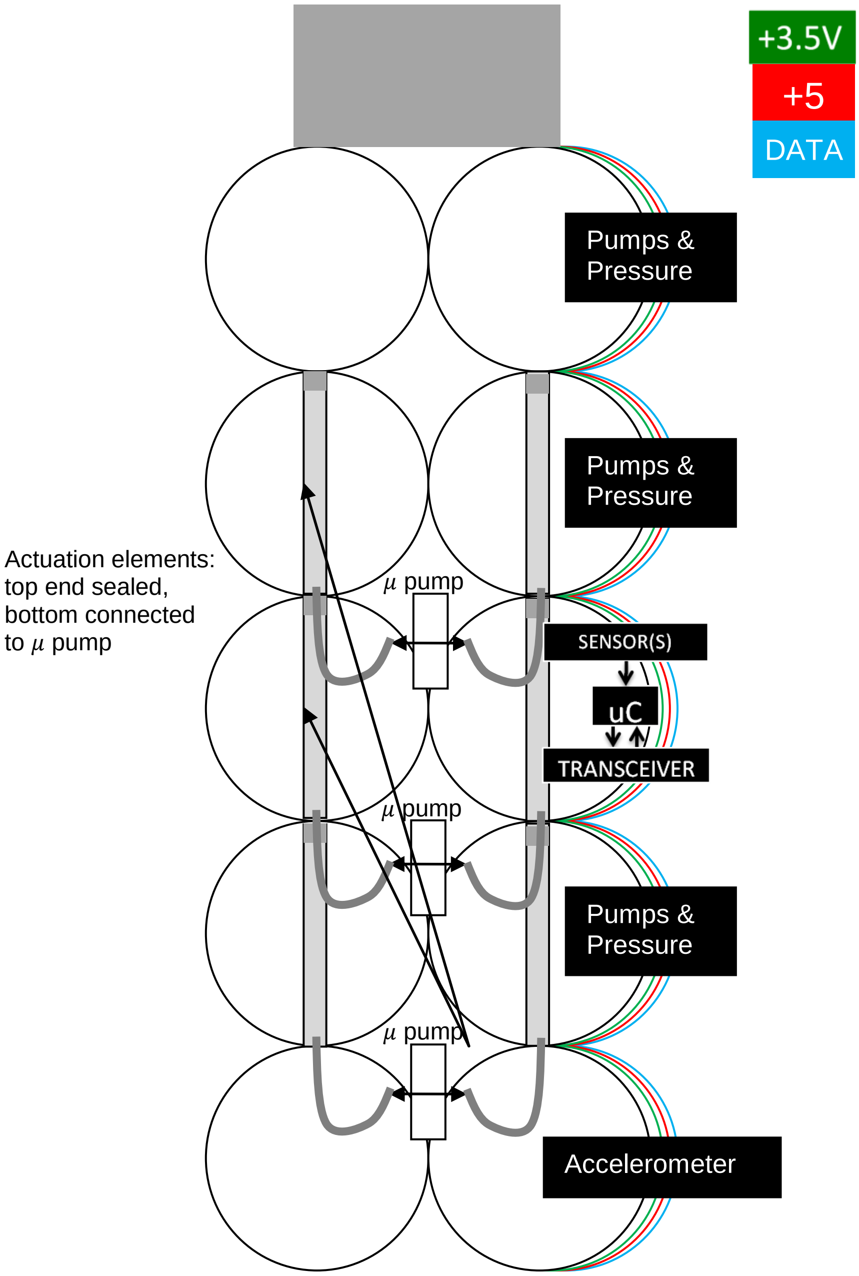


Figure 4-3: Indicative Satellite Architecture

ii. The deployment modules include the interface between the payload and the support structure. The satellite is mounted within the deployment module as shown in section 4.4.2.

iii. The central controller, the hub, is the centre point for communications on the Gondola and connects directly to the BEXUS E-Link and on board power supply for power and communications.

iv. The hub and deployment modules is mounted directly to a support structure and suspended from the roof of the gondola. The mounting is on top of the BEXUS rails.

v. In order to capture the full experiment visually, there are two cameras mounted to monitor deployment. The cameras view the actuation of the satellites going from left to right. Fixed spots on each cell are used with post flight image processing to determine the displacement of the cells. In order to capture accurate information that can be later analysed, it is required to mount the cameras at a similar height to the centre cell and as far from the structure as can be facilitated within the gondola. Through testing, it has been verified that no external booms are required where two cameras are used to capture the deployment. The cameras are hard wired for power and use an SD card to store all recorded data.

4.2 Experiment Interfaces

4.2.1 Mechanical

The following mechanical interfaces exist between the experiment and the BEXUS gondola:

1. There are two deployment modules and a hub mounted to a support structure suspended from the roof of the gondola.
2. There are two cameras mounted on an added cross beam at one side of the gondola.

Each interface withstands the forces specified in the BEXUS manual of -10g vertically, ±5g horizontally.

4.2.1.1 Payload Deployment Modules & hub

This structure is suspended parallel to the BEXUS E-Link. The horizontal supports are clamped to the gondola roof crossbeams.

Figure 4-4: Roof Support Structure

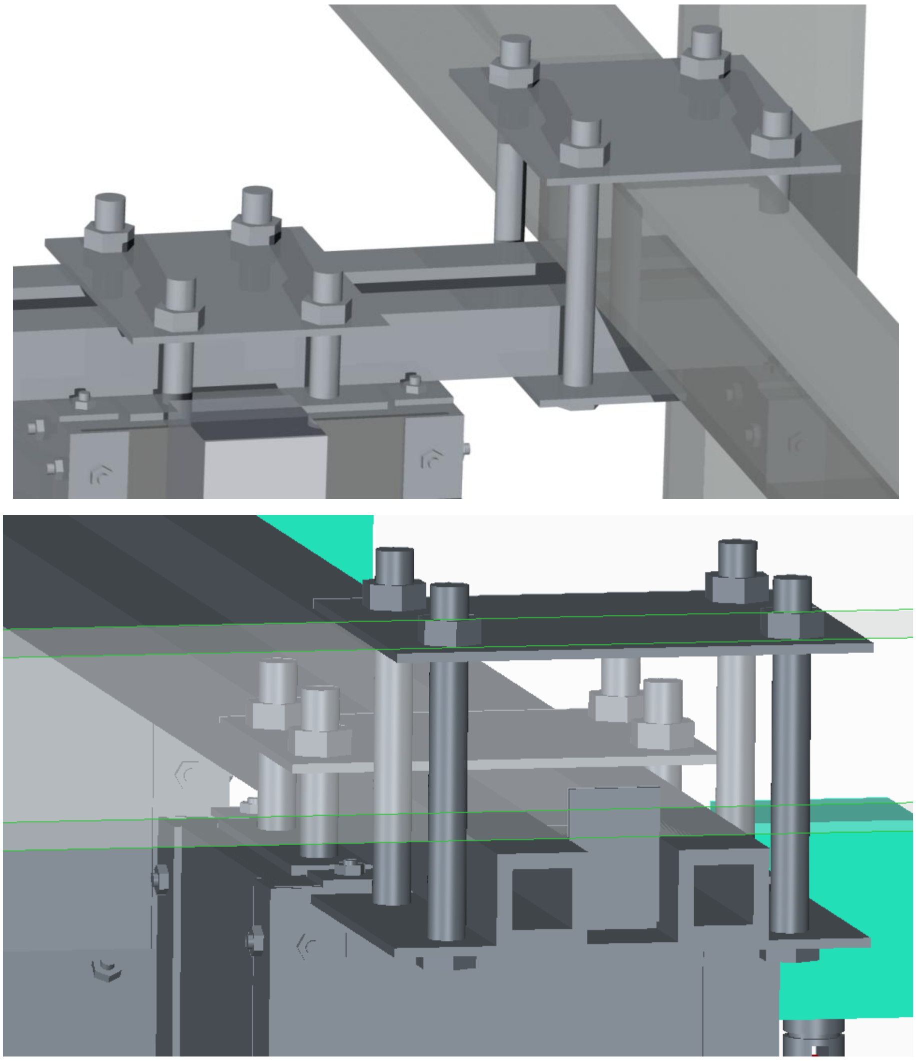


Figure 4-5: Close View of Roof Mount Clamps

4.2.1.2 Cameras

The cameras require a clear view to the deployed payloads and therefore they are mounted directly opposite the deployment modules. A sliding fit bracket with M4 screw and washer fixing around a square cross section tube is used which is in turn clamped directly to the gondola frame, as shown below. A plate is welded to each end of the aluminium tube cross beam and then fixed to the gondola with M8 bolts to the clamp counterpart.

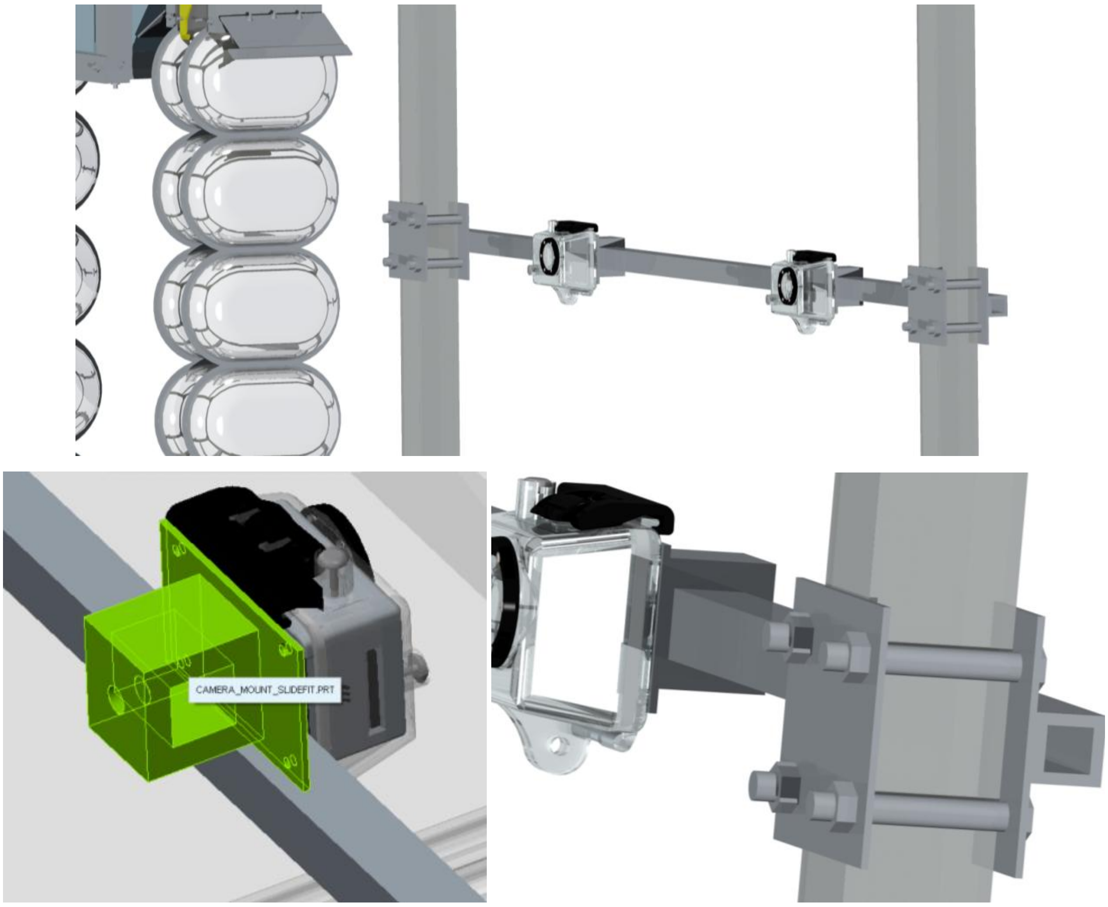


Figure 4-6: Camera interfaces

4.2.2 Electrical

The hub and satellites interface with the BEXUS link through a 4 pin, male, box mount receptacle MIL – C-26482P series 1 connector with an 8-4 insert arrangement (MS3112E8-4P) shown below,

Figure 4-7: Power Interface

The output from this interface is then stepped down and conditioned to suit the component requirements.

To facilitate communication and control during the experiment, the hub incorporates the Amphenol RJF21B connector which interfaces with the BEXUS E-Link.

The component and drilling specification is detailed in the BEXUS user manual and shown below in Figure 4-8

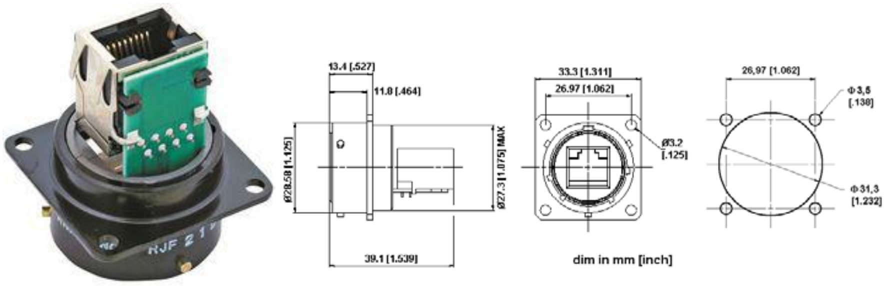


Figure 4-8: Amphenol RJF21B and drilling pattern

The Hub and ground station are connected using an Ethernet connection, TCP/IP and UDP/IP protocols. The data sent from the Ground Station to the Hub uses a TCP socket and the following packet structure:

```
+---------------+-----------+-----------------------+-----------+
| Satellite ID  |  Command  | Payload size (optional) |  Payload  |
|   (1 byte)    | (1 byte)  |        (2 byte)         | (n bytes) |
+---------------+-----------+-----------------------+-----------+
```

If the command does not require a payload, the payload size and payload bytes are not sent. Whenever the Hub receives a command it sends back an ACK.

The data sent from the Hub to the Ground Station uses a UDP socket to send a string with the following pattern which consists in a descriptor and the data:

"Su,C,u,PC,u,A0,f,f,f,A1,f,f,f,T0,f,T1,f,P0,f,P1,f,P2,f\n"

Where:

- u -> unsigned integer;
- f -> float;
- S -> Satellite;
- C -> Clock, time that the satellite is on;
- PC -> Packet count;
- A0, A1 -> Accelerometers;
- T0, T1 -> Temperature sensors;
- P0, P1, P2-> Pressure sensors;
- \n -> new line character.

The data rate is about ten UDP packets per minute (five from each satellite) from the Hub to the Ground Station. The data rate from the Ground Station to the Hub depends on how often the ground crew send commands.

4.2.3 Radio Frequencies (optional)

The satellites and hub communicate wirelessly with an 868/915 MHz panStamp RF module, its main features are:

- Data rate up to 600kbps depending on the modulation used;
- Frequency Shift Keying (FSK) modulation;
- +20 dBm output power at 868 MHz;
- +27 dBm output power at 915 MHz;

The frequency used on the experiment is 868MHz.

4.3 Experiment Components

Each Satellite (x2)

- Inflatable structure
- 6 micro-pumps
  - 6 micro-pump controllers
  - 3 differential pressure sensors
  - 6 soft robotic actuators
- 1 panStamp transceiver
- 2 temperature sensors
- Accelerometer
- Flexible circuit

Deployment Module (x2)

- 1U Deployment module structure
  - Hinged doors, torsion springs, 2mm aluminium T6 sheet & angles
- Solenoid
- RBF-pin
- Accelerometer
- Cable Tie
- Solenoid connector
- Satellite D-sub
- Accelerometer connector

Hub

- Hub structure
  - 2mm Aluminium T6 angles, Insulation (polystyrene)
- Central controller - Raspberry Pi
- 1 panStamp transceiver
- 1 temperature sensor
- Ambient pressure sensor
- E-Link interface
- Power interface
- Power circuitry
  - Power board with regulators
  - Leds
  - Physical switch

Cameras (x2)

- Camera Housing
  - GoPro camera enclosure
- Camera Interface
- HackHD camera

Mounting Structures

- Square tube Aluminium (T6) - 3/4 inch, 10swg
- Array of 10 bright white LEDs with iSEDE webcam

Cables

- Hub – Satellite cable (x2)
- Hub – HackHD cable
- Hub – iSEDEcam/LED cable

Component	Status
Inflatable Structure	Manufactured
Micropumps	Arrived
Micropump Controllers	Arrived
Differential Pressure Sensors	Arrived
Soft Robotic Actuators	Manufactured
Regulators	Arrived
panSTAMP	Arrived
Temperature sensors	Arrived
Accelerometers	Arrived
Flexible power and data connections between circuit boards	Arrived
Deployment module structure	Manufactured
Solenoid	Arrived
Hub structure	Manufactured
2mm Aluminium T6 angles	Arrived
Insulation (polystyrene)	Arrived
Ambient pressure sensor	Arrived
E-Link interface	Arrived
Power interface	Arrived
Camera Housing	Arrived
GoPro camera enclosure	Arrived
HackHD camera	Arrived
Square tube Aluminium (T6) - 3/4 inch, 10swg	Arrived

Table 4-1: Experiment summary table

Experiment Mass: Roof Mounted total (hub + 2xdeployment boxes): Cameras total: **Experiment total mass:**	 4.865kg 1.215kg **6.315kg**
Experiment dimensions (in m): (when deployed)	Satellites – 2x(0.2 x 0.15 x 0.74)m Hub – 0.25 x 0.15 x 0.15m Mounted – 0.83 x 0.3 x 0.74
Experiment footprint area (in m^2):	Satellites – 2x0.03m^2 Hub – 0.0375m^2 Mounted – 0.25m^2
Experiment volume (in m^3):	Satellites – 2 x 0.022m^3 Hub – 0.006m^3 Mounted – 0.18m^3

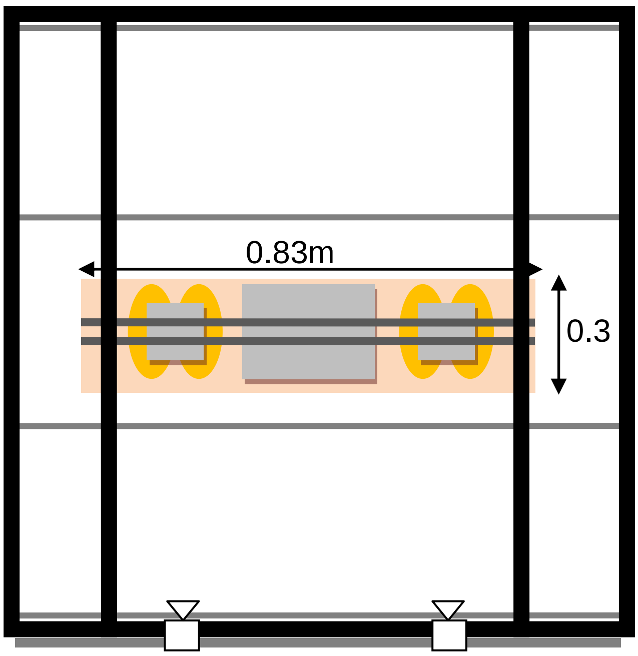


Figure 4-9: Gondola layout

4.4 Mechanical Design

The mechanical design is concerned with the size, shape, strength and mass of the experiment – the iSEDE satellite, the deployment modules, the hub, the camera housing and associated interfaces. Some different constraints apply to each subsystem.

4.4.1 Payload - iSEDE satellite

The iSEDE satellite concept is centred on the successful synergy of inflatable structures and disaggregated electronics enabling distributed control and autonomous operation.

The payload itself then has two primary design challenges. There is firstly the design of the inflatable structure - material, shapes, bonding methods - and secondly the challenge of bonding electronics to the surface and facilitating power and communication bus paths.

The mass of the inflatable structure is negligible and the mass of electronic components contribute most significantly to the overall payload mass.

4.4.1.1 Inflatable Structure

The structure that is deployed is entirely made of inflatable cells. It consists of two rows of 5 elongated ellipsoid cells deployed using the expansion of trapped air in the ellipsoids when subjected to vacuum conditions. These cells have been manufactured from two sheets of mylar and kapton tape. These films are lightweight, strong and can withstand the temperatures that the experiment is subjected to. It is important that these materials have a reflective surface to reduce the UV penetration into the cell. The central cells include an actuation element which enables the structure to alter its shape. This actuation element is not affected by the temperature but can degrade when subject to UV radiation.

Each cell has an un-inflated length of 18cm and height of 13cm with a 1.5cm seam. The deployable structure uses residual air inflation as a deployment mechanism. The inflation of the cell is modelled using the relationships for the inflation of a sphere presented in [10]. This predicts inflated dimensions of length 14.9cm, depth 5.9cm and height 9.9cm.

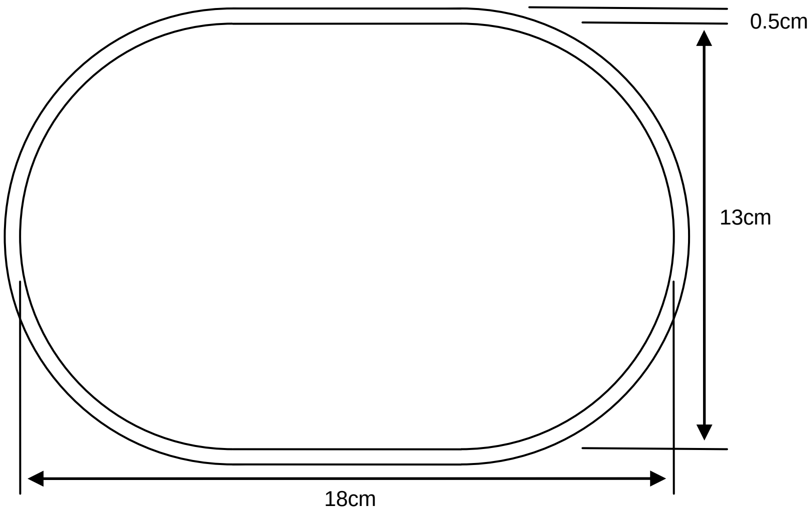


Figure 4-10: Deflated Cell

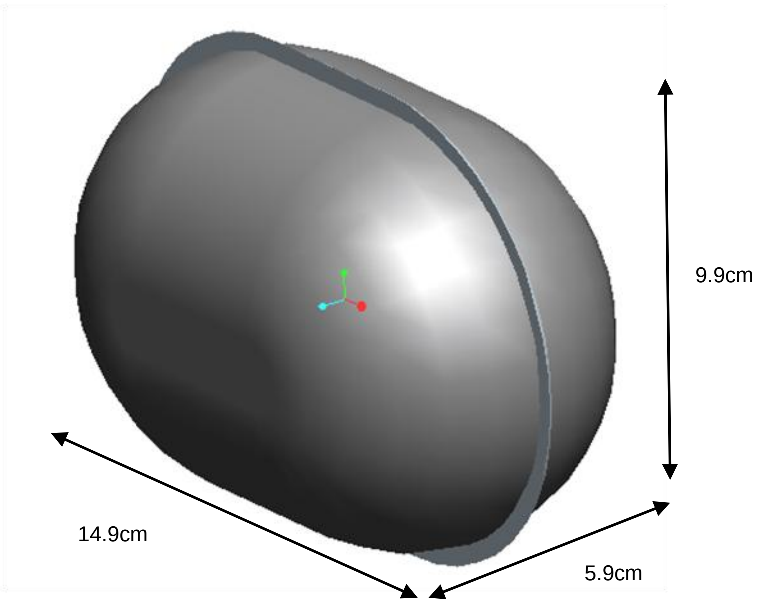


Figure 4-11: Inflated Cell

A fully inflated, deployed structure with two columns of cells and no added mass would therefore have dimensions of 14.9x11.8x49.5cm. With added mass, around a 10% elongation is expected giving an inflated height of around 55cm. The connection between the inflatable structure and the deployment module is through clamped plates.

4.4.1.2 Actuation

The actuation of the iSEDE inflatable is inspired by nature's heliotropism where motor cells in the plants stem change the pressure in-between neighbouring cells and therefore make the stem of the plant flex in order for the flower head to follow the sun over the course of a day [9]. This nature inspired principle is used for the shape alteration of the inflatable iSEDE satellite. Initially the concept was based around micro pumps being attached between two adjacent cells to change their pressure and therefore their volume resulting in a deformation of the entire structure. But due to the fact that the surface material is the rather inelastic Mylar, another actuation principle was developed. A solution is the use of softrobotic elements which are made of highly flexible silicon rubber. Softrobotic elements usually have a cavity inside them which can be inflated which causes a deformation of the element. The advantage of softrobotic elements is that they can be casted in every thinkable shape and their actuation performance can therefore be tailored.

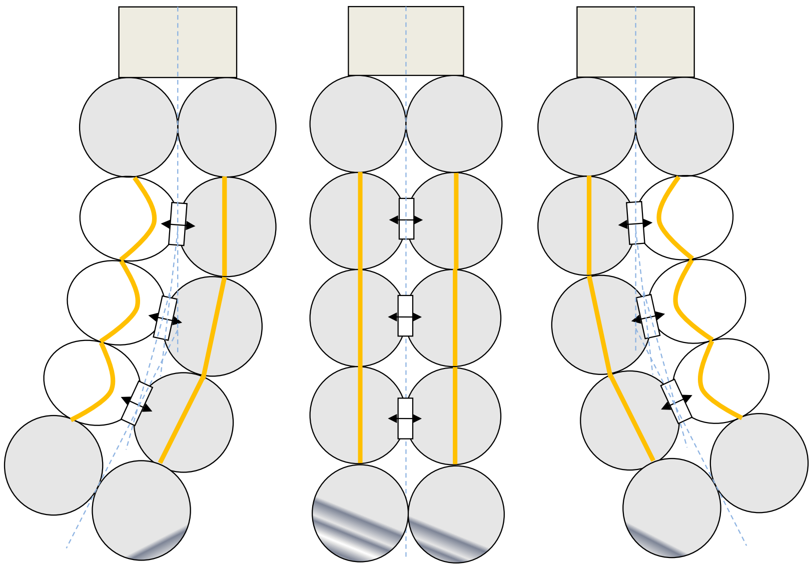


Figure 4-12: Actuation principle of actuators in the three middle cells

By mimicking this principle with micropumps and soft robotic actuators, the iSEDE inflatable obtains the capability of changing its global shape. An actuator element consists of two softrobotic elements, one in each cell that is connected via a micropump. During fabrication, a cavity inside the softrobotic actuator was created with a metal rod. After curing with a nylon wire with a higher stiffness was attached to the bottom of the actuator. If the softrobotic actuator gets inflated which would normally cause an elongation is now getting transformed in a bending of the actuator, which means in plane shortening with a comparably high actuation force.

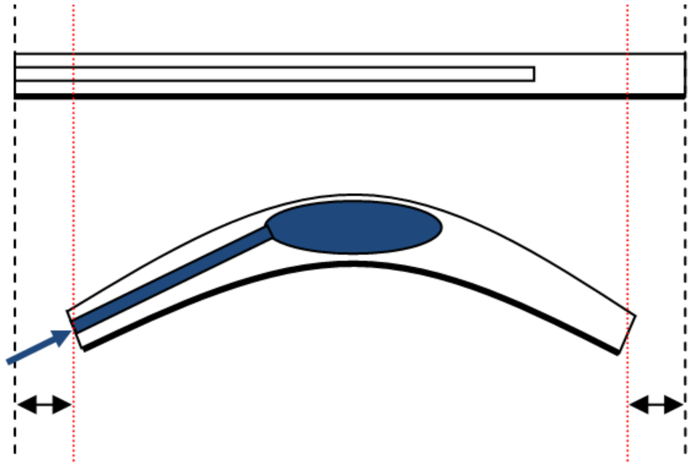


Figure 4-13: Actuation principle of soft robotic element

The soft robotic actuator element inside the iSEDE cells has the a width of 4mm and a height of 4mm with a 2mm diameter to form the cavity inside the soft robotic actuator for inflation through the micropumps.

The soft robotic element is manufactured out of Ecoflex 00-30 platinum-catalyzed silicone which stays highly flexible also at very low temperatures of -60°C. Ecoflex 00-30 is a two component mixture with a ratio of 1:1 and a curing time of ~24 hours.

The maximum displacement of the cells during actuation was estimated to be 18cm. However, due to vibration or wind within the gondola, the inflatable structure is expected to displace no more than 25cm at the bottom cell. It is therefore required to have a clearance of 25cm in actuation direction (nothing mounted on the bottom).

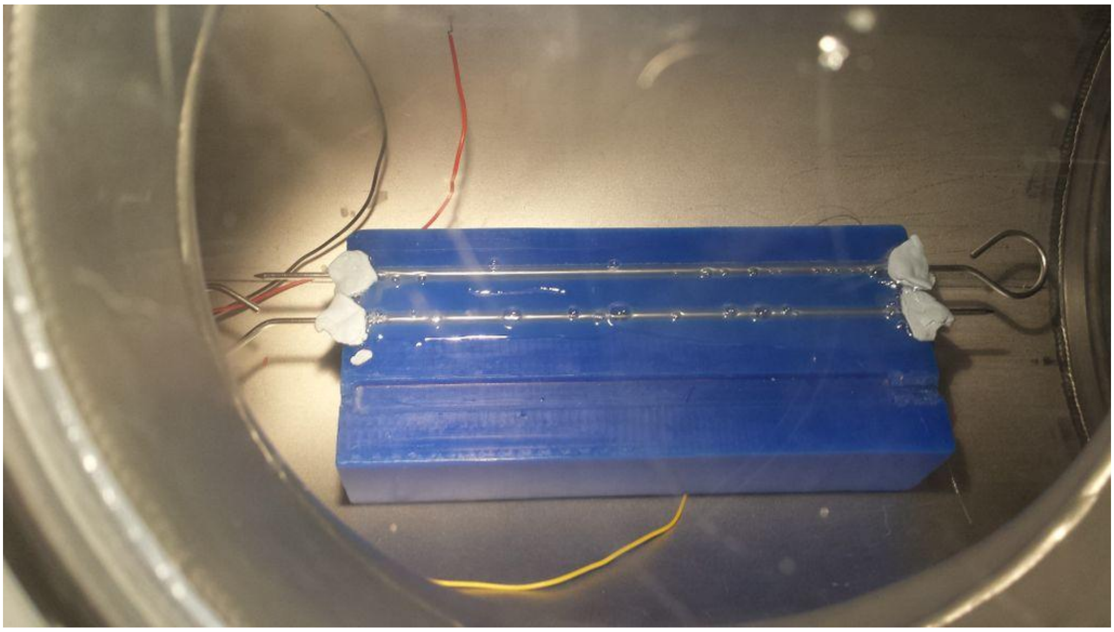


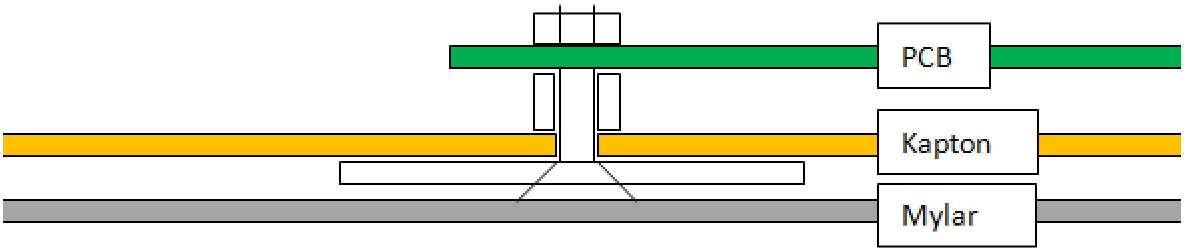
Figure 4-14: Soft robotic element being made in vacuum chamber

As a medium for inflation Glysantin Alu Protect/G 30 from BASF (see datasheet in appendix D) is used. Glysantin was used by the REXUS9 team EXPLORE and proved its capabilities at very low temperature and pressure conditions. The actuation medium change from air to fluid was made due to the incompressibility of fluids which increase the controllability of the softrobotic actuation when subjected to vacuum. The two softrobotic elements are already filled with a defined amount of actuation fluid which pretensions the structure. At cell actuation, the fluid is then pumped from one to the other softrobotic element which shortens one of them and elongate the other, causing the structure to deform.

4.4.1.3 Attachment of Electronics

Electronics on printed circuits and the associated hardwired power and data connections must be connected to the surface of the inflatable structure. This must be done without impairing the structures inflation and must not present any danger to the structure, such as puncture, during the deployment process. Another requirement of the mounting is that the electronic components can be de-attached easily and transferred to another inflatable therefore adhesive bonding is not ideal.

A flexible printed circuit is used to mount the electrical components to the inflatable structure. This allows the structure to remain flexible enough to alter the shape of the entire structure. The only component which this causes a problem with is the IMU on the bottom cell. As the centre of the inflated cell is flat compared to the area around the circumference, then the proposed solution takes advantage of the conventional mounting of PCB with screws and through embedded holes in the PCB. The mounting assembly consists of a M3 plastic screw with countersink head and a large washer. The washer with the head are joined together to obtain a rigid connection, this assembly is then glued between the Mylar inner layer of the cell and the adhesive Kapton outer layer obtaining a mounting point for the PCBs. The sketch of the principle and a first prototype with a metal screw embedded in the Mylar-Kapton inflatable can be seen in the Figure below.



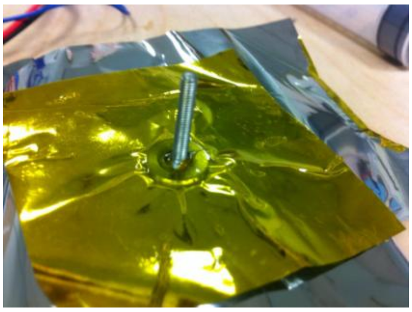


Figure 4-15: Mounting schematic (left) and mounting prototype (right)

To ensure a non-conductive connection between the electronics and the cells, M3 plastic screws and washers are used. This assembly together with wire-to-board connectors enables a fast and reliable change of components on the cells.

4.4.2 Deployment Modules

The mechanical design of the deployment modules is concerned with the structure required to facilitate the deployment of the inflatable structure.

The deployment modules are simple 1U (10x10x10cm) boxes made of lightweight but durable aluminium. One inflatable structure is deployed prior to launch and the other deployed at float altitude.

A lid ejection method cannot be used as this would result in an uncontrollable swinging mass which could compromise the inflatable structure or other experiments. While slightly more complicated, hinged, sprung doors are used to facilitate quick opening which doesn't compromise the structure. The doors are released by mechanism actuated by a solenoid. Figure 4-16 to Figure 4-18 show the prototype module including a vacuum deployment test.

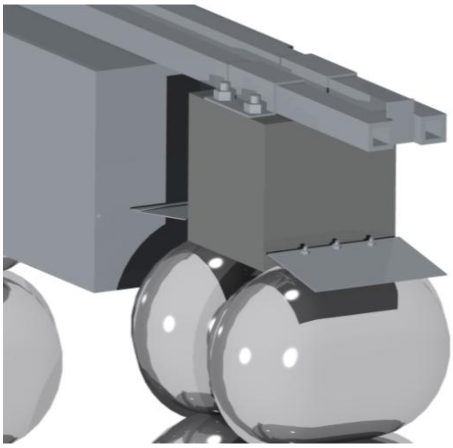


Figure 4-16: Deployment module CAD

Figure 4-17: Deployment module with insulation

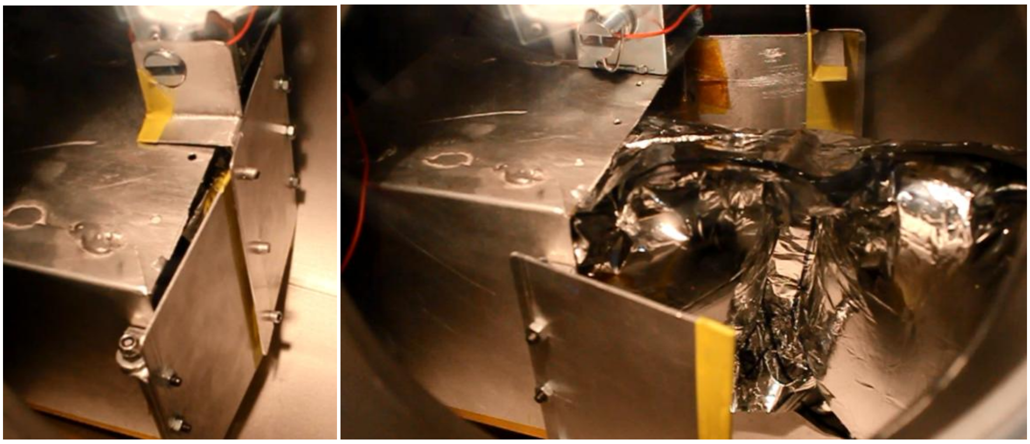
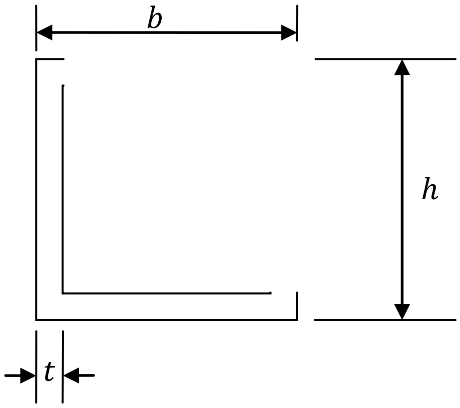


Figure 4-18: Structure deployed from module during vacuum inflation test

The unit in Figure 4-19 was manufactured from folded 1mm aluminium sheet, as recommended by mechanical advisors at the university however; the tolerances required were not achieved, partially due to the scale of manufacture. As such, the flight model is manufactured from CNCed sheets 2mm aluminium and bolted together with nyloc fixings instead of folding, thus retaining the strength of the material and achieving a more accurate product. The following figures illustrate this design.



$$b = h = 16mm$$
$$t = 1.6mm$$

Figure 4-19: Deployment Module Corner Angles

The deployment method used contains a solenoid which is connected to a linkage arm which in turn is connected to a latch. Once the solenoid is activated, the solenoid pin retracts; this pulls the linkage arm vertically upwards. This vertical movement then causes the latch to pivot around the link between the linkage arm and the latch. This motion then causes the hook of the latch to lose contact with the sprung hinged doors, hence, releasing the inflatable structure.

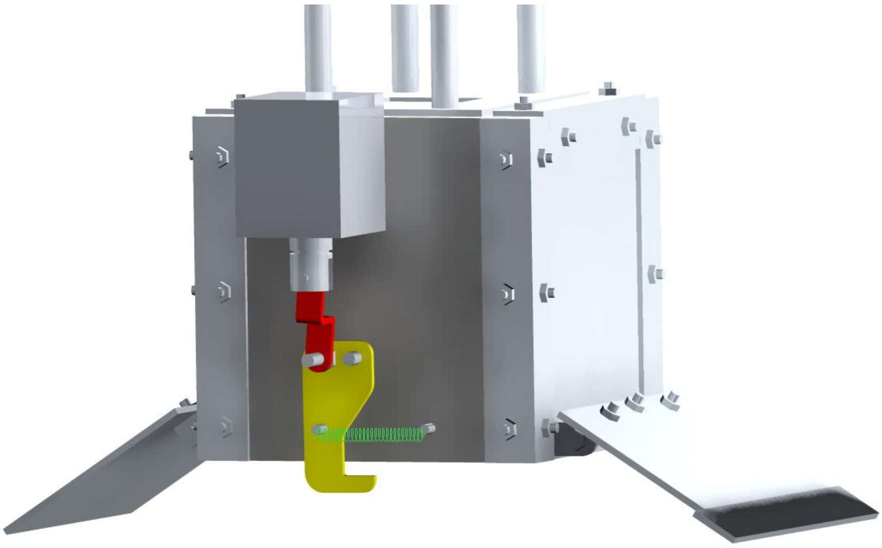


Figure 4-20: Deployment Module CAD

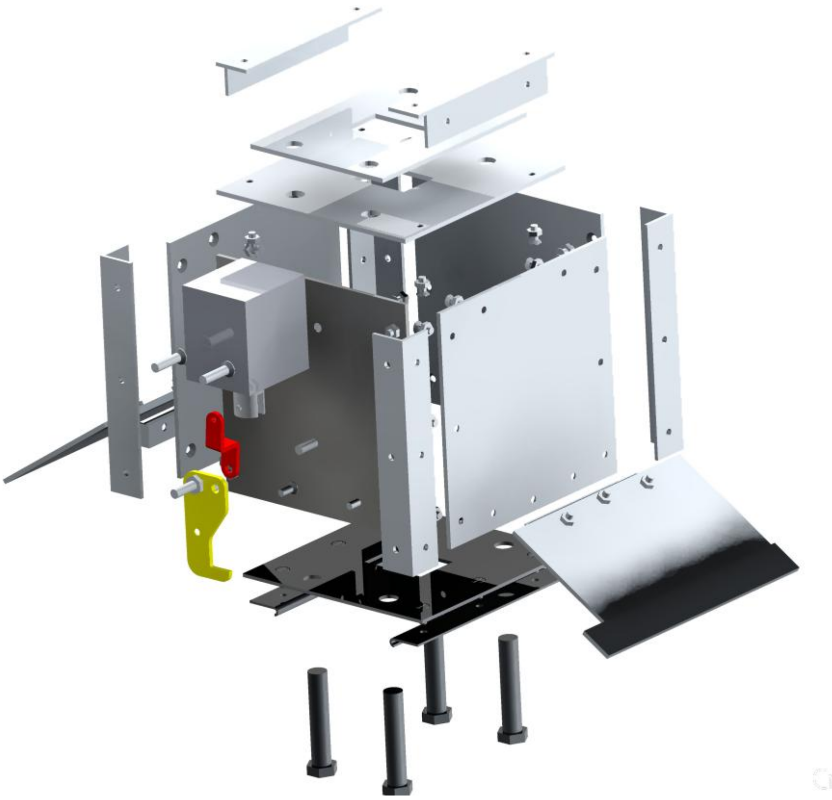


Figure 4-21: Deployment Module CAD Exploded View

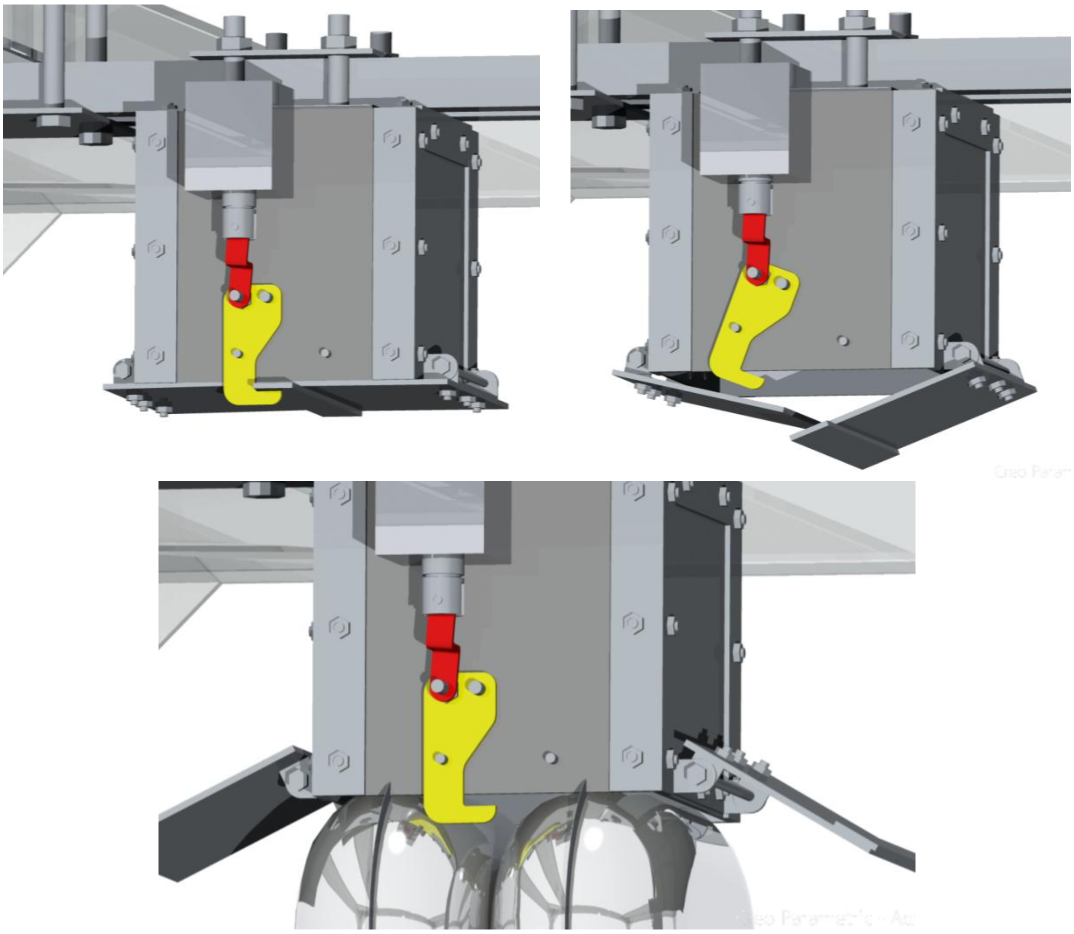


Figure 4-22: Deployment Module Opening CAD

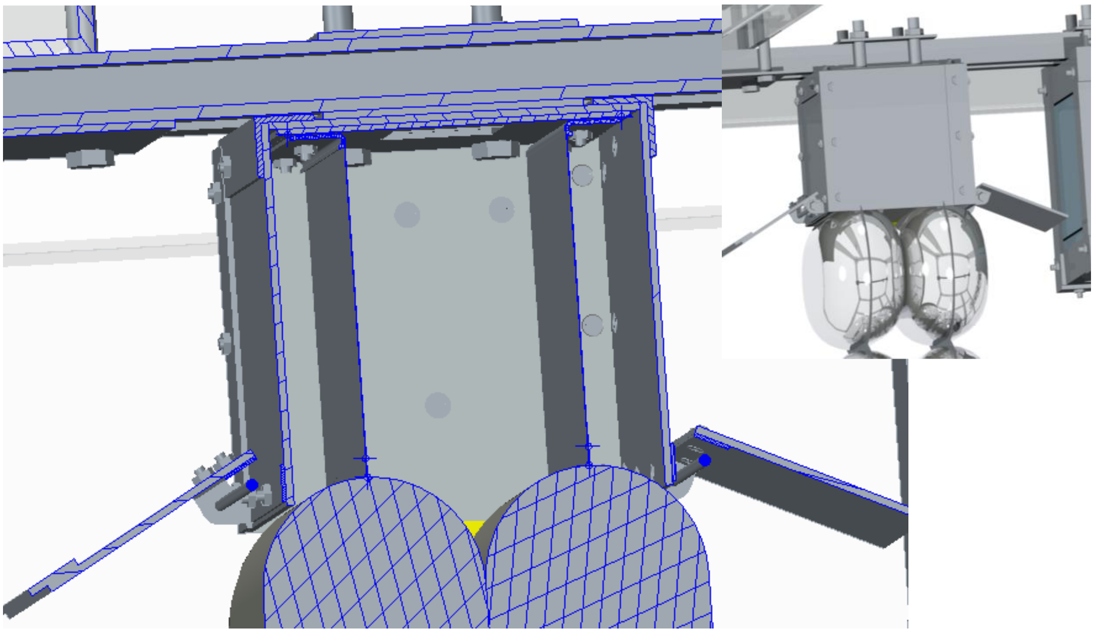


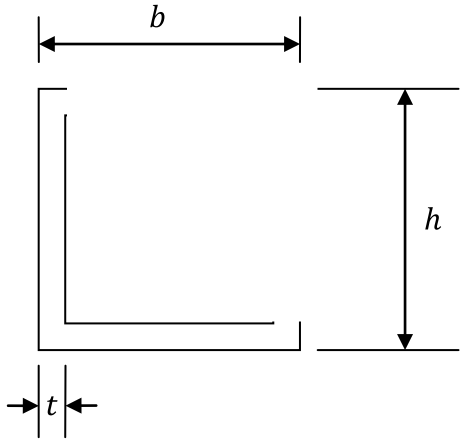
Figure 4-23:Deployment Module Cross Section, Post Deployment

4.4.3 Hub

The hub is a simple structure to house the central electronic intelligence and acts as the controller of the satellites. It is connected wirelessly and hardwired to the payload and cameras. The hub is manufactured from lightweight aluminium angles and polystyrene.

The hub houses the power board and Panstamp data PCB, the Raspberry Pi and physical electrical interfaces to the BEXUS service module and the other iSEDE experiment components.

The hub is insulated using 3cm thick polystyrene in order to protect the central controller from the harsh environment. The dimensions of the aluminium angles are shown in Figure 4-24. The polystyrene was glued and then fitted within the aluminium angle frame.



$$b = h = 25mm$$
$$t = 3mm$$

Figure 4-24: Hub Angles Dimensions

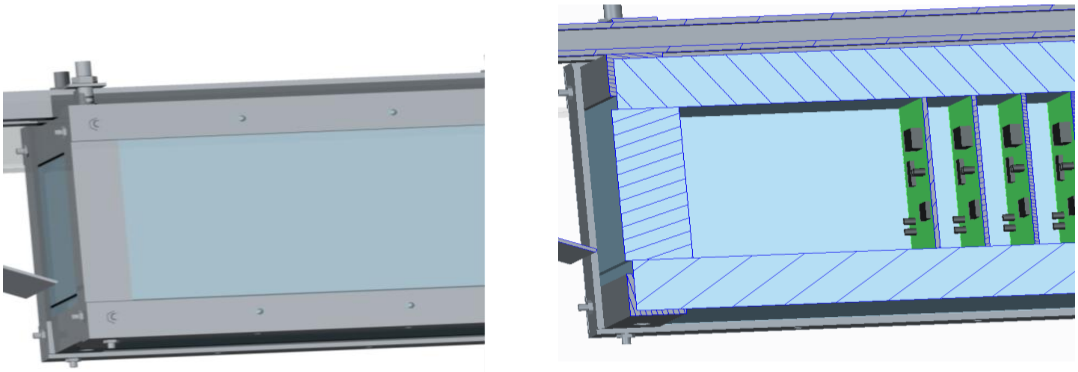


Figure 4-25: Hub Cross Section

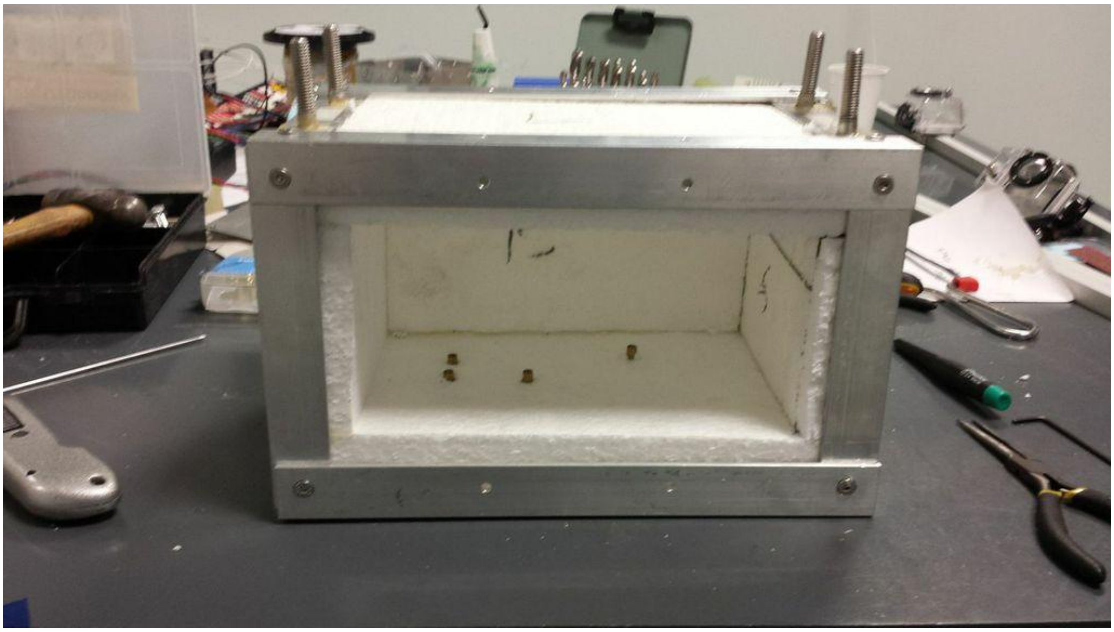


Figure 4-26: Manufactured Hub

To ensure that the Raspberry Pi inside the Hub cannot freely move around during the flight is mounted to the Hub. A thin sheet of Aluminium has been placed between 2 sheets of polystyrene. This allows screws to be used to hold the Raspberry Pi securely in place. The screws do not have access to the ambient outside air inside the gondola; therefore, no conduction can take place directly between the screw and the air. This helps in the insulation of the Raspberry Pi.

4.4.4 Camera Housing

It is critical that the cameras are mounted in a location where there is a clear view to the deployed structures. Figure 4-27 below indicates the optimal layout where there are two cameras - each with a direct line of site, indicated by the bold dashed line, to one satellite and also an indirect angle to another. This allows the inflation to be observed and understood most comprehensively. The Hack-HD cameras have a wide field of view, almost like a fish eye lens.

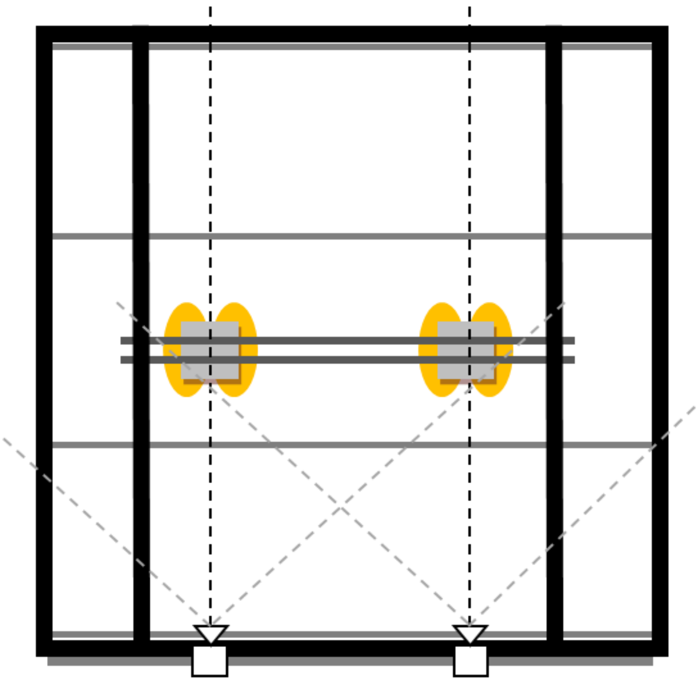


Figure 4-27: Aerial View of the Gondola

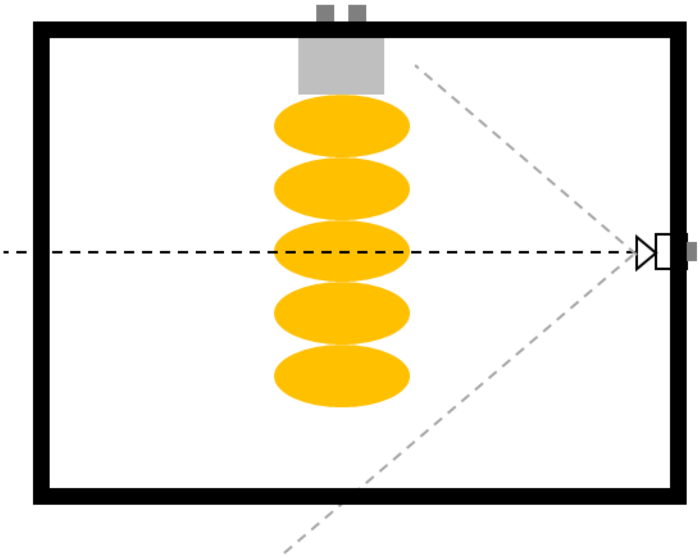


Figure 4-28: Side View of the Gondola

GoPro provides a purpose built enclosure called the skeleton, which houses the HackHD camera well. This structure is designed for use in extreme sports and has been adapted easily for this application. This is mounted using M3 bolts to the mounting plate and sliding fit, as indicated in the camera mechanical interfaces section. Between the two HackHD cameras, a webcam with an array of 10 bright white LEDs is added to light up the inside of the closed gondola. The webcam allows a live feed to the ground station during the flight.

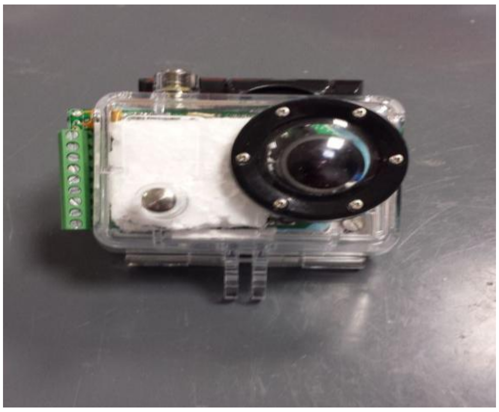


Figure 4-29: GoPro Skeleton Camera Housing with HackHD

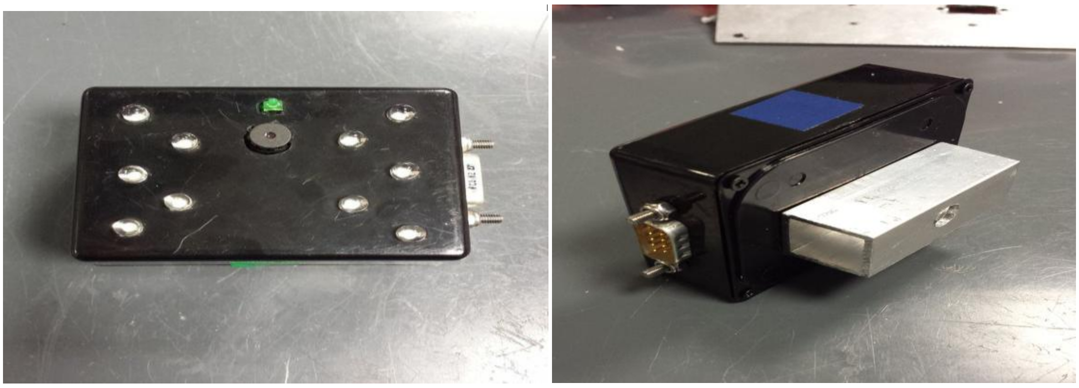


Figure 4-30: iSEDE webcam with LEDs

4.4.5 Mobius Camera

The Mobius camera is used to capture footage outside of the gondola during flight.. The camera is going to be mounted to a part of the gondola rails by way of cable ties and duct tape.

Figure 4-31: Mobius camera

4.4.6 Support structures

There are two primary support structures. A cross beam at one side of the gondola for the cameras and from the roof of the gondola for the deployment modules and hub.

Both of these use 19.05mm square aluminium tube with wall thickness 3.25mm. The Support mount plate is made from T6 aluminium sheet and M8 bolts are used to connect the deployment module with the mount support. The cameras are mounted on one cross piece, as shown in section 4.2.1.2 and indeed weigh less than the mass of the beam itself and the deployment modules and hub are suspended from two beams. The beam cross section dimensions are shown in Figure 4-32.

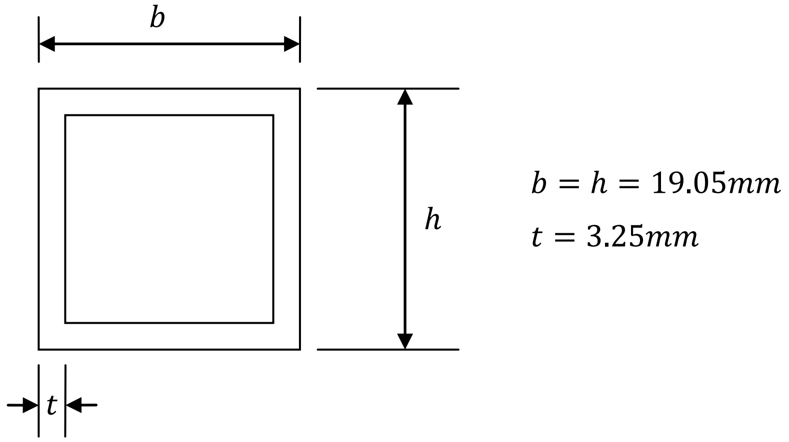


Figure 4-32: Beam Cross Section

Moment of inertia about bending axis:

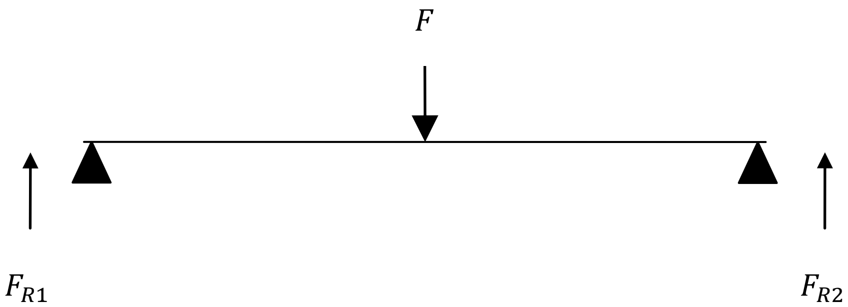
$$I = \frac{b^4 - (b-2t)^4}{12} = \frac{0.019^4 - 0.013^4}{12} = 8.9 \times 10^{-9} m^4$$

Section Modulus:

$$Z = \frac{2I}{h} = \frac{2 \times 8.9 \times 10^{-9}}{0.019} = 9.35 \times 10^{-7} m^3$$

Two beams minimise the height of the support while maximising the mass it can take.

In specifying the beam parameters, a beam supported at both ends with a central point mass was considered as a worst case stress analysis.



For this condition, the maximum stress at an outer fibre and the maximum deflection are defined as

$$\sigma = \frac{FL}{4Z} \quad \Delta_{\max} = \frac{FL^3}{48EI}$$

The young’s modulus for Aluminium 6063-T6 is

$$E = 68.9GPa$$

and it has a shear strength of around 150MPa and yield strength of around 200MPa.

The following calculations show that the beams chosen are significantly below these while not being over engineered and adding unnecessary mass.

4.4.6.1 Camera Supports

For the cameras each having a mass of just 0.1kg and with the total beam mass of 0.5kg, the maximum force to be considered is

$$F = \big((2 \times 0.1) + 0.5\big) \times 9.81 \times 10 = 68.67N$$

The beam length is the distance between the sides of the gondola which is less than 1.2m.

Therefore, the maximum stress experienced by the beam would be

$$\sigma = \frac{68.67 \times 1.2}{4 \times 9.35 \times 10^{-7}} = 22MPa$$

$$\Delta_{\max} = \frac{68.67 \times 1.2^3}{48 \times 68.9 \times 10^9 \times 8.9 \times 10^{-9}} = 0.004m$$

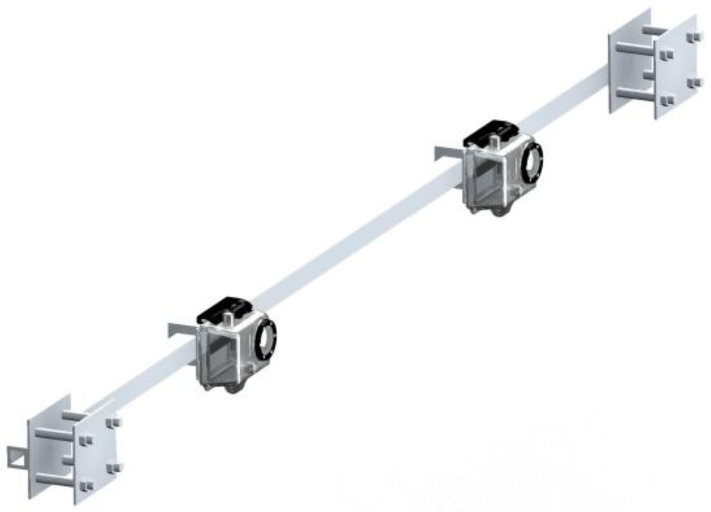


Figure 4-33: Cameras Mounted on Support

4.4.6.2 Deployment Supports

With each deployment module having a mass of around 0.9kg, each payload of mass 0.6kg, a hub of mass 2kg and beams of mass 0.5kg, the total mass supported is 6kg.

As there are two beams, each experiences half of this mass – 3kg.

The maximum force is therefore

$$F = 3 \times 9.81 \times 10 = 161.8N$$

The length of the roof supports is $0.8m$ therefore the maximum stress is

$$\sigma = \frac{161.8 \times 0.8}{4 \times 9.35 \times 10^{-7}} = 63MPa$$

$$\Delta_{\max} = \frac{161.8 \times 0.8^3}{48 \times 68.9 \times 10^9 \times 8.9 \times 10^{-9}} = 0.005m$$

Table 4-2: Mechanical Components Breakdown

Group	Part	Quantity	Additional Info	Supplier
Cameras	CAMERA_MOUNTPLATE	4		*Al T6 Sheet 1*
Cameras	CAMERA_MOUNT_TUBE	1		*Al T6 Tube*
Cameras	GOPRO SKELETON HOUSING	2		GoPro
Cameras	CAMERA_MOUNT_SLIDE FIT	2		*workshop*
Deployment	DEPBOX_CORNER_1	8		*Al T6 Angle 1*
Deployment	DEPBOX_CORNER_BASE	4		*Al T6 Angle 1*
Deployment	CELL_MOUNT	2	inside deployment module	*Al T6 Sheet 1*
Deployment	DEP_LID	2		*Al T6 Sheet 1*
Deployment	DEP_LID_LOCK	2	lid with overlap	*Al T6 Sheet 1*
Deployment	DEPBOX_BASE	2		*Al T6 Sheet 1*
Deployment	DEPBOX_BASE_FILL	2		*Al T6 Sheet 1*
Deployment	DEPBOX_MOUNTPLATE	2		*Al T6 Sheet 1*
Deployment	DEPBOX_SIDE_1	4	Sides with hinges attached	*Al T6 Sheet 1*
Deployment	DEPBOX_SIDE_2	2	Side opposite solenoid	*Al T6 Sheet 1*
Deployment	DEPBOX_SIDE_2_5	2	Side with solenoid mounted	*Al T6 Sheet 1*
Deployment	HINGE_BOX	4		*Al T6 Sheet 1*
Deployment	HINGE_LID	4		*Al T6 Sheet 1*

Deployment	CELL_MOUNT_LOWER	4		*Al T6 Sheet 2*
Deployment	SOLENOID_BODY	2	B22	Farnell
Deployment	SOLENOID_BOLT	2	B22	Farnell
Deployment	HINGE_PIN	4	3mm stainless rod	*workshop*
Deployment	LATCH	2	Deployment mechanism	*workshop*
Deployment	LINK	2	Deployment mechanism	*workshop*
Deployment	SOLENOID_PIN	2		*workshop*
Hub	HUB_CORNER_H	4		*Al T6 Angle 2*
Hub	HUB_CORNER_L	4		*Al T6 Angle 2*
Hub	HUB_CORNER_W	4		*Al T6 Angle 2*
Hub	HUB_MOUNTPLATE	2		*Al T6 Sheet 1*
Hub	HUB_SIDESTRAP	2		*Al T6 Sheet 1*
Hub	HUB_FOAM_BACK	1		*STYROFOAM*
Hub	HUB_FOAM_LARGE	2		*STYROFOAM*
Hub	HUB_FOAM_SIDE	2		*STYROFOAM*
Hub	HUB_FOAM_TOP	1		*STYROFOAM*
Inflatable	CELL	20		MYLAR
Inflatable	CELL_HANGER	4		MYLAR
Roof Mount	SUPPORT_MOUNTPLATE	4		*Al T6 Sheet 1*
Roof Mount	TUBE_LONG	2		*Al T6 Tube*
Roof Mount	TUBE_SHORT	2		*Al T6 Tube*
ZGeneral	M3_NUT	108	M3 stainless nyloc nut	Falcon W/S Supplies
ZGeneral	M3STUBBOLT	104	M3 x 6mm stainless	Falcon W/S Supplies
ZGeneral	M4_BOLT	2	M4 x 10mm stainless	Falcon W/S Supplies
ZGeneral	M4_BOLT_MED	6	M4 x 14mm stainless	Falcon W/S Supplies
ZGeneral	M4_HUB	24	M4 x 10mm stainless	Falcon W/S Supplies
ZGeneral	M4_NUT	28	M4 stainles nyloc nut	Falcon W/S Supplies
ZGeneral	M8_BOLT	8	M8 x 75mm stainless	Falcon W/S Supplies
ZGeneral	M8_BOLT_MED	8	M8 x 55mm stainless	Falcon W/S Supplies
ZGeneral	M8_BOLT_SHORT	12	M8 x 40mm stainless	Falcon W/S Supplies
ZGeneral	M8_NUT	28	M8 stainles nyloc nut	Falcon W/S Supplies
ZGeneral	Al T6 Tube	1	19.05x19.05x3.25mm, 5m	Richard Austin Alloys
ZGeneral	Al T6 Angle 1	1	16x16x1.6mm, 5m	Richard Austin Alloys
ZGeneral	Al T6 Angle 2	1	25x25x3mm, 5m	Richard Austin Alloys
ZGeneral	Al T6 Sheet 1	1	2mm, 2x5m	Richard Austin

				Alloys
ZGeneral	Al T6 Sheet 2	1	1mm	*workshop*
ZGeneral	STYROFOAM	1		*workshop*

4.4.7 Folding Technique

As the satellite is stowed inside a CubeSat box, it is essential to establish an efficient folding technique. Each individual cell is folded twice to fit inside the deployment box. Each side of the cell is folded towards the middle. The satellite is then folded 10 times in a z-fold to obtain a rectangular packaging volume. This technique along with the effect of gravity ensures that the satellite is successfully deployed.

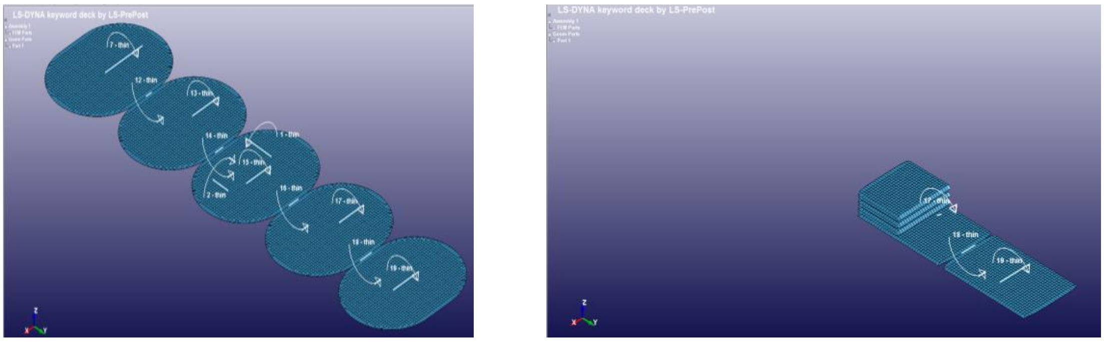


Figure 4-34: Folding Simulation

Where each fold is placed depends on the placement of the electronics onto the inflatable . The same technique is carried out by the same team member to ensure consistency.

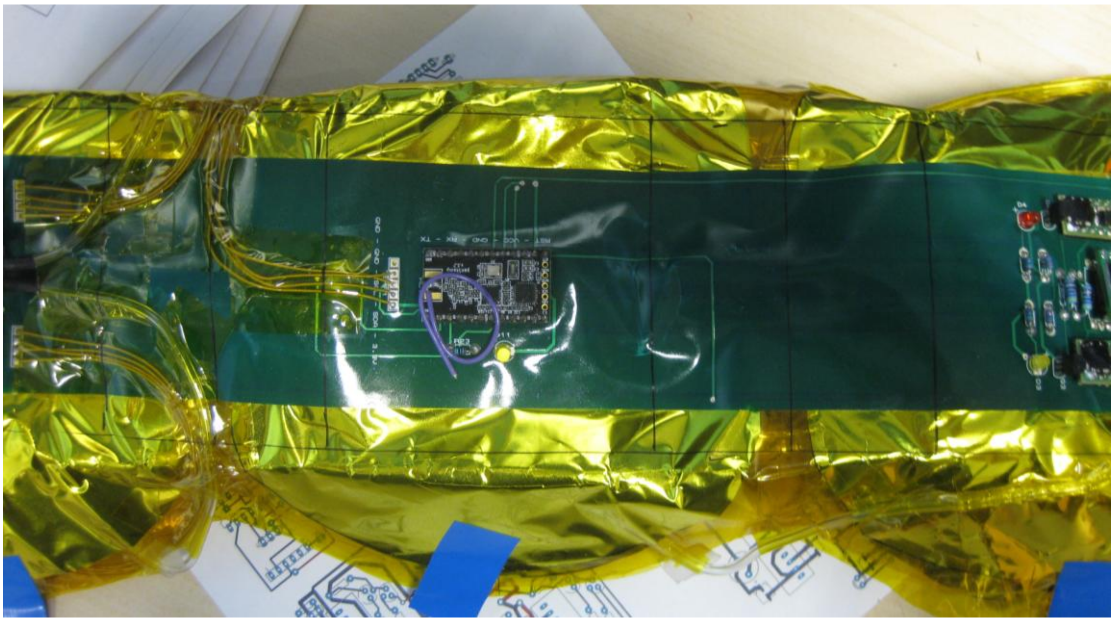


Figure 4-35: Folding lines on flight hardware

4.5 Electronics Design

All components in this experiment are COTS and have been selected as they have low mass, volume and footprint, and they work within the harsh environmental operating conditions. The system architecture is designed to be robust and fulfill its purpose with the minimum components and simplest implementation. At this stage in the project, the electronics design of each subsystem has been completed and is undergoing rigorous prototyping and testing. Section 4.5.1 gives an overview of the electronics implementation.

4.5.1 Electronics Overview

The electrical system can be divided into two subsystems, the Hub and the satellites. Although the experiment launched two satellite units, the electrical systems on each are identical and so are described singularly.

As described, only one satellite is deployed at float altitude, with the other being pre-deployed before launch. The deployable satellite is actuated following a command given manually from the ground support software. Both satellite systems are on standby from launch and fully activated upon receipt of the deployment command.

Throughout the experiment the Hub acts as the primary experiment controller; dictating the operation of the experiment depending on the experiment timeline and user commands from the ground support station. Commands are received through the BEXUS E-Link. The logic and flow of the experiment can be seen in Section 4.8: Software Design.

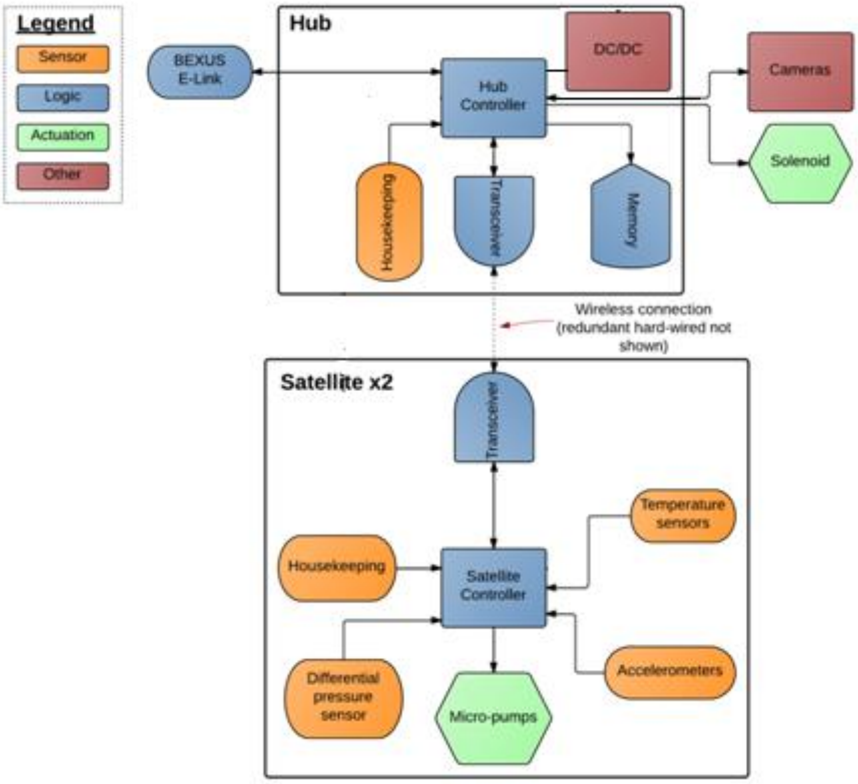


Figure 4-36: Block diagram of the full electrical system, excluding power distribution

The system functionality is described below with reference to Figure 4-36.

The primary purpose of the electronics on board the Hub is to process collected data, save it to the SD card and transmit it through the BEXUS downlink to the ground support software. Additionally, it dictates the operation of the satellites throughout flight and relays commands sent from the ground support software to the respective satellite.

The Hub electronics consist of a data acquisition system, a microcontroller, a power distribution system and wireless transmission system. The microcontroller controls the data acquisition system, communication with the satellites and ground station, experiment timeline, solenoid and operates the cameras.

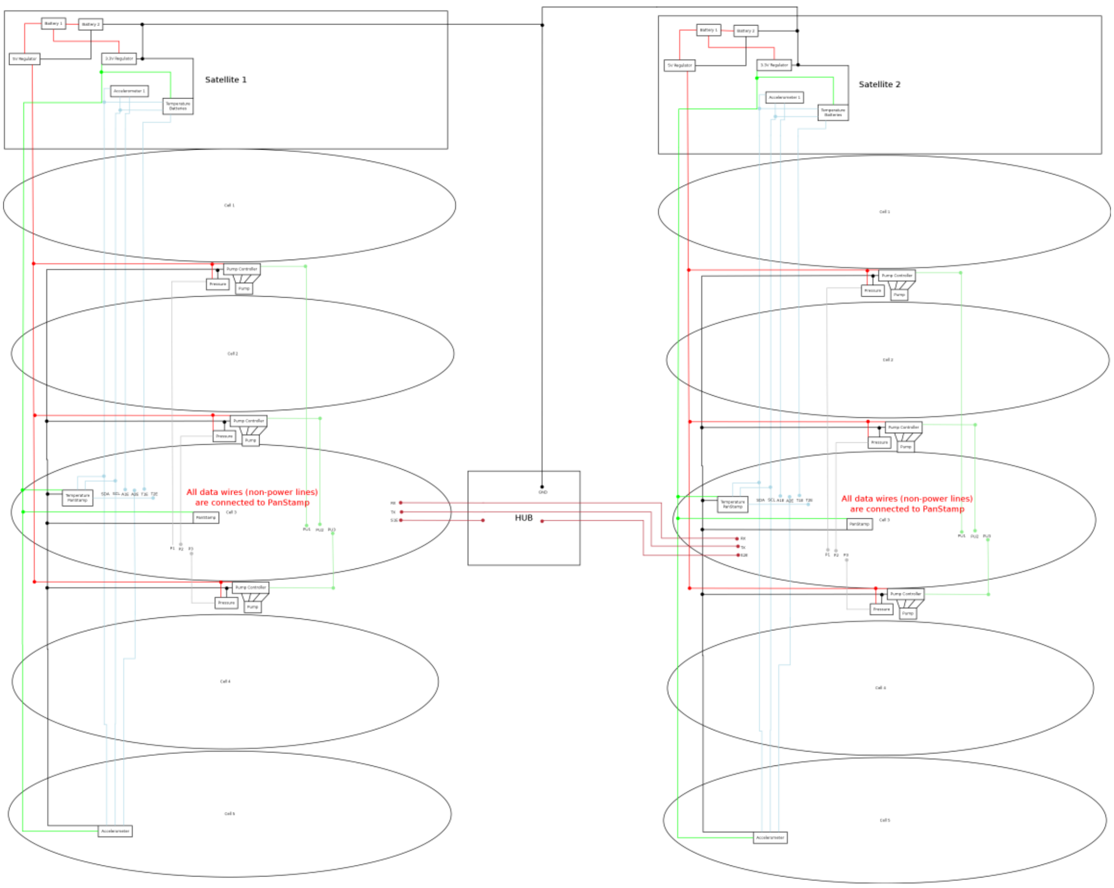
All data received by the Hub over the wireless network is processed by the Hub for storage on the SD card and transmit through the BEXUS downlink to the ground support station.

Each satellite contains a microcontroller, micro-pump actuators with control system and a number of sensors for environmental readings and housekeeping. The satellite's microcontroller is tasked to receive commands from the transceiver; carry out actions accordingly; read sensor data and transmit it to the Hub; actuate the micro-pumps for shape alteration and implement closed loop control on the actuation process.

The control system on each satellite operates using readings from two accelerometers; one static accelerometer situated at the top of the satellite and another moving accelerometer located at the bottom tip of the satellite. It ensures that the deformation of the structure due to actuation remains within pre-defined limits.

It is also worth noting that although there is a wireless link between Hub and both satellites, there is also a hard-wired connection in case of an issue with establishing wireless communication.

All the connections and the wiring between the cell, satellites and hub is shown below.



4-37: Wiring schematic

4.5.2 Hub

The satellites must be monitored and deployed by the ground station. Ideally the communication would be directly from the ground to the satellite, but in order to simplify the experiment it was decided to use the BEXUS E-Link for communication between the ground and the balloon. A controller is needed to act as the interface between the E-Link and the satellites. As the E-Link uses Ethernet, the controller is capable of interfacing with both Ethernet and then wirelessly to the satellites.

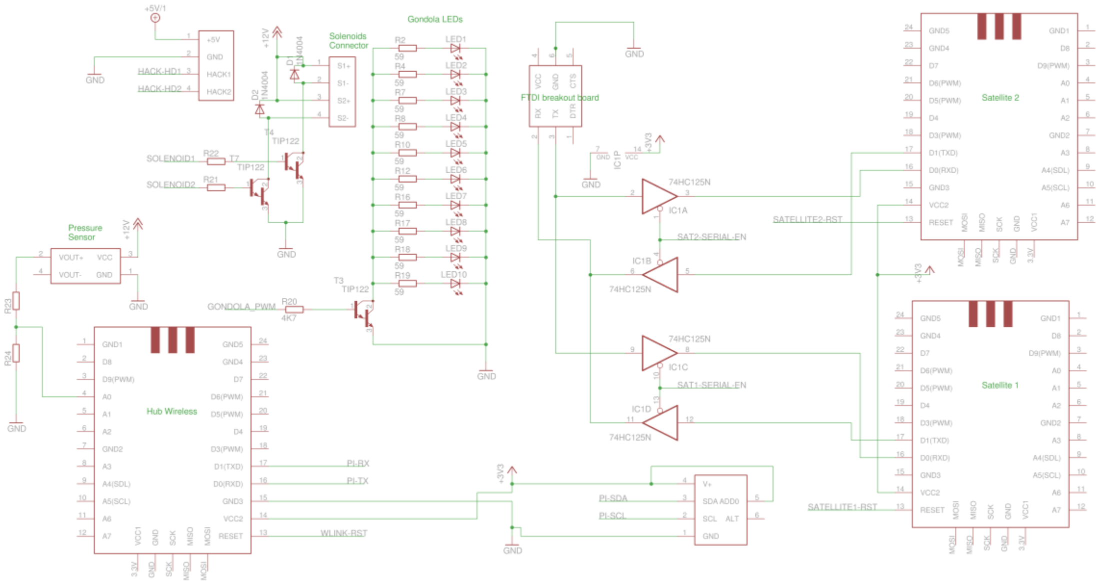


Figure 4-38: Schematic of Hub data board

4.5.2.1 Controller

The Hub is based around Raspberry Pi model B [29] running Raspbian "wheezy" which allows for seamless interfacing with the BEXUS E-Link and ease of programming whilst still providing the required functionality.

The Raspberry Pi is powered by the 5V supply from the 28/5 V DC/DC regulator on board the Hub.

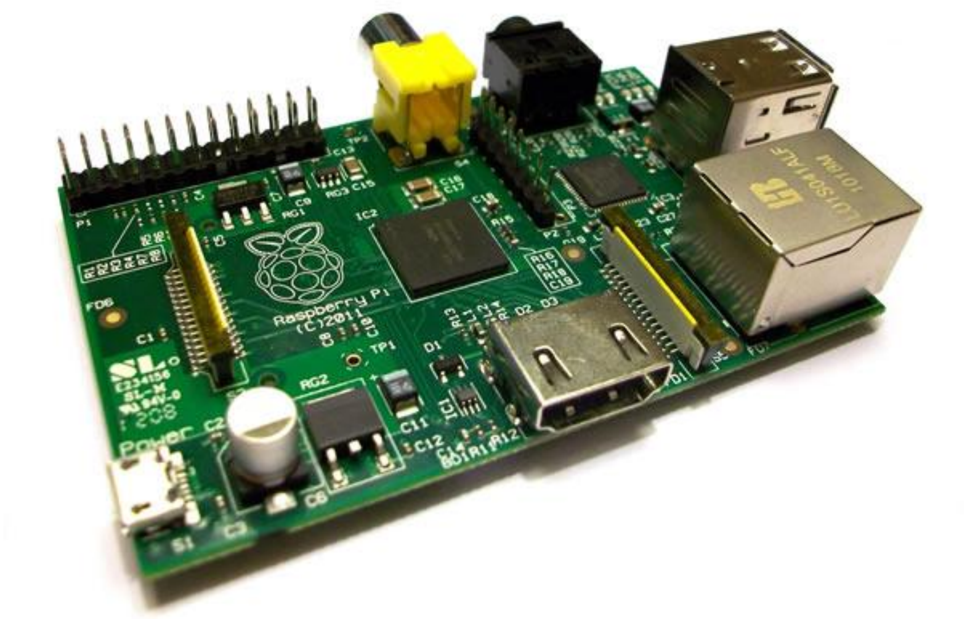


Figure 4-39: Raspberry Pi model B.

The board provides 8 GPIO (general purpose input/output) pins plus access to I²C, SPI, UART, as well as +3.3 V, +5 V and GND supply lines. An SD card is used as a non-volatile memory that stores the operational system. The Figure 4-39 shows the raspberry pi GPIO layout.

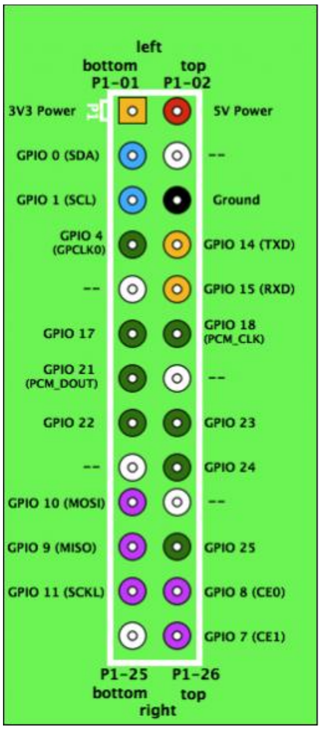


Figure 4-33: Raspberry Pi GPIO layout.

This controller stores an automated version of the experiment timeline so as to allow full operation of the experiment in the circumstance where the BEXUS E-Link is lost. The Raspberry Pi is situated within the Hub unit with connections to the communications, DC/DC regulator and camera boards being housed in the header pins.

4.5.2.2 Data Acquisition & Sensors

As highlighted earlier in this section, the Hub collects data in the form of temperature and housekeeping information as well as data gathered from each satellite throughout flight. The data is stored using the SD card and transmitted through the E-Link to the ground support software.

The Raspberry Pi is linked directly to the panStamp wireless module via UART pins. This data is collected for processing and storage, as described.

The temperature sensor is set to monitor the ambient temperature within the Hub unit. The Raspberry Pi provides a single I^2C bus through pins GPIO2 (SDA) & GPIO3 (SCL); these are used to interface with the temperature sensor used. The temperature sensor is a TMP102 [26], serial output sensor. The device operates from the 3.3V regulated supply.

Housekeeping measurements within the Hub consist of sensing the voltage at the secondary end of each DC/DC regulator and voltage at the unregulated BEXUS power supply. This is done using the panStamp's analogue input that sends all data through UART.

4.5.2.3 Camera

Video cameras are used to record the deployment and actuation of the satellites. This visual data is a significant part of the scientific return of the experiment. As capturing video footage of deployment and actuation is so significant, it is a requirement that the cameras must run as a standalone system. As a result, there is no video-processing requirement for the Hub, simplifying its hardware and software requirements.

HackHD cameras are used as they fit these requirements. The dimensions of the cameras can be seen in Figure 4-40.

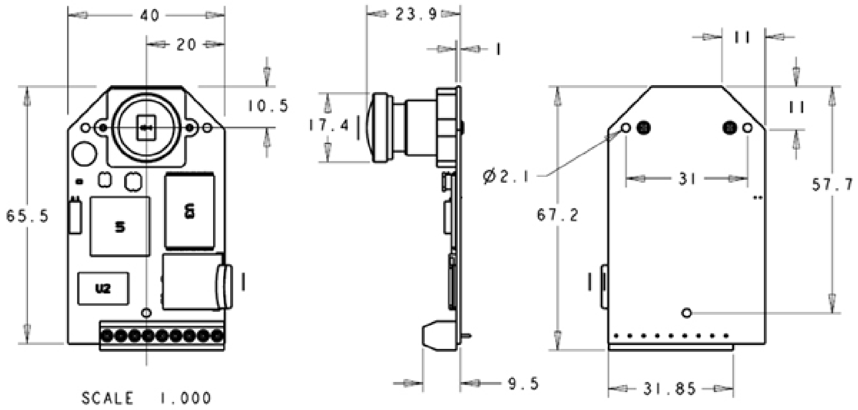


Figure 4-40: HackHD Camera Dimensions

The HackHD uses a simple one-button operation. Referring to Figure 4-41 below, if pin 3 is grounded, the camera is operated and begins recording, providing storage is available on the SD card and power is supplied.

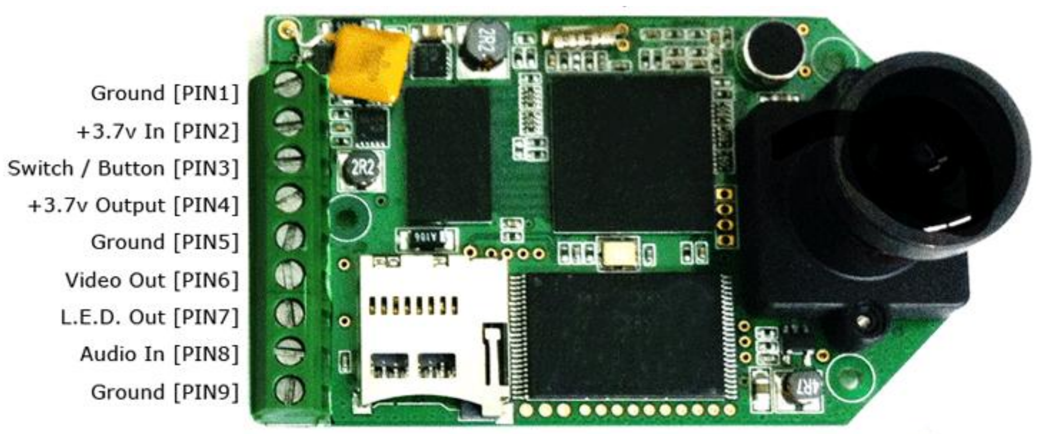


Figure 4-41: HackHD PinOut

Pin 3 is connected to a digital output pin on the Hub Controller. If held low for a fraction of a second, the camera automatically boots up and start to record in auto mode. The camera continues to record until the terminal is grounded again, in which case it stops recording and turn off. By turning off and on when required, power is saved. Alternatively the camera can be put into standby mode by grounding pin 3 for 3 seconds. It stays in standby mode until pin 3 is again grounded for a fraction of a second and it immediately starts recording until grounded again. For simplicity, both cameras are operated in auto-mode.

Pins 1 and 2 are connected to the regulated 5 V power bus from the Hub.

Pin 7 provides a pulsed high signal when the camera is recording. This is used to provide feedback to the Hub controller, allowing for monitoring of the cameras' status.

4.5.2.3.1 Artificial Light

In order to make the deployable visible in the closed gondola and array of 10 bright white LEDs is added between the cameras. This LED array is powered and switched on over the Hub.

4.5.2.4 Solenoid

The solenoid used to actuate the deployment of the deployable satellite is triggered by the Hub. It is crucial that the solenoid specified is capable of holding back the force exerted by the inflatable structure within the deployment box along with the additional shocks specified in the BEXUS user manual. From calculation, the static frictional force required to be overcome by the solenoid should not exceed 6N including a factor of safety of 5.

The solenoid selected is the Ledex® Box Frame Size B22-254-M-36. The component is operated at 25% duty at a stroke of approximately 5mm. This provides an actuation force $\approx 20N$ with a DC voltage pulse of 24V(Nom). Due to the voltage required, the unregulated 28V supply provided by BEXUS is used in conjunction with a MOSFET driven by the Hub controller to operate the solenoid. The proposed circuit is shown below in Figure 4-42:

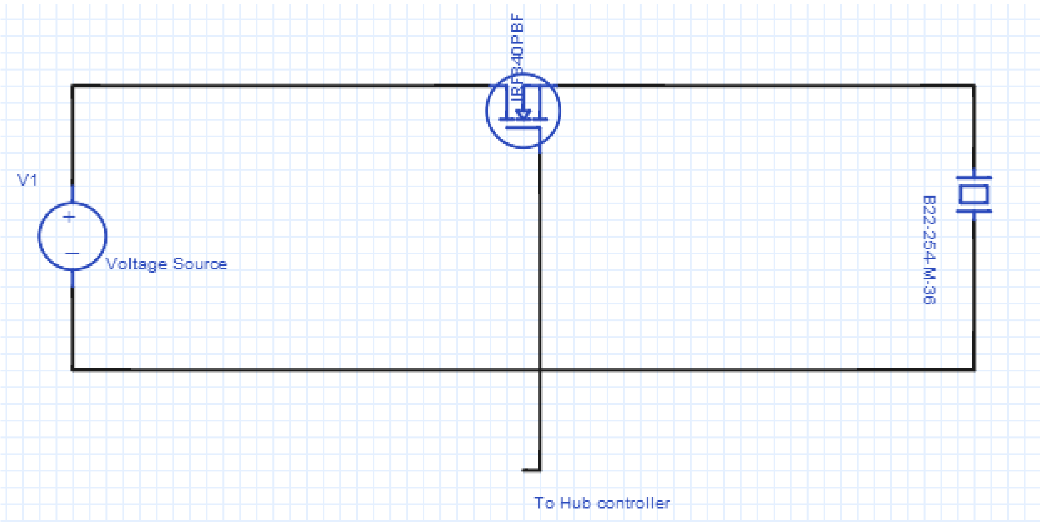


Figure 4-42: Solenoid actuation circuit

A digital high signal (5V) is provided from the Raspberry Pi to drive the MOSFET and activate the solenoid.

4.5.3 Satellites

Each satellite forms the basis of what would be a concentrated control hub as part of a larger smart space structure. As such, its electronics are designed to facilitate intelligence for performing various measurements to monitor and control the performance of the structure. Each satellite gathers ambient and component temperature readings along with important voltage sensing for housekeeping. Differential pressure measurements are also being taken to help characterise the inflation of the structure at deployment and throughout flight.

As described earlier, the actuation is driven by Bartels MEMS micropumps which are connected electrically to the microcontroller through their own sub-controller. The control of the actuation is provided through two accelerometers positioned on the structure.

Data is not stored on each satellite; it is instead only acquired and transmitted to the Hub via the wireless link. The data is then processed, stored and sent to the ground support station.

4.5.3.1 Microcontroller

The satellite controller circuit is a PanStamp based upon the Arduino Pro Mini. It uses an Atmega328 chip and the open source schematics & firmware made available by PanStamp.

This architecture allows for easy development of the embedded systems due to the availability of open source schematics and a wide user base. Development boards have been purchased – these allows the development of software to proceed while the custom PCBs, which are mounted to the surface of the inflatable cells, are being designed and manufactured. As can be seen from Figure 4-43 pins 4 through 12 provide analogue input/output. There are also 9 pins available for digital I/O.

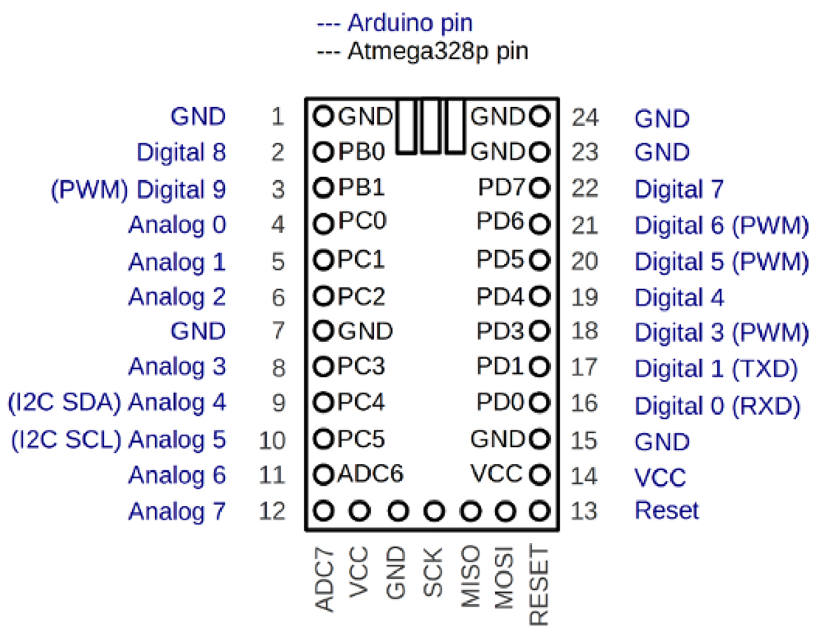


Figure 4-43: PanStamp PinOut

Table 4-3 details the I/O's available on the chosen microcontroller and their use in the electrical design:

Table 4-3: Satellite controller pinout functionality

Pin	Function
D0	TX – Backup link
D1	RX – Backup link
D3	Micro-pump 1
D4	Micro-pump 1 - Reverse
D5	Micro-pump 2
D6	Micro-pump 2 - Reverse
D7	Micro-pump 3
D8	Micro-pump 3 - Reverse
A0	To diff pressure sensor AB/2

A1	To diff pressure sensor AB/3
A2	To diff pressure sensor AB/4
A4	SDA – to I2C SDA bus
A5	SCL – to I2C SCL bus

The microcontroller is powered by the regulated 3.3 V supply on each satellite and draws a maximum of 200mA.

4.5.3.2 Data Acquisition & Sensors

On each satellite there are a number of sensors used to gather ambient and component temperature data; differential pressure between cells; accelerometer data for actuation control; and voltage at critical points in the system.

As stated earlier, all data collected is sent directly through the wireless link (or hard-wired connection if the wireless is unavailable) to the Hub for processing.

The analogue I/O pins of the PanStamp microcontroller allow an input range of between 0 and 3.3 V. This can be changed using the analogue reference pin but shall remain 0-3.3V as default. All inputs out-with this range shall be scaled with a voltage divider.

Temperature Measurement

As in the Hub, TMP102 temperature sensors are used within both satellites. Four sensors are located throughout:

- 1 measuring ambient temperature in gondola
- 1 measuring temperature of Atmega328 microcontroller
- 2 measuring on the cells

All four sensors are located on the single I^2C bus connected to pins A4 and A5 of the PanStamp board.

Differential Pressure Measurement

Differential pressure measurements are taken between the soft robotic elements in adjacent, actuated cells. That is, they measure the differential pressure between two soft robotic actuation elements in each of the three closed systems. The data collected here allows for characterisation of the system and the amount of flow required to perform a particular change in shape.

The differential pressure sensor selected for this task is the LBAS250B [27]. It can be seen in Figure 4-44.

Figure 4-44: LBAS250B Differential Pressure Sensor

The sensor provides an analogue output within the range of 0.5-4.5V and has to be scaled down to interface with the microcontroller.

Accelerometers

Two triple axis accelerometers are used in each satellite in order to provide an input parameter to the actuation control loop.

One accelerometer is placed in a static position on the deployment module box. The second is placed on the bottom cell (5) and changes position with the alteration of satellite shape.

The accelerometers chosen are the ADXL345 accelerometers by Analogue Devices. They have the capability of measuring $\pm$16 G at a resolution of 13 bits.

The accelerometers are both connected via the I^2C bus already containing the 4 TMP102 temperature sensors.

4.5.3.3 Actuation

Micropumps are required to pump between each pair of adjacent soft robotic actuators. This changes the size of the cells in relation to each other and creates a shape change in the overall structure. MP6 micro-pumps from Bartels Mikrotechnik GmbH were selected [28]. The micro pump is a piezoelectric driven micropump with dimensions of 30 x 15 x 3.8 mm, and a flow rate of 18ml/min.

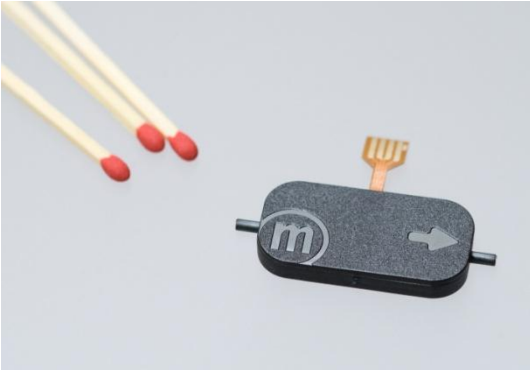


Figure 4-45: Bartels MP6 Micro-pump

The pumps require a specifically generated signal to be applied across each of the 4 input pins to produce the flow rate required. This signal does range between 0-250 V at up to 100 Hz. This has not been a problem as the previous StrathSat-R REXUS experiment also successfully performed vacuum tests on these particular pumps.

In order to produce the signals required to operate the pump, the Bartel mp6-OEM controller is used. This is an additional control board purchased separately from the micropumps. It generates the signal required to drive the micropumps from a 5V supply with maximum current draw of around 30mA. Figure 4-46 shows how the OEM pump controller is connected together with the microcontroller and pump:

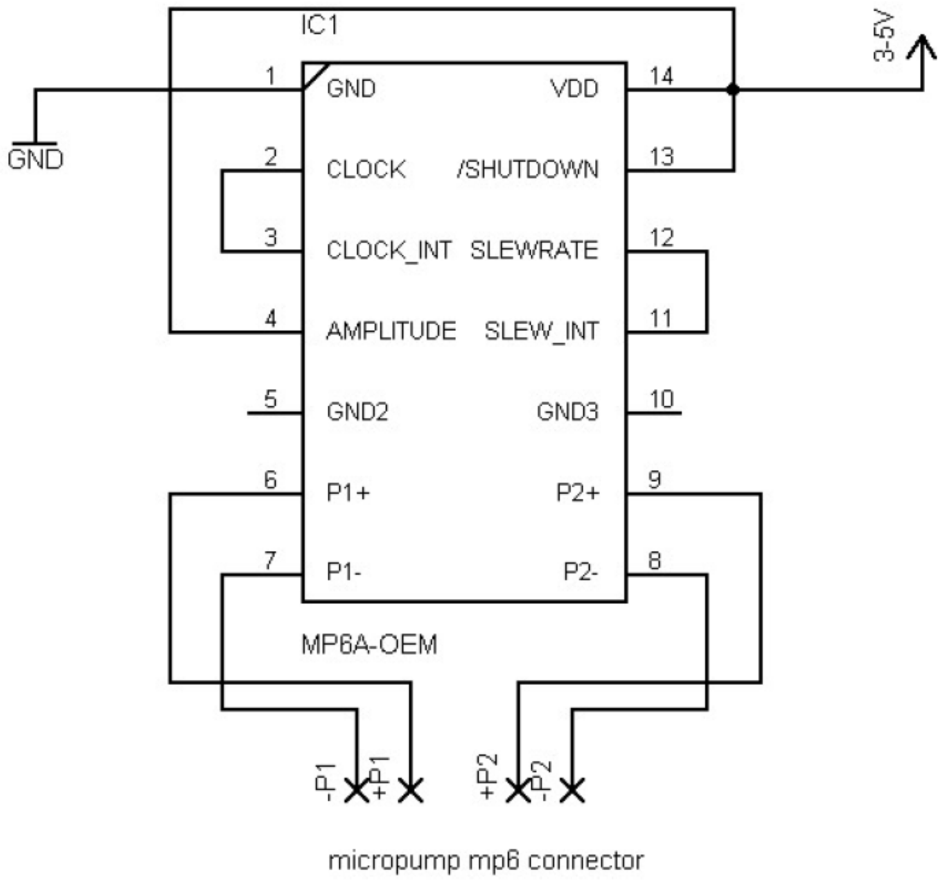


Figure 4-46: mp6-OEm pump controller configuration

Using the configuration shown, the pump is set to a fixed flow rate with an output from the controller of 235 V at 100 Hz.

In this configuration, the shutdown pin is connected to the relevant pin shown in Table 4-3. This allows control over when the pump is operated. As two pumps are connected between each cell pair to allow flow in both directions, an inverter is used to prevent one micropump flowing whilst the other is ON.

4.5.3.4 Circuit Board Implementation

The preferred PCB design for the satellite controller is components soldered to tracks printed on a flexible substrate. This allows easier bonding of the circuit to the inflatable material, reduces the likelihood of a PCB tearing the inflatable during packing or deployment, and places fewer restrictions on the folding and packing of the satellite into the deployment module. An example of the capabilities of this technology is shown in Figure 4-47 in the Arduino Seeed.

Figure 4-47: Arduino Seeed

The iSEDE flexible circuit board is manufactured by the company PCL and it runs over the entire inflatable satellite.

4.5.4 Wireless Communication

Wireless communication is used between the hub and each satellite. The wireless module is integrated with the satellite controller and sensors on the same PCB to create a “mote”, a small wireless sensor and processing unit. The tranciever in use is the panStamp from PanStamp, which is a 868/915MHz ISM band RF module and together with the Atmega328 provides a Miniature PCB mounting solution where a high performance is required from a small space. It can be configured to operate at multiple frequencies, none of which are restricted by the BEXUS User Manual. The data rate is configurable up to 600kbps depending on the modulation used, and a data rate, using Frequency Shift Keying (FSK) modulation, of 250kpbs is sufficient.

With its small, compact design it has the following characteristics:

- Size: 17.7 x 30.5 mm
- Operates from 2.5 VDC to 3.6 VDC
- 1 µA when in deep sleep mode. 2.5 mA whilst transmitting

4.5.5 Cabling Pin Allocation

The following chapter summarized the pin allocation of the cables in-between the hub, the satellites and the cameras. For testing purposes a red and black striped cable has been created that fits in-between all connectors which can be used for troubleshooting.

Figure 4-48: DSUB numbering

Table 4-4: Cable pin allocation

Pin	Hub – Satellite (6 wires)	Hub – HackHD (8 wires)	Hub – iSEDE cam/LED (6 wires)
1	Solenoid (+)	Camera 2 - Ground	iSEDE cam (black)
2	5V	Camera 2 - 5V	iSEDE cam (red)
3	free	free	free
4	3.3V	Camera 1 -Ground	free
5	Solenoid (-)	Camera 1 - 5V	LED (positive)
6	GND	Camera 2 -Signal	iSEDE cam (green)
7	RX	Camera 2 -LED	iSEDE cam (white)
8	TX	Camera 1 -Signal	free
9	RST	Camera 1 -LED	LED (negative)

4.6 Thermal Design

The iSEDE experiment aims to demonstrate synergy in design of inflatable structures with disaggregated electronics. While not a requirement for the BEXUS programme, the iSEDE project considers not only the thermal environment on BEXUS but also the thermal environment that would be typical of a satellite in low earth orbit (LEO).

All components are rated for operation down to -40^{o}C. As such, the only temperature challenges should occur during the ascent and at float where the temperature is significantly lower.

The materials used for the structure of the hub, the interfaces and the inflatable satellite retain their properties across this wide temperature range.

The inflation by residual air should also occur as expected, modelled using gas law equations.

The electronic components that are chosen for the satellite are specified for operation at as low temperatures as possible but it is uncommon for electronics to be rated below -50^{o}C.

Insulation has been used in the hub and camera housings to ensure these devices are kept within a standard operating temperature range.

The iSEDE team are continuing to research options that might be available to reduce heat loss from the printed circuits mounted on the inflatable structures – minimising volume and mass for these structures is paramount to a successful design solution.

4.6.1 Thermal Design for Deployment Mechanism

At the moment the solenoid has only been tested in a vacuum chamber where it was successful.

As the solenoid, link arm and latch is made from the same material thus thermal expansion is not expected to be a problem. Testing the full mechanism at -40°C verifies this expectation.

4.6.2 Thermal Design for Inflatable Structure

A bonded Mylar inflatable structure has been thermally tested down to -30°C for a period of approximately 30 minutes. It was found that the material's properties did not change during the experiment and that the adhesive seal was not weakened by the low temperature.

Further testing is required to establish whether the structure can withstand the expected temperature of -40°C and for a longer period of time (2-3 hours).

It is not expected that the Mylar is affected by the lower temperature as it is used as space blankets, which is why it is being used for the inflatable structure material. The BEXUS16 flight confirmed the correctness of this assumption.

4.6.3 Thermal Design for Mechanical Structure

The deployment modules, rails and mount plates are all made from T6 aluminium, which is the same material used for the gondola. Therefore, thermal expansion is not expected to be a problem.

4.6.4 Thermal Design for Hub

As the hub is made from polystyrene then the inside of the hub should be properly insulated. To ensure this, a simple calculation was performed. By using a general Fourier's Law for conduction equation, the heat transfer rate for the hub design could be calculated.

$$q'' = \frac{(T_2 - T_1)}{l/_k}$$

Assuming that the temperature inside the gondola is -40°C and that the inside of the hub box is at least 0°C, (which is the minimum operating temperature of the Raspberry Pi), the thickness of the polystyrene box is 3cm and the thermal resistance of the polystyrene is 0.033W/mk. This results in a heat rate of 44W/m^2. The hub box totals an area of 0.14274m^2. Then the total conductive heat rate for the hub is 6.3W. Therefore, it should not be necessary to heat the hub as when the Raspberry Pi is in use then it contributes to heating the hub by itself. Therefore, the hub is sufficiently insulated.

4.7 Power System

The Hub is constantly powered directly from the BEXUS link during operation. There was a pre-deployed satellite in the gondola and this requires power during the ascent phase to power sensors and the microcontroller and the cameras are also active. In terms of how the power is distributed, all power systems are hardwired. The BEXUS power source is hardwired to the Hub in addition to the two satellites, via the Hub.

4.7.1 Power Sources

The power source as previously stated is BEXUS.

4.7.1.1 Hub Power Source – BEXUS link

The hub and all components housed within including the cameras are powered directly from the BEXUS link through some power conditioning.

4.7.2 Power Circuitry

The voltage and current levels for both the hub components and the satellite components are regulated from the power source. The BEXUS link supplies a varying voltage around 28V providing up to 1A and so this is regulated down to a constant voltage for the hub components. There is also a degree of filtering in an attempt to provide the components with an as close to perfect power input as possible. In addition, elements of isolation and protection are placed at points in the system to allow shut off if a fault occurs and prevent any damage to components or other experiments.

4.7.2.1 Power Circuitry for the Hub

The components in the hub require regulated 3.3V and 5V levels. This can be seen in Section 4.7.3 Power Budget Breakdown. This requires DC-DC Convertors to step the voltage down. There are two main kinds of regulators, a linear voltage regulator and a switching voltage regulator.

There was an investigation and deliberation into whether the system should use linear or switching regulators. Upon advice, it was decided that from an efficiency point of view as well as a safety point of view, isolated switching DC/DC convertors are used. These provide higher efficiencies than the linear counter parts and the added benefit of isolation of the input from the output should any faults occur.

These incurred a higher price than what was initially thought would be required for regulators but it was decided that the benefits of these would outweigh the negative of the higher cost. The regulators chosen were from TRACO POWER, shown below in the figure below.

Figure 4-49: Isolated SIP Voltage Regulators

The regulators selected were isolated SIP-Packages fixed to regulate to 3.3V and 5V. The Models are

- 3.3V Regulator – TMR6-2410
- 5V Regulator – TMR6-2411

These regulators are said to operate with ‘excellent efficiencies’ down to -40°C.There is also the added advantage in that since both regulators are from the same series the accompanying circuitry is the same.

The regulators also have an input for a ‘Remote ON/OFF’ function which allows the input of a Transistor Logic Level (TLL) to switch on and off the regulator. This means that on top of the passive components required at the power input and output, there is a circuit required to input a TLL into the regulator.

The full power schematic can be found in the appendix which details the circuitry surrounding each regulator and how they connect to the system.

4.7.2.2 Power Circuitry for the Satellite

The components on the satellite require regulated voltage levels of 3.3V and 5V. As in the hub, a voltage regulator is required and a switching regulator is used.

Ideally, due to the design and the concept of mounting electronics to the surface of the inflatable cell, surface mount components are desirable. This posed a possible problem. The surface mount regulators have a smaller current draw than the through-hole devices and this leaves very little safety margin especially when the efficiency will most likely drop at low temperatures.

(The decision was made to move the power circuitry to the HUB.)

~~4.7.3 Charging the Satellite Batteries~~

(Decision (June 13): charging during mission unnecessary)

4.7.4 Power Distribution

The power system is entirely hardwired. There are 2 power buses running through the cells of each satellite with the 3.3V and 5V. Each cell can then tap into the bus of the required voltage level and thus provide the correct power input for the cell's components.

The Hub has the power circuitry inside it and is hardwired directly to each of the satellites.

4.7.5 Power Budget Breakdown

SAT	Quantity	Operating Voltage	Max Current (mA)	Max Power (mW)	Operating Time (hr)	Power Consumption (mWh)	Power Consumption (mAh)
Micropump	3	5	20	100	0.75	225	45
Communications Chip	1	3.3	26	85.8	0.75	64.35	19.5
Accelerometer	2	3.3	0.01	0.066	0.75	0.099	0.015
Temperature Sensor	4	3.3	0.01	0.132	0.75	0.099	0.0075
Pressure Sensor	3	5	5	75	0.75	56.25	3.75
		Total	101.06	260.998		345.798	68.2725
					x2 SATs	691.596	136.545
HUB							
Microcontroller	1	5	300	1500	1	1500	300
Temperature Sensor	1	3.3	0.01	0.033	1	0.033	0.01
Camera	2	5	550	5500	0.5	5500	550
Communications Chip	1	3.3	26	85.8	1	85.8	26
		Total	1426	7085.83		7085.833	876.01

Total BEXUS E-link Requirements		
Max Current Draw	1527.06	mA
Max Power Draw	7346.831	mW
Power Consumption (mWh)	7777.429	mWh
Power Consumption (mAh)	1012.555	mAh

4.7.6 Power Distribution Diagram & Schematics

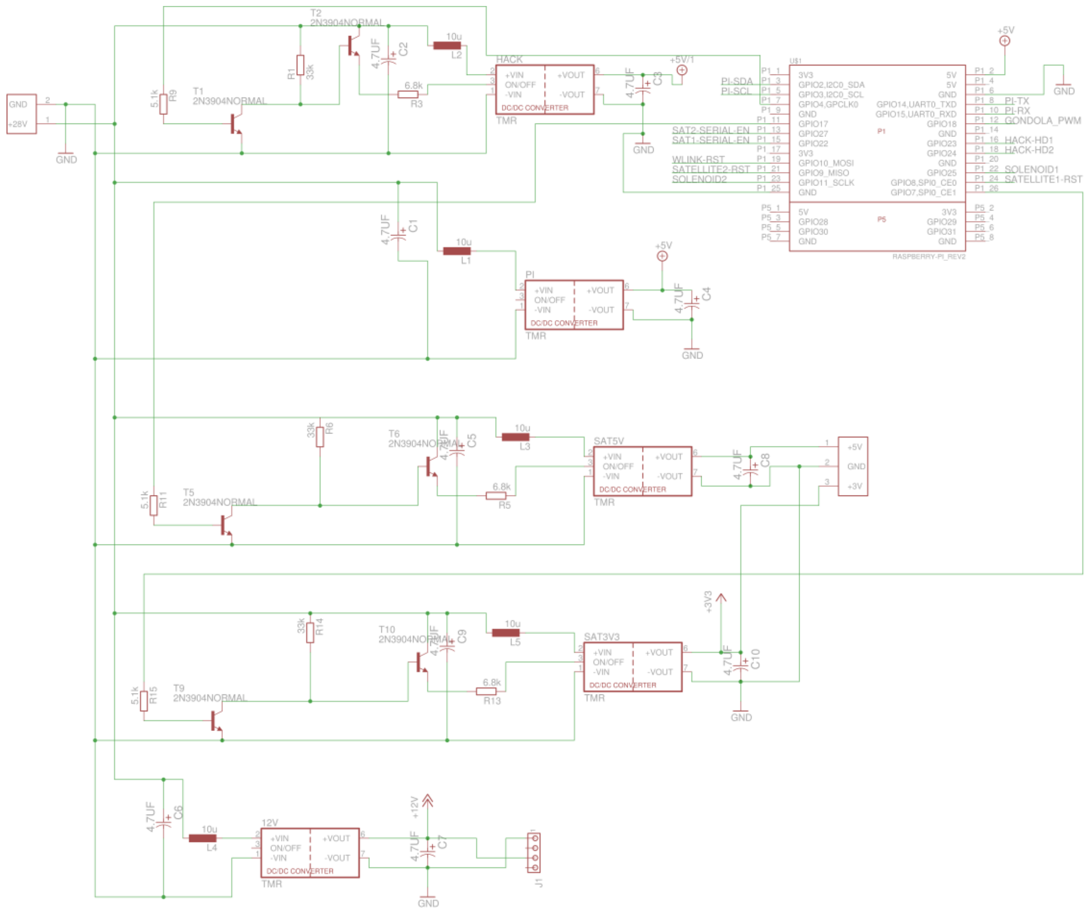


Figure 4-50: Power Schematic

4.8 Software Design

4.8.1 Software Overview

The software implemented across the experiment acts to serve two main purposes:

1) On board data handling

2) Experiment control and operational timeline

For the on-board data handling, each satellite monitors its own deployable structure during adaptive phases, carry out various measurements store and send to the hub, and perform standard housekeeping (voltage, current and critical component temperature monitoring). Cameras capture the deployment and shape alteration throughout the flight; however, the cameras selected are COTS products capable of carrying out their own data processing and storage. Data collected by each satellite is sent to the Hub and stored on SD cards there. More information on the recording times of the cameras can be found in the timeline in Chapter 6.

The software operates in one primary mode once the satellite is fully deployed and systems are online; the operational phase. This mode is described here with reference to Section 6.3. The operational phase runs for 30 minutes and is where most major satellite functions are operated; it is shown in the experiment timeline between FT+2 and FT+32. During this phase, the adaptive phase (AP) of each satellite is demonstrated and the wireless communications between Hub and satellite are tested. Once 1 cycle of operational is complete, it simply repeats until the balloon reaches the end of its float and begins to descend.

4.8.2 Hub

The hub acts as the main experimental controller for the iSEDE experiment. Its tasks primarily include controlling the experiment timeline, storing data and allowing communication between the satellites and ground station through the BEXUS E-Link.

The Hub co-ordinates each satellite according to the experimental timeline and commands received from the ground station. The Hub also ensures that the experiment does not deploy until deemed safe by the ground-crew; a ‘go’ command is sent once the balloon has reached the float altitude of its flight. Upon receiving this command, the first cycle of the experimental timeline initiates. The cameras automatically begin recording and storing data upon receiving command from the hub; they are set to record through all operational phases carried out during the flight. Across the full flight, the Hub generates reports based upon critical data received from each satellite and transmits these through the BEXUS E-Link to the ground station.

4.8.3 Satellite(s)

Each deployed satellite implements the same control and data handling techniques. The main focus of each system is control of the inflatable structure; however, many other functions are present. Each satellite performs its own housekeeping; measuring voltage & current at critical points and ambient & component temperature.

4.8.4 Software Implementation

The software implemented across the experiment is a distributed system loosely coupled with a coordinator (the Hub) that runs across two different open-source hardware platforms: a RISC credit-card-sized single-board computer (Raspberry Pi) and an Arduino based board (PanStamp) that uses an AVR RISC-based 8-bits micrcontroller. The Hub is responsible for handling all communication with the ground station and controls the experiment timeline sending commands to both satellites with instructions or requesting data. The Hub is programmed using C++ and Qt framework, the satellites are programmed using the Arduino programming language (based on Wiring). The integrated development environments (IDEs) used are QtCreator (to write all code) and the Arduino development environment (based on Processing) to compile and upload the code on Arduino based boards. Both IDEs are integrated to work as a single system.

The main features of the satellites are:

- Housekeeping and self-diagnostics;
- Read and process sensor’s data;
- Control inflatable structures;
- Keep running when any non-critical component fails;
- Send self-diagnostic report, sensors readings and experiment data to the Hub.

The main features of the Hub are:

- Housekeeping and self-diagnostics;
- Communication with ground station;
- Activating/deactivating the satellites;
- Activating/deactivating the wireless communication;
- Control satellites’ deployment;
- Log all sensors readings and experiment status;

- Keep running when any non-critical component fails;

4.8.4.1 Satellites

The satellite software is developed based on the concept of a state machine. State changes are driven either by commands sent by the Hub or when completing some tasks. The states are:

- **Initializing:** starts all arduino's peripherals and sensors;
- **Self-diagnostic:** checks all voltage levels, tests communication channels, sensors and actuators;
- **Housekeeping:** checks all voltage levels and communication with the sensors;
- **Receiving data:** When any data arrives the software goes to this state, receives the data, stores it and returns to the last state;
- **Sending data:** sends data to the Hub, in case of failure of the main communication link the backup link is used;
- **Reading sensors:** reads all sensors, process the data and stores it;
- **Changing shape:** controls the changing shape phase;

Idle: Waiting for commands;

There are two communication links: the main link is wireless and it is connected to arduino's SPI bus, the other one is a backup wired link connected to arduino's serial port (also known as UART or USART). Both satellites are connected to the same serial “bus” using tri-state buffers controlled by the Hub to ensure that only one satellite is using the “bus” each time.

When activated the satellite goes to an initializing state where all arduino's peripherals, sensors, actuators and the watchdog are initialized. After that the system goes to an idle state where it stays reading all sensors and sending the readings to the Hub.

Watchdog is a timer/counter with a dedicated clock that allows a software interruption and also a system reset if the counter is not reset before it finishes counting. In the satellite the Watchdog is responsible for identifying communication problems and tries to reconnect to the Hub. When working normally the Watchdog counter is reset when a command arrives and during long states, so if the Watchdog interrupt occurs it is because there are communication problems. The satellite tries to reconnect to the Hub, if it fails, it goes either to a safe-mode which means return the satellite to a default shape and keeps trying to reconnect with the Hub or to a time and altitude based autonomous experiment mode.

The communication with the temperature sensors and accelerometers is done using an I^2C bus, each sensor has a communication protocol defined by its manufacturer.. The pressure sensors are connected directly to arduino's analogue inputs.

The flow diagram is shown in Figure 4-51.

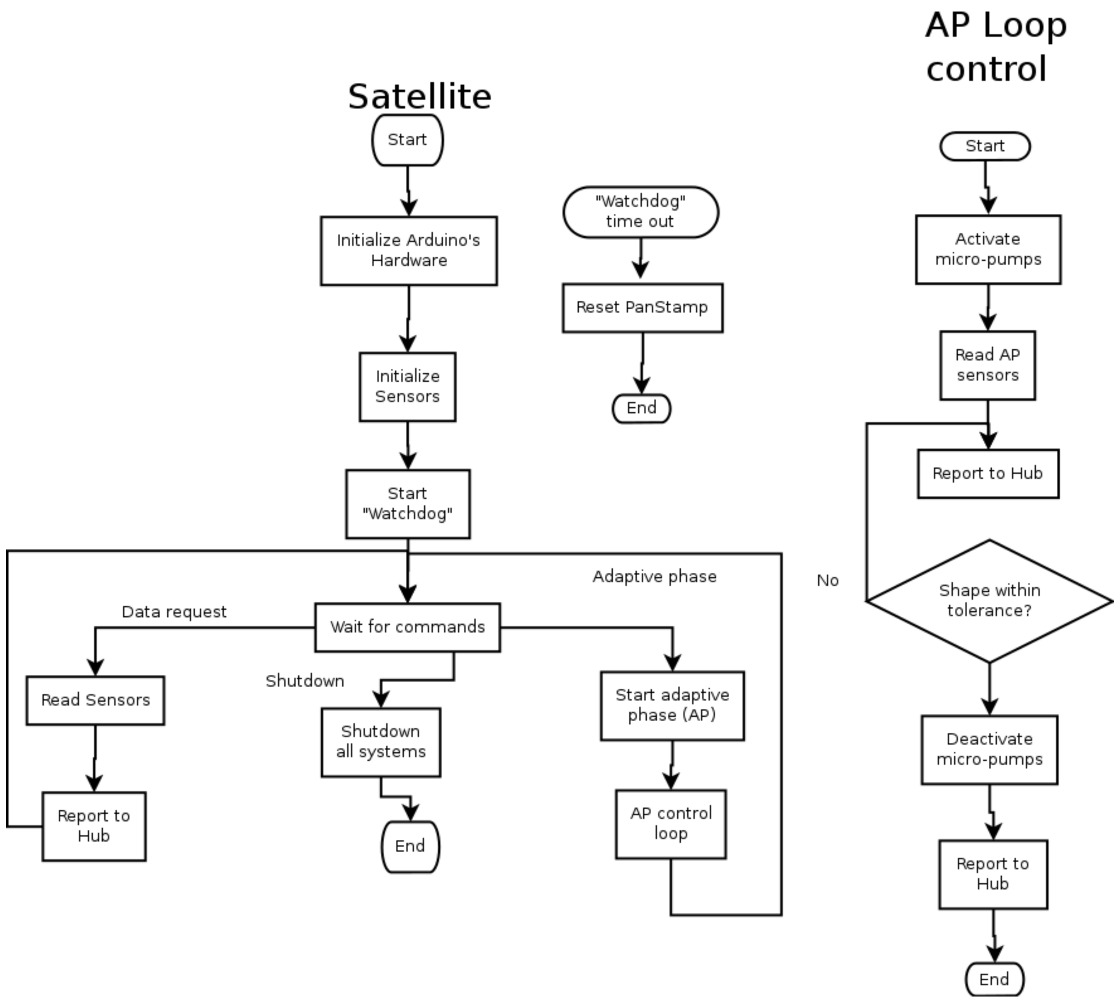


Figure 4-51: Satellite's Flow Diagram

4.8.4.2 Hub

The Hub software is also developed based on a state machine. State changes are driven either by commands sent by the ground station or when completing some tasks. The states are:

- **Initializing:** starts all arduino's and Raspberry Pi peripherals and sensors;
- **Self-diagnostic:** checks all voltage levels, tests communication channels, sensors and actuators;
- **Housekeeping:** checks all voltage levels and communication with the sensors, it also checks the state of the satellites;
- **Receiving data:** When any data arrives the software goes to this state, receives the data, stores it and returns to the last state;
- **Reading sensors:** reads all sensors, processes the data and stores it;
- **Sending data:** sends data to the Hub, in case of failure of the main communication link the backup link is used;
- **Idle:** Waiting for commands.

The Hub has four communication links: an Ethernet interface connected to BEXUS E-Link, two serial ports (also known as UART or USART), one connected to a wireless link and the other is used as a backup wired link with the satellites and an I^2C bus used to communicate with temperature sensors.

When activated the Hub preforms its boot sequence, connects to BEXUS E-Link and starts the Hub Control Software. This software initializes and tests all peripherals, and then it goes to an idle state performing housekeeping, sending UDP packets with satellites' readings and storing all data on its secondary memory.

To detect communication problems the Hub keeps a timer running to each satellite, if the timer counts five seconds without any transmission from the satellite the wired link is activated. If communication is not established it is notified to the ground station and the satellite is considered down. Further attempts to reset the satellite and establish connection can be made.

The same process is used to detect communications failures with the ground station. If there is no communication for more than five seconds, the E-Link is considered down and a new attempt to reconnect is made. If it does not work, the Hub goes to an autonomous mode where it runs the experiment based on time and altitude measurements. Even when in autonomous mode further reconnections attempts are made.

All data received from the Ground station or the satellites are stored with a timestamp, allowing a detailed post-experiment data analysis.

The temperature sensors are used to housekeeping are connected to an I^2C bus and have their own communication protocol defined by their manufacture. Each camera is connected to a digital output and receives a signal to start/stop recording.

The flow diagram is shown in Figure 4-52.

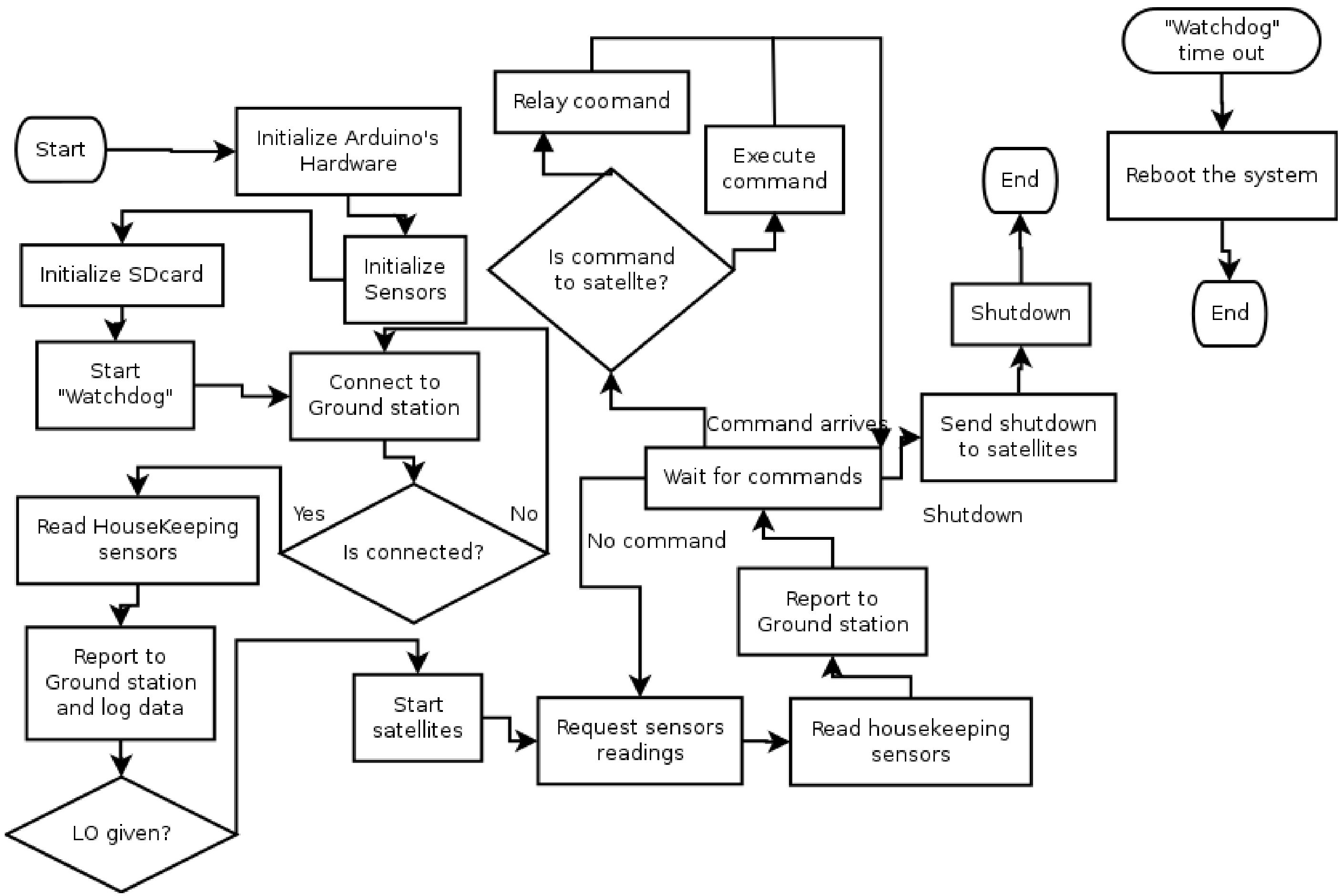


Figure 4-52: Hub Flow Diagram

4.8.5 Data Flow

A preliminary data rate budget has been calculated for four temperature sensors, two accelerometers two voltage measurements and 3 pressure sensors, it is about 150 bytes to transmit all sensors readings (including the protocol overhead). It shows that the maximum throughput that could be observed at any single point throughout the duration of the experiment is < 20 kbps per satellite. This is very low, providing a significant safety factor and allows for increased sampling rates if required. As non-volatile flash storage is required to be used, it can be guaranteed the write speed of the SD card is more than sufficient.

The data throughput within the Hub is of course be twice the throughput per satellite. The wireless communications modules chosen are capable of up to 250 kbps and this far exceeds the data rate required. The on board webcam generates about 300kbps of data as the Ethernet device used has a 100Mbit connection, so the communication bottleneck is PanStamp's processing speed rather than the communication links.

4.8.6 Implementation

As identified in Section 4.5, the Hub houses a Raspberry Pi and each satellite employs a controller design based upon the Arduino Pro Mini 3.3V architecture. The Raspberry Pi runs Raspbian “wheezy” and is programmed using C++ and Qt framework, Arduino based devices are programmed using the high level Arduino programming language.

In March 2013, Larissa & Tiago were recruited into the iSEDE project team to work on the software aspect of the systems. Both students have a Computer Engineering background with Tiago having additional expertise in embedded systems. Since joining the team, the implementation of the software systems has rapidly increased in place with much prototyping and testing being done over the previous months.

So far, the data flow, experiment timing and control algorithms have been defined. Code has been developed, performing all roles to be undertaken by the Hub and Satellite systems.

4.9 Ground Support Equipment

Ground support equipment covers software required for communicating with the experiment during the BEXUS flight. No specific testing hardware is required to perform all necessary health tests and trouble shoots.

4.9.1 Ground Support Software

The ground station software has been made using the programming language Java. Although the development has been on Linux, the software works fine on any operating system, as long as the correct version of the JDK is installed. Furthermore, a connection to the internet is required, in order to make the software's functionalities available, although the GUI and the visualization of pre-stored information do not need internet connection to work. The software consists of a graphical interface to enable the controller to easily interact with the experiment. The table below indicates which telemetry (TM) is sent by the experiment and the telecommands (TC) which are sent from the ground station to control the experiment. Due to the fact that the firing of the solenoid can only be done once during the mission (satellite deploys), a pop up window has been implemented asking the user for a second confirmation. An accidental triggering of the deployment is prevented.

The entire mission of the experiment consists of different phases ranging from preflight testing, launch and ascent to float phase which is the main experimental phase to descent phase after cut off of the balloon. To allow an easy operation and keep a clear interface all information is shown in a single screen using table to most of the data and graphs to more critical data. Figure 4-53 shows the main screen. From this screen it can be clearly seen if one of the systems is experiencing difficulties.

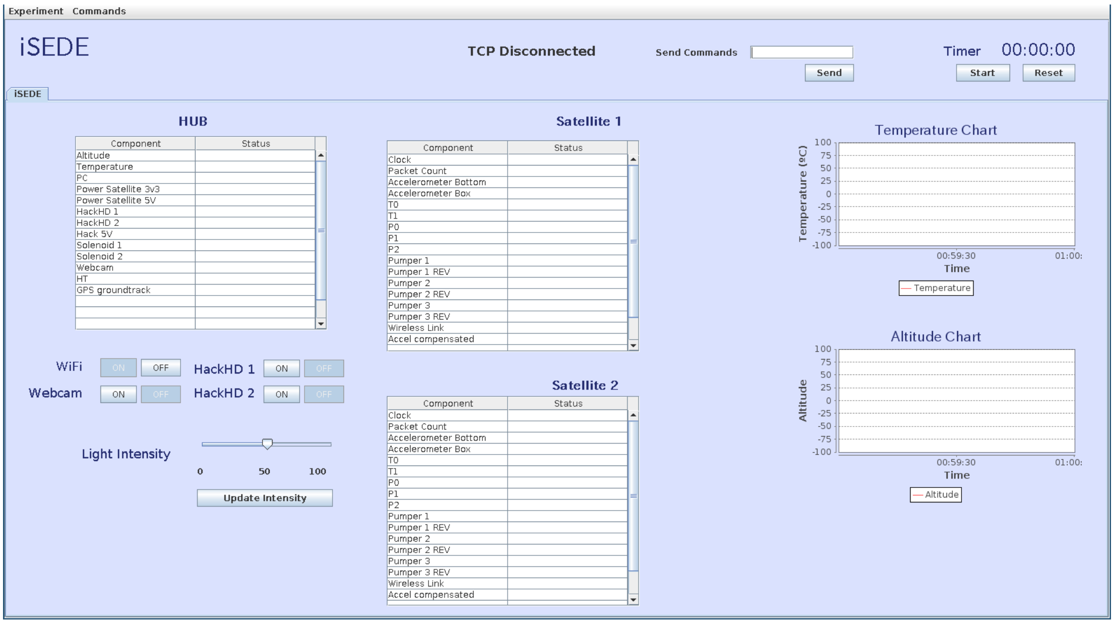


Figure 4-53: Main screen of ground support software displaying all received data of the experiment

In order for the screen not to look over crowded, the information related to the hub and of each satellite is displayed separately, as illustrated above. Also, during the experiment, an extra screen is used to display the pictures sent by the live camera (webcam).

The satellite tables show the acceleration profile of the IMUs mounted on the top of the gondola and at the bottom tip of the iSEDE satellite. If the acceleration of the gondola is low enough, the actuation phase of the experiment can be started with the activation of the pumps 1-3.

The ground station software is able to receive data from the Hub using a UDP communication protocol. The software behaves as a server as it binds to a port of the operating system and waits on an infinite loop to receive packages. Once the package is received, the data is stored in a string. This data contains information about temperature, accelerometers, pressure, elapsed time since the beginning of the experiment and origin of the data. The string is then processed by a method that checks if the string is valid, according to a pre-established pattern. The pattern consists of a string in which all the data is represented, for example: C,34040,A0,-0.348,0.39494,0.45869,A1,-0.945,-0.444,0.7435,T0,20.495,T1,19.984,P0,0.987.

The number after C represents the time since the beginning of the experiment, A0 and A1 and the subsequent numbers represent both accelerometers, T0 and T1 are the numbers for the temperatures and P0 for the pressure. In order to check the validity of the string, the function S*tring.split(",")* is applied to the string to separate and insert it into an array with the data separated by commas. Using the same example as above, the array looks like the following:

C	**34040**	**A0**	**-0.348**	**0.39494**	**0.45869**	**A1**	**-0.945**	**-0.444**	**0.7435**	**T0**	**20.495**	**T1**	**19.984**	**P0**	**0.987**

After checking if the data is valid and the array is on this exact format, the information is stored and then displayed to the user in forms of tables and graphics. After the data is processed, another method checks if any of the information received is critical, by comparing such information to pre-established values already defined as critical. If the data is identified as critical, an alert is displayed on the screen. Data and information from both satellites and the hub is displayed separately for easier identification of the data’s origin and its criticality. For each of the components, the most up to date data is shown on the correspondent tab of the main screen. Furthermore, some information where an indication of a long term change is important is displayed in graphics, such as temperature and pressure.

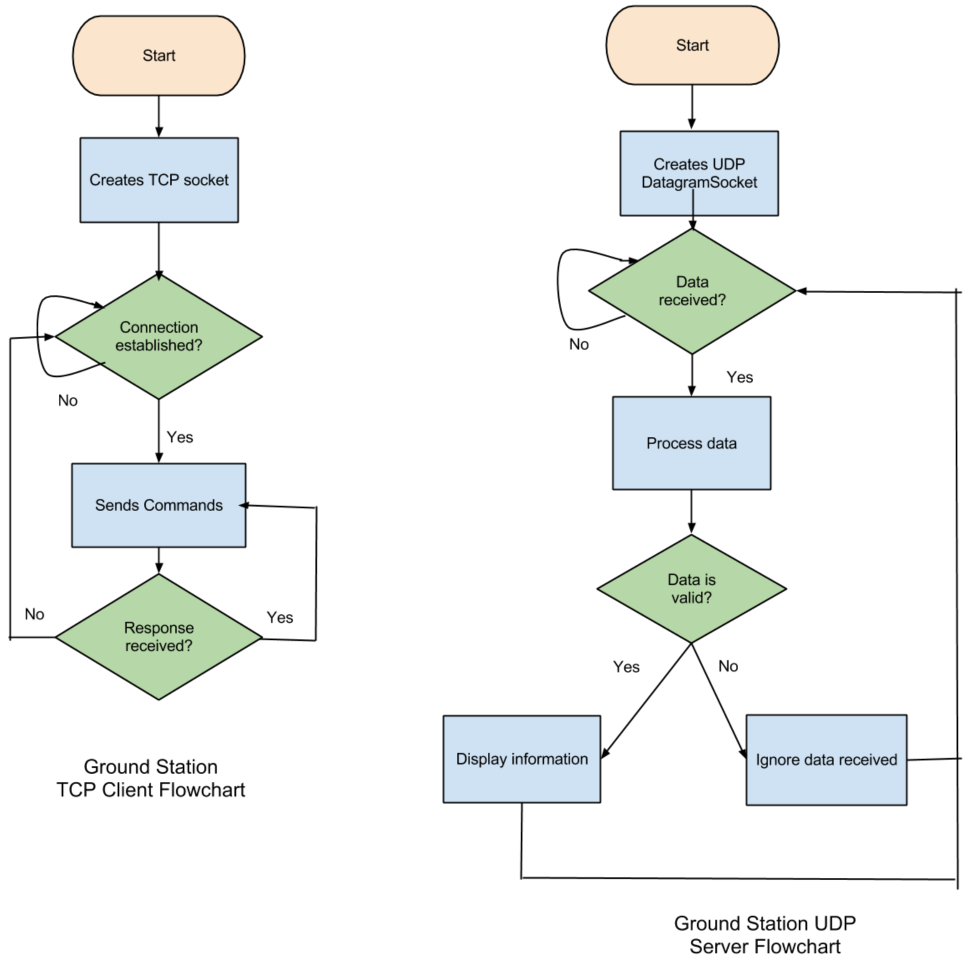


Figure 4-54: Flow chart of ground station

In order for the ground station to be able to communicate and send commands to the satellite, the software relies on a TCP socket. The software behaves like a client, with its main function of sending data instead of receiving. The client keeps trying to establish a connection with the server, and once the connection is established, the ground station is able to send commands to the hub, such as described in Table 4-5. Also, as the command is sent to the hub, the software expects a response, in order to verify if the command has been sent properly and the hub is still connected. If, for any reason, this response does not reach the ground station, the client goes back to the step where it tries to establish a connection to the server.

Table 4-5: Ground Support Software Commands

Command	Process
SC	Start the communication

FS	Fire Solenoid
PUS	Power Up Satellites
PDS	Power Down Satellites
AW	Activate Wireless
DW	Deactivate Wireless
AP	Activate Pumps
DP	Deactivate Pumps
AWe	Activate Webcam
DWe	Deactivate Webcam
AHD	Activate Hack HD
DHD	Deactivate Hack HD
ULI	Update Light Intensity

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

Five established verification methods (for details see: ECSS-E-ST-10-02C):

- Verification by test (T)
- Verification by inspection (I)
- Verification by analysis (A)
- Verification by review-of-design (R)
- Verification by similarity (S)

The following table lists all requirements and specifies their respective verification method(s). The number in the last column relates to the test that verifies the requirement. Tests that still need to be performed are highlighted is without colour, in progress are highlighted in yellow whilst tests already performed and passed are highlighted in green. The abbreviation for the responsible test engineers are: Thomas Sinn (TS), Tiago Queiroz (TQ) and Frazer Brownlie (FB).

Table 5-1: Verification table

ID	Requirement text	Verifi-cation	Status
ER_FU_03	The electronics of each satellite shall be disaggregated across its inflatable structure	R, I	I (05/13) TS
ER_FU_04	Cameras shall capture the deployment and performance of the satellites during the mission	R, A, T	0.9
ER_FU_05	Passive inflation shall be demonstrated by each satellite	R, S, T	0.1
ER_FU_06	Wireless communication shall be established between the satellites and hub	R, T	0.7, 5.0
ER_FU_07	Each satellite should measure the ambient temperature and pressure	R, T	0.10, 5.0
ER_FU_09	Each satellite shall demonstrate an alteration of its shape	R, A, S, T	0.3, 0.4
ER_FU_10	Control of any shape alteration shall be demonstrated	R, T	0.5
ER_PE_01	Resolution of images captured by the camera(s) shall be at least 800x600 pixels	R	R (08/13) TQ
ER_PE_02	Images captured shall have at least 16 bit colour	R	R (08/13)

			TQ
ER_PE_03	Temperature measurements of critical components shall take place at a frequency of at least 0.2Hz	R	R (08/13) TQ
ER_PE_04	Ambient temperature measurements shall take place at a frequency of 0.2 Hz	R	R (08/13) TQ
ER_PE_05	All temperature measurements shall have a minimum sensitivity of ±5 ^{o}C	R	R (08/13) TQ
ER_PE_06	Differential pressure measurements shall be taken at a frequency of 0.1 Hz during adaptive phase	R	R (08/13) TQ
ER_PE_07	Differential pressure measurements shall have a minimum sensitivity of ± 20 Pa	R	R (08/13) TQ
ER_PE_08	Any shape alteration shall be within ±5 cm of desired position	R, A, T	0.4
ER_PE_09	During shape alteration the bottom cell should not be displaced by more than 20 cm.	R, A, T	0.4
ER_PE_10	The wireless link between the hub and each satellite shall be able to communicate with a bandwidth of at least 75 kbps	R	R (08/13) TQ
ER_PE_11	All shape alterations should be completed in under 20 minutes	R, A, T	0.4
ER_PE_13	Differential pressure sensors must be capable of measuring between -250 – 250 Pa	R, I	R, I (08/13) TQ
ER_PE_14	Component temperature measurement must be capable between -30 – 40 °C	R, I	R, I (08/13) TQ
ER_DE_01	The experiment shall be designed to work within the temperature profile of the BEXUS balloon	R, A, T	0.13 3.0
ER_DE_02	The experiment shall be designed to operate in the vibration profile of the BEXUS balloon with special consideration given to the launch and landing stages	R, A, T	4.0
ER_DE_03	The experiment shall be designed in such a way that it shall not disturb or harm the gondola or any other experiment	R, I, T	1.0

ER_DE_07	The deployment box for each satellite shall be no larger than 1U	R, I	I (08/13) FB
ER_DE_08	Each satellite shall consist of ten interconnected inflatable cells	R, I	I (05/13) TS
ER_DE_09	One central control unit (the Hub) shall be located inside the gondola to control the experiment timeline and relay data up and down the BEXUS E-Link	R, I	I (05/13) TS
ER_DE_10	Component circuitry shall be laid out in such a way to allow each satellite to be folded down into their deployment box before the experiment commences	R, A, T	0.6
ER_DE_11	COTS components shall be used where applicable and affordable	R, I	I (06/13) TS
ER_DE_12	The experiment shall be mounted on the inside of the BEXUS gondola	R, I	I (05/13) TS
ER_DE_13	No components or parts shall become detached from the experiment at any point during the BEXUS flight	R, I	I (08/13) TS
ER_DE_14	The peak current draw from the BEXUS umbilical shall not exceed 1A at 28V	R, I, T	5.0
ER_DE_16	Each satellite shall have a redundant, hard-wired data connection to the Hub	R, I	I (08/13) TQ
ER_DE_17	Communication between the satellites and the hub shall be wireless	R, I	I (08/13) TQ
ER_DE_18	The hub shall have a communications link with the BEXUS E-Link	R, I	I (08/13) TQ
ER_DE_19	Communication up down the BEXUS E-Link shall not exceed 300 Kbps	R, I, T	0.12, 5.0
ER_DE_20	The wireless communication system shall have a bandwidth capable of transmitting all data defined within the data budget	R, I	I (08/13) TQ
ER_DE_21	The deployment box of the satellite deploying at float altitude shall remain sealed until deployment command is given	R, I, T	0.2

ER_DE_22	The deployment boxes shall not cause any damage to the deployable structure	R, I	I (08/13) TS
ER_DE_23	The hatch on each deployment box shall remain attached after deployment of the inflatable structure	R, I, T	0.2
ER_DE_24	The inflatable cells shall not burst when subjected to vacuum pressure	R, A, T	0.2
ER_DE_25	Pressure shall be measured inside at least 2 adjacent cells in each satellite	R, T	0.10, 5.0
ER_DE_26	Critical components shall have the embedded capability of measuring their temperature	R, I	I (08/13) TQ
ER_DE_27	All PCB's shall be resin-coated to be prevent arcing in vacuum pressures	R, I	I
ER_DE_28	All tracks and wires should withstand environmental conditions	R, I	0.14, 0.15, 2.0, 3.0, 4.0
ER_DE_29	Tracks and components mounted on each satellite shall withstand the strain exerted during folding	R, T	0.6
ER_DE_30	All interfaces shall be secured tight to prevent loosening due to any vibrations during flight	R, I	I (08/13) FB
ER_DE_31	Solid state, non-volatile data storage shall be used	R, I	I (08/13) TQ
ER_DE_32	Capacity of storage memory shall be sufficient to store all measurement and status data	R, I	I (08/13) TQ
ER_DE_33	Cameras shall be positioned suitably to capture deployment of all satellites	R, I, T	0.9, 5.0
ER_DE_34	Cameras shall carry out all image processing and store images locally	R, I	I (05/13) TS
ER_DE_35	A redundant power line shall be provided from the BEXUS module to the satellites	R, I	I (08/13) TQ
ER_DE_36	The hub shall be powered by the BEXUS link	R, I	I (08/13) TQ

ER_DE_37	Status updates shall be generated and sent down the E-Link to the ground station regularly for each critical component	R, T	0.12, 5.0
ER_DE_38	A control algorithm shall control the shape alterations of each satellite	R, T	0.5
ER_DE_39	All data shall be communicated back to the hub for storage in its SD card	R, T	0.8, 5.0
ER_DE_40	Each satellite shall store all its data on an SD card locally	R	R (08/13) TQ
ER_DE_41	The ground station shall be capable of sending commands to each satellite and receiving data through the BEXUS E-Link	R, T	0.12, 5.0
ER_DE_42	Feedback data shall be sent down the BEXUS E-Link to the ground station	R, T	0.8, 0.12, 5.0
ER_DE_43	The hub shall be insulated to provide thermal protection	R, S	S (08/13) FB
ER_DE_44	The hub shall have an Ethernet port for connection to the BEXUS E-Link	R, I	I (08/13) FB
ER_DE_45	Any change in shape shall not interfere with electronics or external structures	R, A,T	0.4
ER_DE_46	The wireless communications shall not use any BEXUS prohibited frequency bands	R	R (08/13) TQ
ER_DE_47	Each satellite shall be securely fastened to the gondola	R, I	I
ER_DE_48	The hub shall be securely fastened to the gondola	R, I	I
ER_DE_49	The experiment structure should be no longer than 650 mm	R, I	I (08/13) TS
ER_DE_50	There shall be a minimum of two deployable satellites	R, I	I (05/13) TS
ER_DE_51	A light source shall be mounted inside the gondola to illuminate the experiment	R, I	I (08/13) TS
ER_DE_52	The soft robotic actuator element shall not leak fluid into the environment	R, I, T	0.4, 0.13, 2.0,3.0

			4.0,5.0
ER_DE_53	The fluid in the soft robotic actuator element shall not freeze at the temperatures to be expected during the balloon flight	R,T	0.13, 3.0
ER_DE_54	A switch shall be mounted on the outside of the experiment to switch in-between flight and test mode	R,I	I (08/13) TS
ER_DE_55	A clearance (nothing mounted on the bottom) of 25cm in actuation direction on the bottom of each satellite is required.	I	I
ER_OP_01	One satellite shall be pre-deployed before launch	R, I	I
ER_OP_02	The hub shall accept commands from the ground station at any time	R, T	0.8, 5.0
ER_OP_03	The Hub shall be active from launch command given through the E-Link from the ground support station	R, T	0.8, 5.0
ER_OP_04	At float altitude all systems shall become active	R, T	0.8, 5.0
ER_OP_05	Data storage shall begin as systems are online	R, T	0.8, 5.0
ER_OP_06	Any adverse behaviour identified through housekeeping should be reported down the E-Link to the ground station	R, T	0.8, 0.12, 5.0
ER_OP_07	Status of critical components shall be reported to the ground station	R, T	0.8, 0.12, 5.0
ER_OP_08	One satellite shall be deployed at float altitude	R	R
ER_OP_09	Wireless communication between the hub and satellites should be established after deployment	R, T	0.7, 5.0
ER_OP_10	Shape change shall begin upon receipt of command from ground station	R, T	0.2, 0.8, 5.0
ER_OP_11	Electronic systems shall operate autonomously	R, T	0.8, 5.0
ER_OP_12	The satellites shall conduct measurements autonomously	R, T	0.8, 5.0

ER_OP_13	The experiment shall accept a request for radio silence at any time while on the launch pad	R, T	0.12, 5.0
ER_OP_14	All data shall be relayed back to the hub SD card for storage	R, T	0.8, 5.0
ER_OP_16	The experiment light inside the gondola shall be switched on before launch	R,I	I
ER_OP_17	The float phase of the balloon shall be at least two hours to run through experiment cycle twice	R	R
ER_OP_18	A atmospheric pressure at flow altitude shall be lower then 20mbar (altitude higher then 25km) to ensure inflation of the satellite cells	R	R
ER_OP_19	During the actuation phase of iSEDE, other experiments on the gondola shall not introduce any movement to the gondola	R	R
ER_OP_20	The side walls of the gondola shall be attached during the flight	R,I	I
ER_OP_21	Remove Before Flight pins shall be attached to the satellite boxes to ensure safe handing	R,I	I

5.2 Test Plan

5.2.1 Test Schedule

The completed and future tests are summarised below:

Table 5-2: Mechanical tests schedule

Time of Test	**Test**
November 2012 – February 2013	Inflation tests of deployable
March – August 2013	Tests of shape changing capabilities of satellites
March - August 2013	Test of functionality of entire electronics
August - September 2013	Thermal, vacuum and vibration tests of the entire experiment

October 2013	Functionality of whole experiment at balloon campaign

See below a more detailed list of the tests planned. Test numbers starting with a '0' denote tests of subsystems at a pre-integration stage. All other numbers stand of tests of the integrated experiment.

Table 5-3: Test #0.1

Test number	0.1
Test type	Residual air inflation
Test facility	University of Strathclyde / Vacuum Chamber Department of Physics
Tested item	Inflatable structure
Test level/procedure	Proof of concept of residual air inflation of prototype of inflatable structure.
Test duration	1 week
Date / status	March 2013 / completed (15.01.2013)

Table 5-4: Test #0.2

Test number	0.2
Test type	Deployment of Satellites
Test facility	University of Strathclyde / Vacuum Chamber Department of Physics
Tested item	Satellites with inflatable cells with and without disaggregated electronics.
Test level/procedure	Residual air inflation test of various prototypes in vacuum chamber.
Test duration	Various days during time span

Date / status	March – August 2013 / completed (07.08.2013)

Table 5-5: Test #0.3

Test number	0.3
Test type	Functionality test pumps
Test facility	University of Strathclyde / Vacuum Chamber Department of Physics
Tested item	Micro pumps
Test level/procedure	Testing functionality of micro pumps at ambient pressure and vacuum.
Test duration	Various days during time span
Date / status	May - August 2013 / completed (15.08.2013)

Table 5-6: Test #0.4

Test number	0.4
Test type	Shape change of structure
Test facility	University of Strathclyde / iSEDE lab
Tested item	Deployed satellite
Test level/procedure	Satellite with inflated cells was attached to test stand at ambient pressure to perform actuation tests with various actuators to validate shape change. 0.4-1 Deformation of structure without soft robotic actuator, added electronics, manual actuation. 0.4-2 Deformation of structure with added electronics. micropump actuation

Test duration	2 months
Date / status	0.4-1 11.03-15.04.2013 / completed (15.04.2013) 0.4-2 10.08-02.09.2013 / completed (20.08.2013)

Table 5-7: Test #0.5

Test number	0.5
Test type	Measure actuation displacement with onboard sensors
Test facility	University of Strathclyde / iSEDE lab
Tested item	Deployed satellite
Test level/procedure	Test to validate control algorithm to control shape of deployed satellite via micro pumps. Set up similar to test #0.4.
Test duration	2 weeks (+ 2 days at launch campaign)
Date / status	10.08-14.10.2013 Completed

Table 5-8: Test #0.6

Test number	0.6
Test type	Folding and packaging
Test facility	University of Strathclyde / iSEDE lab
Tested item	Satellite structure with and without electronics.
Test level/procedure	Folding test to ensure that structure can be folded efficiently into deployment box and ensuring functionality of electronics afterwards.
Test duration	2 weeks
Date / status	April - August 2013 / completed (10.08.2013)

Table 5-9: Test #0.7

Test number	0.7
Test type	Wireless communication
Test facility	University of Strathclyde, iSEDE lab
Tested item	Entire experiment
Test level/procedure	Test of wireless communication between the satellites and between each satellite and the hub.
Test duration	2 weeks
Date / status	April – July 2013 / completed (20.07.2013)

Table 5-10: Test #0.8

Test number	0.8
Test type	On-board microcontroller test
Test facility	University of Strathclyde / iSEDE lab
Tested item	Satellite and hub microcontroller
Test level/procedure	Functionality and performance evaluation of microcontroller onboard satellites and hub, validation of performing desired tasks.
Test duration	2 month
Date / status	March – July 2013 / completed (15.07.2013)

Table 5-11: Test #0.9

Test number	0.9
Test type	Camera view angle test
Test facility	University of Strathclyde / iSEDE lab
Tested item	Cameras

Test level/procedure	Test of cameras in mock gondola, ensuring that the cameras can capture displacement correctly.
Test duration	1 week (+ 2 days at launch campaign)
Date / status	April & October 2013 / Completed

Table 5-12: Test #0.10

Test number	0.10
Test type	Performance validation of onboard sensors
Test facility	University of Strathclyde / iSEDE lab
Tested item	All sensors
Test level/procedure	Validation of performance of all sensors proving that they can be read by the onboard computer.
Test duration	3 weeks
Date / status	February - August 2013 / completed (31.07.2013)

Table 5-13: Test #0.12

Test number	0.12
Test type	BEXUS-Experiment Communication
Test facility	University of Strathclyde / iSEDE lab
Tested item	Entire experiment
Test level/procedure	Validation that the experiment can communicate to the BEXUS service module and that all the necessary comments can be sent and received.
Test duration	3 week (+ 2 days at launch campaign)
Date / status	May & October 2013 / Completed

Table 5-14: Test #0.13

Test number	0.13
Test type	Thermal test of critical components
Test facility	University of Glasgow / Thermal Chamber
Tested item	0.13-1 Microcontroller ~~0.13-2 Batteries~~ 0.13-3 Charging circuit components 0.13-4 Sensors 0.13-5 Wireless components 0.13-5 Micropumps 0.13-6 Cells with adhesive 0.13-7 Soft robotic actuators (+fluid)
Test level/procedure	Test if components breaks at temperatures up to -70C, define if components need to be heated.
Test duration	Various days
Date / status	March - August 2013 / completed (08.08.2013)

Table 5-15: Test #0.14

Test number	0.14
Test type	EMC test
Test facility	University of Strathclyde / tba
Tested item	Electronics
Test level/procedure	Test on the behaviour of the experiment components in a EMC chamber. To ensure that equipment items or systems dosen't interfere with or prevent each other's correct

	operation through spurious emission and absorption of EMI.
Test duration	1-2 days
Date / status	August 2013 / completed (20.08.2013) (simplified test set up, components were all working together when everything was switched on)

Table 5-16: Test #0.15

Test number	0.15
Test type	Conductance test
Test facility	University of Strathclyde / tba
Tested item	Electronics
Test level/procedure	Conductance test of all components, connections and cables, validating grounding scheme.
Test duration	Various days
Date / status	August 2013 / completed (20.08.2013) (simplified test set up, components were all working together when everything was switched on)

Table 5-17: Test #0.16

Test number	0.16
Test type	Software Implementation test
Test facility	University of Strathclyde / tba
Tested item	Electronics/Software
Test level/procedure	Full system was switched on and the software ran for 4 complete experiment timeline cycles

Test duration	1 day
Date / status	September 2013 / completed (10.09.2013) (experiment switched on and software ran through 3 complete experiment timeline cycles)

Table 5-18: Test #0.17

Test number	0.17
Test type	Roof Mounting test
Test facility	University of Strathclyde
Tested item	Entire experiment
Test level/procedure	To see if all parts of the experiment can be mounted to the roof mounting tubes.
Test duration	1 day
Date / status	September 2013 / completed (10.09.2013)

Table 5-19: Test #0.18

Test number	0.18
Test type	HackHD SD card storage test
Test facility	University of Strathclyde
Tested item	Hack HD
Test level/procedure	To see the maximum amount of footage that the SD card can hold.
Test duration	1 day
Date / status	August - October 2013 / completed (27.08.2013)

Table 5-20: Test #1.0

Test number	1.0
Test type	Integration test
Test facility	University of Strathclyde
Tested item	Entire experiment
Test level/procedure	To see if all parts of the experiment can be integrated as planned, and measure the total mass after integration.
Test duration	1 week
Date / status	August - October 2013 / completed (27.08.2013)

Table 5-21: Test #2.0

Test number	2.0
Test type	Vacuum test
Test facility	University of Strathclyde / Vacuum chamber Department of Physics
Tested item	Entire experiment
Test level/procedure	Vacuum test of entire experiment according to BEXUS User Manual.
Test duration	1 day
Date / status	September 2013 / Completed (06.09.2013)

Table 5-22: Test #3.0

Test number	3.0
Test type	Thermal test
Test facility	University of Strathclyde / Department of Mechanical & Aerospace Engineering

Tested item	Entire experiment
Test level/procedure	Thermal test of entire experiment according to BEXUS User Manual.
Test duration	1 day
Date / status	September 2013 / Completed(05.09.2013)

Table 5-23: Test #4.0

Test number	4.0
Test type	Vibration test
Test facility	University of Strathclyde / Department of Mechanical & Aerospace Engineering
Tested item	Entire experiment
Test level/procedure	Vibration test of entire experiment according to BEXUS User Manual.
Test duration	1 day
Date / status	September 2013 / Completed(04.09.2013)

Table 5-24: Test #5.0

Test number	5.0
Test type	Inspection and functionality tests
Test facility	University of Strathclyde
Tested item	Entire experiment
Test level/procedure	Complete functionality test of the entire experiment. Simulation of several experiment cycles. 5.1: After first assembly

	5.2: At balloon campaign
Test duration	3 weeks
Date / status	5.1 August 2013 / completed (27.08.2013) 5.2 October 2013 Completed

5.2.2 Test Matrix

The test matrix gives the connection between each test and the experiment requirements that are covered by it. The colours in the table indicate if the test is finished (green), in progress (yellow) or not started yet (white).

Table 5-25: Test matrix

Test Number	Test Text	Experiment Requirement
0.1	Residual air inflation	ER_FU_05
0.2	Deployment of satellites	ER_DE_21, ER_DE_23, ER_DE_24, ER_OP_10
0.3	Functionality test pumps	ER_FU_09
0.4	Shape change of structure	ER_FU_09, ER_FU_10, ER_PE_08, ER_PE_09, ER_PE_11, ER_DE_45, ER_DE_52
0.5	Measure actuation displacement with onboard sensors	ER_DE_38
0.6	Folding and packaging	ER_DE_10, ER_DE_29
0.7	Wireless communication	ER_FU_06, ER_OP_09
0.8	On-board micro controller test	ER_DE_39, ER_DE_42, ER_OP_02, ER_OP_03, ER_OP_07, ER_OP_11, ER_OP_12, ER_OP_14
0.9	Camera view angle test	ER_FU_04, ER_DE_33
0.10	Performance validation of onboard sensors	ER_FU_07, ER_DE_25
0.12	BEXUS-Experiment Communication	ER_DE_19, ER_DE_41, ER_DE_42, ER_OP_13
0.13	Temperature test of critical components	ER_DE_01, ER_DE_52, ER_DE_53
0.14	EMC Test	ER_DE_28
0.15	Conductive Test	ER_DE_28
1.0	Integration test	ER_DE_03, ER_DE_06
2.0	Vacuum test	ER_DE_28, ER_DE_52
3.0	Thermal test	ER_DE_01, ER_DE_28, ER_DE_52
4.0	Vibration test	ER_DE_02, ER_DE_28, ER_DE_52
5.0	Inspection and	ER_FU_06, ER_FU_07, ER_PE_12,

	functionality tests	~~ER_DE_06~~, ER_DE_14, ER_DE_19, ER_DE_25, ER_DE_33, ER_DE_37, ER_DE_41, ER_DE_42, ER_DE_52, ER_DE_53, ER_OP_02, ER_OP_03, ER_OP_07, ER_OP_09, ER_OP_10, ER_OP_11, ER_OP_12, ER_OP_13, ER_OP_12, ER_OP_14

5.3 Test Results

5.3.1 Test Results Breakdown

Table 5-26: Test Results #0.1

Test number	0.1 / complete (15.01.2012)
Test type	Residual air inflation
Results	Tests found residual air inflation to be a reliable method of inflation. The inflatable elements had sufficient trapped air to inflate at the pressures they experienced at heights above 30km.  **Figure 5-1: 10 Cell Inflation Test with Indicative Masses**

Table 5-27: Test Results #0.2

Test number	0.2 / completed (07.08.2013)
Test type	Deployment of Satellites
Results	Tests of deployment of the inflatable structure have been carried out using the horizontal configuration of the vacuum chamber. Deployment was successful.

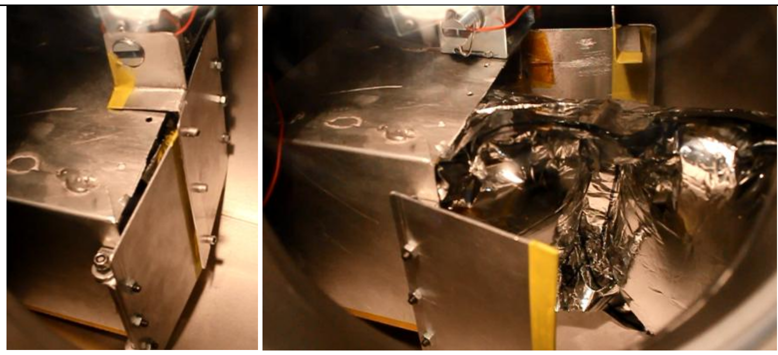
	 **Figure 5-2: Deployment in Vacuum Chamber** Inflation tests have been repeated in vertical configuration and successfully completed.

Table 5-28: Test Results #0.3

Test number	0.3 / completed (15.08.2013)
Test type	Functionality micro pumps
Results	Controller was able to actuate Bartels micro pumps in and outside the vacuum chamber. When connected to the soft robotic actuator, micro pump was able to inflate actuator.

Table 5-29: Test Results #0.4

Test number	0.4 / completed (20.08.2013)
Test type	Shape changing of structure
Results	04-1 Deformation of structure without soft robotic actuator, micropums and added electronics was proven with manual actuation. Single cells in the 5x2 satellite were deflated and a deformation was observed. 04-2 When connected to the soft robotic actuator, micro pump was able to inflate actuator.

Table 5-30: Test Results #0.5

Test number	0.5 / Completed
Test type	Feedback position control
Results	Readings of IMUs and cameras were taken in lab assembly but need to verified during launch campaign.

Table 5-31: Test Results #0.6

Test number	0.6 / completed (10.08.2013)
Test type	Folding and packaging
Results	Full structure was folded with and without flexible electronics, tests proved that the whole deployable fits within the 1U cube satellite box.

Table 5-32: Test Results #0.7

Test number	0.7 / completed (20.07.2013)
Test type	Wireless communication
Results	Wireless communication between hub and both satellites over PanStamp is working (also with back up hardwired link).

Table 5-33: Test Results #0.8

Test number	0.8 / completed (15.07.2013)
Test type	On-board microcontroller test
Results	The microcontroller can read data from the IMUs, pressure sensors, can trigger the cameras, control the pumps and communicate wirelessly and hardwired with the hub.

Table 5-34: Test Results #0.9

Test number	0.9 / in progress
Test type	Camera view angle test
Results	Both cameras are able to capture the whole deployment and the satellites in the gondola without the requirement of having the cameras mounted outside the gondola. Cameras are now mounted on one of the sides of the gondola.

	 **Figure 5-3: Camera placement tests in the iSEDE lab** Final calibration test needs to be undertaken at the launch campaign with the actual BEXUS gondola.

Table 5-35: Test Results #0.10

Test number	0.10 / completed (31.07.2013)
Test type	Performance validation of onboard sensors
Results	IMUs, temperature sensors and pressure sensors are fully functional and can be read by the onboard microcontrollers and sent to the ground station.

Table 5-36: Test Results #0.12

Test number	0.12 / in progress
Test type	BEXUS-Experiment Communication
Results	communication over Ethernet port works, validation during launch campaign still missing.

Table 5-37: Test Results #0.13

Test number	0.13 / completed (08.08.2013)
Test type	Thermal test of critical components
Results	Most components are tested down to -30C due to limitations of the thermal chamber. See test report TEST-001 in the appendix for more details on the cell bond line

	testing.

Table 5-38: Test Results #0.14

Test number	0.14 / completed (20.08.2013)
Test type	EMC test
Results	Simplified test set up, components were all working together when everything was switched on.

Table 5-39: Test Results #0.15

Test number	0.15 / completed (20.08.2013)
Test type	Conductance test
Results	Simplified test set up, components were all working together when everything was switched on.

Table 5-40: Test #0.16

Test number	0.16 / completed (10.09.2013)
Test type	Software Implementation test
Results	The software was successfully used for 3 complete experiment timeline cycles.

Table 5-41: Test #0.17

Test number	0.17 / completed (10.09.2013)
Test type	Roof Mounting test
Results	The deployment boxes, hub and roof mounting plates were connected to the mounting tube using nyloc nuts.

Table 5-42: Test #0.18

Test number	0.18 / completed (10.09.2013)
Test type	HackHD Camera SD card storage test
Results	The HackHD camera was turned on and the SD card was able to store 6 hours' worth of footage.

Table 5-43: Test Results #1.0

Test number	1.0 / completed (27.08.2013)
Test type	Integration test
Results	After fabrication of all mechanical and electronic components and systems a first integration tests showed that everything fits together as planned.

Table 5-44: Test Results #2.0

Test number	2.0 / completed (16.09.2013)
Test type	Vacuum test
Results	A fully assembled experiment was tested and showed that that the full system worked in near vacuum conditions (15mbar). Including Mobius camera.

Table 5-45: Test Results #3.0

Test number	3.0 / completed (05.09.2013)
Test type	Thermal test
Results	A fully assembled experiment was tested and showed that the full system worked at low temperature (-30°C), similar to environmental conditions during flight.

Table 5-46: Test Results #4.0

Test number	4.0 / completed (04.09.2013)
Test type	Vibration test
Results	Full experiment was tested in the boot of a car to replicate vibrations during flight. Full system was still intact and no accidental firing of the release mechanism occurred.

Table 5-47: Test Results #cm5.0

Test number	5.0 /Completed
Test type	Inspection and functionality tests
Results	Final inspection and functionality test were undertaken at BEXUS launch campaign.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and mass

Table 6-1: Experiment mass and volume (measured at EAR (12.09.2013))

Experiment Mass: Roof Mounted total (hub + 2x deployment boxes): Cameras total: Outside camera: **Experiment total mass:**	 *4.865kg* 1.215kg 0.235kg **6.315kg**
Experiment dimensions (in m): (when deployed)	Satellites – 2x(0.2 x 0.15 x 0.74)m Hub – 0.25 x 0.15 x 0.15m Mounted – 0.83 x 0.3 x 0.74
Experiment footprint area (in m^2):	Satellites – 2x0.03m^2 Hub – 0.0375m^2 Mounted – 0.25m^2
Experiment volume (in m^3):	Satellites – 2 x 0.022m^3 Hub – 0.006m^3 Mounted – 0.18m^3

6.1.2 Safety risks

The table below is taken from the risk register previously given in section 3 Project Planning. This table details the possibility of interference with other experiments in the BEXUS gondola and possible safety risks when manufacturing and integrating the final build.

SF10	Premature deployment may compromise other experiments	C	3	Low	Test release mechanism. Liaise with other experiment teams. RBF strap attachment
SF20	iSEDE wireless link may interfere with other experiments	B	4	Low	Collaborate with SSC/DLR and other teams.
SF30	Premature wireless transmissions may interfere with BEXUS or other experiments	B	4	Low	Experiment on standby until float altitude.

SF40	Failure or leak of batteries may cause damage during integration, transport or flight	B	4	Low	Ensure temperature range of batteries can handle expected temperature during all transport and mission phases. Test batteries in vacuum.
SF41	Failure or leak of batteries may cause damage during integration, transport or flight	A	1	Low	No more batteries in iSEDE experiment
SF50	Injury while manufacturing and integration	B	5	Medium	Consider safety before using tools or moving heavy objects.
SF60	Electrostatic Discharge	C	3	Low	Ground experiment and operator (electrostatic wrist band)

As a safety precaution and to ensure a safe handling of the inflatable payloads, a Remove Before Flight (RBF) pin is placed on both cube sats during transport and preparation. This RBF is red and clearly visible, see description below.

6.1.3 Electrical interfaces

Table 6-2: Electrical interfaces applicable to BEXUS (measured at EAR (12.09.2013))

BEXUS Electrical Interfaces		
E-Link Interface: E-Link required? Yes		
	Number of E-Link interfaces:	1
	Data rate - downlink:	300 Kbit/s
	Data rate – uplink	50 Kbit/s
	Interface type (RS-232, Ethernet):	Ethernet (1x)

Power system: Gondola power required? Yes		
	Peak power (or current) consumption:	1.2A (for few millisec.), (measured, solenoid firing)
	Average power (or current) consumption:	17W, 0.6A (measured)
Power system: Experiment includes batteries? No		

6.1.4 Launch Site Requirements

6.1.4.1 General Requirements

We require

- Power sockets
- Internet access
- Working/Assembly Bench (2 “pillars” approximately 1.3m to assemble the roof mounting)
- Any PPE (Personal Protection Equipment) required

6.1.4.2 Mechanical Requirements

The mechanical team requires basic tools including,

- Basic tool box items (set of screwdrivers, pliers,…)
- Exotic tools will be provided by the iSEDE team

6.1.4.3 Electrical Requirements

The electrical team requires,

- Variable DC power source
- 2 x Multimeters
- 4 x UK/European Plug Adapters (provided by iSEDE team)
- Monitor with DVI connector
- USB Mouse
- USB Keyboard

6.1.5 Balloon Mounting & Mission Requirements

The following requirements are taken from Chapter 2 and outline the requirements on the BEXUS balloon flight:

ID	Description

ER_DE_55	A clearance (nothing mounted on the bottom) of 25cm in actuation direction on the bottom of each satellite is required.
ER_OP_17	The float phase of the balloon shall be at least two hours to run through experiment cycle twice
ER_OP_18	The flight altitude shall be at least 25km (low pressure required for cell inflation)
ER_OP_19	During the actuation phase of iSEDE, other experiments on the gondola shall not introduce any movement to the gondola
ER_OP_20	The side walls of the gondola shall be attached during the flight

6.2 Preparation and Test Activities at Esrange

The following list outlines tasks that needs to be undertaken at Esrange in order to get the iSEDE experiment ready for launch:

Table 6-3: Pre Flight Procedures

No.	Procedure	Tools	Components	Duration (mins)	Responsible Person
1	Unpack all components	Camera (pictures documentation)	NA	30	FB
2	Ensure that all components have arrived. Check off with packaging list	Packaging List	NA	60	FB
3	Set up equipment in allocated workspace	Camera (pictures documentation)	NA	30	FB
4	Check all structures to ensure that they have not been damaged during transportation	Camera (pictures documentation)	NA	10	FB
5	Check all electrical connections: cables within the Hub and cables that connect Hub to satellites and cameras.	Camera (pictures documentation)	NA	20	TQ
6	Set Pi’s IP address (/etc/network/interfaces) and GS’ IP	Power Source, Monitor, USB keyboard, USB mouse	NA	10	TQ
7	Check connectivity between Hub and GS	Power Supply, network cables (x2)	NA	10	TQ

8	Secure SD card with kapton tape	Camera (pictures documentation)	Kapton tape	5	TQ
9	Reassemble Hub and check connectivity with GS and satellites	Power Supply, network cables, Camera (pictures documentation	NA	20	TQ
10	Check all inflatable cells for any punctures or damage	Camera (pictures documentation)	NA	5	FB
11	Test the deployment method to ensure that it works on ground	Power Supply, Camera (pictures documentation)	NA	5	FB
12	Ensure that camera lens is lined up properly	Camera (Pictures Documentation)	Polystyrene	5	FB
13	Mount the cameras to the camera tube.	M4 hex screw (x3), washer (x3), M4 Allen Key, Camera (pictures documentation)	NA	10	FB
14	Connect valves to tubing	Scissors, Valves, Camera (Pictures Documentation)	NA	30	FB
15	Insert Anti-freeze to soft robotics	Camera (Pictures Documentation)	Anti-freeze	30	FB
16	Check that the soft robotic actuators and micropumps are working	Camera (pictures documentation)	NA	10	FB
17	Attach hub to roof mount tubes	Wrench, Camera (Pictures Documentation)	hub mounting plate (x2), M8 Nyloc Nut (x4)	10	FB
18	Begin to fold satellites into deployment boxes (until top cell)	Camera (Pictures Documentation)	NA	20	FB
19	Attach deployment boxes to roof mount tubes	M8 Allen key, Camera (pictures documentation)	Filler Plate (x2), Dep. Box mounting plate (x2),	20	FB

			M8 bolt short (x8), M8 Nyloc nut (x8)		
20	Finish folding satellite into box (top cell and close doors, insert RBF pin)	Camera (Pictures Documentation)	RBF Pin	10	FB
21	Check that roof tubes with deployment boxes attach to gondola	M8 Allen key, wrench, Camera (pictures documentation)	Roof tube mounting plates (x4), M8 bolt long (x8), M8 Nyloc nuts (x8)	20	FB
22	Check that camera tubes mount to gondola	M8 Allen key, wrench, Camera (pictures documentation)	Camera Mounting Plate (x4), M8 bolt short (x4), M8 Nyloc nut (x4)	10	FB
23	Confirm camera view angle with Eurolaunch	Camera (pictures documentation)	NA	30	FB
24	Erase Memory from Hack HD's SD card and delete all tests logs from Pi's SD card	Laptop, micro-SD card adapter	NA	10	TQ
25	Secure SD card with kapton tape	Camera (Pictures Documentation)	Kapton tape	5	TQ
26	Connect deployment boxes harnessing to hub and connect to gondola	Cable Ties, Camera (pictures documentation)	NA	20	FB
27	Connect cameras harnessing to hub to connect gondola	Cable Ties, Camera (Pictures Documentation)	NA	30	FB
28	Connect Mobius camera to gondola	Cable Ties, Camera (pictures documentation)	NA	5	FB
29	Connect BEXUS Power to hub	Camera (pictures documentation)	NA	1	FB

30	Connect BEXUS E-link to hub	Camera (pictures documentation)	NA	1	FB
31	Interference test	NA	NA	60	FB
32	Fold float altitude deploying satellite	Camera (pictures documentation), RBF pin	NA	10	FB
33	Flight Compatibility Test	NA	NA	60	FB
34	Sweet spot test	NA	NA	30	FB
35	Switch off experiment (turn off HackHD properly)	NA	NA	60	FB
36	Deploy pre-deployed satellite	Camera (pictures documentation)	NA	1	FB
37	Physically switch on experiment via switch on hub	Camera (pictures documentation)	NA	1	FB
38	Remove RBF Pin for the “deployable” deployment box	Camera (pictures documentation)	NA	1	FB
39	Switch on Mobius Camera	Camera (Pictures Documentation)	NA	1	FB

6.2.1 Remove Before Flight (RBF) pin

To prevent premature deployment of the deployables from the two cube satellite boxes, a simple retractable pin is used. Each deployment box has one pin with a RBF flag attached to it. The pin runs through a hole in the moving part of the latch mechanism and an aligning hole in the rigid deployment box and therefore preventing the doors of the deployment box to open.

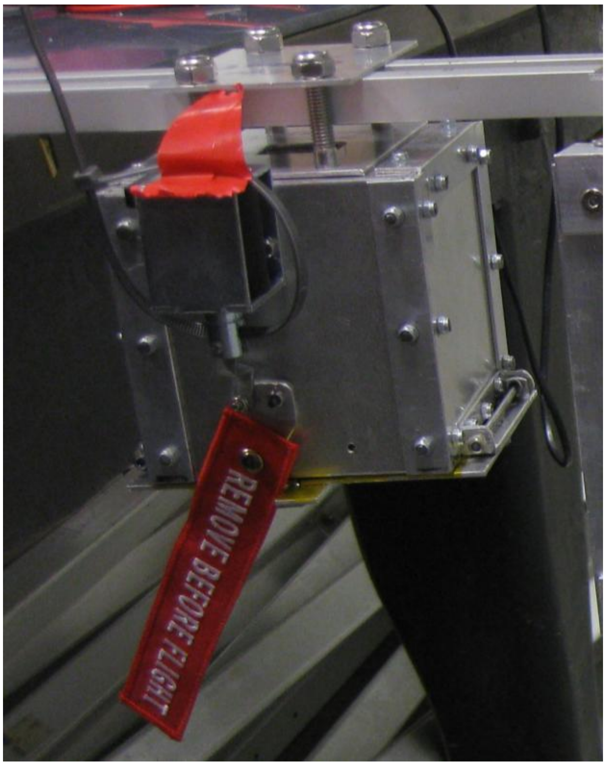


Figure 6-1: RBF pin to prevent premature deployment on storage boxes

6.3 Timeline for countdown and flight

Table 6-4: Experiment Timeline

Time (mins)	Action

T-1d	Interference Test: Just experiments with the gondola E-link
	• all systems switched on (physical switch)
	    ○ start all daemons using screen
	• communication test
	• fire solenoid test (deploy satellite)
	• Switch off experiment
	    ○ Hack-HD in standby
	    ○ Raspberry Pi shut down
	    ○ Physical switch to OFF

T-1d	Flight Compatible Test (FCT) • all systems switched on • both satellites deployed • full communication test • fire solenoid (both satellites deployed) • Switch off experiment ○ Hack-HD in standby

<table>
<tr><td></td><td colspan="2">○ Raspberry Pi shut down
○ Physical switch to OFF</td></tr>
<tr><td>T-1d</td><td colspan="2">• Fold both satellites (TO BE CONFIRMED WITH BEXUS)</td></tr>
<tr><td>T-250</td><td colspan="2">Roll out of gondola</td></tr>
<tr><td>T-200 (Sweet Spot Test)</td><td colspan="2">• Sweet Spot Test:
• All systems on (physical switch)
○ start all daemons using screen
• Final test of the functionality and communication
• Switch on both HackHD cameras and webcam
• Switch off experiment
○ Hack-HD in standby
○ Raspberry Pi shut down
○ Physical switch to OFF</td></tr>
<tr><td>T-199</td><td colspan="2">• Un-deploy one satellite (BRU) (TO BE CONFIRMED WITH BEXUS)
• Remove RBF pins
• switch on experiment (physical switch)</td></tr>
<tr><td>T-80</td><td colspan="2">Inflation of balloon</td></tr>
<tr><td>T-60</td><td colspan="2">Power from Hercules switched to BEXUS internal batteries</td></tr>
<tr><td>T-0</td><td colspan="2">Balloon Launch</td></tr>
<tr><td>T+45 (15km)</td><td colspan="2">Activate the Hack HD Camera on the Pre-deployed Satellite (BRU)</td></tr>
<tr><td>FT (Approx. = T+90)</td><td colspan="2">Float Phase (account for ‘oscillation’ of the gondola at float phase wait until constant pressure)</td></tr>
<tr><td>FT+3</td><td colspan="2">Start second HackHD (for IRN)</td></tr>
<tr><td>FT+4</td><td colspan="2">Activate Solenoids to Start Deployment (after gondola has movement within requirements). “Are you sure?”</td></tr>
<tr><td>FT+5</td><td colspan="2">Power up the other half of newly deployed satellite (IRN)</td></tr>
<tr><td>FT+10</td><td colspan="2">Start Operational Phase (after gondola has movement within experiment requirements (groundcrew))
▪ Start the Actuation of the 2 Satellite structures
▪ Monitor the actuation through the accelerometers by sending readings to Ground Station via Hub
▪ Take continual pressure and temperature readings
▪ Take video with both HackHD cameras of actuation
Transmit the data to the Ground Station via the Hub</td></tr>
<tr><td>Operational</td><td>SAT 1 (IRN)</td><td>SAT 2 (BRU)</td></tr>
</table>

Phase		
OP+0	Pump 1 (+)	Pump 1 (-)
OP+10	Pump 1 (+) & 2 (+)	Pump 1 (-) & 2 (-)
OP+20	Pump 1 (+), 2 (+), 3 (+)	Pump 1 (-), 2 (-), 3 (-)
OP+30	All pumps off	All pumps off
OP+40	Pump 1 (-)	Pump 2 (+)
OP+50	Pump 1 (-) & 2 (-)	Pump 2 (+) & 3 (+)
OP+59	Switch both Hack-HD off and then on, to save stored data	
OP+60	**Full Cycle Complete. Repeat until cut down when systems go on standby.**	
CUT-5	iSEDE team notified by mission control that 5min until balloon cut off iSEDE team will command automated CUT- sequence	
CUT-4	Automated CUT sequence: o Both Hack-HD recording off (safe data) o Both Hack-HD start recording	
CUT	**Balloon Cut Off**	
CUT+15	Automated CUT sequence (timed: 20min after CUT sequence start command): o Hack-HD in standby to safe data o Hack-HD shut down o Raspberry Pi shut down	
Landing	Landing	

6.4 Post Flight Activities

The main post flight activity was to recover the SD cards from the cameras and hub on board the gondola. Following this, analysis of experiment data was undertaken as described in Section 7. Data analysis allowed us to characterise how successful the mission has been for documentation and presentation at the results symposium. After the experiment data is securely copied on at least two computers, the experiment was getting dismounted and prepared for shipping. The table below describes a list of procedures that were planned to be carried out post flight;

Table 6-5: Post Flight Procedures

N	Procedure	Tools	Duration	Responsibl.

o.			(mins)	Person
1	Make at least two copies on different storage devices of all data received at the groundstation.	Groundstation, flash drive	30	TQ
2	Disconnect BEXUS power from hub	Camera (documentation)	1	FB
3	Disconnect BEXUS E-link from hub	Camera (documentation)	1	FB
4	Remove camera harnessing (cable ties)	Scissors, camera (documentation)	10	FB
5	Remove Deployment boxes harnessing (cable ties)	Scissors, camera (documentation)	10	FB
6	Dismount camera mounting tube	Wrench & M8 Allen key, camera (documentation)	5	FB
7	Dismount Roof mounting tubes from gondola	Wrench & M8 Allen key, camera (documentation)	5	FB
8	Dismount Deployment boxes from roof mounting tubes	Wrench & M8 Allen Key, camera (documentation)	5	FB
9	Dismount hub from roof mounting tubes	Wrench, camera (documentation)	5	FB
10	Place HackHd SD cards in silicate to dry for at least a day in case of water damage	SD card box, silicate pad, camera (documentation)	1 day	TQ
11	Carefully fold satellites back into deployment boxes	NA, camera (documentation)	10	FB
12	Put RBF pin back in to hold the deployment boxes shut	NA, camera (documentation)	1	FB
13	Copy SD card data on	SD cards,	120	TQ

	computer via bit by bit copy (after one day drying phase).	computer		
14	Make at least two copies on different storage devices of SD card data.	Computer, external hard drive	120	TQ
15	Wrap all components with bubble wrap for safe transport.	NA, camera (documentation)	120	FB
16	Take boxes back on flight to MAE department.	NA	5	FB

7 DATA ANALYSIS PLAN

7.1 Data Analysis Plan

This project is a technology demonstrator so the analysis isn't as big a task as for example a scientific experiment but there are criteria that shall be looked at. The project was meant to demonstrate

1) That the residual air inflation gives us a viable means to create an inflatable space structure.
2) That it is possible to successfully deploy a large inflatable structure in space from a small volume
3) That the electrical subsystems usually contained within a hub can survive and function when disaggregated across the inflatable surface of a satellite.
4) That it is possible to communicate wirelessly between the satellite and the Hub and then to ground in the conditions
5) That the inflatable structure can be altered in shape effectively from a command given from ground

A large portion of this analysis was done through the videos captured by the cameras on board the gondola. This allowed the team to study the deployment, how the cells inflate and monitor the shape change of the inflatable structures. This also partially proved the operation of the electrical subsystems disaggregated across the surface of the satellites by watching the structure change shape.

Through the reports sent back from the satellite during the flight, we can prove the power and communications systems work in near space conditions. We can also use temperature values and pressures measured to model what happened during the flight and use this data to build on for future experiments.

7.2 Launch Campaign

7.2.1 Day 1: 4th October

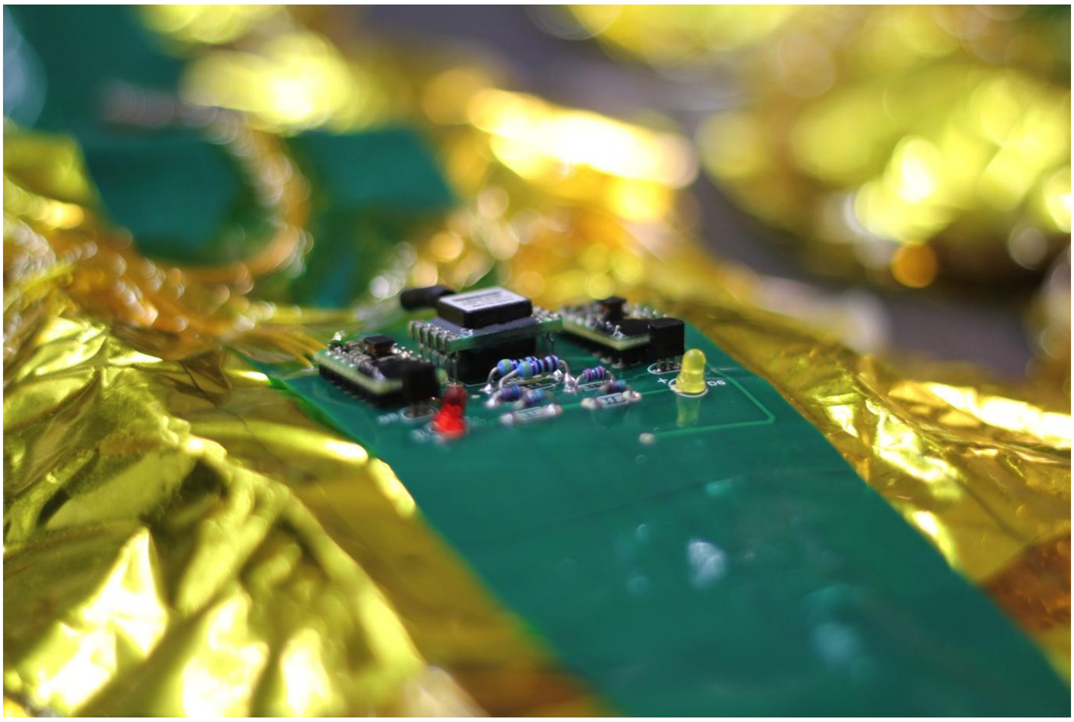
Arrived at Esrange around 2330. Received security badges and room keys.

7.2.2 Day 2: 5th October

Attended safety briefing at 0815 detailing the roles of SSC, DLR, ESA and ZARM personnel for the launch campaign. Informed of areas off limits, emergency procedures and fire procedures.

Proceeded to the Dom to unpack experiment. Checked off each item against packing list and found that everything had arrived safely. Checked satellites for damage during shipping. The inspection of Irn revealed a hole in the flex

PCB and possibly the satellite cell itself, due to the sharp pins of the Panstamp wireless board. Luckily the hole had not damaged any flex PCB tracks. Further scratches found were found on Irn and also on Bru.



All sharp edges should be eliminated from future designs. File down pins or cover in Kapton tape or similar non-conductive material. The satellite was fixed with the materials available, with the holes being patched with Tear Aid and Kapton tape.

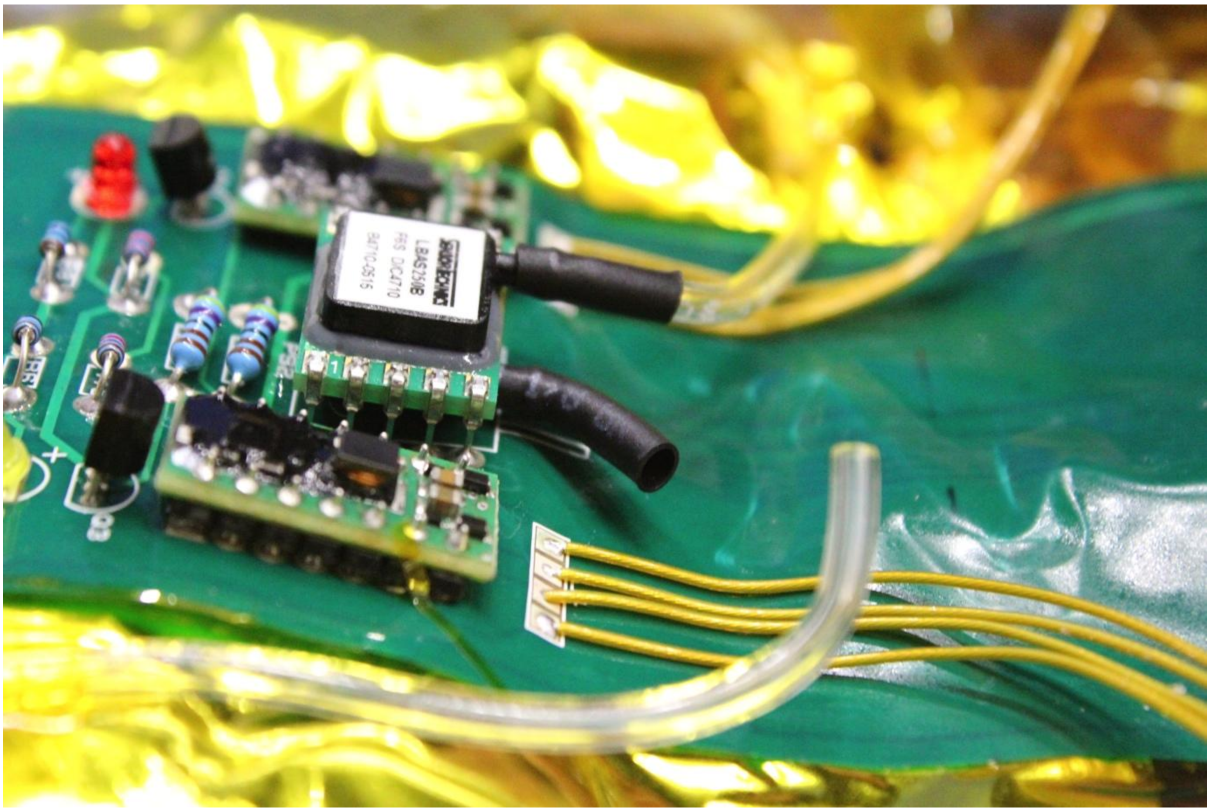
The functionality of micropumps was then tested using the pumps and the pump test board. It was found that the pumps were pumping antifreeze around the y connector (possibly because the pressure is lower in the tubing than in the soft robotics?). No fluid entered the soft robotic element, The fluid was taking the path of least resistance. It was not possible to pump both ways because of this problem. The pumps were reconfigured so that they were both pumping the same direction.

This problem occurred because the concept was not thoroughly tested before the launch campaign. This was due to difficulties in manufacturing suitable soft robotic elements. The manufacturing technique perhaps needs further development, as the area where soft robotics join pumps were also prone to leakage.

The amplifier to amplify the voltage output of the atmospheric pressure sensor was not working correctly. It amplified the input by double the value stated on the data sheet. Changing the resistor that sets the gain of the amplifier had no effect. It was either a problem with the reference voltage being supplied to the amplifier, or the component was broken. This is not a major problem as it is a backup system that was only be used to deploy the satellite at float altitude if contact is lost with the balloon over E-Link. As it was not a major problem it was decided to focus on getting the experiment ready to flight without the pressure sensor.

Both satellites were then powered on using the Hub. The flexible circuitry on Bru was found to be broken. Although appearing undamaged on visual inspection earlier in the day, the satellite would not power up correctly. After removing the flexible circuitry, we could clearly see that the sharp pins of through hole components have pierced the Kapton tape and mylar. As well as damaging the inflatable cell, this short-circuited some of the flexible electronics on the board, which required extensive troubleshooting. Through hole components present many sharp edges, any of which could pierce a cell. Mylar is not an ideal material for constructing cells as it is conductive, any contact with components can cause a short circuit.

Heat shrink tubing had come loose from some of the pressure sensors. The problem seemed to be that the pump tubing was not physically connected to the pressure sensor, and is only held in place by the heat shrink tubing.



The camera supports and the hub were then fitted to the gondola and the cameras were checked to make sure that they could capture images of the whole experiment.

7.2.3 Day 3: 6th October

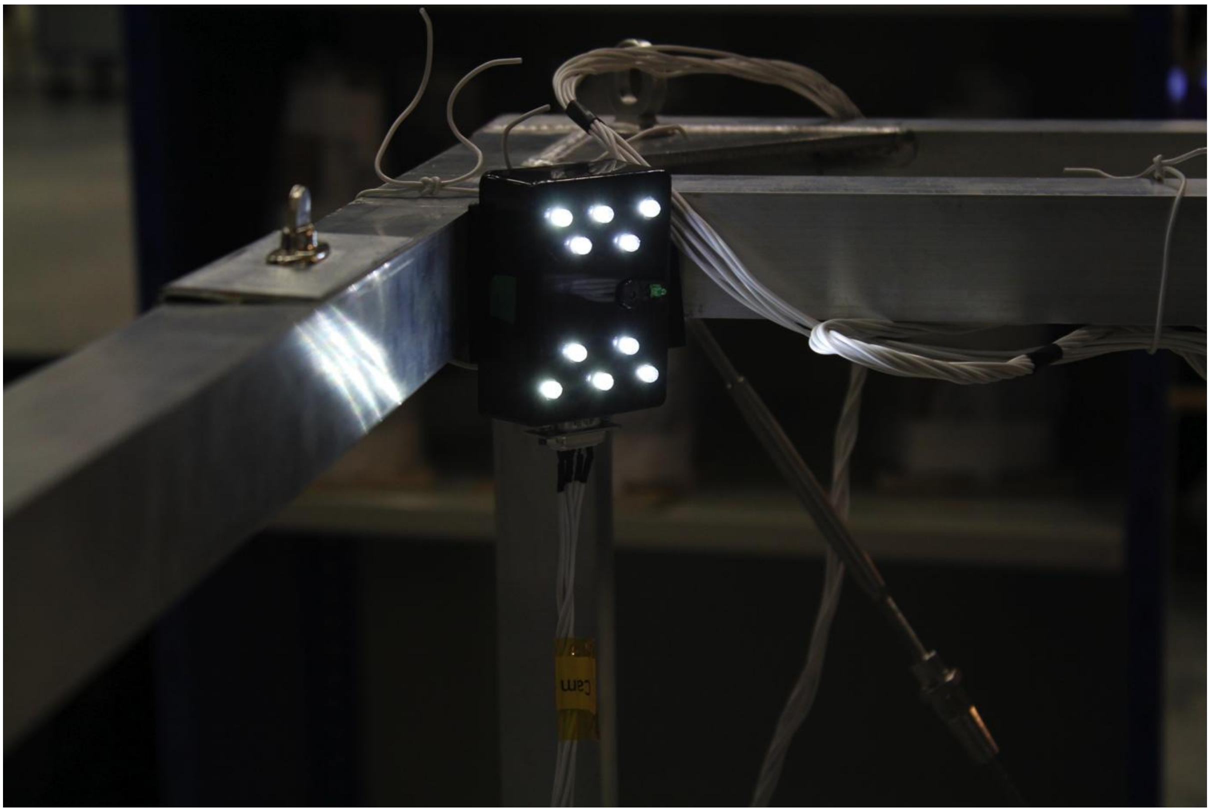
The damaged section of flexible circuitry on Bru had its components desoldered and removed, and the power was rerouted around it with wires. This restored the functionality of the remaining circuitry.

The hub electronics were then integrated into the hub.

The experiment was then tested with flight batteries with the BEXUS electronics expert present. The experiment was powered on and off successfully during this test.

It was found during this test that the webcam providing the live feed did not have the field of view to see the satellites and the LEDs on the hub at the same time.

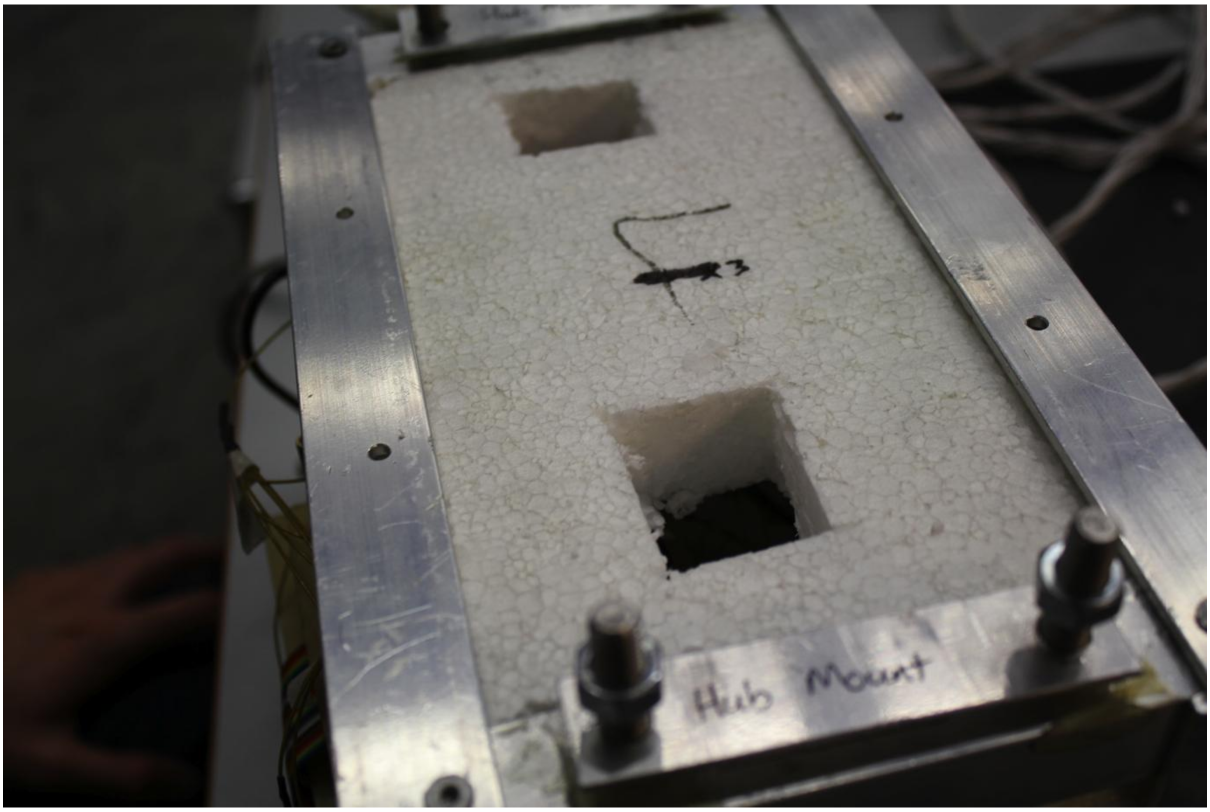
The webcam had to be repositioned at the top corner of the gondola. This allowed a view of the LEDs on the Hub and a partial view of one satellite.



The wired E-Link test was then conducted with the BEXUS electronics expert still present. The test failed initially. The ground station successfully connected to the experiment then would sporadically disconnect. Disabling the network manager on the ground station laptop solved this issue as network manager was overriding the manual setting of the IP addresses on the ground station laptop.

The wireless E-Link test was then conducted. This failed on the ‘break test’, where the connection was deliberately disconnected and then connected again in order to simulate what would happen in the event that contact was temporarily lost with the balloon. When running this test, the ground station could not re-establish contact with the experiment. This issue was solved by changing way the network settings were done in the ground station and Raspberry Pi (flight hardware).

Holes were cut in the polystyrene of the hub to increase the air flow into the electronics on ascent. This was to aid the cooling of the Raspberry Pi when it was sitting on the ground and also during ascent.



SSC wanted to fit the gondola batteries in a position that got in the way of the cameras observing one of the satellites. After a long discussion it was decided that one of the battery boxes could be fitted on the roof of the gondola, allowing the cameras full view of the experiment.

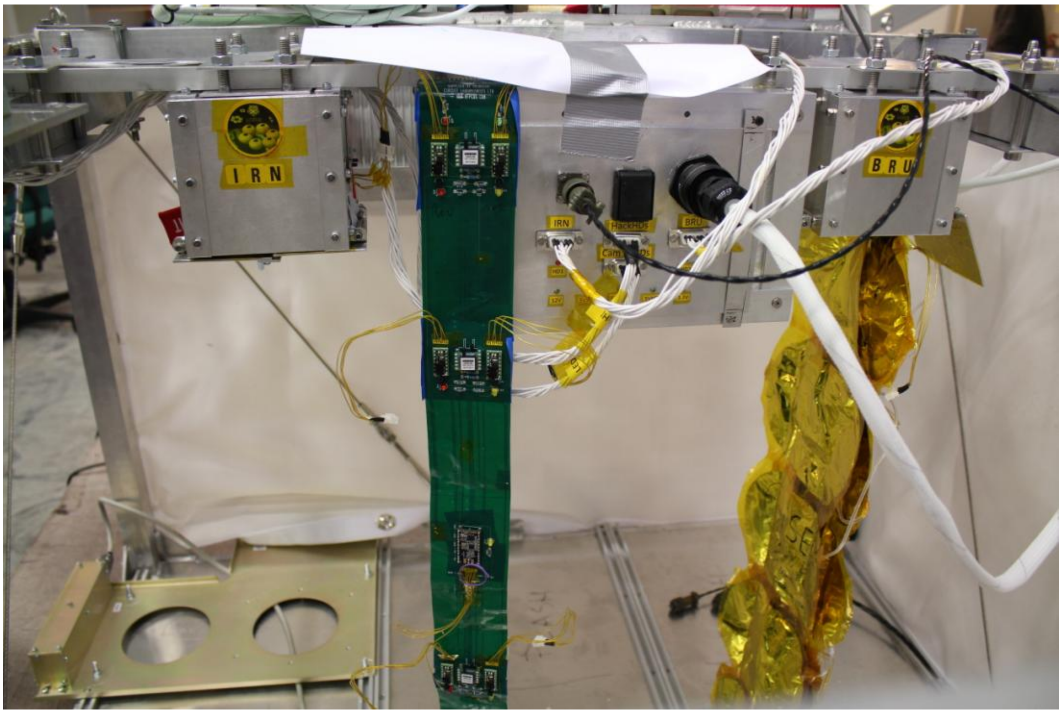
As one of the final steps before full final testing, the pumps were connected up to the soft robotics and primed with anti-freeze. It was found that all of the soft robotics elements of Irn were leaking anti-freeze. All of the antifreeze was slowly bleeding out of the system.

The experiment had to be hung up overnight to try and drain the leaked antifreeze. This may have had a negative effect on the seals of the cells, as antifreeze is a known solvent for the types of adhesives used in tape.

7.2.4 Day 4: 7th October

At the morning meeting each experiment team leader told the others teams where they were with preparation. The FCP was pushed back to 1200 from 0900, which gave the team an extra three hours to repair the experiment. Even with the full three hours, the team was rushed to complete the modifications in time. One satellite had the flexible electronics and pumps removed, and all tubes entering and exiting cells sealed with Tear Aid and Kapton tape. This was to give the maximum chance of a satellite deploying and inflating after the previous problems.

The final experimental configuration is shown below.



Irn is stowed inside the box with its electronics removed and hung from the roof supports. Bru is pre-deployed and still had the semi-functioning disaggregated electronics attached.

The FCP test was successful. The ground station maintained communication with the satellite, the pumps activated when instructed, all telemetry data was being received successfully and the solenoid successfully deployed the satellite.

7.2.5 Day 5: 8th October

Went to Dom at 0400 to start countdown for launch. The launch log follows

- Sweet spot everything working
    - Turned on
    - Both HDs turned on
    - Confirmed with webcam
    - IRN pumps turned on
    - Could see both HDs LED blinking
- E-link cable blocking camera 2 LEDs
- Package count SAT 1 too high (integer overflow)
- New version of GS software cannot deal with package the overflow and keeps crashing
- Using old version of GS – can handle package count overflow a few times

- Lost logging data for a set time (09:07-lost,)(09:42-older version working)
- Launch Sweet spot – Time Stamped
- Launch Flight – Time Stamped

Time Stamped logged data

Commands sent, received, actions, readings from GS, observations from webcam live stream.

Time (Local)	Description
10:30	Launch
10:42	Ascent- Everything working (software, GS)
10:44	Power on 5V Hack: 1. Command sent 2. Arrived 3. LED on (visual confirmation from webcam)
10:45	Both Hack HDs on: 1. Command Sent 2. Arrived 3. Camera 1 – No clear visual from webcam 4. Camera 2 – View blocked from the Ethernet cable
10:46	Webcam visual of Hack HD 1 blinking 1st time
10:49	Webcam visual of Hack HD 1 blinking 2nd time
10:56	(-25°C) T_0 Sat 2 (from GS)
10:57	(-27°C) T_0 Sat 2 (from GS)
11:03	(-40°C) T_0 Sat 2 (from GS)
11:06	10km (information provided by SSC)
11:06	(-47°C) T_1 Sat 1
11:08	Gondola Spinning (webcam visual)
11:15	Packages sending & receiving (GS visual)
11:32	(-40°C) T_1 Sat 1 (from GS)
11:49	• HUB (ambient temperature): 30.6°C • SAT 1: (-36°C) • SAT 2: (-35°C)
12:04	• Float reached: 27.3km
12:04	• SAT 1: (-17°C)

	• SAT 2: (-25°C)
12:08	• First activation of solenoid – Nothing happened (webcam visual)
12:09	• 2nd attempt of solenoid activation – Nothing happened (webcam visual)
12:12	• Power 5V • Command Sent • Command Received
12:13	• LED not on for Power 5V possibly broken due to thermal & vacuum chamber
12:14	• 5V regulator Working • Pressure Reading Received (GS confirmation) • 1.6V pressure on both sides the same (no inflation indication)
12:18	• Beginning of IRN pump cycle (no attached pumps)
12:18	• Pump 2 SAT 1 • Command Sent • Received • LED on(possible visual from webcam)
12:20 (20:49 webcam time)	• Pump 2 Rev Sat 1 • Command Sent • Did not arrive • Command Resent • Arrived • LED on (visual from webcam)
12:21 (20:49 webcam time)	• SAT 1 pump 1 • Command Sent • Arrived • LED on (webcam visual)
12:24 (20:52 webcam time)	• Beginning of BRU cycle (Pre-deployed, with connected pumps) out of range of webcam view
12:24	• SAT 2 Pump 2 • Command Sent • Received
12:24	• SAT Pump 2 Rev • Command Sent • Received
12:24	• Timer started for 20 minutes
12:33	• SAT 2 T_1: (-11°C) • SAT 2 T_0: (-14°C)

	• SAT 1 T_1: (-5°C)
12:35	• Activate solenoid • Command sent • Received • No deployment (visual from webcam)
12:43	• SAT 2 Pump 3 • Command Sent • Didn't arrive • Command resent • Arrived
12:43	• SAT 2 Pump 3 Rev • Command sent • Arrived
13:05 (21:34 webcam time)	• All pumps off, both satellites
13:08	• Both Hack HDs turned off • Command sent • Arrived • Appears to be off from webcam visual
13:10	• Both Hack HDs turned on • Command Sent • Arrived
13:11 (21:39 webcam time)	• Solenoid activated • Command Sent • Arrived • Nothing happened (Visual from webcam)
13:20	• SAT 2 Pump 2 • Command Sent • Arrived • LED out of view of webcam
13:20	• SAT 2 Pump 2 Rev • Command Sent • Arrived • LED out of view of webcam
13:20	• SAT 2 Pump 3 • Command Sent • Arrived • LED out of view of webcam
13:20	• SAT 2 Pump 3 Rev • Command Sent • Arrived

	• LED out of view of webcam
13:41 (22:10 webcam time)	• All pumps off • Command sent for all pumps • Command arrived at all pumps
13:43	• Both Hack HD's off (to save data) • Command Sent • Command Arrived • 10 Second wait
13:43	• Both Hack HD's turned on • Command Sent • Command arrived • No visual from webcam for LEDs
13:44	• 5V Sat turned off • Command Sent • Command Arrived • 5V Sat LED off (visual confirmation from webcam)
13:47	• Rapid Fire solenoid
13:50	• Fire solenoid for 5 seconds • Wait for 1 second • Rapid fire 0.2 seconds, 15 times
13:56	• Long fire & rapid fire did not work (visual from webcam)
13:58	• Hack HDs turned off
14:11	• Hack HD's turned on
14:18	• Code ready to fire solenoid during descending & also switch off systems safely
14:21	• Fire solenoid for 1 second • Wait 5 seconds • 100 cycles
14:31	• 15 minute countdown
14:36	• Software stopped, data saved
14:37	• Data copied on Raspberry pi SD card
14:44	• 150 cycle sequence to fire solenoid • 1 second on • 5 seconds off • Then turn off HD1, HD2
14:45	• CUT
14:58	• Stop at 130 cycles
14:58	• Enough time to start another 80 cycles so decision made to try another 80 cycles

15:07	• Everything shut down

The packed satellite failed to deploy. Solenoid was fired in a variety of ways (short pulses, long pulses, ‘rapid fire’) in attempts to deploy satellite. Solenoid was rapid fired after cut away to see if satellite would deploy on descent. Jamming could have been due to inflated cells pushing on the hatch therefore jamming the latch mechanism.

The team formulated a plan to find root cause of failure using fault tree analysis and fault management analysis. Having experienced a failure during operational phase the team sat down and developed a recovery plan in order to have the best chance of identifying what the cause was of the latch failing to open.

Having discussed this plan as a team a meeting with Simon, SSC (Alex Kinnaird) and ESA stakeholders was arranged in order to report to them on the issues that were faced by the team during the operational phase and Frazer gave a short presentation on what our plan of action was. Alex suggested a full Fault Tree Analysis in order to get to the root cause of the failure.

A failure investigation was started, to obtain the root cause of the failure. All available data was gathered in order to try and find the cause. A ‘What’s Different Analysis’ was also conducted to aid in the investigation. This is where we highlighted any differences in the experiment or the environment between the last successful test (FCP) and the failure (flight). This discussion revealed a number of differences.

Some causes of failure discussed were:

- short circuit due to moisture? no current at solenoid
- cold caused mechanical jam (ice)
- hinge manufacturing defect
- cold stopped solenoid from firing
- transistor failure
- inflation (due to vacuum) caused excessive friction in latch mechanism (solenoid not capable of overcoming force)
- latch manufacturing defect (point of rotation)
- loose wire - solenoid wire or inside hub

The results of the ‘What’s Different?’ Analysis were:

- Vacuum -- inflated cells
- Temperature -- latch freezing solenoid freezing
- All nuts changed to nyloc
- Electrical disconnected and reconnected

- Movement and vibration during flight
- Air flow -- open gondola roof (not as per previous understanding)
- Latch position
- taped spring in deployment box (rushed job)
- accelerometer resoldered on IRN
- VGA camera rerouted

The team was first to the gondola after recovery at midnight that night. Took photos of everything of interest. Most attention was paid to:

- Connection of solenoid (electrical)
- Position of latch mechanism
- Anti-friction tape on hatch door
- Any signs of ice of freezing
- Indication of short circuits on solenoid wires
- All angles of deployment module
- Solenoid – inside and out (all angles)
- solenoid wire solder broken (photo shows good connection before flight), maybe due harsh landing
- latch position incorrect (can't prove or disprove from pre-flight images)
- anti-friction tape on hatch door
- solenoid connection
- latch position

The recovery plan consisted of:

- Visual inspection and photos of all components and connections without any removal of gondola experiments
- visual: solenoid, hatch, mechanism, BRU
- other teams to dismount experiments (carefully!) + E-link
- Hub visual/ (invasive) inspection for moisture
- HD1 and HD2 remove SD and backup (watch videos)

if point 3 all clear: power up and perform full functional test:

solenoid -> HD1 -> HD2 -> pumps

disassemble from gondola:

cable routes

camera connections

roof structure

camera structure

non-invasive inspection of deployables

further bench testing as required

disassemble all structures

s/c tests, broken tracks, solenoid maloperation or mechanism failure?

return to Glasgow: invasive inspection of deployable units.

7.2.6 Day 6: 9th October

Conducted fault analysis. ‘What’s different?’ analysis, pedigree analysis, fault tree analysis.

In order to ensure that nothing was going to be disturbed or possibly made worse planning the testing procedures to be undertaken and by whom was essential. A full list of actions was developed and records were taken for each.

Having agreed as a team what the best course of action was, exploration of all the failure possibilities was undertaken. It was concluded, with strong photographic evidence, that a broken cable connection was the result of the solenoid failing to fire during float. Further details of this can be found in the Solenoid Failure Analysis Report (SFAR).

Once the team were all fully satisfied that we had found the root cause, we gathered all the supporting evidence and held another meeting was arranged with Payload Manager (PM) Simon, Alex, SSC and ESA members. The team discussed their findings and the conclusion was agreed that there were a number of failings on both sides but a lot had been learnt as a result of the failure.

7.2.7 Day 7: 10th October

Functional testing of experiment was undertaken for two reasons:

- to see what systems were still operational
- to try and recreate failure states

Functional testing was performed while the experiment remained mounted to the gondola to try and recreate fault circumstances and observe the results. Photo and video records support the findings which can be found in the SFAR.

The Mobius Action Cam was successfully fitted on BEXUS 17. The BEXUS 17 balloon was launched. BEXUS 17 lost contact with E-link after reaching float phase and did not regain contact for the duration of the flight.

7.2.8 Day 8: 11th October

Wrote reports. Received recovery photos from BEXUS 16 recovery. The gondola landed upside down which could explain how the IRN accelerometer ripped off and the bottom cell joint also ripped.

7.2.9 Day 9: 12th October

Created campaign party video. Attended campaign party.

7.2.10 Day 10: 13th October

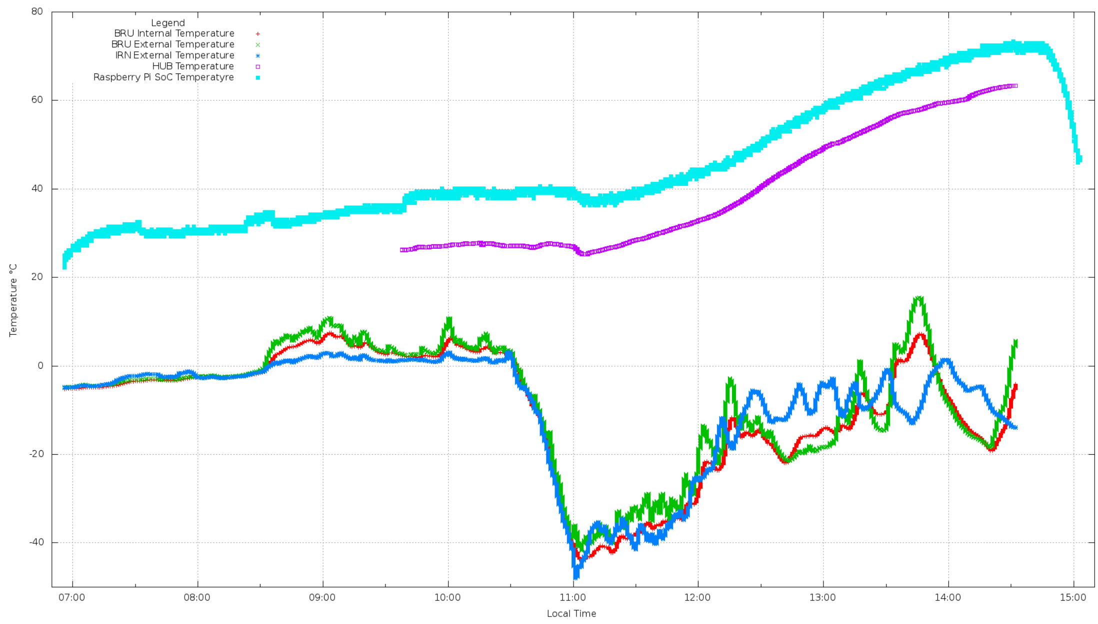
Packed experiment for travel with the team back to Glasgow.

7.3 Results

The experiment proved that the disaggregated electronics and wireless communication are feasible to inflatable and distributed satellites. The architecture using a powerful central controller (Hub) and simpler and less capable slaves (satellites) also proved to be very efficient.

The experiment also proved that to student experiments it is possible to use non-space graded hardware, thus making it easier for students to prove their concepts.

The graph below shows the logged temperature data on the Hub, both satellites and Raspberry Pi SoC.



7.4 Discussion and Conclusions

All the disaggregated electronics worked with wireless communication, control. Even more, all components were fully functional even at -50C, well below their specification. One satellite was deployed, the other got stuck in the box. Due to antifreeze leakage the deployed satellite did not inflate.

There were various reasons why the experiment was partially unsuccessful. A significant example of this is that the team did not have a sufficient budget to cover all costs. Therefore, the team were forced to manufacture a lot of the components in house. It can be seen that the most successful aspect of the experiment was the disaggregated electronics. All of these components were bought in and the flexible circuit was professionally manufactured. The complexity of the experiment was increased significantly when we had to incorporate a shape changing element to the structure. The team ultimately ran out of time to manufacture successful soft robotic actuators and to find a successful manufacturing technique incorporating them. Ideally we would have found a company who could manufacture them to a high enough standard. However, the team did not have enough budget for this. Ideally the inflatable structure would have been manufactured professionally also as it was vital it had to be completely sealed to ensure inflation. However, this was not the case and the manufacture of the inflatable structures were not at a high enough standard.

Another issue that faced the team was the departure and absence of team members. As some team members left the team at the start of the summer it was anticipated that a lot of work had to be done right up until the launch campaign, however, it was thought that there would be enough manpower to cover the work. However, certain team members did not pull their weight over the summer which meant that the experiment was not fully tested. If there was sufficient manpower, the likelihood of the experiment being unsuccessful would have been reduced.

Although the team discovered many issues throughout the BEXUS process, the possibility of inflatable structures working successfully in space applications is still high. This has been proven in the testing that has been carried out by the team and the success of the electronic components used by the team.

7.5 Lessons Learned

The lessons learned are split into the following subchapters. Further lessons learned can be found in [30].

7.5.1 Experiment Design & Requirements

- Keep numbers of deleted requirements to make documentation coherent
- Don't put anything outside of gondola
- Collaborate with other teams on-board your gondola

The gondola roof might not be covered. The ideal is to have it decided and agreed with ESA at most at CDR as an open roof implies in design modifications

7.5.2 Mechanical (Design & Fabrication)

- Talk about design concepts with the workshop who will be manufacturing the product – find the best methods of manufacture and materials that are suitable to machine. While the specification is required, compromise and redesign to suit the manufacturing methods can improve the product produced and save time for everyone
- Manufacture always takes longer than expected. Get designs in early!
- The iSEDE concept requires complex and careful manufacturing – if a project requires such consistent and perfect manufacture, there should be a focus on finding funding to do it properly – developing industry partnerships in heat sealing could have significantly improved the quality of iSEDE inflatable manufacture.
- Folding aluminium sheet and welding produced a poor manufactured box. Better to have sheets with screws.
- Potential problem with using solenoid to deploy satellite due to low temp and pressure. However, more reliable than pyro cutters
- Self-clinching nuts are very useful for applications where you don't have access to get to the nuts.
- Don't over design; the aluminium pieces for the hub were too thick.
- Expect delays and problems when getting components manufactured. Leave enough time to overcome problems.
- Creating a perfect seal is very difficult with tubes and wires creating small holes through the seal.
- Thin walled silicon actuators are difficult to manufacture without having small holes.
- Silicon actuators are easily punctured.
- Difficult to add tubing to the silicon actuators and ensure that they do not leak.
- Anti-freeze dissolves the adhesive layer of the Kapton tape.

- Anti-friction tape can be used to help reduce the friction in the deployment mechanism system. This allows the solenoid to be fired if the solenoid is not powerful enough to release the doors.
- A window cleaning squeegee can be used to ensure that no air bubbles is trapped between the layer of Kapton tape and Mylar.
- Double sided tape can be used to connect the two 5 cell arrays.

7.5.3 Electrical (Design, component selection, fabrication, testing)

- Electronics and software design have to be made together.
- When choosing microprocessor/microcontrollers always include in the requirements at least one communication interface exclusive for debug purpose.
- Bottom-up is the best approach to electronic design: first choose sensors, actuators and any other peripheral and then the microcontrollers/processors that are capable to communicate with them.
- Make sure that the electronic and software team know how to use, programme and integrate every component considered in the design before putting them in the final design and buying them.
- I2C devices are good to reduce the number of physical connections, however if one device breaks down the whole bus can be compromised. Avoid putting all critical components in the same bus.
- When possible always use open source hardware and free software as they are easier to be modified to suit project needs as well as it usually is easier to get support.
- At design phase make sure that all facilities needed to develop and test prototypes are available.
- If electronics components/boards are on the surface of inflatable/flexible structures design all board with component on only one side (the one that is not in contact with other structures) and use only surface mount components.
- Use professional manufacture and assembly to all PCBs and cables.
- When connecting different boards use standard cables and connectors.
- Ready to flight spare boards are highly recommended to be brought to the launch camping.
- Software/electronics designers and experts must be at launch campaign. No one has a better understanding of flight software and hardware than the person/group that developed it.

7.5.4 Software (Design, Implementation, Testing)

- Keep a strict control version, log and back up of every version of the software, thus allowing a fast swap if needed at launch campaign.
- Allocate more time than needed to software development, it always takes longer than planned;
- Develop and test the ground station software in the same laptop/PC that is going to be used at launch campaign, this avoids machine specific bugs/issues.
- Do not make any change in software after it been fully tested, even an small change in graphical user interface/data visualisation can introduce critical bugs.

7.5.5 Testing & Validation (Suggested tests, problems, time allocation)

- Ensure testing is booked well in advance to ensure it can occur at the correct times.
- Mylar is useless to bond together. Ideally kapton with printed circuits would be used
- Double sided tape produced most reliable seal during thermal and vacuum testing
- Mylar is so thin that it is very difficult to experimentally find its characteristics, e.g. Young's modulus, inertia of cell & satellite, change of cell area & length, Specialist equipment required
- Plastic template to create cells is better than cardboard (ink soaks into cardboard and ruins template)
- Double sided tape needs to be bonded directly onto Mylar, cannot be touching the permanent marker ink
- Epoxy does not bond well to Mylar
- Need to bond tape to dull side of Mylar, shiny side does not bond well
- Wetting table to stick Mylar to it, allows you to remove any creases and kinks
- By adding straws for on ground inflation causes problems. Small gaps are difficult to reseal.
- Straw for each cell works better rather than having connecting straws through the entire structure
- Ensure that thermal chamber can go to desired temperature!!!!

- Mylar's material properties does not change significantly down to -30°C
- Man-made manufacture produces a lot of inconstancies. Ideally the satellite would be produced by machine
- Heat sealing would be best alternative to adhesives to seal cells

7.5.6 Workshops & Launch Campaign (Who should attend, travel suggestions, preparation)

- Carefully choose who attends design reviews considering their role in the overall project. Where possible, lead engineers should attend but they should understand fully all the subsections and other work that has been completed by colleagues.
- Everyone who attends launch campaign should be briefed in fully so that they understand their role at the campaign. Which means that they know what they are meant to be doing while at the launch campaign and can help out other colleagues.
- Comparison website, www.p4d.co.uk, is a useful website to find a cheap courier service for shipping the experiment.
- The lead engineers should establish a procedure and check list for their area. They should then combine the lists and discuss which procedures should get priority. This helps to ensure that all required tasks are done during the launch campaign.
- However, if problems occur during the launch campaign then tasks need to be pushed back or done in parallel by other team members.
- Specialised and commonly used tools in assembling the experiment should be taken by the team.

7.5.7 Project Management (+ software tools, outreach and risk assessment)

- Ideally it should be the same project manager throughout the project.
- Conferences are very useful for outreach.

7.5.8 Miscellaneous

- Ensure that when people are getting a part of the project handed over to them that they understand and know everything that is going on in their field, so fewer surprises are likely to occur.
- Ensure that all material and parts are constantly recorded and up to date
- Ensure that you have a clean and peaceful working environment (M6 was dusty and had a lot of people coming in and out)

- Ensure that all team members are willing to put in a lot of time and effort. Especially the months leading up to the launch campaign.
- Ensure that there is sufficient budget.
- While connected to the E-link network all software that use internet (e.g. Dropbox, Skype and etc) should be deactivated/closed to avoid unnecessary broadcasts.
- Wireshark and other similar network tools can be used to store all network packets, thus allowing to recover data if the ground station crashes before storing it. Using a plaintext data also helps.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

This section contains a list of all abbreviations used in the document.
Add abbreviations to the list below, as appropriate.
In version 5 of the SED (final version), delete unused abbreviations.

1U	1 unit cube (dimensions of 10x10x10cm)
AIT	Assembly, Integration and Test
AP	Adaptive Phase
asap	as soon as possible
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CDR	Critical Design Review
COG	Centre of gravity
CRP	Campaign Requirement Plan
CUT	Cut off balloon
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FA	Float Altitude
FB	Frazer Brownlie
FD	Flight Descent
FAR	Flight Acceptance Review
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
FT	Float
GSE	Ground Support Equipment
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document

I/F	Interface
IPR	Interim Progress Review
LO	Lift Off
LT	Local Time
LOS	Line of sight
Mbps	Mega Bits per second
MEMS	Microelectromechanical Systems
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
SED	Student Experiment Documentation
SNSB	Swedish National Space Board
SODS	Start Of Data Storage
SOE	Start Of Experiment
SOC	State of Charge
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or -
TBC	To be confirmed
TBD	To be determined
TC	Telecommand
TM	Telemetry
TQ	Tiago Queiroz
TS	Thomas Sinn
T&V	Testing and Validation
WBS	Work Breakdown Structure

8.2 References

(Books, Paper, Proceedings)

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APPENDIX A – EXPERIMENT REVIEWS

Terms & Conditions at Selection Workshop Stage

Terms

The offer comprises (subject to passing PDR):

• A flight for your experiment on a stratospheric balloon during the BEXUS 16 & 17 campaign.

• Two reviews of your experiment design by a panel of experts drawn from space agencies and industry.

• Technical support by ESA and EuroLaunch, during the payload integration phase, and during the launch campaign.

• Sponsorship by the ESA Education Office, for the travel and accommodation expenses of students attending reviews and the campaign (conditions apply).

General Conditions

• You must ensure compliance with the requirements of the BEXUS User Manual.

• You must comply with the overall project schedule and any requests made of you by ESA, SNSB, DLR or EuroLaunch in relation to the execution of the project.

• You must update and submit the Student Experiment Document (SED) at the specified milestones, including the final post-flight report (even if the experiment is not considered to have been successful). The organisers may also distribute your SED to current and future participants for specific examples.

• In case of a problem in your experiment that might affect its performance, impact the schedule, or have safety implications, you must inform ESA and EuroLaunch immediately.

• The realisation of an outreach programme is mandatory.

Specific Conditions (to be addressed at PDR)

1. You shall expand the scope of your experiment to include either a structural interest or an electronics/communications interest. For structural interest you can consider the inclusion of an element of stiffness, surface volume or strength, for electronics you may consider a communication element across your electronics.

2. You shall reconsider the configuration of the external appendages as presented in your oral presentation at the Selection workshop.

REXUS / BEXUS
Experiment Preliminary Design Review

Flight: BEXUS 16/17

Payload Manager: Alexander Schmidt

Experiment: iSEDE

Location: DLR, Oberpfaffenhofen, Germany **Date:** 04 Feb 2012

1. Review Board members

Mikael Inga	SSC – Science Services
Olle Persson	SSC – Science Services
Hans Henriksson	SSC – Science Services
Torbjörn Eld	SSC – Science Services
Klas Nehrman	SSC – Science Services
Natacha Callens	ESA – Education Office
Lucio Scolamiero	ESA – Tech. Structures and Mechanisms
Koen DeBeule (Chair)	**ESA – Tech. Mechanical Eng. Dept.**
Alex Kinnaird (minutes)	**ESA – Education office**
Martin Siegl	DLR – Institute of Space Systems

2. Experiment Team members

Craig Hay
Adam Rowan
Darryl Black
Andrew Allan
Thomas Sinn (available on skype)

3. General Comments

- Presentation
  - Style is good, this presentation answered some of the questions the board had from the pre-discussion. There is some evolution from the selection workshop.
  - The board suggests you are very 'stiff' during your presentation, try to be enthusiastic and look up!
- SED
  - In general the document is OK, and is at a PDR standard.
  - Try not to send PDF with the comments inside.

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
  - You have some problems with the classifications, the minimum number of satellites (i.e. 2) is a design requirement. You should look at the formulation of the requirements and consider the verification.
  - The satellite been deployed prior to launch is an operational requirement for the wording you're currently using.
  - Design requirement number 8 is difficult to verify.
  - Consistency between design requirement 12 and functional requirement 1, shall or

should. The team clarified this is due to the placement (inside vs. outside) not the number of the satellites – this is acceptable.
  - You have successfully covered the important design requirements from the safety point of view.
  - One of the operational requirements makes it confusing about when the satellites are deployed.
  - In your next SED make the above point clear. It is not immediately obvious for non-native speakers to define the difference between 'deploy' and 'inflate'.
  - You should 'test' your SED on someone outside the team.

- Mechanics (SED chapter 4.2.1 & 4.4)
  - It was unclear in the document about the overall envelope. A good overall dimensioned drawing would be good.
  - **There were questions about the release of material due to a possible 'explosion' of the inflatable structure.**
  - The team preferred internal mounting.
  - It is possible to mount to the roof on the gondola, but this is bespoke and can be difficult.
  - **There is a possibility to fly with a panel open with the camera mounted externally.**
  - Shocks is not included in risk.
  - FEA or numerical analysis is required for the shocks.
  - There should be a procedure for the folding, and this should preferably be done by the same person each time.
  - The release of the hatch should be well documented in the SED and it should be clear that it is safe.
  - **Try to reduce the footprint by integrating the hub.**
  - There's a tendency for condensation on the go-pro case, you should check this in TVAC and modify the case (take the seal off or drill through).

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)
  - Pumps in previous experiments have had problems starting at low pressure – this should be tested.
  - **If the 'soft robotics' element is to be included then you should inform your contact person before CDR.**
  - You should keep the short duration of the project in mind when considering additions in the project.
  - You have to be able to connect external power to your experiment.
  - You should thermal test your hack-HD batteries and consider changing them.
  - Your electronic design is a little under developed.
  - It's not clear how many seeds you have (one on each cell?).
  - What type of wiring is used between the cells? It should consider the rigidity. Look at litze wire.
  - The charging concept through the lines is not clear, consider from BEXUS power to your satellite power and clearly document this.
  - The battery charging should be a functional requirement.
  - You should be aware of the dangers of li-po cells.
  - Your charging introduces extra risks. Overcharge could be a problem, you should have a clear safety strategy.
  - You should use safety goggles when working with charging the batteries.
  - It's possible that the charging of the batteries could be a 'step to far'.
  - You should verify that the other experiments do not use the same module and mess up your signal.
  - Use fixed resistors instead of potentiometers.
  - As the cameras are crucial for the experiment success you may consider powering them from the main power source rather than on-board batteries.

- Thermal (SED chapter 4.2.4 & 4.6)
  - Thermal will become an issue if you fly with the side open as suggested.
  - You should expand this section a little.
  - You should state in this section that the electronics and cells are able to withstand the temperatures.

- You should consider faster discharge of camera batteries in the thermal environment.

- Software (SED chapter 4.8)
  - You should definitely include more software engineers.
  - This section needs to be elaborated.

- Verification and testing (SED chapter 5)
  - You included some 'typical mistakes'.
  - Batteries are to be qualified for use on the balloon uses ALL verification methods – this is expensive and could be reduced.
  - Design requirement 49 referring to length – this is done by test, not inspection.
  - Overall the testing section is pretty complete.
  - The timings for the testing and location is good.
  - The test matrix is good.

- Safety and risk analysis (SED chapter 3.4)
  - Overall it's a good start, but there is still some work to be done.
  - The personnel risks are good.
  - You should include the budgetary risks.
  - You may also include 3rd party risks (people on the ground).
  - TC120, difficulties in assessing microprocessors for programming (should be 'before putting them on the cells' – not first time!).
  - There is a risk that charging your batteries on board may damage other experiments or the vehicle in the case of over charging.

- Launch and operations (SED chapter 6)
  - It was clarified that the team intends to deploy but not inflate one of the two satellites before launch.
  - You should be aware of the increased stiffness of the cables when cold before deployment of the second satellite.
  - In the countdown schedule (pg 88) at T-60: your attachment would be done well before this.
  - Latest access is T-60 minutes, there is no access after this. It is highly preferable to avoid access after pick up.

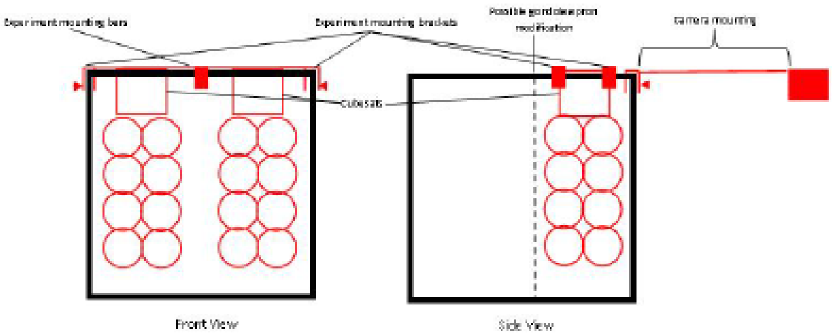
- Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)
  - It is a good start and very clear.
  - Because of your schedule (having a prototype before CDR), you should also schedule time for design changes after CDRs if it is needed.
  - You say you are looking for new members, but also some are leaving, you should look carefully at this.
  - You could look at advertising on your blog and/or facebook page for new members, this has been successful in the past.
  - Include a table only for the budget, do not just refer to it on a component list.
  - Don't wait too long to find sponsors.
  - Include the SSC logo on the blog.
  - Keep things updated (especially the blog).
  - Keep the organisers informed of conferences (send us a copy of the paper/abstract).

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Address the issues related to the mechanical mounting
    1. It is suggested that you may still mount internally, but as it cannot be guaranteed that your camera view will be un-obscured you should consider mounting the camera(s) (perhaps use one camera and a fish eye lens) on an external boom looking in. This will introduce an open side to the gondola and the organisers may insist on fixing the curtain between your experiment and rest of the gondola.

2. For the fixation to the gondola it is suggested you mount your CubeSats to a 'frame' that can sit on top of the gondola.
    - A suggested concept is included below, this should be discussed in detail with your contact point and with SSC (Olle Persson) in parallel with the preliminary accommodation plan. There is a scope for also fixing your hub to the mounting bars and reducing your lower footprint or 'flattening' your hub and mounting directly below the deployables.
3. Look at reducing your footprint by integrated the hub box.

- Finalise your battery charging concept and make this clear in your SED.



- PDR Result: pass
- Next SED version due:
    - V2-0 on 13th May 2013.

BEXUS
Experiment Critical Design Review

Flight: BEXUS 16/17

Payload Manager: Alexander Schmidt or Mikael Inga

Experiment: i-SEDE

Location: ESA-ESTEC, The Netherlands **Date:** 30th of May 2013

1. Review Board members

Kristine Dannenberg	Swedish National Space Board
Mikael Inga (chair)	SSC Science Services
Alf Vaerneus	SSC Science Services
Martin Siegl	DLR Institute of Space Systems
Alexander Schmidt	DLR MORABA
Stefan Voelk	DLR MORABA
Alex Kinnaird (mins)	**ESA Policies Dept. – Education and Knowledge Management Office.**
Natacha Callens	ESA Policies Dept. – Education and Knowledge Management Office.
Sylvain Vey	ESA Technical Directorate – Mechanical Engineering Dept., Thermal Div.
Nick Panagiotopoulos	ESA Technical Directorate – Electrical Engineering Dept., Data System Div.

By telecon:
Olle Persson SSC Science Services

Document review only:
Lucio Scolamiero ESA Technical Directorate – Mechanical Engineering Dept. Structures and Mechanisms Div.

2. Experiment Team members

Craig Hay
Adam Rowan
Darryl Black
Frazer Brownlie
Tiago Queiroz
Thomas Sinn

3. General Comments

- Presentation
  - The panel apologises for the chaotic start of your review.
  - The power architecture slide was a little difficult to read from the back of the room.
  - Try and engage the whole panel when giving your presentation, not just one member.
  - Handing out hardware during the presentation is not the best idea. (Engineers distract easily).
- SED
  - Some minor grammar errors that would have been picked up in a proof read (“as can as can be”).
  - Some minor formatting errors (cantered text in section 4,5.4).
  - Some missing images (“insert image”).
  - The Eurolaunch logo has dropped out, check the template.

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
  - There are no flight requirements (altitude, duration, daylight?). Not 'as high as possible'. These should be derived from the other new requirements (probably pressure).
  - Classic mistake – don't commit to dates (unless for a scientific reason) in the mission statement.
  - Don't use 'may', use should and shall, remember Koen's presentations.
  - The frequency of the temperature measurements is very high (5Hz), is this frequency is really needed.

- Mechanics (SED chapter 4.2.1 & 4.4)
  - Risk for shocks at launch has been included.
  - Shock FEM analyses were also requested at PDR, but not found.
  - Overall experiment envelope is provided, but if inflatable elements can deviate from vertical direction (because of inflatable cells shape changes or wind or other...) and how much is not given.
  - The deployment mechanism to open the box lids is described (spring driven) and is tested in vacuum which is good. The holding system is based on solenoid. This is not sized (min force provided by the solenoid vs. required forces) and would be nice to be tested or at least verified by analyses.
  - Risk associated to possible material release was raised at PDR, but an answer not found.
  - A folding test is identified, but how to fold the balloons and to ensure the last folding will be properly done (procedure/same person…) is not identified and is recommended to be included.
  - You should be consistent with the location of the hub, some parts of your document state the gondola rails.
  - You should definitely document the distance required between the camera and the middle cells
  - Include more details on the roof mount clamps and the camera mounts in terms of material type, bolt specifications.
  - You should be aware of thermal issues in your mechanical attachments (including your door mechanism).
  - You should rigorously test the opening mechanism in the environment conditions.
  - You should update the document to reflect the final choice for camera casing.
  - You should be sure of the start-up of the pumps in lower pressure.
  - Your experiment component list does not meet the requirements of the guidelines (order status, specification).

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)
  - A grounding scheme should be followed. -
  - It is clear the satellite harnessing is still to be confirmed.
  - The physical position of wires in the satellites should be documented, including their attachment.
  - You will need to apply for frequency permission from the PTS, you should include the radiated power, bandwidth, antenna type and pattern and modulation. This should be forwarded to Esrange for permission. Esrange are currently investigating this.
  - You have very precise numbers for the power calculations. Does this really account for all the DC/DC converter losses.

- Thermal (SED chapter 4.2.4 & 4.6)
  - The thermal design seems 'in progress'.
  - If you're not connecting the sensor to PCBs during the test then you should wait 1 or 2 hours to be sure the board has temperature has stabilised.

- Software (SED chapter 4.8)
  - The philosophy with regards to loss of wireless signal (how long before it switches to

wired and re-try etc.) should be documented.
- There is a fault in the flow diagram if no connection is made to the ground station.
- The procedure is not clear with regards to re-set or crash for example. At the moment you are dependent on the ground station for this restart.
- You should be sure that you cannot overwrite the previous saved data.

- Verification and testing (SED chapter 5)
  - There is no EMC test, at least some conductance test should be included.
  - “Two satellites shall be deployed” should be changed.
  - You should rephrase the house keeping requirement.
  - You cannot complete the camera view angle test until the exact distance is confirmed by Eurolaunch.

- Safety and risk analysis (SED chapter 3.4)
  - You should consider an RBF to prevent an accidental deployment. You should make sure that you don’t burn out your system if it’s actuated when the RBF is in.
  - You should include the data sheet for the new actuation fluid. You should be aware of the disposal method.

- Launch and operations (SED chapter 6)
  - You should really check over the timeline.
    - Power On
    - Attachment on structure
    - Ground deployment
  - You should be clear about the testing at T-180.
  - All pre-flight activities should be expanded into verifiable checklists.
  - Your post flight activities should include mechanical dismounting, packing, disposal of any materials, shipping.
  - During the FCT all electronics should be operated (solenoid and wireless links).
  - You should consider the time between deployment and actuation, maybe this should vary between timeline and command.
  - Maybe have a ‘as you sure you want to do this?’ on the deployment command.
  - PPE will be provided by Esrange.
  - British power adapter will not be provided by Esrange.
  - FT refers to a pressure sensor then a time sensor.

- Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)
  - It wasn’t clear in the budget about the amount for the non-sponsored students’ travel.
  - Change ‘ascl’ to ‘space’ in the website URL
  - Provide the URL for your Facebook in the main document.
  - You should be clear how many students you are (Thomas is a student or an advisor).

- Others
  - You should coordinate with ARCADE-R2 (via the CRP/FRP) to be sure that you don’t both try actuate at the same time.

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Address of all the above minor points.
  - Complete the thermal design.
  - Consider implementation of an RBF.

- CDR Result: pass

- Next SED version due: 2 weeks prior to the IPR, provisionally the 24^{th} of June.

Review of BX17_iSEDE_SEDv3-0_24June13 (with iSEDE team member task allocation)

General

- Document ID date is DDMMMYY, i.e. 24Jun13 *THOMAS (Date: 01/07/13, Comment: corrected)*
- The old Eurolaunch logo STILL appears from page 129 onwards. *THOMAS (Date: 01/07/13, Comment: corrected)*
- Spl. Charing, page 49 *THOMAS (Date: 01/07/13, Comment: corrected)*
- Blank page 127 *THOMAS (Date: 01/07/13, Comment: corrected)*
- Grey highlighting on page 131. *THOMAS (Date: 01/07/13, Comment: corrected)*

2.4 Operational Requirements

- ER_OP-18: Is 25km really sufficient? You should have margin on the pressure required, in the 1976 20mbar isn't achieved until slightly above 25km. Some models may place the pressure at 25km up to 30mbar. To be discussed at IPR

3.2 Schedule

- You should update your Gannt Chart, at least your progress line. CRAIG **TO BE REVISED AFTER IPR**
- In general it seems you're a little behind the preferred schedule. CRAIG **TO BE REVISED AFTER IPR**

3.3.1 Manpower

- It's not clear from your manpower section that you have the resources over summer to complete the fabrication and testing. You should re-read the guidelines about this section *THOMAS (Date: 03/07/13, Comment: sentence added that Darryl, Frazer, Tiago and Larissa working full time on project over summer)*

3.3.2 Budget

- You should provide a breakdown of the total project cost (i.e. include the travel costs) and the sources of funding. *THOMAS (Date: 07/07/13 Comment: updated the budget, added travel)*

3.4 Outreach

- The URL is still broken for the project page, you should replace 'space' with ascl. *THOMAS (Date: 03/07/13, Comment: Link got corrected, somehow it was changed back and forward from space to ascl.)*
- You should keep on posting on the wordpress site, aim for at least once a month. *EVERYONE (Date: 07/07/13 Comment: blog will be updated once a week from now on)*
- You should reference appendix B in this section. *THOMAS (Date: 03/07/13, Comment: reference to Appendix B added)*

3.5 Risk Register

- TC120; does the mechanical design mitigate this risk yet? *FRAZER (Date: 01/07/13 Comment: Added TC 121)*

- MS80; have these simulations been performed yet? *FRAZER (Date: 01/07/13 Comment: Added MS81)*
- MS100; this should have been mitigated. *THOMAS (Date: 03/07/13, Comment: mitigated with extensive testing and impmentation of resistive heating)*
- PE10 and PE60 and PE80; This is a real risk – I'm not convinced your probability isn't B. *THOMAS (Date: 03/07/13, Comment: DONE, most of the risks are mitigated and we are applying for travel grants for Tiago to attend the launch campaign)*
- SC10 and SC20; have all components been ordered now? *THOMAS (SC10) (Date: 03/07/13, Comment: DONE, most of components already ordered), FRAZER (SC20) (Date: 01/07/13 Comment: Added SC21)*

Experiment Concept

- **Page 38: "The hub will be mounted conventionally on the base of the gondola" vs figure 4-1 where the hub is clearly mounted on the support structure near the roof of the gondola AND the statement immediately afterwards (iv)! To be discussed at IPR**
- You should confirm the use of the super bright LEDs or not. *THOMAS (Date: 07/07/13, Comment: Yes, LEDs are used. Added array of 10 bright LEDs to experiment components and camera section (mechanical and electronic))*
- Is the data (from the Satellite to the Hub) sent simultaneously over the wireless and hardwire? If not what is the philosophy here? *TIAGO (Date:01/07/13 Comment: 4.1)*
- Do you transmit the camera images? If not your storage becomes critical (camera SD card is a SPF?). *TIAGO (Date: 01/07/13 Comment:4.1 and 3.5, table)*
- It's assumed the actuation of the satellites is back and forth (i.e. toward and away from the camera. Is there no way to use relative sizing/distortion of a fixed sized spot on the final size to help verify the displacement? How confident are you with the accelerometer method? *THOMAS (Date: 04/07/13, Comment: DONE, the actuation is from left to right and it is planned to use fixed points on the structure to obtain the displacement with image processing after the mission)*

Electrical Interface

- You should detail the data rate and protocol of information sent over the e-link. *TIAGO (Date: 01/07/13 Comment: revised)*

Radio Frequencies

- You should confirm the details of the panStamp RF module, such as bandwidth, power level and modulation. *TIAGO (Date:01/07/13 Comment: DONE, 4.2.3)*
- You should confirm with your SSC IPR reviewer that the frequencies have been cleared with Esrange To be discussed at IPR

Experiment Components

- You should at least outline the development status of each of these components (ordered, to be ordered, manufactured, etc). You may add this information to the tables in each section and reference it in the experiment components section. *FRAZER & DARRYL (Date:01/07/13 Comment: Added table with order status)*
- What is the CPU used for the hub? The Pi is not mentioned here. *TIAGO (Date: 01/07/13 Comment: ADDED 4.3)*

Mechanical Design

- **Is the maximum displacement 30cm from the vertical for the bottom cell (i.e. the clearance all around your bottom cell should be 30cm? This should be clear in chapter 6. What margin is included here? *THOMAS*** *(Date: 04/07/13, Comment: This is the margin at the bottom cell, it was changed to 25cm in actuation direction. We just included in Chapter 6 as a requirement)*
- More information is needed on the solenoid and the actuation device (reference section 4.5.2.4). FRAZER *(Date: 01/07/13 Comment: Added descripton of how the solenoid and latch will work)*
- The IPR should be the latest decision point for the Go-pro vs 3D printed camera case. *FRAZER (Date: 01/07/13 Comment: Amended)*
- Does the HACK-HD have the possibility of using a fish eye lens to increase the FoV and therefore decrease the necessary separation? *THOMAS (Date: 04/07/13, Comment: DONE, The HackHD already has a fish eye lens)*

Electronics Design

- You may find it difficult to mount the Pi, and allow easy access to the pins AND the SD card. *FRAZER (Date:01/07/13 Comment: DONE, Description of how Pi will be mounted inside of hub)*
- In general your mooting and internal mechanical design (in terms of PCBs) is far from clear. *(Date: 01/07/13, Comment: DONE, see point above)*
- You should provide the automated timeline with notes on what triggers the events (e.g. pressure sensors vs. schedule for deployment). To be discussed at IPR
- **The attachment of the PCBs to the inflabtable material is critical – this should be finalised before the IPR.** *THOMAS (Date: 07/07/13, Comment: DONE, Chapter added on mounting of PCB on inflatables via srews)*
- **Why are there no schematics at all except for power? *DARRYL* & *TIAGO*** *(Date: 06/07/13, Comment: DONE, Schematics added on wiring and component placement)*

Power Design

- It's not obvious that the 15 minutes of charge is sufficient. *DARRYL (Date: 05/07/13, Comment: No more charging required during flight, all references deleted)*

Thermal Design

- **This is immature – a static thermal analysis for the float phase should done be done for the hub to determine the level of insulation required and whether any heating will be required. *FRAZER*** *(Date: 01/07/13 Comment: Thermal calculation of polystyrene hub)*
- Heating for the battery power required for the battery may be significant, an analysis is required here in order to sure up the power budget. *DARRYL (Date: 06/07/13, Comment: Batteries will be placed in deployment box)*
- **Thermal design for deployment mechanism – this is also critical, and should be tested soon. TO BE TESTED AFTER FABRICATION**

Software Design

- **Section seems immature TO BE DICUSSED AT IPR**

- Does at least one camera record during ascent to capture the pre-deployed satellite's inflation? *THOMAS (Date: 04/07/13, Comment: Added reference to timeline in Chapter 6)*
- Figure 4-45 is unclear (too many lines on top of one another). *TIAGO (Date:01/07/13 Comment: 4.8.4.1,figure 4.45)*
- You should be careful using 'LO' as your start of experiment signal, most people associated this as the lift off signal. *TIAGO (use SOE) (Date:01/07/13 Comment: 4.9.1, table 4.5)*

Launch and operations

- You should include a photo of the RBF attached (following fabrication) **TO BE ADDED AFTER FABRICATION**
- You should show how to reattach the RBF is the recovery crew find the system with the satellite undeployed (this should be discussed with your IPR reviewer). TO BE DISCUSSED AT IPR
- As discussed in 6.2 the detailed procedures should be ready for EAR. **TO BE ADDED AFTER IPR**
- You should be aware of the 'bounce' of the gondola at float phase, you may want to wait until constant pressure before deployment. If the flight continues in the dark the gondola will also descend up to 2km. *THOMAS (Date: 04/07/13, Comment: Added it to the timeline)*
- It's not recommend to have anything running after cut, experiment should be shut down before cut OR you risk been on during landing (possible corruption of storage). TO BE DISCUSSED AT IPR
- You may suffer detachment of the satellites at landing, this probably isn't an issue, but you may need to instruct the recovery crew to retain these if they open up the gondola for any reason. **TO BE ADDED AFTER IPR**
- You may still have a risk of material release during the deployment, this doesn't seem to have been addressed. TO BE DISCUSSED AT IPR
- You should implement an 'are you sure?' check on the deployment command *LARISSA , THOMAS (Date: 04/07/13, Comment: Added to ground support section)*

BEXUS

Experiment Integration Progress Review

Page 1

1. REVIEW

Flight: BEXUS-16/17

Experiment: iSEDE

Review location: University of Strathclyde, Glasgow, UK

Date: 10th July 2013

Review Board Members

Nick Panagiotopoulos	ESA Technical Directorate
Mikael Inga	SSC Science Services
Alex Kinnaird	ESA Education Office (document review only)

Experiment Team Members

Thomas Sinn	Darryl Black
Tiago de França Queiroz	Frazer Brownlie

2. GENERAL COMMENTS

2.1. Presentation

- No comments.

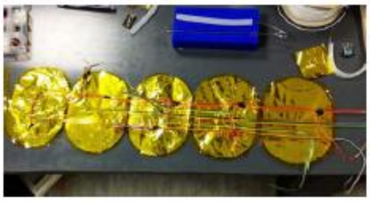
2.2. SED

- Reviewed by Alex Kinnard.

2.3. Hardware

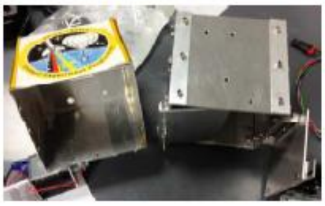
- Design still not frozen (mechanical, electrical, software).
- Lots of open design decisions.
- Still working/testing of subsystems instead of complete system.

3. PHOTOGRAPHS



TM of one row of inflatable cells

(Actuator elements can also be seen in photo)

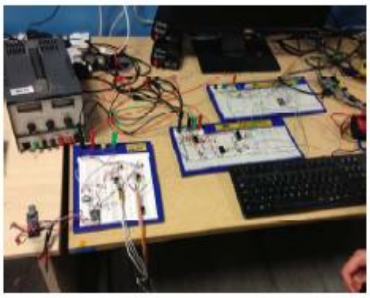


TM of deployment modules

BX_IPR_Isede_V1-0_17Jul13.Doc

BEXUS

Experiment Integration Progress Review



Electronic system

Hack-HD Camera inside housing

4. REVIEW BOARD COMMENTS AND RECOMMENDATIONS

4.1. Science

- Focus on main objectives if necessary.

4.2. Requirements and constraints (SED chapter 2)

- ER_OP_18: Altitude will be minimum 25km, but EuroLaunch can not guarantee a pressure below 20mBar.

4.3. Mechanics (SED chapter 4.2.1 & 4.4)

- Changes of the inflatable cells were made. Specifically:
  - The material of the cells is going to be changed into a different material. The reason for this action is that there is going to be a better bonding with the other units with the cells.
  - Cables that are connected with the units at the side of the cells are attached on them. This type of design was not fully accepted by the reviewers due to the high probability of failure from the stiffness of the cables and the way they are attached. Several advices and ideas were proposed to the team.
- Possible problems were identified regarding the inflation procedure and the boxes. It might be the case that the inflation of the balloons will not allow them to come out of the box. Folding strategy might solve the issue.
- The images' quality of the cameras might be affected by the light coming from the opposite frame of the gondola. Probably shading the frame might solve the issue.
- The thickness of the actuators are going to be changed (thinner and smaller) to improve the actuation.
- Mount the roof support structure on top of the E-Link cradle support bars.

BEXUS

Experiment Integration Progress Review

4.4. Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- Homemade PCBs were manufactured. But the result was not accepted. Too many manufacturing errors. It has been proposed to use a PCB manufacturer.
- The transistors connected with the LEDs for the lighting should be replaced with ones that have metallic case in order to avoid thermal problems.
- Watchdog should be implemented in order to avoid deadlock and other issues. Hardware watchdog was recommended.
- Not fully prototyped, not the full system on board, this should have been done now.
- The cables used for the harness should be exchanged with cables that suites the need better (avoid the ribbon cables, there is better cables).

4.5. Thermal (SED chapter 4.2.4 & 4.6)

- Raspberry Pi cooling issues in low pressure (almost no convection), has to be tested.

4.6. Software (SED chapter 4.8)

- Finalize EGSE SW and test.
- Finalize on-board SW and test.
- Finalize automatic timeline.
- Implement TC verification (at least TC Cmd counter in TM).
- Full system use/test should be done asap.
- How to trigger the automatic sequence has to be finalized.
- If shut-down cmd is implemented check if cmd it is valid when received.

4.7. Verification and testing (SED chapter 5)

- System level testing should be performed (not only subsystem level testing).
- Test harness issues asap (thermal, unfolding etc).

4.8. Safety and risk analysis (SED chapter 3.4)

- RBF not necessary for safety.
- There is no need for safety straps (or RBF) after landing for safety.

4.9. Launch and operations (SED chapter 6)

- Maybe no RBF needed for operations but if keep it simple.
- How to detect if in float phase (also mentioned in 4.6).
- No risk of material release during deployment.
- No bounce more like oscillations up to 100m in beginning of float phase.
- Close files etc before landing, notice will be given before termination of flight.

- Launch crew will bring everything (that they will find) back.
- RF frequency 868/915MHz? SSC, Esrange...
- Team requests 1hour minimum on float phase (better with 2h).
- Revise timeline, update SED.

4.10. Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- Detailed weekly planning from now, open issues has to be assigned to members.
- EAR week 36-37, start planning.
- Ship the experiment latest 23rd of September to Esrange.

4.11. End-to-end Test

- Yes, breadboard electronics/sw was demonstrated.

5. FINAL REMARKS

5.1. Summary of main actions for the experiment team

- Finalize design, manufacture and perform system level tests.

5.2. Summary of main actions for the organisers

- Put Campaign Requirement Plan (CRP) on Teamsite.
- SSC, Esrange has to decide frequency (868/915MHz).
- Confirm campaign date.

5.3. IPR Result: pass / conditional pass / fail

- Conditional pass, new SED to be delivered.

5.4. Next SED version due

- SED Chap 6 to be updated.
- Address the still open points from Alex K. review.
- Latest before EAR.

6. INTEGRATION PROGRESS REVIEW – IPR

Experiment documentation must be submitted at least five working days (the exact date will be announced) before the review (SED version 3). The input for the Campaign / Flight Requirement Plans should be updated if applicable. The IPR will generally take place at the location of the students' university, normally with the visit of one expert.

The experiment should have reached a certain status before performing the IPR:

- The experiment design should be completely frozen
- The majority of the hardware should have been fabricated
- Flight models of any PCB should have been produced or should be in production
- The majority of the software should be functional
- The majority of the verification and testing phase should have been completed

The experiment should be ready for service system simulator testing (requiring experiment hardware, electronics, software and ground segment to be at development level as minimum)

Content of IPR:

- General assessment of experiment status
- Photographic documentation of experiment integration status, with comments were necessary
- Discussion of any open design decisions if applicable
- Discussion of review items still to be closed
- Discussion of potential or newly identified review item discrepancies
- Discussion of components or material still to be ordered or received by the team
- Clarification of any technical queries directed towards the visiting expert
- Communication and functional testing (Service system simulator testing and E-link testing for REXUS and BEXUS respectively)

APPENDIX B – OUTREACH AND MEDIA COVERAGE

20.06.2013 Mechanical and Aerospace Engineering Department / University of Strathclyde

STUDENTS ONE STEP CLOSER TO LAUNCH EXPERIMENT ONBOARD STRATOSPHERIC BALLOON

On 30 May, Craig Hay, Adam Rowan, Frazer Brownlie, Darryl Black, Tiago Queiroz and Thomas Sinn from Strathclyde's iSEDE experiment team were at the European Space Agency's (ESA's) European Space Research and Technology Centre in Noordwijk, Netherlands, for the Critical Design Review (CDR) of their experiment.

The iSEDE (Inflatable Satellite Encompassing Disaggregated Electronics) experiment has the purpose to deploy a shape changing inflatable structure with disaggregated electronics on its surface in the stratosphere. Traditional satellites have a rigid structure defining the basic configuration of the satellite and holding in place all the subsystems. A variation of the shape or configuration of the satellite is normally achieved through the use of deployable structures or appendices (antennas, solar arrays, booms, etc.). Although modern structural solutions are modular and multifunctional, the structure of a satellite still represents a significant portion of its mass and a limitation on the achievable configuration and packing efficiency during launch. The idea of this project is to replace classical rigid structures with lightweight inflatable ones.

The CDR consisted of a twenty minute presentation that was followed by a sixty minute discussion with a panel of experts from the ESA, the German Aerospace Centre (DLR), Swedish Space Centre (SSC) and Swedish National Space Board (SNSB). During the discussion all topics of the mission were covered and the experts were quite pleased with the progress so far.

iSEDE will be launched during the launch campaign in October 2013 at SSC's Esrange Space Centre in Northern Sweden onboard the BEXUS17 balloon. With the positive feedback during the CDR, the team will now finalise the fabrication of the experiment and begin subsystem, system and environment testing. In order to survive the stratospheric balloon flight the experiment needs to withstand temperatures down to -60C and pressures of just a few millibar over two to five hours. The next review is the Interim Progress Review (IPR) in Mid July.

APPENDIX C – TEST REPORTS

iSEDE	**Thermal Testing of Inflatable Cell Bond Lines**	**Doc-No:** TEST-001 **Page:** 1 **Date:** 12/05/2013

Prepared by:	Frazer Brownlie	Date: 10/05/2013
Checked by:	Thomas Sinn	Date: 12/05/2013

Summary

Thermal testing was carried out to establish how the inflatable structure material behaved in low temperature conditions and also to establish which glue worked best sealing the cells. The thermal tests occurred between a temperature range of 21.8°C to -30°C. Once the temperature reached -30°C the chamber was left at this temperature for 10 minutes before the cells were removed.

Different cell configurations were tested, individual cells, double cells and complete 10 cell structure. For the individual cells a variety of glues were used to create the seal of the cells. All of the cells were tested under the same conditions to keep the tests fair and valid.

Contents

Summary 1

1. Single Cell 2
   1.1. UHU Contact Power Glue 2
   1.2. Double Sided Tape 2
   1.3. Stick it! Roller 2
   1.4. Glue Dots Glue Strips 3
2. Double Cell 3
   2.1. UHU Contact Power Glue 3
3. Multiple Cells 3
   3.1. 10 Cell Structure with UHU Contact Power Glue 3
4. Results 4

	Thermal Testing of Inflatable Cell Bond Lines	Doc-No: TEST-001 Page: 2 Date: 12/05/2013

Figure 1: Cell samples in thermal chamber

1. Single Cell

1.1.UHU Contact Power Glue

Once removed from the thermal chamber it was found that the material of the cell did not fell any colder than before it went into thermal chamber. However, when trying to peel away the glue, the seal was broken rather easily, with minimal force being applied. Therefore, the UHU Contact Power Glue would not be an appropriate glue to be used to seal the inflatable structure at high altitude.

1.2.Double Sided Tape

Again the material was not cold when removed from the thermal chamber. It was found that a lot of force was required to peel apart the cells. Therefore, this would be an acceptable glue to use for sealing the material.

1.3.Stick it! Roller

The material again was found to be not cold when removed from the thermal chamber. Not a lot of force was required to break the seal of the cell. It was found to be not as strong as the double sided tape; however, it was a lot stronger than the UHU Contact Power Glue.

	Thermal Testing of Inflatable Cell Bond Lines	Doc-No: TEST-001 Page: 3 Date: 12/05/2013

1.4.Glue Dots Glue Strips

The material was not cold once removed from the thermal chamber. The seal was extremely strong and could not be broken when a high amount of force was applied. Therefore, this would be a very appropriate glue to seal the joints. This glue was found to work the best when compared to the three other glues as the seal could not be broken at all.

2. Double Cell

2.1.UHU Contact Power Glue

From initial manufacturing testing it was found that UHU Contact Power glue worked well as it was the fastest at manufacturing cells and created a strong seal. Three different double celled structures were placed inside the thermal chamber. Two of these structures had a 1cm gap, one with a connecting straw and one with a separate straw for each cell. The third structure had a 2cm gap with two separate straws.

It was decided before the experiment to inflate one of the cells of the structure with the 1cm gap and 2 separate straws. When removed from the thermal chamber it was found that very little of the cell was deflated. Therefore, it retained the air within the cell while at a low temperature. It was also found that very little force was required to be break the seal of the outer perimeter of the cell. However, at the joint which connects the two cells, it was found that the seal was very difficult to break.

The structure with the 1cm gap with a connecting straw was found to be harder to break the outer perimeter of the cell and easier to break the joint which connects the two cells. This was contrast to the other the structure with separate straws. However, this was to be expected as the connecting straw would create a weak point in the joint of the cells.

For the double celled structure with a 2cm gap with two separate straws, it was found that it was a lot more difficult to unpeel the outer perimeter of the cells and at the joint of the two cells. At certain points of the outer perimeter where the seal was attempted to be broken, some of the material ripped at this section. Some of the remaining glue holding the material together. It was to be expected that the joint of the connecting cells would be more difficult to break as more glue was applied to the 2cm gap than the 1cm gap.

For all of the double celled structures, the material was not cold when removed from the thermal chamber.

3. Multiple Cells

3.1.10 Cell Structure with UHU Contact Power Glue

The final structure which was inside the thermal chamber was a full 10 cell structure with UHU Contact Power Glue as the glue which sealed the material. However, it was found that it did not retain the air very well so small strips of reinforced tape was used to seal the small holes which air was escaping from.

It was found that the reinforced tape did not stick very well once removed from the thermal chamber. It could be easily peeled away. The outer perimeter of the cells was also found to fail when a small force was applied to break the seal. This was also found to be true for the joint which connected the cells together. UHU Contact Power Glue was also used to connect the 2 arrays of 5

	Thermal Testing of Inflatable Cell Bond Lines	Doc-No: TEST-001 Page: 4 Date: 12/05/2013

cells, with a small strip of the glue used at the centre of each cell to hold them in place. However, it was found that the cells could easily be unpeeled from one another. The findings show that the UHU Contact Power Glue is not an appropriate glue to use as the sealant for the cells.

4. Results

Thermal testing found that the material was not cold when removed from the thermal chamber and that the material was not any more or less rigid. These would be advantageous to the overall experiment as the material would act as an insulator for the glue, so the cold environment should not affect the glue at all.

It was also found that the glue which worked best was the Glue Dots Glue Lines. This would be the best glue to use out of all that was tested as this was the most consistent and the seal could not be broken. The worst performing glue was the UHU Contact Power Glue. This was the less consistent of the glues which were tested, and the seal was easily broken.

APPENDIX D ADDITIONAL TECHNICAL INFORMATION

1. Bartel mp6 Micropump Datasheet

microComponents

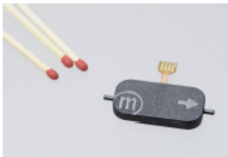
Technical Data of the mp6 [1]

mp6	Order code: mp6
Pump type	piezoelectric diaphragm pump
Number of actuators	2
Dimensions without connectors	30 x 15 x 3.8 mm³
Weight	2 g
Fluidic connectors	barbed tube clip (outer diameter 1.9 mm, length 3.5 mm) [2]
Electric connector	flex connector / Molex FCC 1.25 mm pitch
Power consumption	< 200 mW
Self-priming	yes [3]
Pumping media	liquids, gases and mixtures
Operating temperature	0 – 70°C
Life time	5000 h [4]
IP code	IP33 [5]
Materials in contact with media	polyphenylene sulphone (PPSU) [6]
Suitable evaluation controller	mp-x, mp6-EVA and mp6-OEM

Typical values of flow and back pressure for selected media (values defined with mp-x: 250 V, SRS):			
Gases		Max. flow	18 ml/min (300 Hz)
		Max. back pressure	100 mbar (300 Hz)
Liquids	Water	Max. flow	7 ml/min +/- 15% (100 Hz)
		Max. back pressure	600 mbar +/- 15% (100 Hz)

[1] Typical values. Values can vary under application conditions. Content is subject to changes without notice.
[2] recommended tubing: 1.3 mm inner diameter.
[3] Conditions: suction pressure < 10 mbar, DI water, settings mp-x: 100 Hz, 250 V, SRS, the max. flow rate will be reached after a few minutes of operation time.
[4] Conditions: DI water, room temperature, settings mp-x: 100 Hz, 250 V, SRS.
[5] Can be changed to IP44.
[6] The mp6 is not stable against concentrated alcoholic solutions as MeOH or EtOH.

Please find more information concerning the controller and the equipment in the corresponding data sheets.



Technical Information

TI/ES 1425 e
December 1998

Supersedes edition of September 1996

Glysantin® G 30

® = Registered trademark of BASF Aktiengesellschaft

Glysantin G 30 is a nitrite-, amine-, phosphate-, silicate-, borate-free coolant based on ethylene glycol, which must be diluted with water before use.

Properties

Glysantin G 30 gives outstanding protection against frost, corrosion and overheating in all modern engines, but especially highly loaded aluminium engines. It effectively protects against corrosion and deposits in the cooling system with its vital parts, the coolant channels in the block and cylinder head, the radiator, the water pump and the heater.

Glysantin G 30 is approved by Volkswagen for all engine coolant applications. Glysantin G 30 remains effective for a long time, so that the first coolant change can typically be done after not less than four years. Follow the vehicle manufacturers recommendations.

Glysantin G 30 is miscible and compatible with previous silicate containing coolants meeting VW standard TL774B or C such as for example Glysantin G 48, Glysantin Protect plus or VW Coolant G 11.

Miscibility

Since the special advantages of Glysantin G 30 such as improved protection for Aluminium and longer change intervals will only be achieved using pure Glysantin G 30, **mixing with other coolants should be done only in exceptional circumstances.**

Glysantin G 30 should be diluted 1:1 by volume with water* before filling into the cooling system.

** For preparation of the coolant use clean, not overly hard water. Waste water from mining, sea water, brackish water, brine, industrial waste water are all unsuitable.*

The analysis of the water should not exceed the following limits:

Water hardness	*0 to 25 °Clark (0 – 3.6 mmol/l)*
Chloride content	*max. 100 ppm*
Sulphate content	*max. 100 ppm*

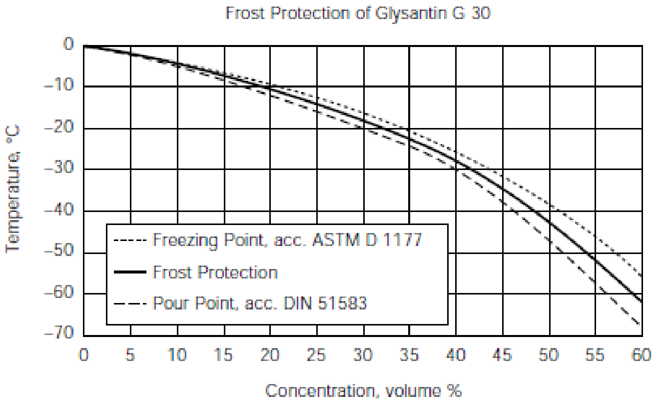
Should the analysis of the water exceed the approved limits, then it has to be suitably treated, for example by mixing with pure, distilled or deionised water. Excessive chloride or sulphate levels can be corrected in this way.

Specialty Chemicals

Glysantin G 30

Chemical nature	Monoethylene glycol with inhibitors		
Appearance	Clear liquid, without solid contaminants.		
Properties	Density at 20°C	1.122 – 1.125 g/cm³	DIN 51757 procedure 4
	Viscosity at 20°C	22 – 26 mm²/s	DIN 51562
	Refraction at 20°C	1.432 – 1.436	DIN 51423
	Boiling point	> 160°C	ASTM D 1120
	Flash point	> 120°C	DIN ISO 2592
	pH value	8.2 – 9.0	ASTM D 1287
	Reserve alkalinity M/10 HCl	8.5 – 11 ml	ASTM D 1121
	Ash content	max. 2 %	ASTM D 1119
	Water content	max. 3 %	DIN 51777
Solubility	Miscibility with water	in all proportions	
	Miscibility with hard water	no precipitation	
Stability	Inhibitor stability after 168 h	no separation	VW TL 774 D
	Hard water stability after 10 days	no separation	VW-PV 1426

Technical data for Glysantin G 30 – water mixtures



The values of frost protection are calculated according to the arithmetical means arising from freezing point and pour point.

2

Viscosity DIN 51562

at 0°C	50% in water 33% in water	8–10 mm^2/s 5– 6 mm^2/s
at 20°C	50% in water 33% in water	3– 5 mm^2/s 2– 3 mm^2/s
at 80°C	50% in water 33% in water	0.9–1.1 mm^2/s 0.6–0.8 mm^2/s

Foaming tendency ASTM D 1881 max. 50 ml/1–3 s

Rubber swelling with commonly used SBR and EPDM qualities

80°C/168 h 50% in water	0–3%	similar to pure water

Corrosion tests

Glassware test ASTM D 1384

Metal or alloy	typical weight loss in mg per coupon	limit ASTM D 3306
copper	–0.8	max. 10
solder	–1.2	max. 30
brass	–0.9	max. 10
steel	+0.1	max. 10
cast iron	+1.3	max. 10
cast aluminium	–4.0	max. 30

Simulated service corrosion test ASTM D 2570

Metal or alloy	typical weight loss in mg per coupon	limit ASTM D 3306
copper	–2.8	max. 20
solder	–1.7	max. 60
brass	–1.4	max. 20
steel	–0.3	max. 20
cast iron	+3.0	max. 20
cast aluminium	–3.3	max. 60

Cavitation – erosion – Corrosion test ASTM D 2809

	evaluation	limit ASTM D 3306
Al water pump	9	min. 8

Heat transfer test ASTM D 4340

	typical weight change in mg/cm^2/week	limit ASTM D 3306
G AlSi6Cu4:	–0.3	max. 1.0

Polarisation resistance NF R 15-602-9

		limit
Aluminium:	$1.2 * 10^6\ \Omega{*}cm^2$	$>10^6\ \Omega{*}cm^2$

3

Quality control	The data given here are typical data at the time of preparation of this data sheet. They do not represent a product specification. Specified values are contained in a special Product Specification.
Storage Stability	Glysantin G 30 is stable for at least 2 years if stored in airtight containers. Because of corrosion galvanised containers should not be used.
Safety data sheets	A safety data sheet according to EC regulations 91.155 is available.
Handling and protective measures	The usual precautions for handling chemicals must be observed. In particular the place of work must be well ventilated, the skin protected and safety glasses worn at all times. Avoid contact with the skin.

Note

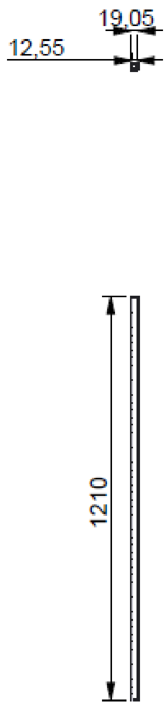
The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

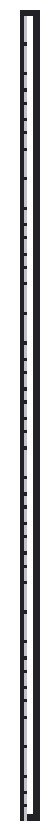
BASF Aktiengesellschaft
Marketing Spezialchemikalien II
67056 Ludwigshafen, Germany

Printed in Germany

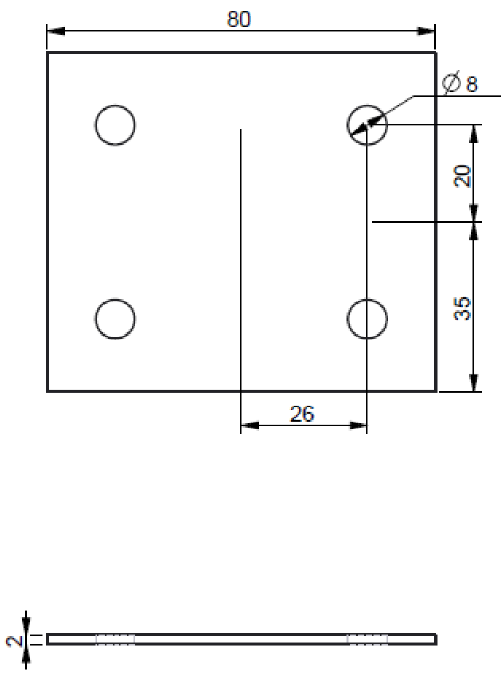
BASF

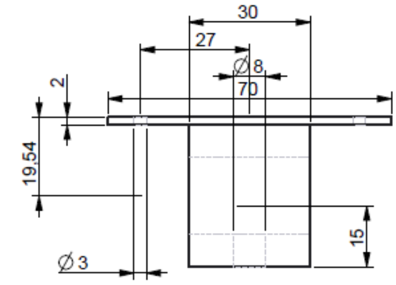
Frazer Brownlie	iSEDE
Camera Mount Tube	Measurement:mm Tolerance:0+0.25



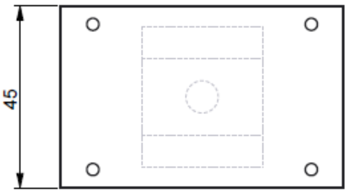


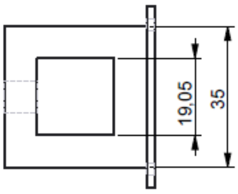
Frazer Brownlie	iSEDE
Camera Mountplate	Measurement:mm Tolerace:0+0.25

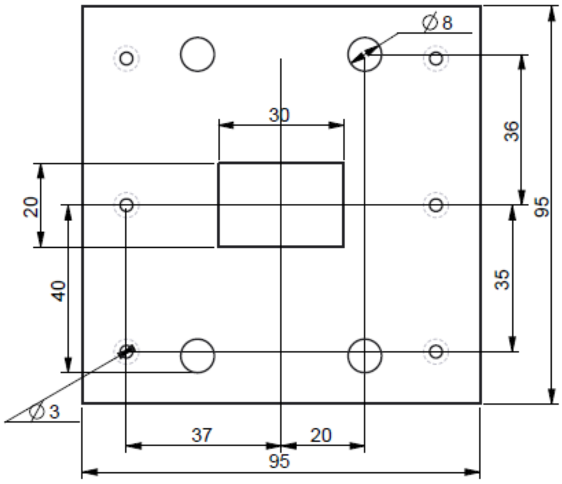




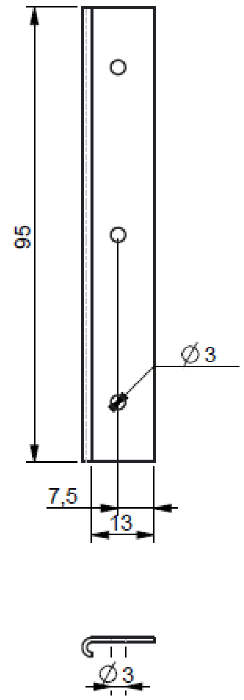
Frazer Brownlie	iSEDE
Camera Slidefit	Measurement: mm Tolerances: 0+0.25



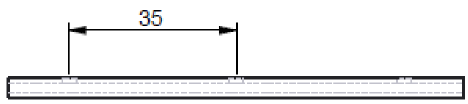


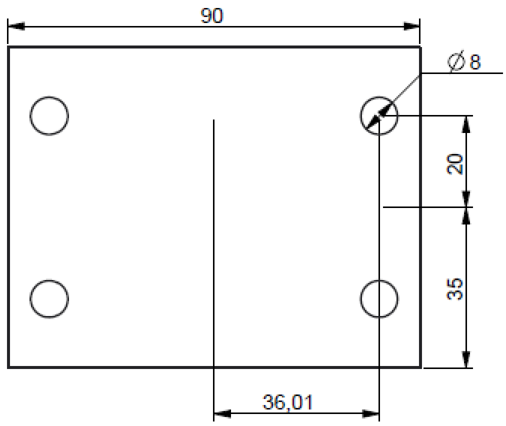


Frazer Brownlie	iSEDE
Cell mount	Measurement: mm Tolerances: 0 + 0.25

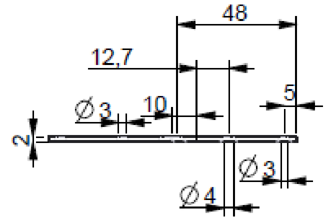


Frazer Brownlie	iSEDE
Cell Mount Lower	Measurement:mm Tolerances: 0+0.25

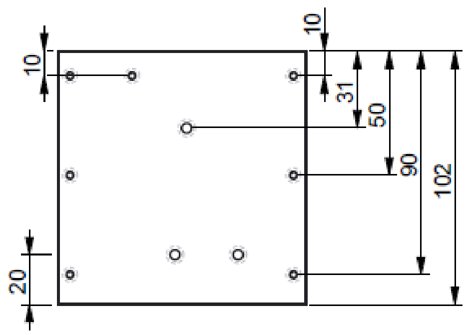


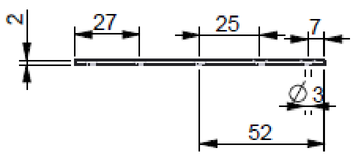


Frazer Brownlie	iSEDE
Deployment Box Mount Plate	Measurement:mm Tolerances: 0+0.25

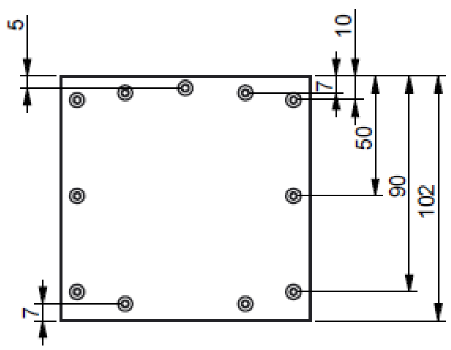


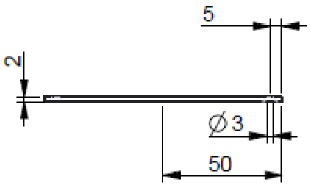
Frazer Brownlie	iSEDE
Deployment Box Side 3	Measurement:mm Tolerances: 0+0.25



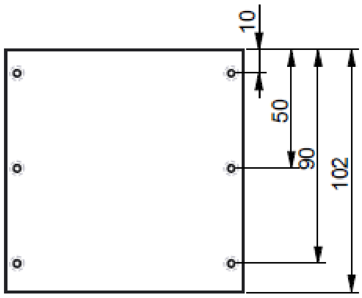


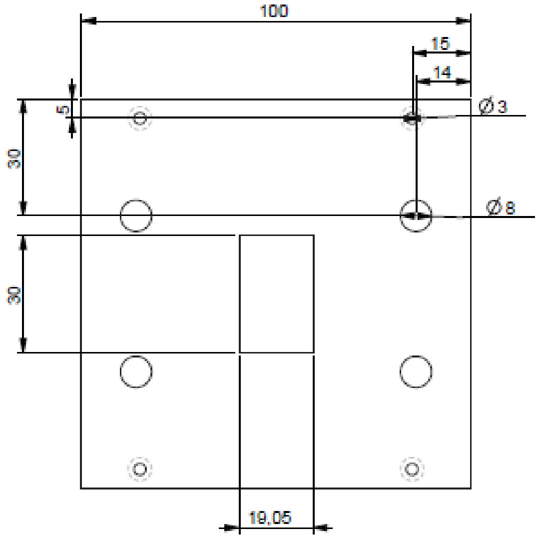
Frazer Brownlie	iSEDE
Deployment Box Side 1	Measurement: mm Tolerances: 0+0.25



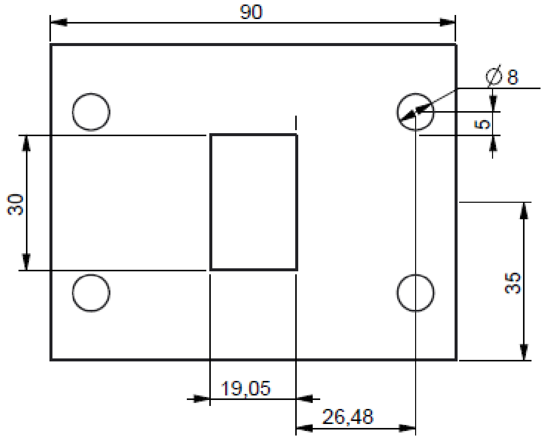


Frazer Brownlie	iSEDE
Deployment Box Side 2	Measurement:mm Tolerances: 0+0.25

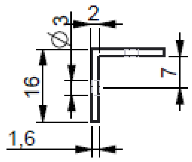




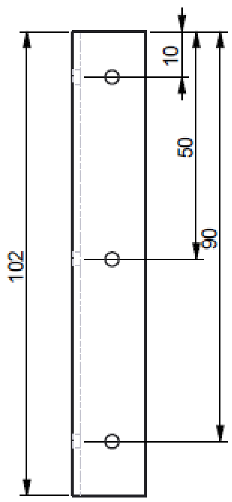
Frazer Brownlie	iSEDE
Deployment Box Base	Measurement:mm Tolerances: 0+0.25

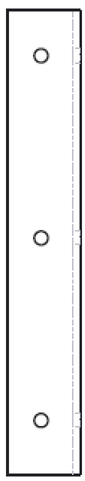


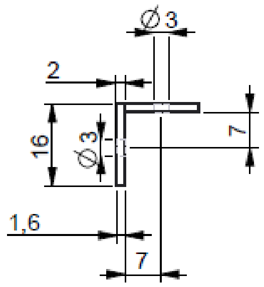
Frazer Brownlie	iSEDE
Deployment Box Base Fill	Measurement:mm Tolernace: 0+0.25



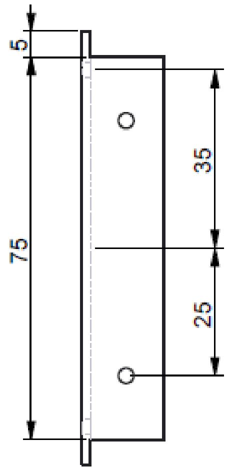
Frazer Brownlie	iSEDE
Deployment Box Corner	Meaurement:mm Tolerance:0+0.25

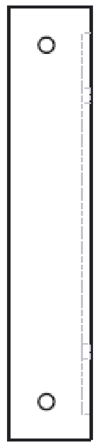


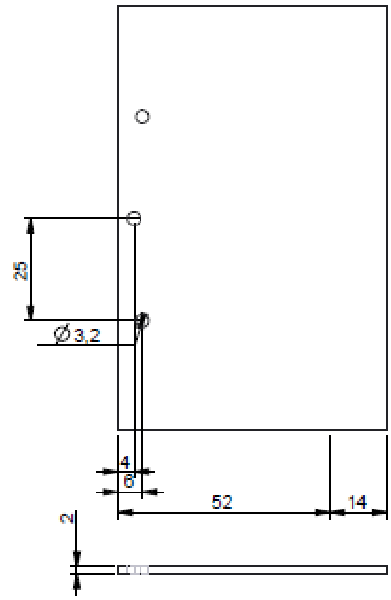




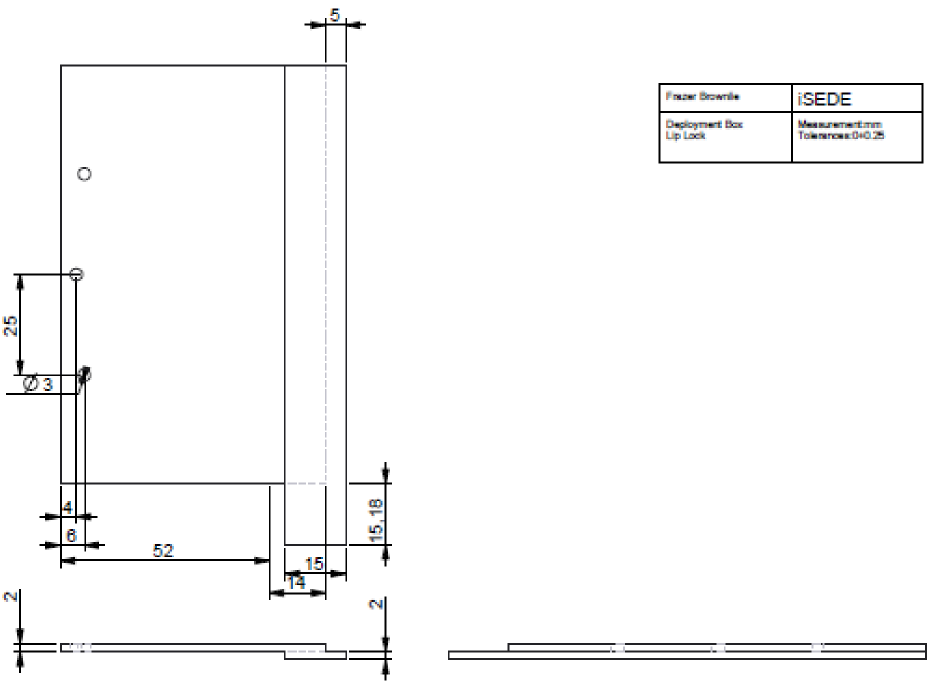
Frazer Brownlie	iSEDE
Deployment corner Base	Measurement:mm Tolernaces:0+0.25



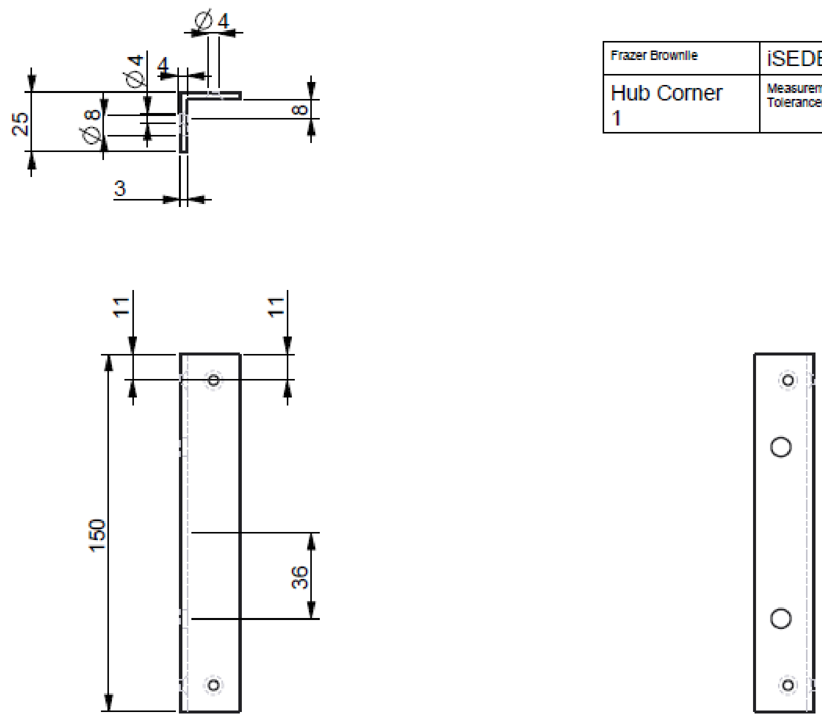




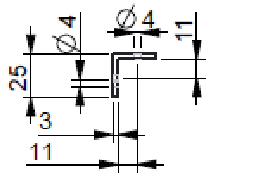
Frazer Brownlie	iSEDE
Deployment box Lip	Measurement:mm Tolernaces: 0+0.25



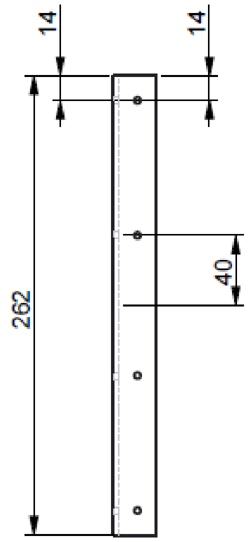
Frazer Brownlie	iSEDE
Deployment Box Lip Lock	Measurement:mm Tolerances:0+0.25

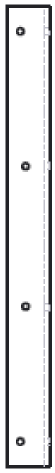


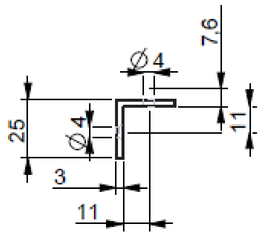
Frazer Brownlie	iSEDE
Hub Corner 1	Measurement:mm Tolerances:0+0.25



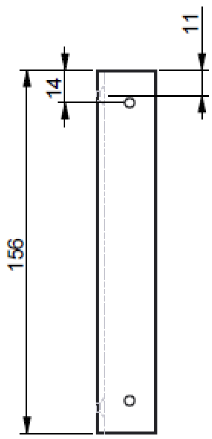
Frazer Brownlie	iSEDE
Hub Corner 2	Measurement:mm Tolerances:0+0.25

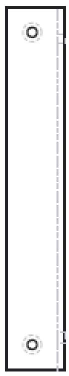


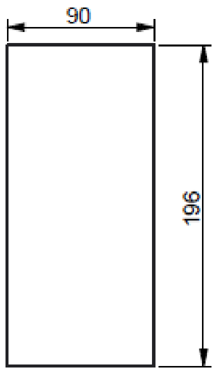




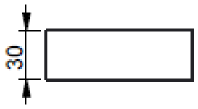
Frazer Brownlie	iSEDE
Hub Corner 3	Measurement:mm Toerances:0+0.25

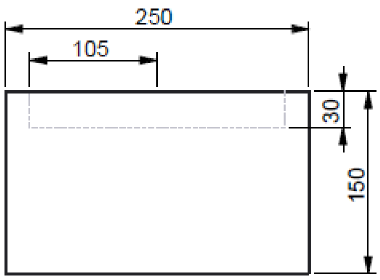




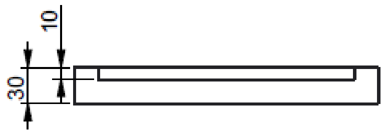


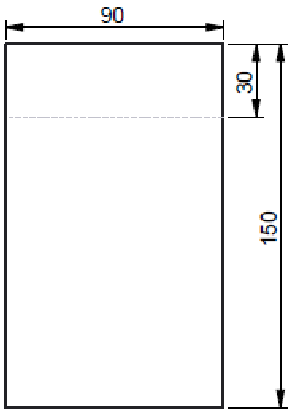
Frazer Brownlie	iSEDE
Hub Foam Back	Measurement:mm Tolerance:0+0.25



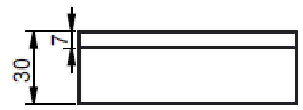


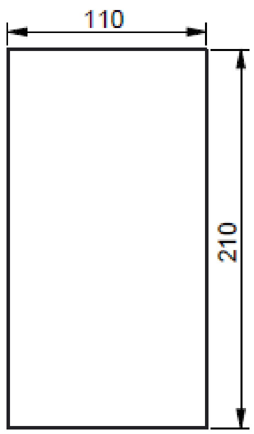
Frazer Brownlie	iSEDE
Hub Foam Large	Measurement:mm Tolerance:0+0.25



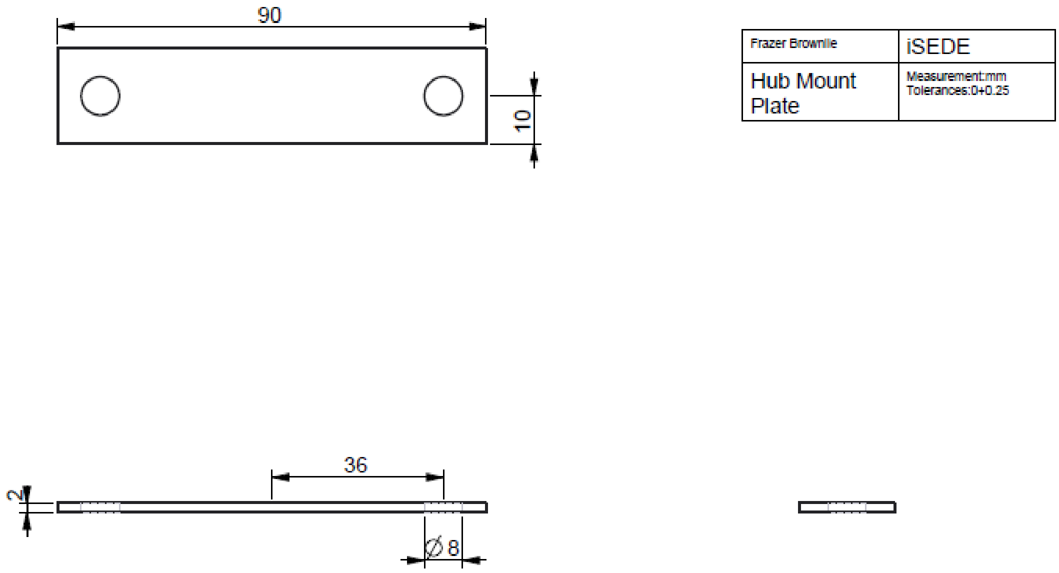


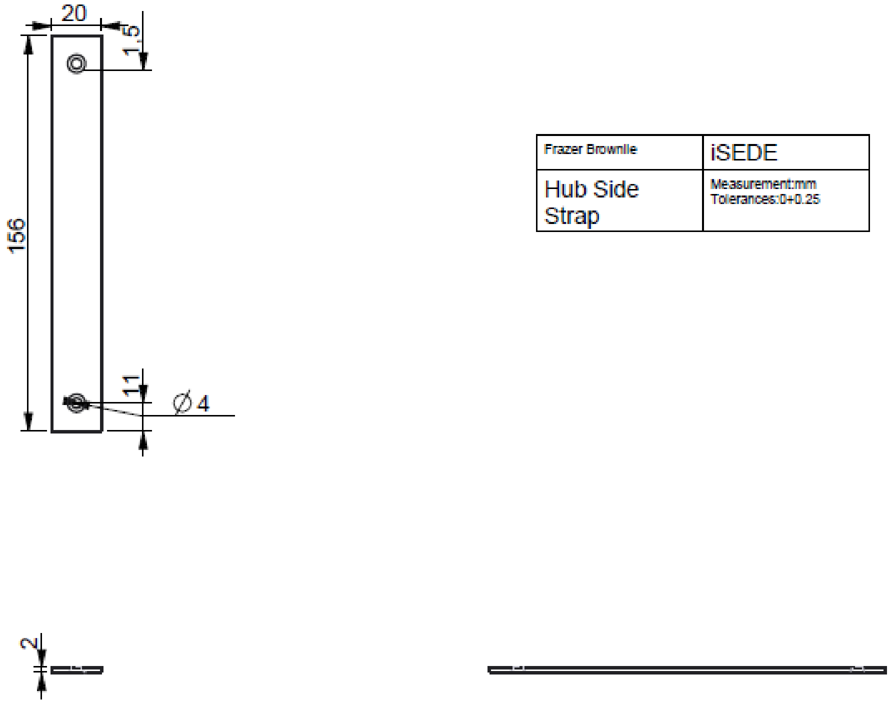
Frazer Brownlie	iSEDE
Hub Foam Side	Measurement:mm Tolerance:0+0.25

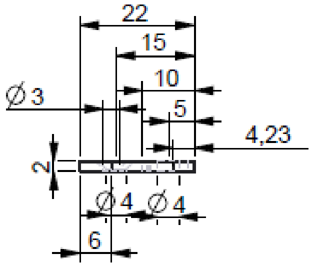




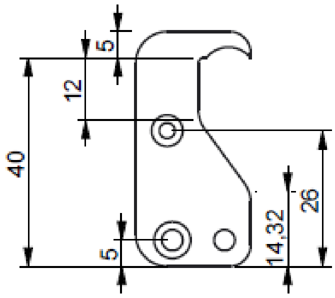
Frazer Brownlie	iSEDE
Hub Foam Top	Measurement:mm Tolerance:0+0.25

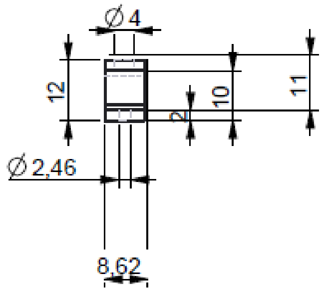

90
10
36
2
Ø 8
Frazer Brownlie
iSEDE
Hub Mount Plate
Measurement:mm
Tolerances:0+0.25


20
1.5
156
11
Ø 4
2
Frazer Brownlie
iSEDE
Hub Side Strap
Measurement:mm
Tolerances:0+0.25

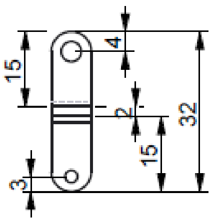


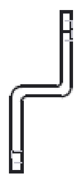
Frazer Brownlie	iSEDE
Latch	Measurement:mm Tolerance:0+0.25

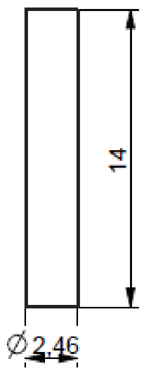




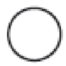
Frazer Brownlie	iSEDE
Link	Measrement:mm Tolerance:0+0.25

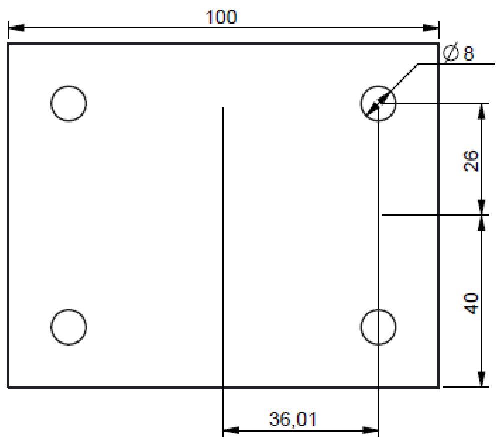




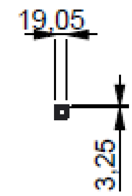


Frazer Brownlie	iSEDE
Solenoid Pin	Measurement:mm Tolerace:0+0.25

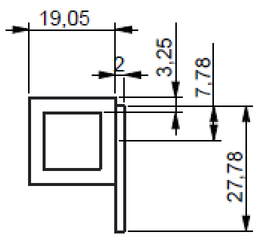




Frazer Brownlie	iSEDE
Support Mountplate	Measurement:mm Tolerances:0+0.25



Frazer Brownlie	iSEDE
Tube Long	Measurement:mm Tolerances: 0+0.5



Frazer Browlie	iSEDE
Tube Short	Measurement:mm Tolernaces:0+0.25