SED

Student Experiment Documentation

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Mission: Rocket EXperiment for University Students (REXUS)

Team Name: Telescobe 2

Experiment Title: Novel Telescopic Boom Demonstration

Team	**Name**	**University**
Student Team Leader:	Stephen Curran	Dublin Institute of Technology (DIT)
Team Members:	Paul Duffy	
	Johnalan Keegan	
	Dinesh Vather	
	Mark Nolan	
	Sean Ludlow	
	Keelan Keogh	
	Ronan Byrne	

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Paul Duffy

Experiment Scientist

Approved by:

Stephen Curran

Payload Manager

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ABSTRACT

Telescobe 2 was an experiment developed by students from Dublin Institute of Technology, Ireland that launched on board the REXUS 11 sounding rocket from Esrange space centre in Sweden in November 2012.

The experiment concerned the development and testing of a novel carbon fibre, telescopic boom system for deploying measurement probes from sounding rockets in the upper atmosphere. A problem with the experiment's computer during the flight meant that no telemetry was sent to the ground station. Despite this, the experiment can be deemed to have been successful. The carbon fibre, telescopic boom deployed and settled quickly at T+86s and remained stable until T+177s, a period of time that took it through the apogee of the flight. As such, this boom system has been shown to be suited for use on sounding rockets where the fast deployment time lends itself to the short payload flight time.

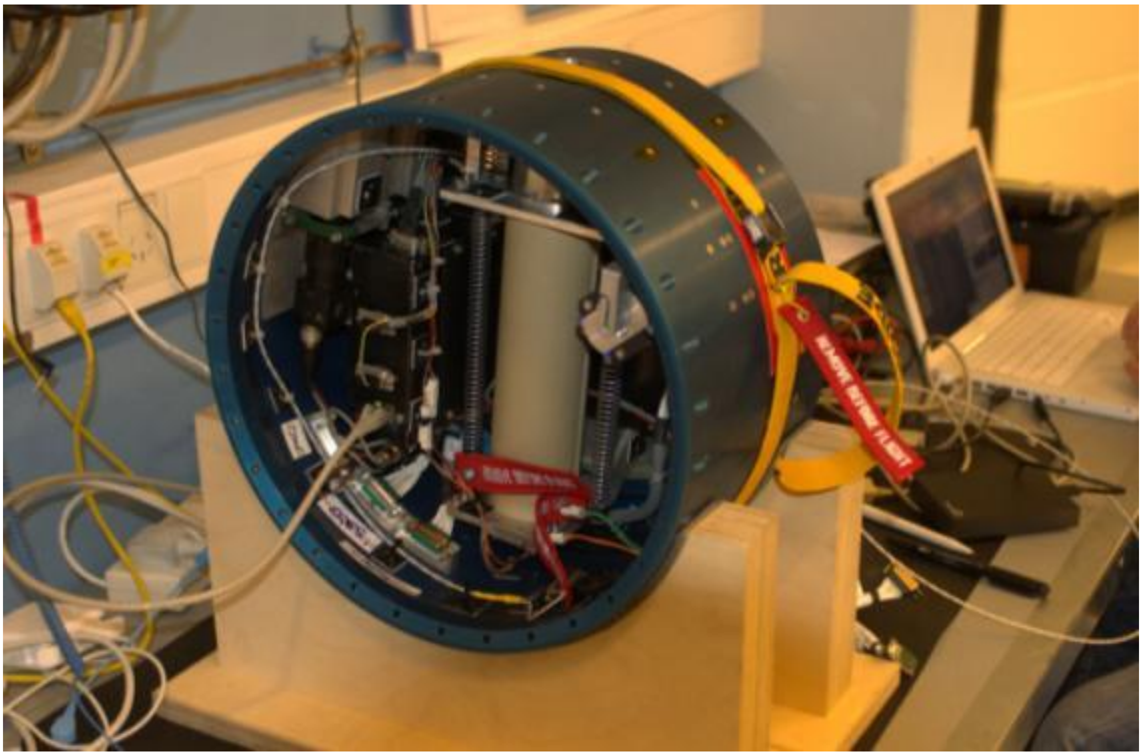


Figure 0-1: The complete experiment module, armed and ready for final integration with the rest of the REXUS 11 payload.

1 INTRODUCTION

Telescobe 2 was a project being undertaken by postgraduate and undergraduate engineering students from the Dublin Institute of Technology (DIT), Ireland. The aim of the project was to design, build and test a telescopic boom system capable of being used to deploy E-Field and Langmuir probes for use in upper atmospheric research. A telescopic boom system makes more efficient use of the allowable space when compared with typical non-telescopic boom systems on-board spacecraft. Since stowage space and mass are critical, telescopic boom systems are potentially more desirable to design engineers. The potential for the more rapid deployment of a telescopic boom system also points to it being particularly suited for use on sounding rockets, which tend to have a relatively short flight time.

This experiment was launched on a near-space flight on the REXUS 11 sounding rocket in November 2012. It is a successor to the original Telescobe experiment which was launched from Esrange in February 2011. Due to a malfunction with the experiment hatch, the original Telescobe experiment didn't function as expected. As a result, it was redesigned and flew under the name Telescobe 2. Telescobe 2 was originally supposed to be launched on the REXUS 12 sounding rocket in March 2012. However, as the payload for REXUS 12 was deemed to be excessively heavy, Telescobe 2 was switched to REXUS 11 at the beginning of the launch campaign, despite all integration, bench and service module tests to that point having been conducted with REXUS 12. As a result of this switch, REXUS 12 was launched before REXUS 11 and experienced a sub-nominal flight. This resulted in the launch of REXUS 11 being re-scheduled to November 2012.

The REXUS / BEXUS programme is realised under a bilateral Agency agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through collaboration with the European Space Agency (ESA).

1.1 Scientific/Technical Background

Upper atmospheric research provides many valuable insights to scientists. Information on the composition of the atmosphere and magnetosphere can be studied. In doing so, the effects of both solar weather and pollution on our atmosphere can be understood. Figure1-1 below highlights how the solar winds interact with the atmosphere (left) and also shows the Earths atmospheric temperature profile (right). From the thermal profile shown below, it is obvious that this harsh environment can be challenging for any effective measurement methods. Upper atmospheric research can be carried out using a number of methods, such as, high altitude balloons, sounding rockets and satellites. High altitude balloons offer a relatively cheap and simple method of conducting this research. Experimental payload design and testing is also relatively quick but the maximum attainable altitude is usually no more than 45 km.

Sounding rockets provide a method for conducting upper atmospheric research at much greater altitudes, typically between an altitude of 45 km and 160 km. However, some sounding rockets can reach altitudes of over 1500 km [1]. The minimum altitude for satellite research is just above this 160 km. The advantage of satellite experiments is that they can take measurements in the space environment for much longer periods of time. Satellites can also conduct similar research on other celestial bodies. However, payload design and testing is much longer and overall costs are much higher than either sounding rockets or high altitude balloons.

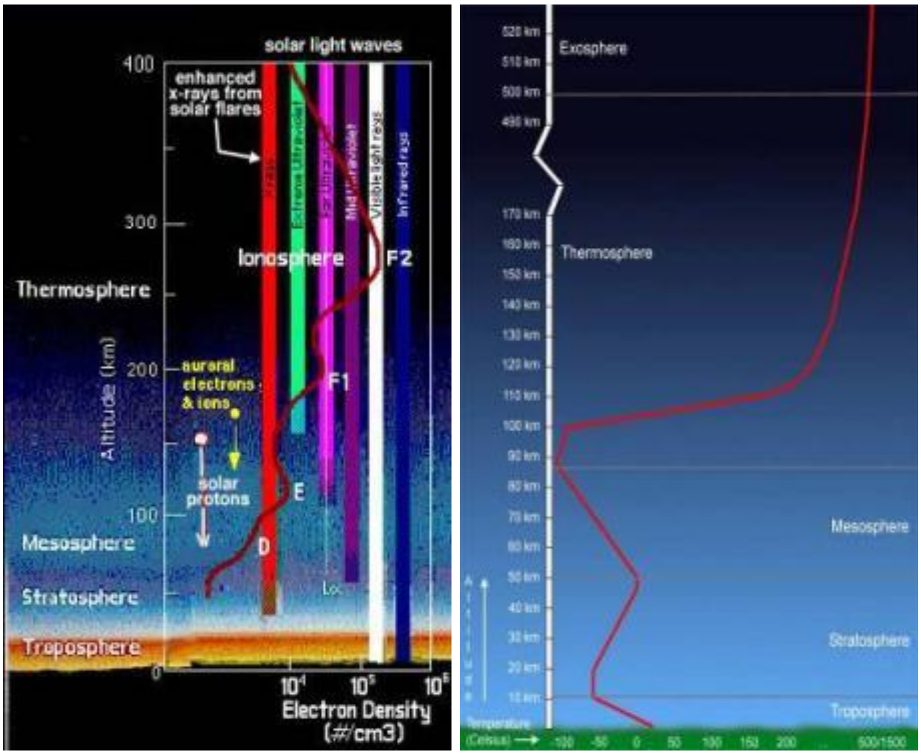


Figure1-1: Images Showing Solar Interaction with Atmosphere and Temperature Profile of Atmosphere [2] [3]

Measurements of the Earth's magnetic field and the atmospheric plasma electron density are typically measured by E-Field probes and Langmuir probes.

Electric field, or E-Field, probes as their name suggests, are used to measure the magnitude of the electric fields in the atmosphere. They can be split into two main classifications: active or passive probes and are usually deployed in pairs. Langmuir probes are used to measure the ionisation energy and electron temperature of plasma. Measurements can be made using one probe however as many as five probes have been used with certain configurations.

Figure 1-2 shows an E-Field and a spherical Langmuir probe side by side.

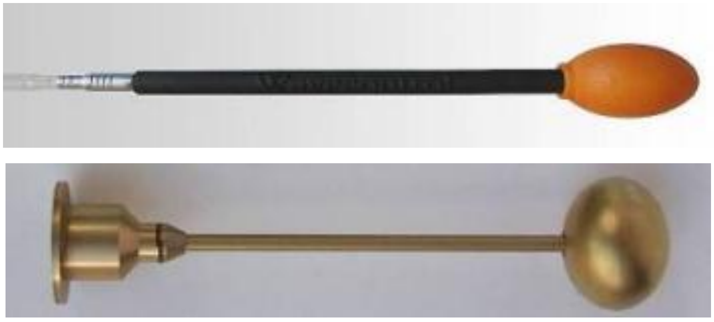


Figure 1-2: An E-Field Probe (top) and a Spherical Langmuir Probe (bottom)[4],[5]

In order to take their measurements these probes have to be extended out from the balloon/rocket/satellite payload bay. The attitude of the probes must be known at all times for accurate measurements. It is also necessary to extend the measurement probes so they clear any wake turbulence or electromagnetic fields created by the main vehicle. There are a number of different systems available to deploy these probes. Probes extended from the spacecraft by wires are compact. However the vehicle must be spinning in order to take advantage of centrifugal forces which are used to deploy the probes. These probes are prone to oscillation (as they lack rigidity) in turn effecting measurement accuracy. Single rigid booms can support larger probes and are less prone to oscillation than wire deployment. However, they require a large amount of stowage space in the main vehicle. Folding booms may require less stowage space than single rigid booms but may weigh more due to the more joints in their design as shown in Figure 1-3. Screw driven telescopic booms can require less stowage space than either folding or rigid booms. However they can take time to deploy and cannot take advantage of the centrifugal force generated by spin stabilized craft to deploy.

It is clear from the above descriptions that each boom system has both advantages and disadvantages. Figure 1-4 shows some of the different systems mentioned above. In this case the probes are deployed from a sounding rocket (left) and a satellite (right).

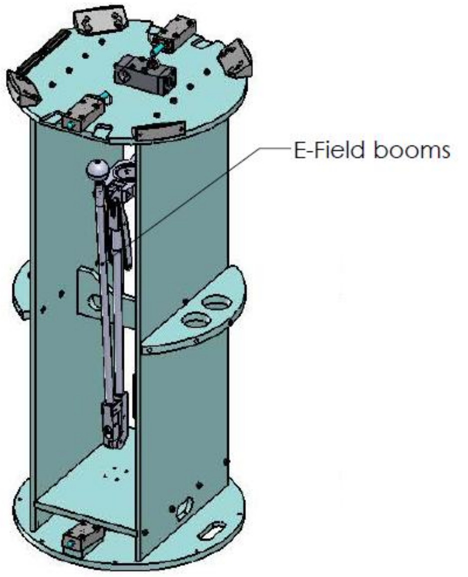


Figure 1-3: Folded E-Field Boom Configuration [6]

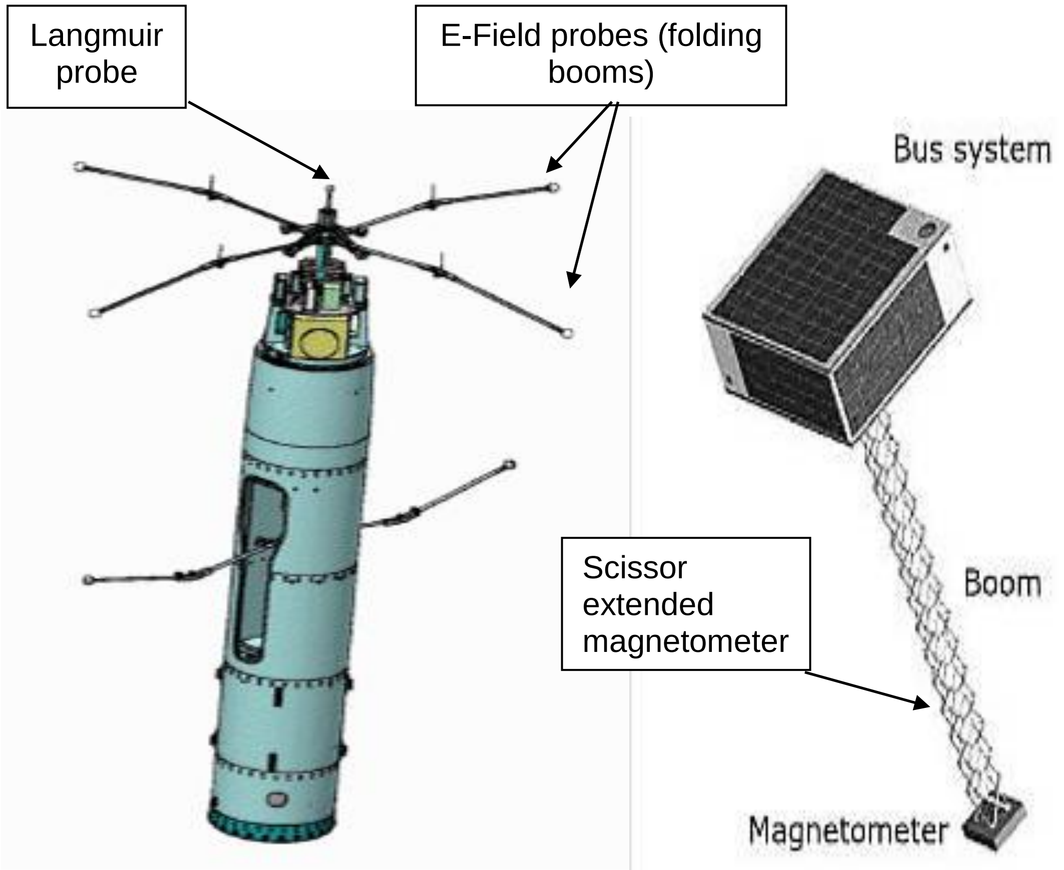


Figure 1-4: Different Boom Applications [6], [7]

A spring loaded telescopic boom system offers stowage advantages (similar to that of screw driven telescopic boom). It can also take advantage of the centrifugal force generated by spin stabilised spacecraft to deploy, but does not solely rely on this for deployment.

The lack of a mechanical drive system in its design may also results in both mass and cost savings compared to a screw driven boom. The quick deployment time of a spring loaded boom system means that it is suited to sounding rocket flights where data acquisition times may be limited to a short period of time due to the flight plan in place.

A spring loaded telescopic boom would have potential applications in many of these activities. It is hoped that these types of boom may also be used to deploy antennae and solar panels as well as other types of measurement probes.

1.2 Experiment Objectives

The primary objectives of our experiment are:

- To design and build a telescopic boom, boom deployment and boom jettison system.
- To **safely** test this system on a near-space flight aboard the REXUS 11 sounding rocket.
- To monitor and record boom deployment length, boom displacement, boom amplitude of vibration at distal end and boom jettison.
- To monitor and record vibration and deflection data.
- To collate, analyse and disseminate experiment data via presentations and publications.
- To promote the activities of Team Telescobe, DIT, REXUS, ESA, DLR, SNSB and SSC through an extension outreach program.

The secondary objectives of our experiment are:

- To measure the thermal profile of the experiment module throughout the flight.
- To validate our simulation models using flight data.
- To verify that telescopic boom is suitable for use in the deployment of E-Field and Langmuir probes in the ionosphere.
- To recover experiment hardware.

Performing E-field measurements did not fall within the scope of the experiment. Instead a probe housed an accelerometer (for boom vibration measurement) and six LEDs (which were used to provide data points for deployment and deflection measurements). The probe and cabling used were of similar specification to actual E-Field probes and associated cabling.

1.3 Experiment Overview

The experiment consists of a telescopic boom capable of deploying a probe to a distance of approximately 1.7m from a REXUS sounding rocket. The boom is initially stored in a 30cm long housing inside the experiment module. At an appropriate time during the flight, a hatch in the skin of the experiment module opens. A pyrotechnic guillotine is then used to cut a cable that retains two tension springs in their extended position. When these springs are released they accelerate the tapered sections of the boom out through the hatch. The sections then lock into one another to give a rigid boom. The probe is attached to the smallest boom segment and is also forced out of the housing by the springs. When the boom has been deployed, data on the deployed length, boom deflection and any boom vibration data is gathered using two measurement cameras in the experiment module and an accelerometer mounted in the probe. The boom is then be jettisoned before the re-entry of the sounding rocket payload into the earth’s atmosphere. This is to ensure that it doesn’t interfere with the operation of the payload recovery system. A live TV feed provides real-time monitoring of the deployment and jettisoning of the boom. A solid model of the experiment module is shown in Figure 1-5.

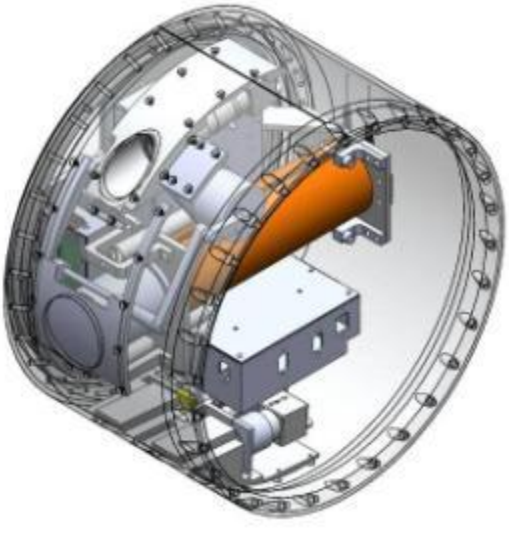


Figure 1-5: Solid model of the Telescobe 2 experiment module

1.4 Team Details

1.4.1 Contact Point

The Telescobe 2 team can be contacted via the following:

Email: spaceresearch@dit.ie

Phone: +353 1 4024062

Interested parties are also welcome to join and communicate with us through our Facebook page (alias "Rexus Dit") or our website: http://spaceresearch.dit.ie

1.4.2 Team Members

The Telescobe 2 team consists of eight core members, five post-graduate students and three undergraduate students from Dublin Institute of Technology (DIT). All of the postgraduate team members are undertaking this work in addition to their current studies and no form of academic credit is being awarded. The three undergraduate team members undertook this project as part of their final year theses and were be awarded academic credit for their participation in the project. Team biographies are as follows:

Stephen Curran

Responsibilities: Team Leader. Electrical System Design and Testing

Graduated from the DIT with a Bachelor's Degree (Honours) in Mechanical Engineering in 2005. Currently pursuing a doctorate in DIT in the area of robotics.

Johnalan (Jack) Keegan

Responsibilities: Electronic System and Software Design

Graduated from DIT with a Bachelor's Degree (Honours) in Electrical/Electronic Engineering in 2005. Currently pursuing a doctorate in DIT. He is integrating bioelectrical and biomechanical signals for rehabilitation and assistive technology. Has prior experience in industry as a software developer, IT systems engineer and project manager.

Paul Duffy

Responsibilities: Outreach, Risk Management and Mechanical

Graduated from the DIT with a Bachelor’s Degree (Honours) in Mechanical Engineering in 2008. Currently pursuing a doctorate in DIT. He is developing a monitoring and control system for water supplies incorporating a biosensor capable of detecting specific target DNA sequences. Attended the Space Studies Program 2009 run by the International Space University in NASA Ames.

Dinesh Vather

Responsibilities: Mechanical and Electrical Design

Graduated from the DIT with a Bachelor’s Degree (Honours) in Manufacturing Engineering in 2008. Currently pursuing a doctorate in DIT titled ‘The Optimisation of the Mechanical Design Aspects of a High Resolution Near-infrared Echelle Spectrograph (NAHUAL)’. Worked as a manufacturing technician and design engineer with Xsil Ltd. for five years. Worked for Intel as a metrology operative for one year

Keelan Keogh

Responsibilities: Hatch System Design

Graduated from the DIT with BEng Tech in Automation Engineering in 2010 and with a Honours Bachelor’s Degree in Manufacturing and Design Engineering in DIT in 2012.

Ronan Byrne

Responsibilities: Camera System

Graduated from the DIT with a Honours Bachelor’s Degree in Manufacturing and Design Engineering in 2012.

Sean Ludlow

Responsibilities: Spin Table and Boom Retention System

Graduated from the DIT with a BEng Tech in Mechanical Engineering in 2012.

Mark Nolan

Responsibilities: Surface Mount Devices & PCB Fabrication

Graduated from the DIT with a Bachelor’s Degree (Honours) in Control Systems and Electrical Engineering in 2005. Currently pursuing a doctorate in DIT titled “Applications of Measurement Sensors in Assistive Technology”

2 EXPERIMENT REQUIREMENTS

The following section details the experiment requirements. These are broken down into functional, performance, design and operational requirements. The words *shall*, *should* and *may* are used respectively to depict mandatory requirements, those that will be considered but are not seen as mandatory, and requirements that will be considered when all other requirements have been satisfied.

2.1 Functional Requirements

	Requirement
F.1.	A hatch *shall* open.
F.2.	The telescopic boom *shall* safely deploy.
F.3.	Boom deployment *shall* be recorded.
F.4.	Deflection and vibrations at the distal end of the boom *shall* be recorded.
F.5.	Boom deployment, deflection and vibration *should* be monitored and recorded in real time by the ground station.
F.6.	The boom *shall* be safely jettisoned before re-entry.
F.7.	Temperature readings *may* be recorded inside the experiment module during the flight.
F.8.	The strain on the boom housing *may* be measured

Table 2-1: Functional Requirements

2.2 Performance Requirements

	Requirement
P.5.	The telescopic boom *shall* deploy in less than 1.5 seconds. *Response to Req.F.2.*
P.6.	The boom *shall* deploy to 1.7m total length. This is the distance from the payload roll axis to the tip of the probe fitted to the distal end of the boom. *Response to Req.F.2.*
P.7.	Boom deployment length accuracy *shall* be such that the distance between the tip of the boom and the REXUS roll axis does not vary by more than 0.5% of max boom length *Response to Req.F.2.*
P.8.	Boom deflection and vibration amplitude at the distal end of the boom shall result in the top of the boom being displaced by an angle not greater than 2 degrees from an axis through the boom mounting that is perpendicular to the REXUS roll axis.
P.9.	The boom *shall* be jettisoned away from spacecraft at T+220 seconds. *Response to Req.F.6.*
P.10.	Boom deployment *shall* be recorded by a camera system. *Response to Req.F.3.*
P.11.	Boom deflection *shall* be recorded using the camera system. *Response to Req.F.4.*
P.12.	The camera system *shall* be capable of recording up to 30 frames per second (FPS). *Response to Req.F.4.*

	Requirement
P.13.	Real time camera data *should* be transmitted to ground station using the RXSM TV transmitter. *Response to Req.F.5.*
P.14.	Other real time data *should* be transmitted to the ground station using the RXSM telemetry system. *Response to Req.F.5.*
P.15.	Measurements from the data acquisition system *shall* be stored for post flight analysis. *Response to Req.F.3. and Req.F.4.*
P.16.	Vibrations *shall* be recorded by an accelerometer at the distal end of the boom. *Response to Req.F.4.*
P.17.	The accelerometer *shall* record data of a sampling rate 20 times the expected maximum boom vibrational frequency. *Response to Req.F.4.*
P.18.	Temperature readings *may* be taken in the "Telescobe" module using thermocouples. *Response to Req.F.7.*
P.19.	Thermocouples *may* sample at a rate of 1 sample per second. *Response to Req.F.7.*
P.20.	Thermocouples *may* be capable of measuring temperature range 173-473K. *Response to Req.F.7.*

Table 2-2: Performance Requirements

2.3 Design Requirements

	Requirement
D.1.	The experiment *shall* fit into a module of inside diameter 348.6mm.
D.2.	The experiment *shall* fit into a module of height 220mm.
D.3.	The experiment *shall* be capable of withstanding the REXUS temperature profile (173-473K).
D.4.	The experiment *shall* be capable of withstanding the pressures experienced during the flight (0.5mBar absolute).
D.5.	The experiment *shall* be capable of withstanding acceleration of up to 20*g*.
D.6.	The experiment *shall* consume less than 28W of power at all times, except during boom deployment and jettison.
D.7.	The solid-state memory device *shall* be capable of withstanding an impact at 8m/s.
D.8.	The solid-state memory device *shall* be capable of storing the data stream from the video acquisition system.
D.9.	The experiment *shall* be capable of withstanding the vibration of the REXUS rocket as described in the REXUS user manual.
D.10.	The experiment *shall* interface with the RXSM through a D-SUB 15 male connector.
D.11.	The experiment shall interface with the RXSM TV transmitter via a BNC connector.

D.12.	The experimental module *shall* have a mass of less than 5kg.
D.13.	The experiment *shall* be thermally insulated such that it does not cause a change in temperature in neighbouring modules of more than ±50K.
D.14.	All cables used in the experiment *may* be twisted.
D.15.	Cables used in the experiment *may* be shielded.
D.16.	The experiment *shall* not heat feed-through cables to other experimental modules by more than 70K.
D.17.	The experiment *shall* not induce vibrations greater than a frequency of 25Hz to the rocket.
D.18.	The experimental systems *should* survive power cycling.
D.19.	A foam cap *shall* be used to dampen boom vibrations during the flight.
D.20.	An umbilical connection may be required
D.21.	All blind holes *shall* be vented

Table 2-3: Design Requirements

2.4 Operational Requirements

	Requirement
O.1.	Combustible substances should not be used.
O.2.	Compressed fluids shall not be used.
O.3.	All systems shall be in a secure mode before landing.
O.4.	The experiment shall be controlled by control lines from the RXSM.
O.5.	The experiment shall be designed so it can be safely handled.
O.6.	The experiment shall be able to conduct measurements autonomously in case connection with the ground segment is lost.
O.7.	The experiment shall accept a request for radio silence at any time while on the launch pad.
O.8.	Unless otherwise stated, M4 socket head cap screws and below shall use Loctite222 thread locker.
O.9.	Unless otherwise stated, M5 and up socket head cap screws shall use Loctite243 thread locker.
O.10.	Unless otherwise stated, Loctite601 retainer shall be used on all dowels.
O.11.	All permanent screws shall be marked with tamper evident seal.
O.12.	If tamper evidence seal is not required (e.g. adjustable brackets) a small dot on the cap shall be sufficient to show the screw is properly 'torqued'.
O.13.	Pre-launch checks shall be devised to ensure that all systems are

	operational.
O.14.	All wire connections to screw terminals shall be ferruled in accordance with the French colour code standard (DIN 46228)
O.15.	The hatch on the outer skin of the module *shall* open fully. *Response to Req.F.1.*
O.16.	The hatch *shall* open at least T+75 seconds after launch. *Response to Req.F.1.*
O.17.	The hatch *shall* open outwards. *Response to Req.F.1.*
O.18.	The telescopic boom *shall* deploy at least T+78 seconds after rocket is de-spun at T+63 seconds. *Response to Req.F.2.*
O.19.	The boom *shall* be jettisoned away from spacecraft after T+220 seconds. *Response to Req.F.6.*

Table 2-4: Operational Requirements

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

A work breakdown structure (WBS) for the project was created. It outlines that tasks that were required to upgrade the original Telescobe experiment to create Telescobe 2. It is divided into six sections. These are Spin Table, Boom Retention System, Hatch System, Camera System, Experiment General Software Upgrade and Experiment General Electrical Upgrade. Details of the WBS are given in Appendix F.

3.1.1 Schedule

Figure 3-1 shows a Gantt chart for the project. This gives an outline of the expected project timeline from mid-September 2011 (when Telescobe 2 was granted a place on the REXUS11/12 program) to the initially expected date for the REXUS 11/12 launch campaign in February 2012. This launch campaign eventually took place in March 2012 and, as a result of the sub-nominal flight of REXUS 12, Telescobe 2 was not finally launched on REXUS11 until November 2012. This is not reflected in the Gantt chart.

To maintain clarity, the different events are simplified compared to those in the WBS. However, the events represented by green bars on the Gantt chart relate to the spin table and boom retention system sections of the WBS. The events represented by red bars relate to the hatch system section of the WBS. The events represented by grey bars relate to the camera system section of the WBS. The events represented by blue bars relate to the general electrical and software upgrade sections of the WBS. Finally, the events represented by the purple bars relate to events that are carried out in conjunction with Eurolaunch.

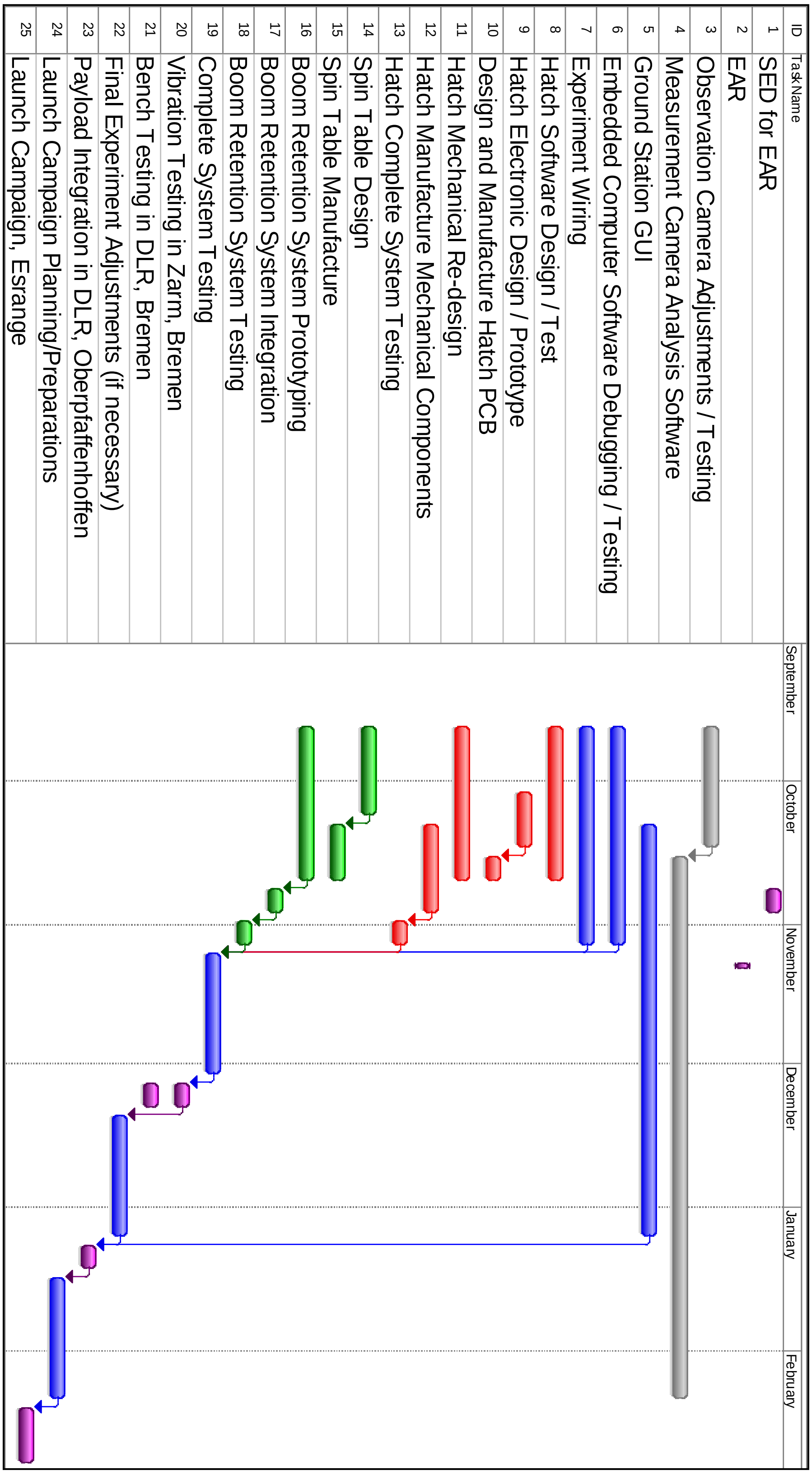


Figure 3-1: Project Gantt Chart

3.2 Resources

3.2.1 Manpower

Only four of the team members detailed in Section 1.4.2 are still actively involved with this project. These are: Stephen Curran (Team Leader), Johnalan Keegan, Paul Duffy and Dinesh Vather. All of these team members are currently in the final stages of their studies and are working on the Telescobe project on a part-time basis. All of the undergraduate team members completed their studies in DIT in June 2012.

3.2.2 Budget

The budget for the Telescobe 2 project is shown in Table 3-1. Most of the equipment for the Telescobe 2 project has been re-used from the original Telescobe experiment. Funding for the Telescobe 2 experiment was provided by ESERO Ireland and DIT. In addition, some funding was still available from the budget for the original Telescobe experiment. Funding for the original Telescobe experiment was provided by Dublin Institution of Technology, Enterprise Ireland and ACRA Control.

Telescobe 2 Budget		
	Debit	**Credit**
Funding and Sponsorship		**€2,700.00**
From original Telescobe experiment		€700.00
ESERO Ireland		€1,500.00
DIT		€500.00
Expenditure	***€2,419.03***	
Hatch PCB	€62.46	
Replacement pyro and probe PCB's	€92.00	
Motor + Gearbox	€351.53	
Pyrotechnic guillotines	€611.01	
Assorted Components (Farnell)	€331.34	
Spare carbon fibre boom	€423.00	
Observation camera filter	€43.30	
Manuf. link arm and hatch enclosure	€289.19	
Spare boom sleeve	€128.00	
Assorted Components	€87.20	
Balance	***€280.97***	

Table 3-1: Telescobe 2 budget

3.2.3 External Support

For both the Telescobe and Telescobe 2 projects, external support has been provided by the following individuals and organisations:

- CREST (Centre for Research in Engineering Surface Technology):

  CREST is a research group formed within DIT and has advised the Telescobe team on thermal insulation and material selection.
- Lars Helge Surdal, Andoya rocket range, Norway:

  Lars worked as an electronic engineer for Andoya rocket range and has provided general advice to the Telescobe team throughout the project
- Enterprise Ireland:

  Enterprise Ireland provided financial support for the project.
- ESERO Ireland:

  ESERO Ireland provided financial support for the project.
- ACRA Control Ltd:

  ACRA Control provided financial support for the project.

3.3 Outreach Approach

We aim to publicise our activities through:

- Print media
- The Internet via Website, Blog, Facebook and Twitter
- Presentations and seminars

We will encourage future involvement in aerospace through:

- Presentations in secondary schools
- Presentations to third level students
- Acting as ambassadors for Science Foundation Ireland

We will disseminate our findings through:

- Article in professional body magazines
- Articles in peer reviewed papers and presentations at conferences. Previous papers for the original Telescobe experiment include:

- ESA PAC conference 2011, Hyeres, France.
- International Manufacturing Conference (IMC) 2010, Galway, Ireland.
- International Conference on Material (MATRIB) 2010, Croatia.

An abstract has also been submitted for the ESA PAC conference 2013, which takes place in Thun, Switzerland.

See Appendix B for a more detailed description (including outreach milestones).

3.4 Risk Register

A summary of the experiments risk register is provided in Table 3-2. A detailed risk register is shown in Appendix F.

Risk Type	V. Low	Low	Medium	High	V. High	Total
Technical	3	24	11	0	0	**38**
Cost	1	3	2	0	0	**6**
Schedule	0	5	4	0	0	**9**
Others	0	7	1	0	0	**8**
Total	**4**	**39**	**18**	**0**	**0**	**61**

Table 3-2: Summary of risk register

Where:

Green	= Minimal or acceptable risk
Yellow	= Can be a source for the failure of the mission or safety
Red	= Unacceptable risk

4 EXPERIMENT DESCRIPTION

In the following chapter the technical details of the Telescobe 2 experiment are discussed. The section on experiment setup below is an overview of all of the experiment's main subsystems and how they interact with one another. The subsequent chapters on Experiment Interfaces, Experiment Components, Mechanical Design, Electrical Design, Power System, Thermal Design, Software Design and Ground Support Equipment provide detailed information on how each of these subsystems are realised.

4.1 Experiment Setup

The objective of the Telescobe 2 experiment is to deploy a novel, lightweight telescopic boom from the REXUS sounding rocket, monitor its performance during the deployed phase and safely jettison the boom from the rocket before re-entry. The telescopic boom is made from carbon fibre. At lift-off it is stored inside the rocket. It then deploys to its full length of approximately 1.7m during the flight, after rocket de-spin. The telescopic boom is designed to carry measurement probes, such as E-field or Langmuir probes. However, no measurements of this type are taken by the Telescobe 2 experiment. Instead, a probe is fitted to the end of the boom to simulate the mass and dimensions of an actual probe. Boom deployment and jettison systems have also been developed. Both of these systems use the energy stored in springs to initiate boom deployment and boom jettison. When a suitable command is sent from the experiment control system, pyrotechnic guillotine devices for the deployment or jettison systems are activated. These sever nylon cables that hold the boom in position, thus freeing the springs to deploy or jettison the boom.

The experiment control module monitors the performance of the boom when it is deployed. To do this it uses an accelerometer located in the probe at the distal end of the boom and a camera system mounted inside the main body of the experiment. The monitoring system allows the deployed length, deflection magnitude as well as the amplitude and frequency of any vibrations in the boom to be measured. The heart of the experiment is the experiment control system. It receives commands from the REXUS service module (RXSM) and data from the boom performance monitoring subsystem. It also controls the boom deployment system and boom jettison system. It saves the data it receives from the boom performance monitoring system to data memory and transmits a portion of it, along with information on the condition of the experiment to a ground station through the RXSM.

When the experiment is integrated into the sounding rocket, the skin of the experiment forms part of the outer skin of the sounding rocket. Power and signal cables for other experiments and the nose-con ejection system pass through the Telescobe 2 experiment module. These cables are retained in position using a bracket secured to the inside of the skin. Cable ties and cable tie pads are used to ensure that these cables do not move and interfere with the operation of the experiment during the flight.

4.2 Experiment Interfaces

4.2.1 Mechanical

There are three distinct mechanical interfaces between the experiment and the REXUS rocket module. These are the bulkhead, hatch and camera brackets.

- Bulkhead

  The majority of the experiment components are mounted to the bulkhead, which was supplied by EuroLaunch. Threaded holes in the bulkhead allow the experiment components to be bolted to it using M5 socket head cap screws. The bulkhead is attached to the rocket. The module is supplied by EuroLaunch. The bulkhead is secured to the rocket module using M4 x 14mm socket head cap screws. Thread locking adhesive is used on all screws to ensure that they do not become loose during the flight due to vibrations.

- Hatch

  There is a 65mm diameter hole in the skin of the rocket. The hatch covers this hole during lift-off and is intended to open before the deployment of the telescopic boom. It should then close again after the boom was jettisoned.

- Camera Brackets

  There are three cameras used in the Telescobe experiment. Small openings are provided in the skin of the rocket to allow the cameras to look out at the boom. Each of the cameras is mounted to a bracket, which is attached to the skin of the rocket using M3 countersink screws. Threaded M3 holes were bored in the camera brackets. A small float glass window is also mounted into each of the brackets. This protects the cameras from the high temperatures experienced during the flight.

4.2.2 Electrical

There are three electrical connections between the experiment and the RXSM. Two of these connections are made through the experiment interface connectors. The third is made through the TV transmitter connector.

- Experiment RXSM Interface Connection 1

  This is the primary connection between the experiment and the RXSM. On the RXSM it is a 15 pin D-Sub type connector. It is required that the 15 pins on this connector are assigned as outlined in Table 4-1.

Pin #	Name	Description	Note
1	+28V	Battery Power	
2			Not used
3	SODS	Start/Stop of data storage	
4	SOE	Start/Stop of experiment	
5	LO	Lift Off	
6	EXP out+	Non-inverted experiment data	RS422
7	EXP out-	Inverted experiment data	RS422
8	28V Ground	Power ground	
9	+28V	Battery power	Not used
10 - 12			Not used
13	EXP in+	Non-inverted control data	RS422
14	EXP in-	Inverted control data	RS422
15	28V Ground	Power ground	

Table 4-1: Pin out of RXSM connection 1

- Experiment RXSM Interface Connection 2

  This connection provides power for actuating the hatch and firing the two pyrotechnic guillotines in the experiment. On the RXSM it was a 15 pin D-Sub type connector. It is required that the 15 pins on this connector are assigned as outlined in Table 4-2.

Pin #	Name	Description	Note
1	+28V	Battery Power	
2 - 7			Not used
8	28V Ground	Power ground	
9	+28V	Battery power	
10 - 14			Not used
15	28V Ground	Power ground	

Table 4-2: Pin out of RXSM connection 2

- TV Transmitter Interface
  The TV transmitter connector is a male, BNC type. The connector on the RXSM is a female type. Data is sent from the experiment observation camera directly to the TV transmitter in the RXSM through this interface.

4.3 Experiment Components

Manufacturing drawings of custom mechanical components, details of the custom printed circuit boards used and information on major purchased components used in the Telescobe 2 experiment module are included in Appendices G, E and D respectively.

4.3.1 Experiment Summary

Expected Experiment mass	12kg (including Bulkhead and skin) 5Kg experiment only
Experiment dimensions (Height x Diameter)	220mm x 347.6mm
Experiment footprint area	0.001092m^2
Experiment volume	0.000240240m^3
Experiment expected COG	X=81.13, Y=-9.76, Z= -10.05

Table 4-3: Experiment summary

4.4 Mechanical Design

This section outlines the major components of the boom assembly design and the other sub-assemblies that support operation of the experiment. Manufacturing drawings of all mechanical components are given in Appendix G.

4.4.1 Mechanical Design Overview

Figures 4-4, 4-5 and 4-6 show isometric, side and top views respectively of a solid model of the complete experiment assembly.

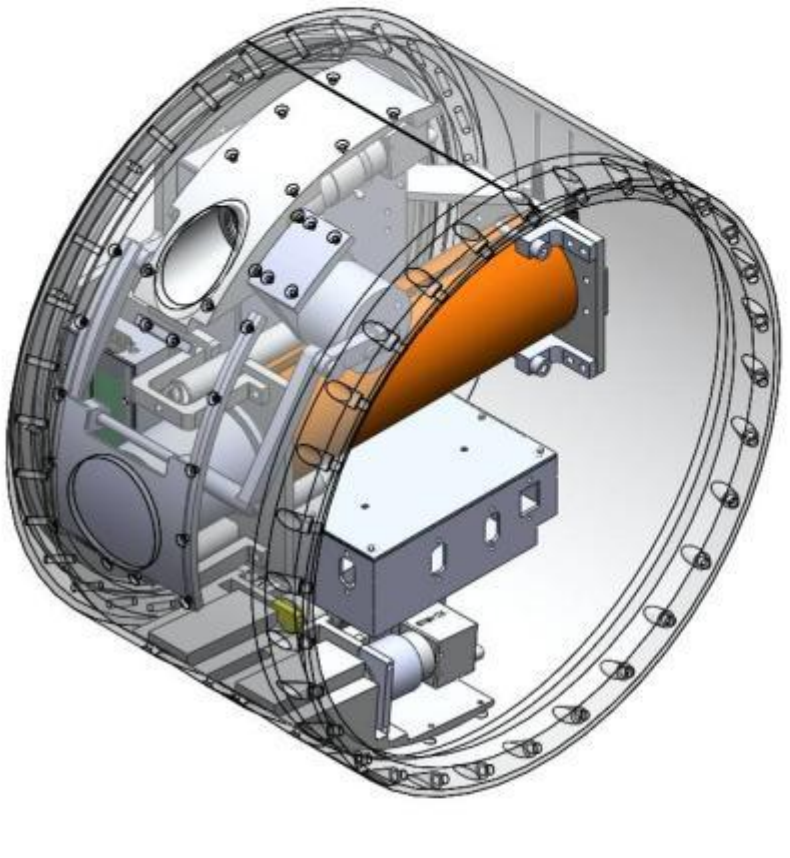


Figure 4-1: The complete experiment module. Isometric View

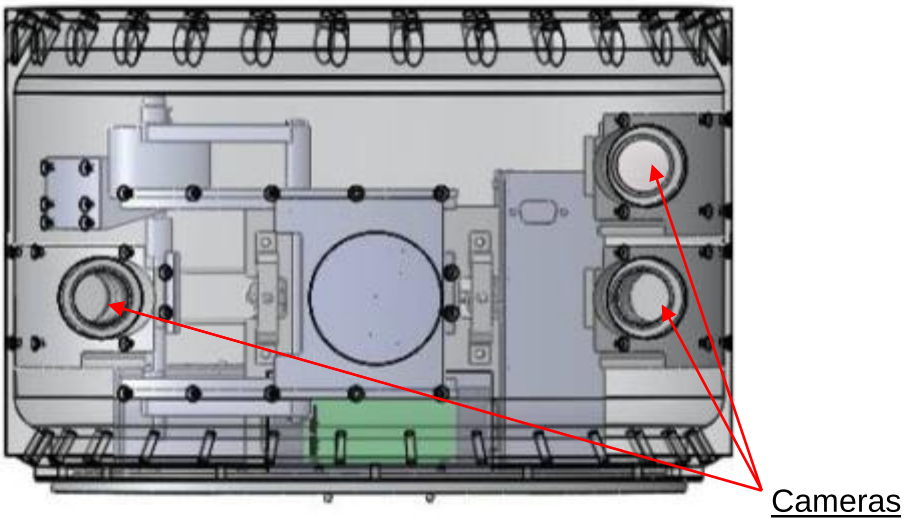


Figure 4-2: The complete experiment module. Side View

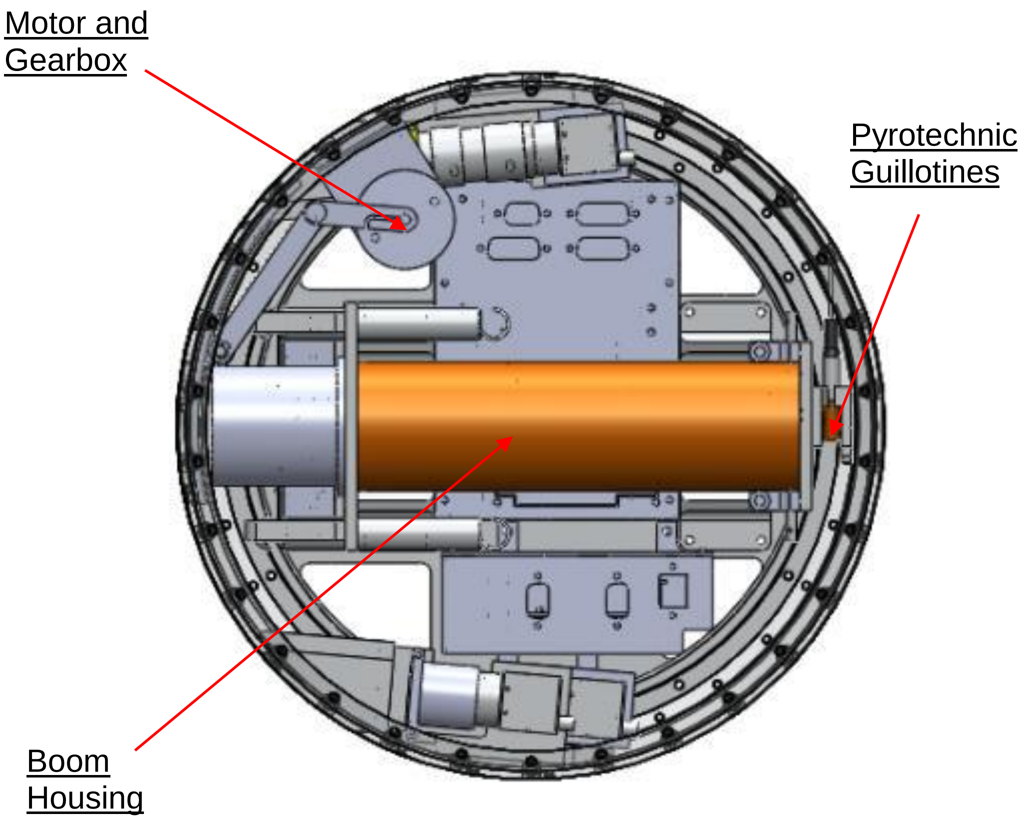


Figure 4-3: The complete experiment module. Top view

4.4.2 Boom Assembly Description

The boom is mounted in the rocket in its stowed position pre-flight. All boom sections are collapsed and retained in the largest section. During flight the hatch in the rocket skin opens and the boom deploys through the opening, extending the probe out to a position where typical measurements would be taken. This is referred to as boom deployment.

After the readings have been taken, in accordance with guidelines from EuroLaunch, all physical connections with the boom and probe are broken. The boom and probe are then ejected from the rocket. This is referred to as boom jettisoning. The boom assembly refers to the boom, probe, deployment system, jettisoning system and mountings.

4.4.3 Probe

In service, E-Field probes are typically connected by a coaxial cable that would be fed through the centre of the boom. For this experiment, a probe, with a diameter of 20mm and a mass of 50g was selected to simulate an actual E-Field probe. The probe houses a 3-axis accelerometer and six LEDs. The accelerometer is used to measure vibrations and a six LED ring is used as a datum point for the camera measurement system discussed in Section 4.5.7.

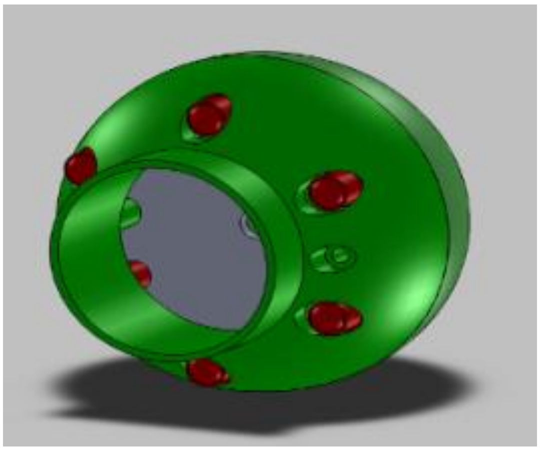


Figure 4-4: Probe assembly

An assembly image of the probe is shown in Figure 4-4**.** The probe is spherical, having an outer diameter of 45mm. The probe consists of two hemispherical sections, connected at two points by M2.5 socket head cap screws. A 27.35mm outer diameter collar protrudes from the front shell of the probe to allow mating with the central boom section. Six equi-spaced LEDs face back towards the cameras mounted in the experiment module. These are retained on a PCB which is mounted in the front shell.

Figure 4-5 shows an exploded view of the probe. The PCB contains three 4mm diameter holes across its central axis. The two outer most holes allow the connection of the front and back shell mating posts. The central hole serves two purposes. Firstly, during manufacture it is used to mount the unfinished PCB in the relevant machinery. Secondly, it allows the coaxial cable from the data acquisition system to pass through the PCB and reach the retaining post located in the centre of the back shell. This post provides a strong anchoring point for the cable, minimising the risk of electrical connections being damaged during deployment. Also, the use of a pull plug system to disconnect the cable in the main module during jettison requires a strong anchoring point to function. This cable is also anchored at the other end of the boom as a further precaution to ensure that it disconnects during jettison.

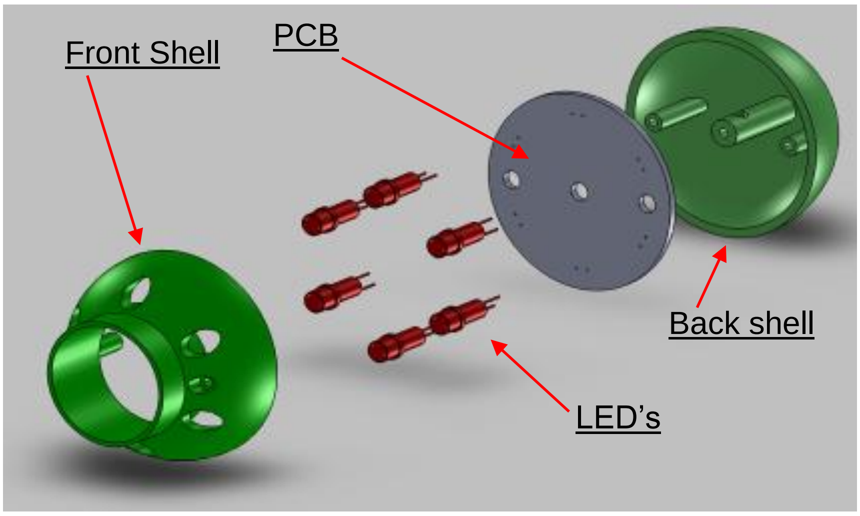


Figure 4-5: Exploded view of probe assembly

4.4.4 Probe Protector

The probe protector, as shown in Figure 4-6, mounts to the front of the boom assembly. It comprises of a guide tube that is 5mm from the hatch door. Inside the guide tube the probe sits surrounded by three split sections made from acetal and containing open cell foam that is used to dampen the vibrations of the probe during the early stages of the flight, before it is deployed. The slot in the guide tube allows a retaining wire, discussed in Section 4.4.9, to sit against the acetal split sections. At deployment, this retaining wire snaps under the force of the deployment mechinism. The split sections are carried out of the rocket along with the probe where they seperate and fall off.

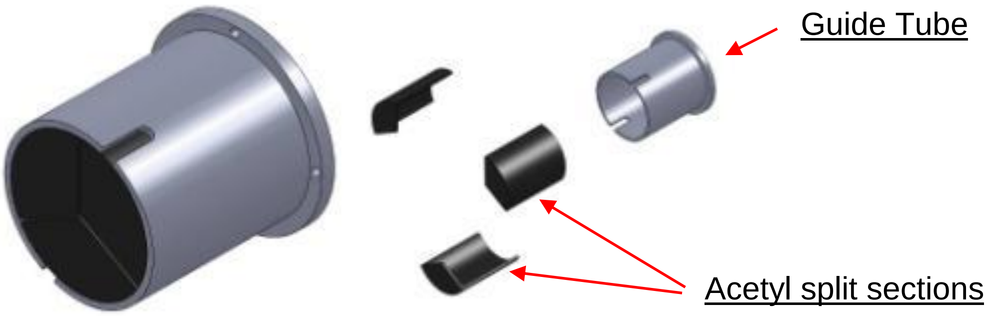


Figure 4-6: Probe protector and probe protector exploded view

4.4.5 Boom Assembly

Figure 4-7 shows the exploded boom assembly. The boom consists of eight 230mm sections. The lockout of each section is 30mm and the total deployed length is 1705mm. (During the flight of the experiment on REXUS 11 a boom deployment length of 1708.3 ±6mm was measured). In Figure 4-8 the boom is shown in its boom sleeve in its collapsed, deployed and jettisoned state.

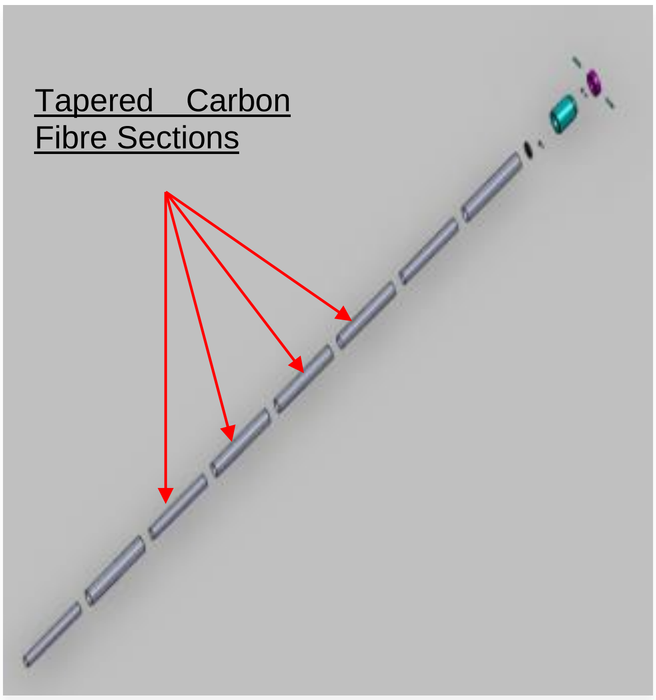


Figure 4-7: Exploded view of boom assembly

Launch

Deployment

Jettison

Figure 4-8: Boom Configuration during main experiment stages

The boom is made from an altered carbon fibre fishing pole. After testing a combination of manufacturing techniques, it was found that the most effective method of cutting the carbon fibre is using a lathe and rotary cut-off tool (Dremel). The rotary tool was first clamped to the lathe carriage allowing precision positioning of the cutting disc using the lathes digital measurement system. Following this, lengths of the fishing pole were mounted in the lathes three jaw chuck. Whilst spinning, the lathe jaws were manually rotated and the cut off wheel was slowly moved into the carbon fibre section. This gives a clean cut with no burs or splitting. The front surface of the disk was then used to grind the cut surface of the carbon fibre section. Figure 4-9 shows the boom being manufactured.

A foam backing is glued to the inside of the boom sleeve. The sections of the boom are pressed against the foam when the boom is in its stowed position, preventing the sections from moving around during flight. The largest section of the boom is then glued to the boom sleeve as shown in Figure 4-10. The dowel shown in this figure is a press fit into the cord retainer. One cord retainer fits into the boom sleeve. The deployment cord loop anchors to the dowel. The other cord retainer goes into the pusher cup for the jettison cord. Along the boom housing two springs are attached to the spring posts that are screwed into the pushing cup. The boom sleeve sits into the pushing cup and is propelled forward by the cup when the deployment cord is cut.

Figure 4-9: Boom manufacture

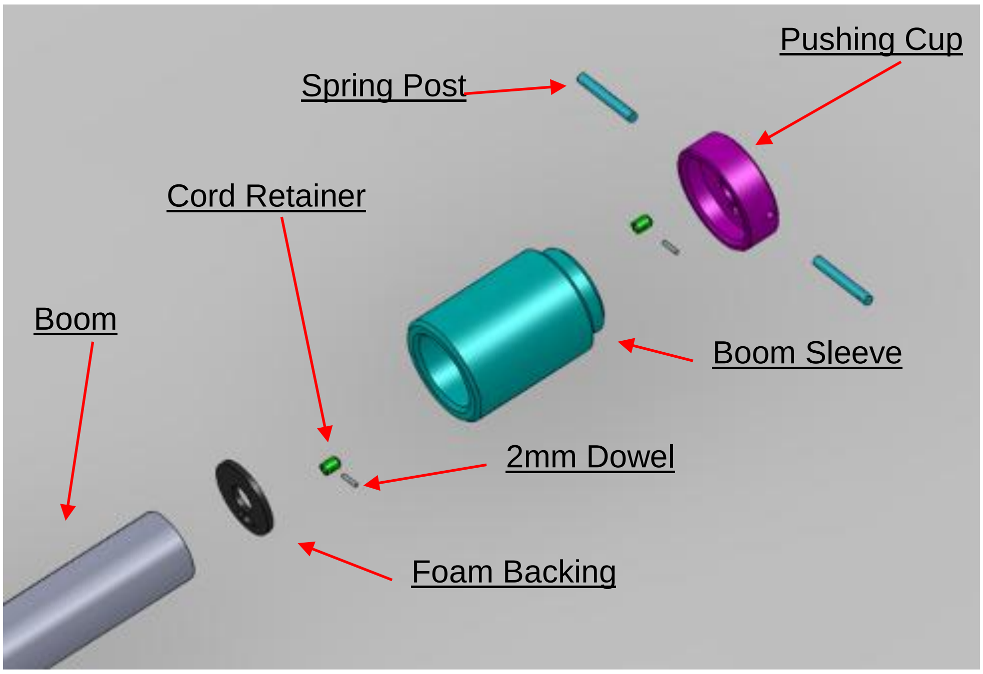


Figure 4-10: Exploded view boom sleeve and cup

4.4.6 Boom Housing

Figure 4-11 and Figure 4-12 below show assembled and exploded views respectively of the boom housing. The boom housing is the interface between the boom and the rest of the experiment. The boom deployment and jettison systems are also integrated into the boom housing. The Boom Housing is supported by the front housing mount and the rear housing mount. The boom assembly sits in the boom housing. Fixed to the rear housing mount is the pyro bracket, the pyro bracket holds the two pyrotechnic guillotines and acts as an anchor point for the deployment and jettison cords as well as supporting the fixed Winchester plug. Winchester plugs are 'pull plug' connectors and are used to disconnect the cable running up the boom at jettison. The two springs are attached to the spring posts on the boom assembly as well as the two frontal spring brackets.

The boom housing is made from PEEK (polyether ether ketone). PEEK was selected because of its favourable strength to weight ratio and its relatively low co-efficient of friction. The boom sleeve and pushing cup are made from aluminium. Dissimilar materials have been chosen for the boom housing and boom sleeve to ensure that there is no possibility of the materials fusing together.

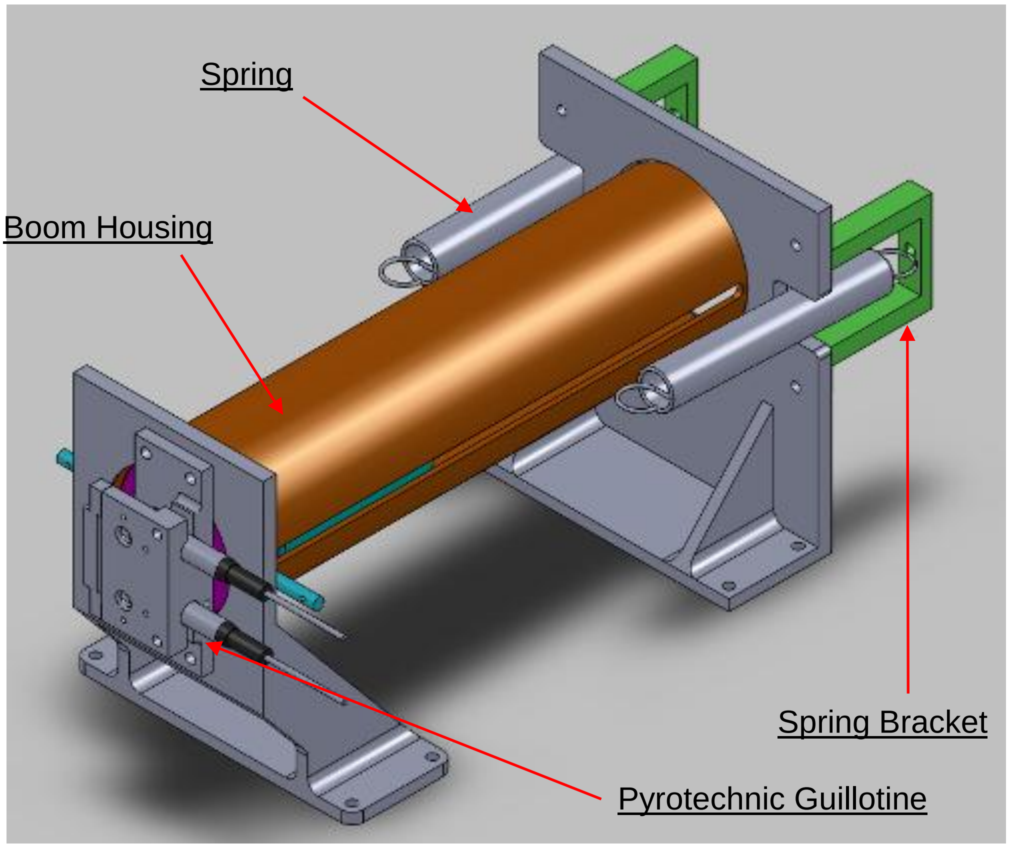


Figure 4-11: Boom housing Assembly

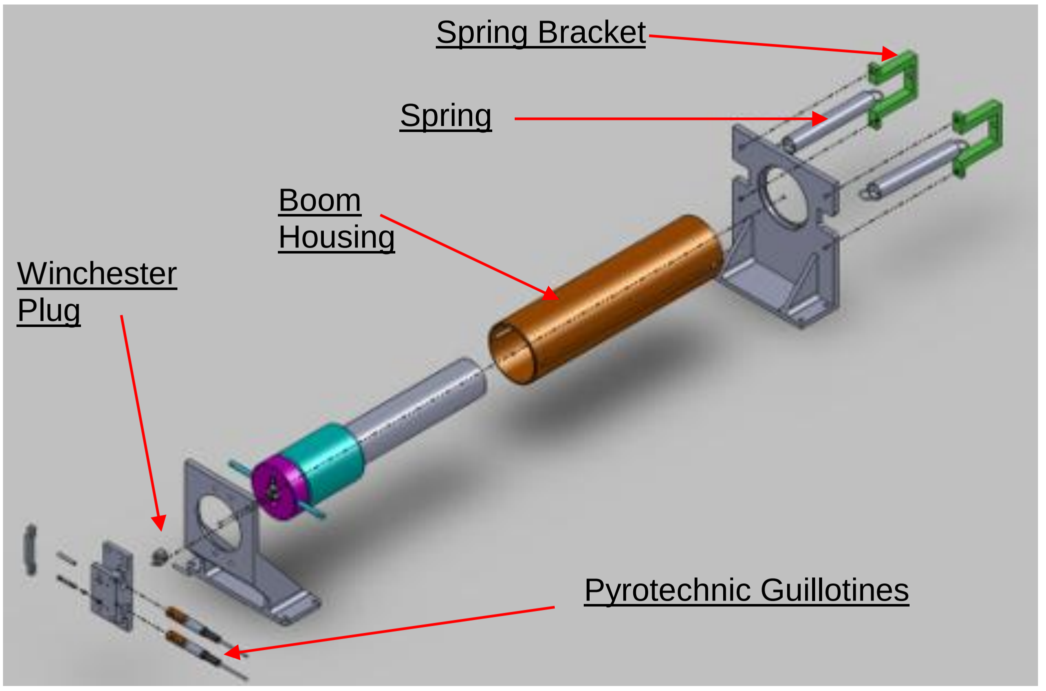


Figure 4-12: Exploded view of boom housing assembly

4.4.7 Boom Deployment

The following steps explain how the boom deployment system works.

- The two springs are connected to the pushing cup and held under tension.
- The pushing cup is retained in position by a nylon cable which passes through the eye of the deployment pyrotechnic cutter.
- The deployment pyrotechnic cutter is activated and cuts through this nylon cable.
- The pushing cup is pulled forward by the springs, pushing the boom and boom sleeve along with it.
- A second nylon cable is attached to the boom sleeve and passes through the eye of the jettison pyrotechnic cutter. This cable is slack when the boom is in the stored position.
- When the boom sleeve has moved through approximately 80mm this cable tensions, causing the boom sleeve and the largest section of the boom to stop suddenly.
- The other sections of the boom keep travelling out until they all lock into one another with an interference fit, thus fully deploying the boom.
- An electrical cable connects the probe on the distal end of the boom to the experiment control system. This cable is stored in a special housing above the boom housing when the boom is in the stored position. As the boom deploys it pulls this cable up through its centre.

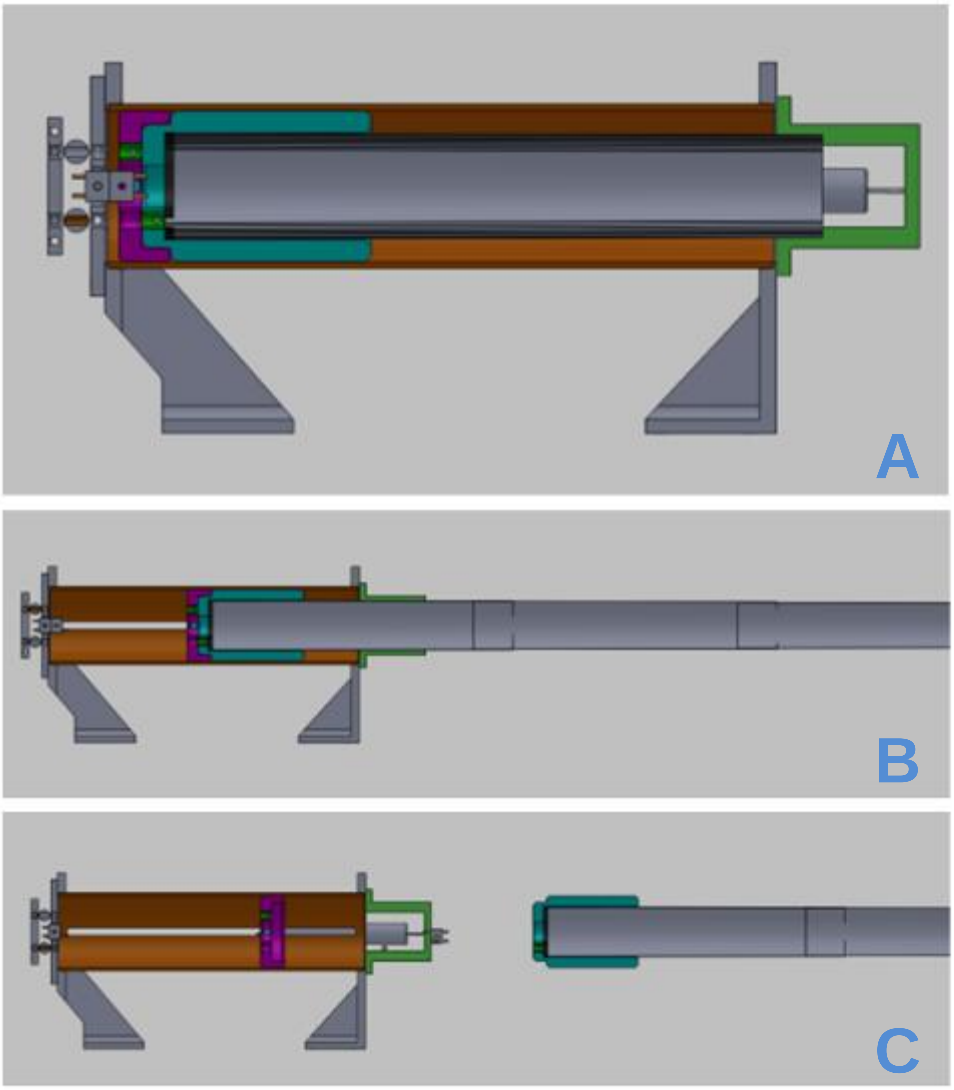


Figure 4-13: Deployment steps. A cross section of the boom and boom housing is shown. (A) The boom is in the stowed position. (B) The boom is in the deployed position. (C) The boom is in the jettisoned position.

4.4.8 Boom Jettison

The following list of steps explains how the boom jettison system works.

- The jettison pyrotechnic guillotine is activated, cutting the nylon cable that is holding the boom sleeve in position.
- The springs then pull the pushing cup, boom sleeve and the extended boom forward.

- After travelling approximately 100mm, the two dowel pins protruding out of the pushing cup reach the end of their guide slots and impact against the boom housing.
- The boom and boom sleeve continue travelling out of the rocket, separating from the pushing cup.
- A Winchester plug is fitted to the electrical cable that passes through the boom to the probe. As the boom passes out of the rocket, this cable is tensioned thereby causing the Winchester plug to disconnect. One half of the Winchester plug, along with a section of electrical cable is also pulled outside the rocket along with boom and probe.

4.4.9 Boom Retention

During the ascent phase of the flight, centrifugal forces act to pull the boom out of the boom housing. This is undesirable as it could cause the experiment hatch to jam and could damage the boom. As such, a boom retention system has been incorporated into the spring brackets. Figure 4-14 shows a side view of one of the spring brackets. The slot in one corner of the spring bracket forms part of the boom retention system. Monofilament wire, rated for a maximum tensile load of 9 N is used to retain the boom in position during the ascent phase of the flight. This passes across the face of the probe cap and through the slots in each of the spring brackets. A dowel in each of the slots is used to hold the string in position. An M3 SHC is screwed through a threaded hole in the spring bracket and pushes the dowel against one end of the slot, firmly clamping the wire in position.

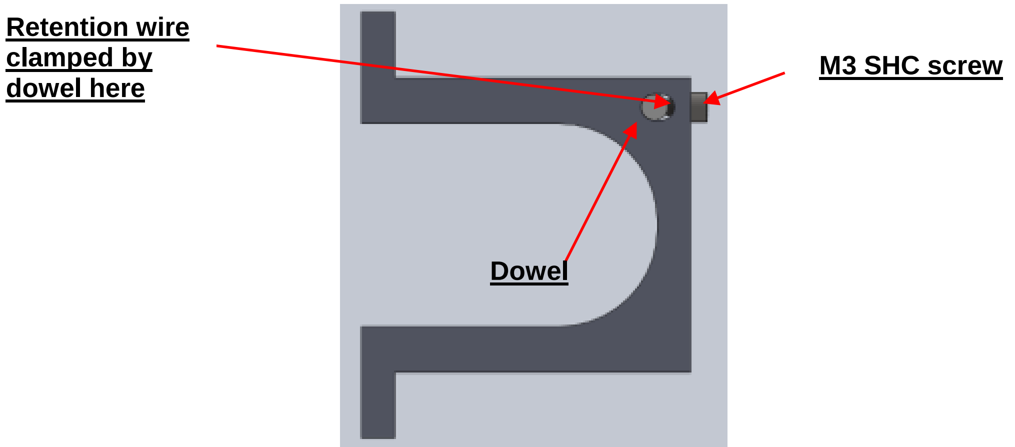


Figure 4-14: Boom retention method

During the flight, two springs are used to deploy the boom. When fully extended, these springs exert a force of approximately 138 N. Before boom deployment, the boom is retained by nylon parachute cord that anchors the back of the boom assembly to the boom housing. When the experiment receives the SODS signal from the RXSM, a pyrotechnic guillotine is activated and cuts through this cord. The fully force of the springs is then exerted on the boom retention wire, causing it to break. The boom then deploys.

4.4.10 Springs

Two springs are used as part of the boom deployment and jettison system. Their specification is given in Table 4-4.

Type	Tension Springs
Material	Music Wire
Free length	113mm
Outside Diameter	15mm
Spring Constant	0.434N/mm

Table 4-4: Spring specification

The springs are extended through 160mm. This is in excess of their recommended maximum extension length but testing has shown that this does not affect their performance substantially.

4.4.11 Camera Mounting

Three cameras of similar dimensions are used in the experiment. Figure 4-15 and Figure 4-16 show an assembly and an exploded view of the camera mounts. The bracket holds the camera securely and maintains alignment during flight, allowing accurate measurements of boom deployment and deflection. The two measurement cameras are mounted in the same horizontal plane and angled towards the boom at five degrees. The positioning of the observation camera is not as critical to experiment success. All cameras look out through holes in the skin of the experiment. The camera mounts also contain a cell to mount shock resistant float glass, rated for an extended temperature range. This acts as a window, which is maintained parallel to the camera lenses by a M31 x 0.5 retaining ring. The camera bracket and the float glass act to seal the hole in the skin to protect the internal components in the experiment.

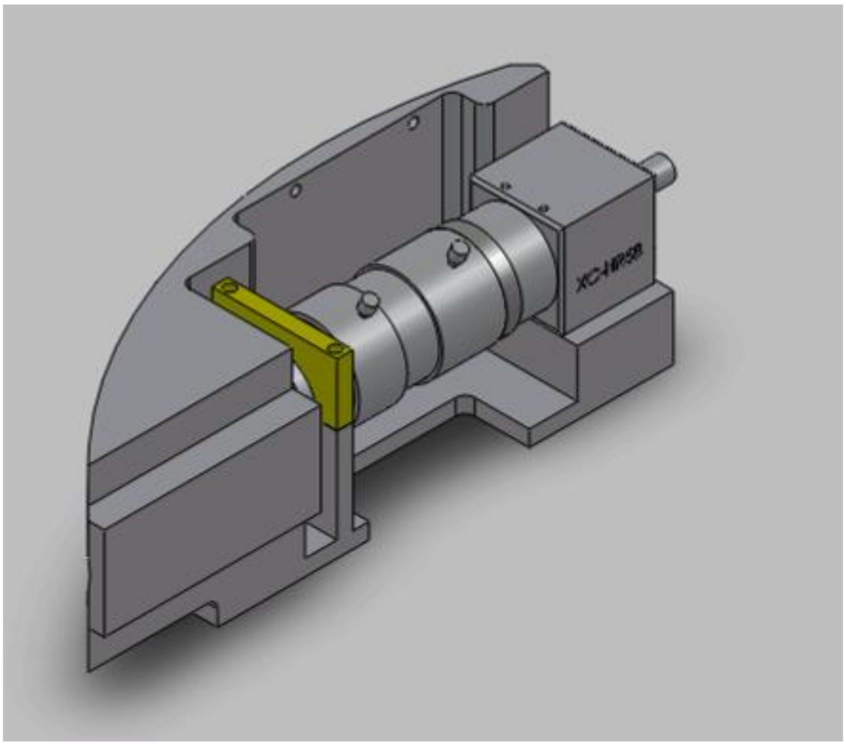


Figure 4-15: Camera bracket assembly

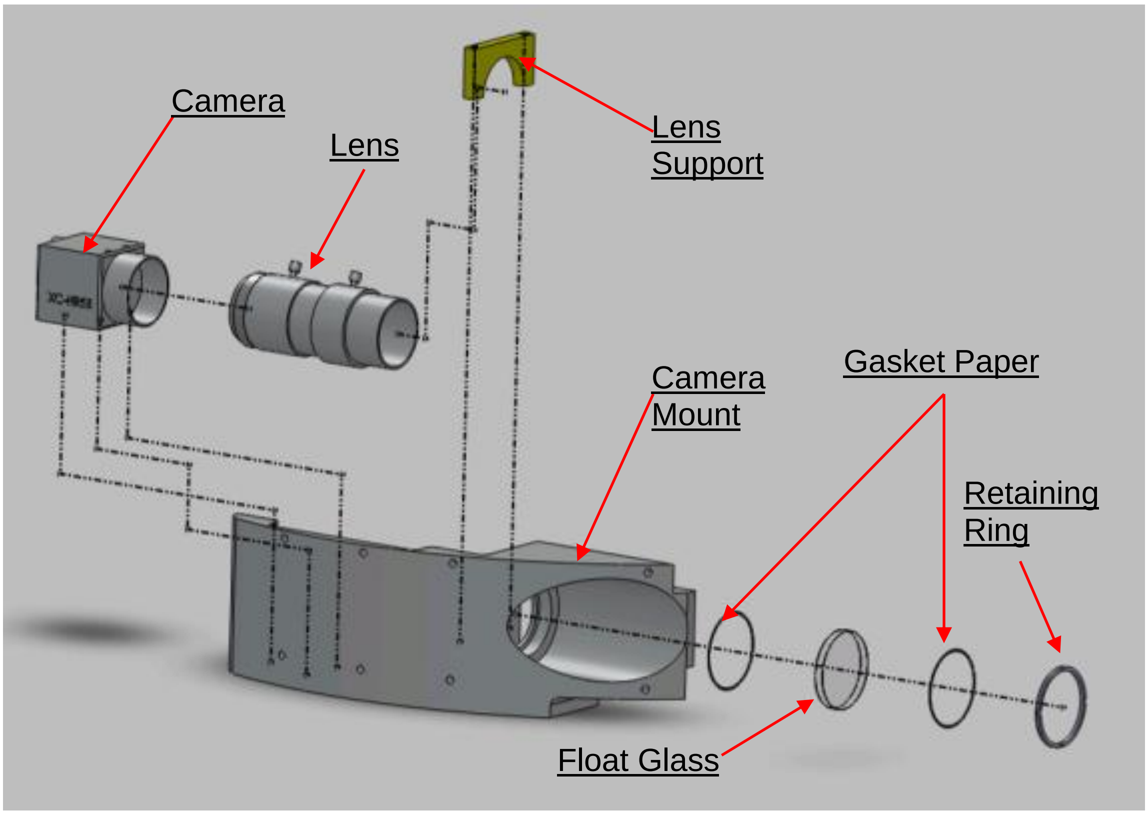


Figure 4-16: Exploded view of camera bracket assembly

4.4.12 Hatch Assembly

An exploded view of the hatch assembly is shown in Figure 4-19. The hatch design consists of Maxon EC 12 Watt brushless motor and a planetary gearbox (reduction ratio of 690:1) housed inside an aluminium sleeve. The planetary gearbox is not back-drivable and its shaft is connected to a set of armatures, consisting of a short “S” shape armature and long armature. The short armature is radially clamped to the top of the gearboxes 4mm output shaft using a nut and a bolt. On the other end of the short armature is a tolerenced hole with a press fit g6 copper alloy bushing that mates with a tolerenced surface on a fulcrum pin. The copper alloy oil-free bushing allows the short armature to rotate freely around the fulcrum pin. The fulcrum pin is screwed into the end of the long armature. On the other end of the long armature is an extended sleeve that allows a longer bushing to be press fit with the shaft connected to the hatch through this bushing. The extended bushing allows the armature to rotate around the shaft and with its larger contact area helps prevent cross locking of the hatch door. There are two bosses on the sliding door that have holes to allow the shaft to rotate. There is a boss on the top and bottom of the door to minimize the cross locking that might occur if the door was only attached in one corner. E-clips are used at the top and bottom of the shaft to retain it. The short armature is above a pair of inductive sensors, which provide feedback to indicate whether the hatch is opened or closed.

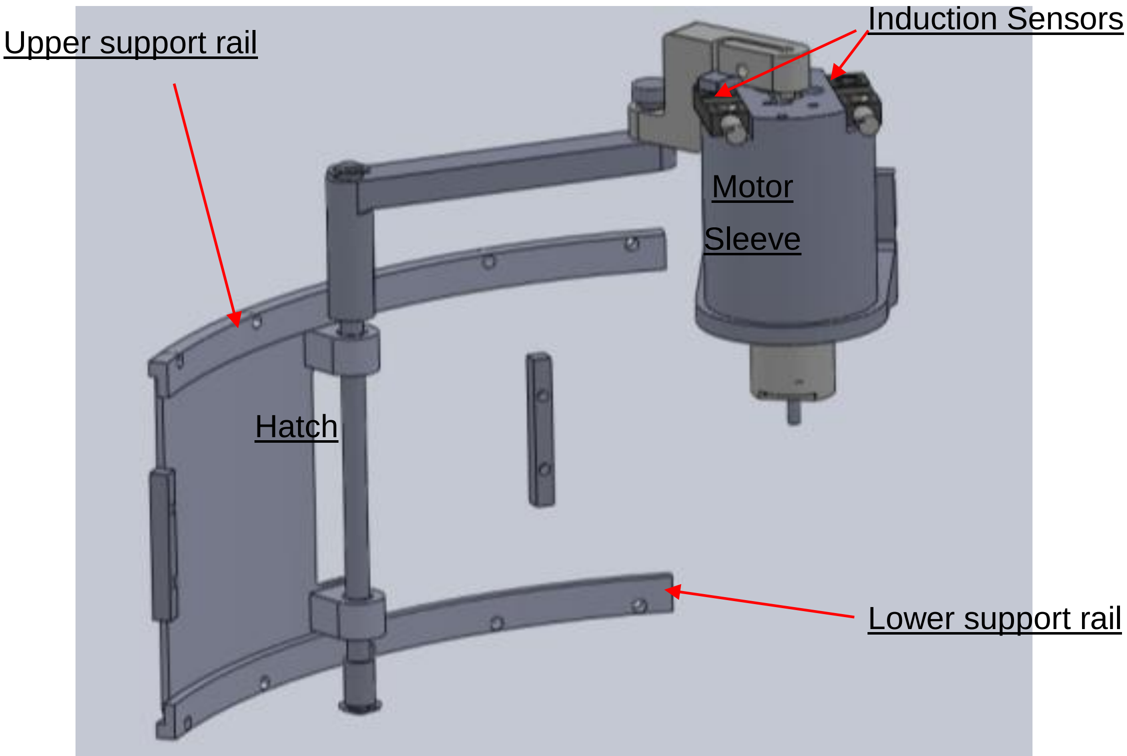


Figure 4-20: Hatch assembly

The hatch door is operated by a microcontroller and motor controller. When 24 volts is sent to the motor driver card, a ready signal is sent to the microcontroller. This is the signal for the hatch door to open and power is sent to the motor. Initially it was intended to use the inductive sensors to determine when the motor should be switched off. However, as a result of doubts over how they would perform during the flight and the critical nature of proper hatch functionality meant that a timer on the microcontroller is used instead such that the short armature rotates through 95 degrees. The feedback from the inductive sensors is used purely for logging and telemetry purposes.

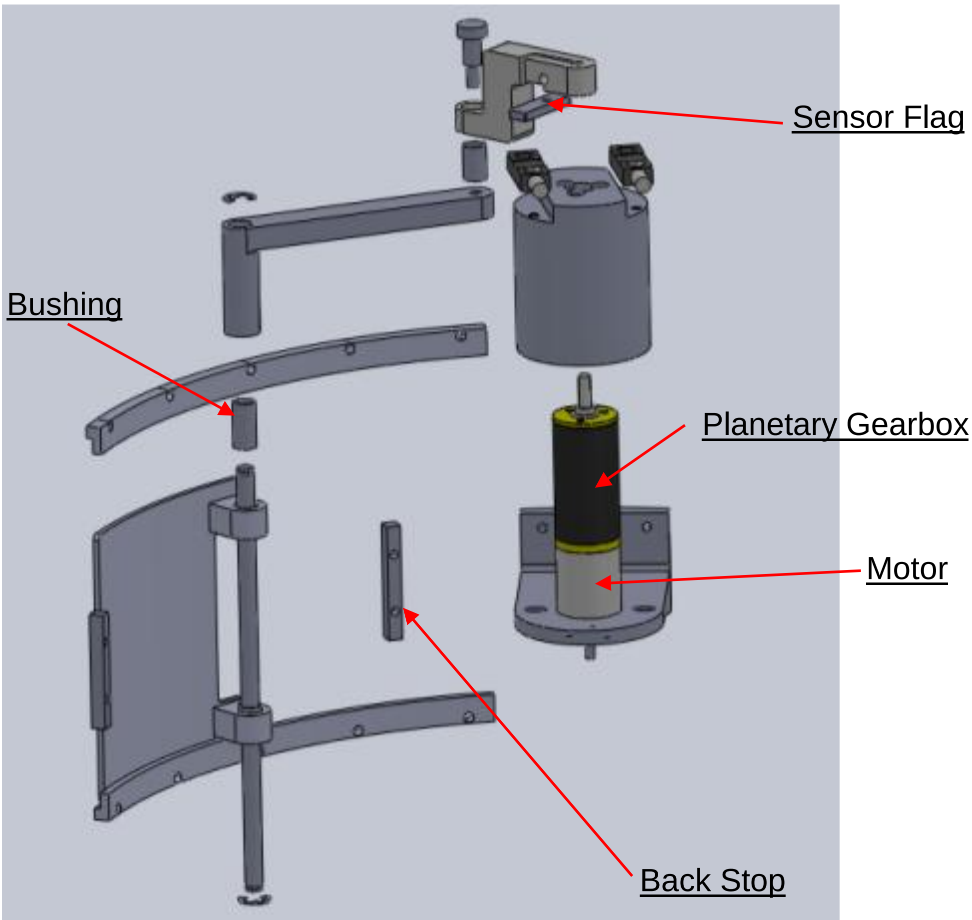


Figure 4-21: Exploded view of hatch assembly

4.4.13 PC104, Hatch PCB and Electronics Enclosures

There are three aluminium enclosures inside the experiment: the PC104 Enclosure, the Hatch PCB enclosure and the Electronics Enclosure. The location of these enclosures inside the experiment module is shown in Figure 4-17. The flight computer and frame grabber are mounted together inside the

PC104 enclosure. They are secured together using four steel 15mm risers and then both secured to the aluminium enclosure using five socket head cap screws through the heat sink of the flight computer. There is a large amount of cabling inside the PC104 Enclosure. This is held securely in position using cable ties and cable tie bases adhered to the aluminium enclosure. These prevent the cables from moving around and either being damaged or damaging one of the boards during flight. Four connectors on the outside of the PC104 Enclosure allow the flight computer and frame grabber to interface with the rest of the experiment. Also, an Ethernet port on the top of the enclosure allows for remote connection of an external computer to the flight computer. This acts as a means of monitoring the activities of the flight computer and frame grabber and also provides a means of editing the control software without having to dis-assemble the experiment. Additionally, two cables pass through a cable gland in the base of the enclosure. These cables carry power for the flight computer and frame grabber.

The Hatch PCB is mounted inside the Hatch PCB enclosure. Two D-Sub connectors protrude from each end of this enclosure. These interface the Hatch PCB with the rest of the experiment. Additionally, a small heat sink for a linear regulator is fixed to the lid of this enclosure.

The ACS-5151 power board, the Distribution and Switching PCB and the Pyro PCB are mounted together inside the Electronics Enclosure. There is also a large amount of cabling inside this enclosure, which is also all held securely in position using cable ties and cable tie bases adhered to the enclosure. Four D-Sub connectors mounted on the Distribution and Switching PCB protrude through the lid of the enclosure. Also, two wires which provide power for the flight computer, frame grabber and hatch system, pass through a cable gland at one end of the enclosure. Finally, there is a D-Sub connector on one side of the enclosure. This is for RXSM connection 2.

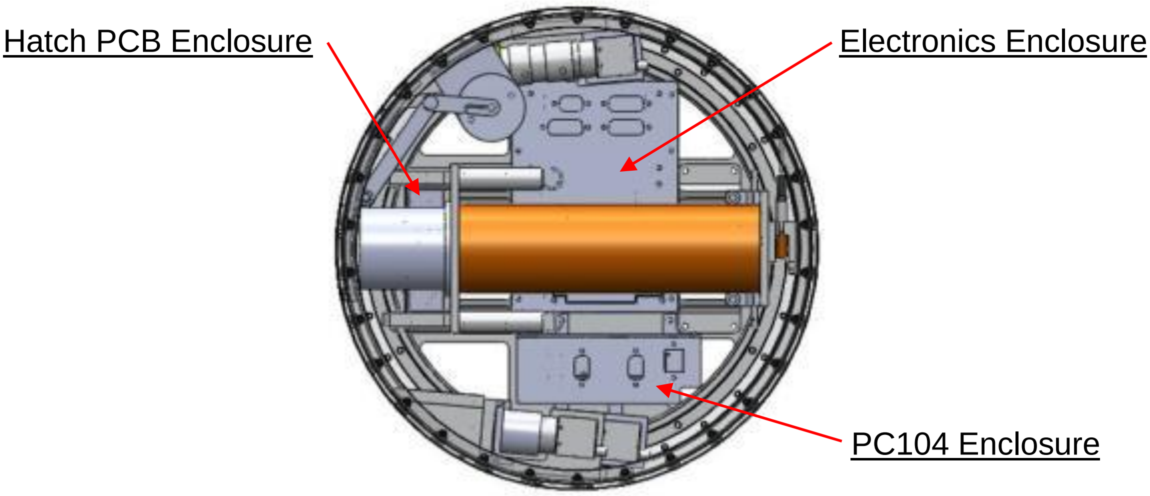


Figure 4-17: Top view of the experiment module with the PC104 and Electronics Enclosures labelled.

4.5 Electronic Design

4.5.1 Electronic Design Overview

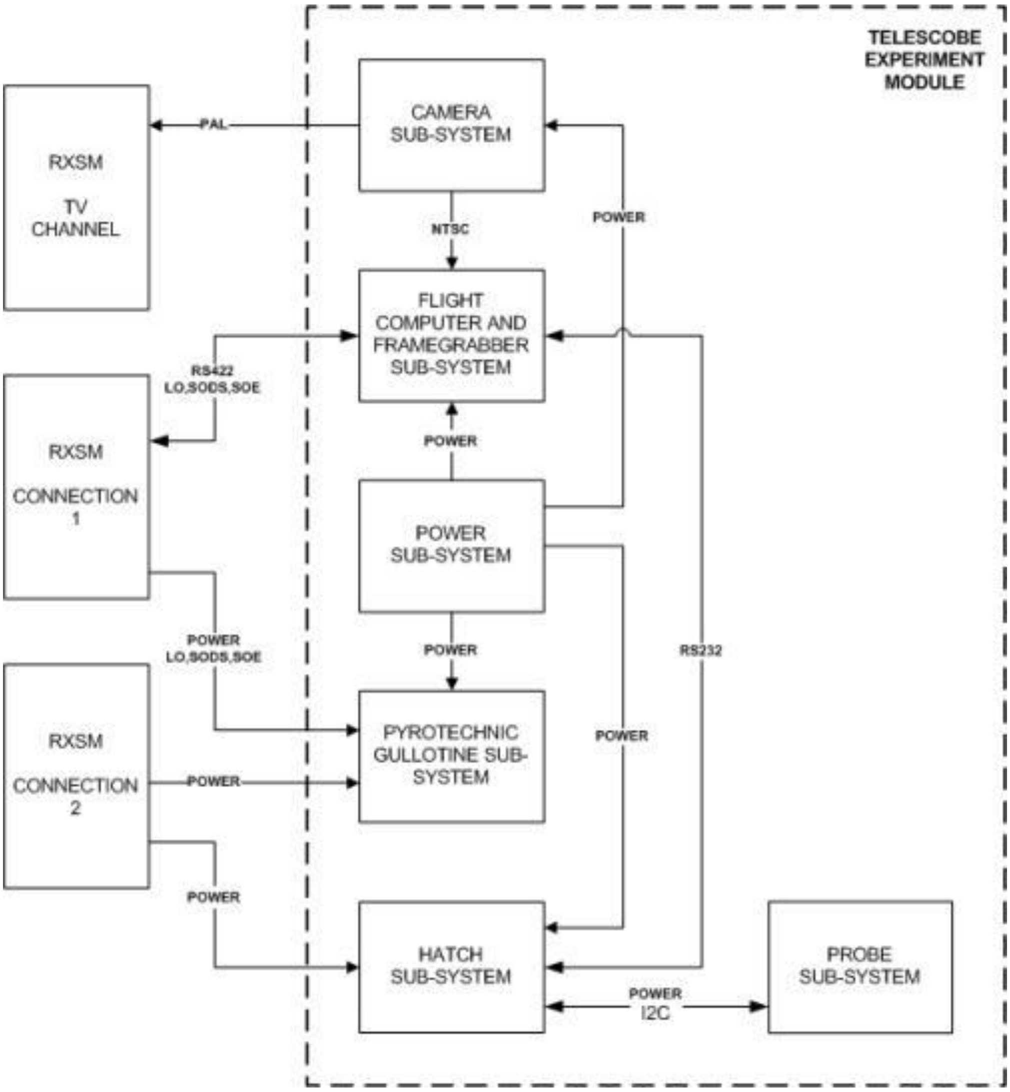


Figure 4-18: Overview of the experiments electronic sub-systems showing how they interact with each other and the RXSM.

Figure 4-18 shows all of the experiments major electronic sub-systems and how they interact with one another. Each of these sub-systems is discussed in the following sections.

4.5.2 Power Sub-System

Figure 4-19 shows an overview of the power sub-system. Power is supplied to the experiment module at 24V-36V from RXSM connection 1. However, the various experiment sub-systems require power to be provided at 12V, 5V or 3.3V. To achieve this, a Eurotech ACS-5151, PC/104 type power management board is used. The ACS-5151 is mounted the experiments Electronics Enclosure. Power at 5V is supplied directly to the flight computer, frame grabber and Hatch PCB, through an external mini Wago clamp terminal. Also, power at 12V and 3.3V is supplied to the Distribution and Switching PCB from where it is supplied to the hatch, probe, camera and pyrotechnic guillotine sub-systems. More detailed descriptions of how the power sub-system interacts with the other sub-systems are presented in Sections 4.5.3 to 4.5.7 for further technical information; a data sheet of the ACS-5151 board has been included in Appendix D.

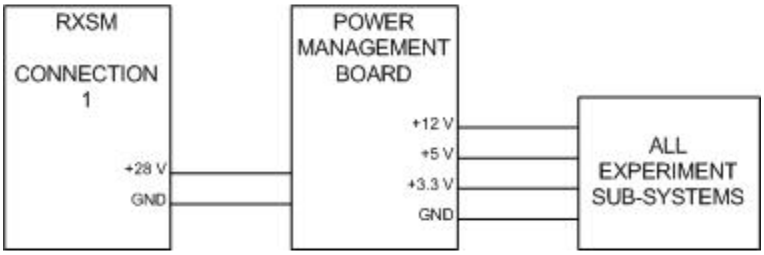


Figure 4-19: Overview of power sub-system connections

4.5.3 Flight Computer and Framegrabber Sub-System

The flight computer is a Eurotech ISIS-XT, PC/104-Plus type. It is mounted inside the modules PC104 Enclosure along with the framegrabber. It was a fan-less design that instead incorporates a large heat sink which is in contact with the aluminium skin of the enclosure. This acts to dissipate to dissipate the waste heat generated in order to keep the computer within its rated temperature range. Heat sink paste is used between the heat sink and the skin of the box to enhance thermal conductivity.

Figure 4-20 shows a connection diagram for the flight computer. The ISIS-XT has two built in serial ports, one of which can be configured as RS422. This serial port is used during the flight to transmit selected telemetry information, through the REXUS telemetry system, to the ground station. This allows the status of the experiment to be monitored remotely before lift-off and during the flight. The second serial port is configured as RS232. This is used to send commands to and receive data packets from the hatch sub-system, discussed in Section 4.5.6. There are also eight general purpose digital I/O (GPIO) ports available on the ISIS-XT. These ports are 3.3V (5V tolerant) CMOS type. They are used to read the status of the control lines from the RXSM into the software running on the ISIS-XT. The computers operating system, all the flight telemetry and images acquired from the two measurement cameras are stored on an internal 2GB memory. For additional security, the flight telemetry and camera images are also stored on a 2GB industrial grade SD card that plugs into a SDIO slot on-board the flight computer.

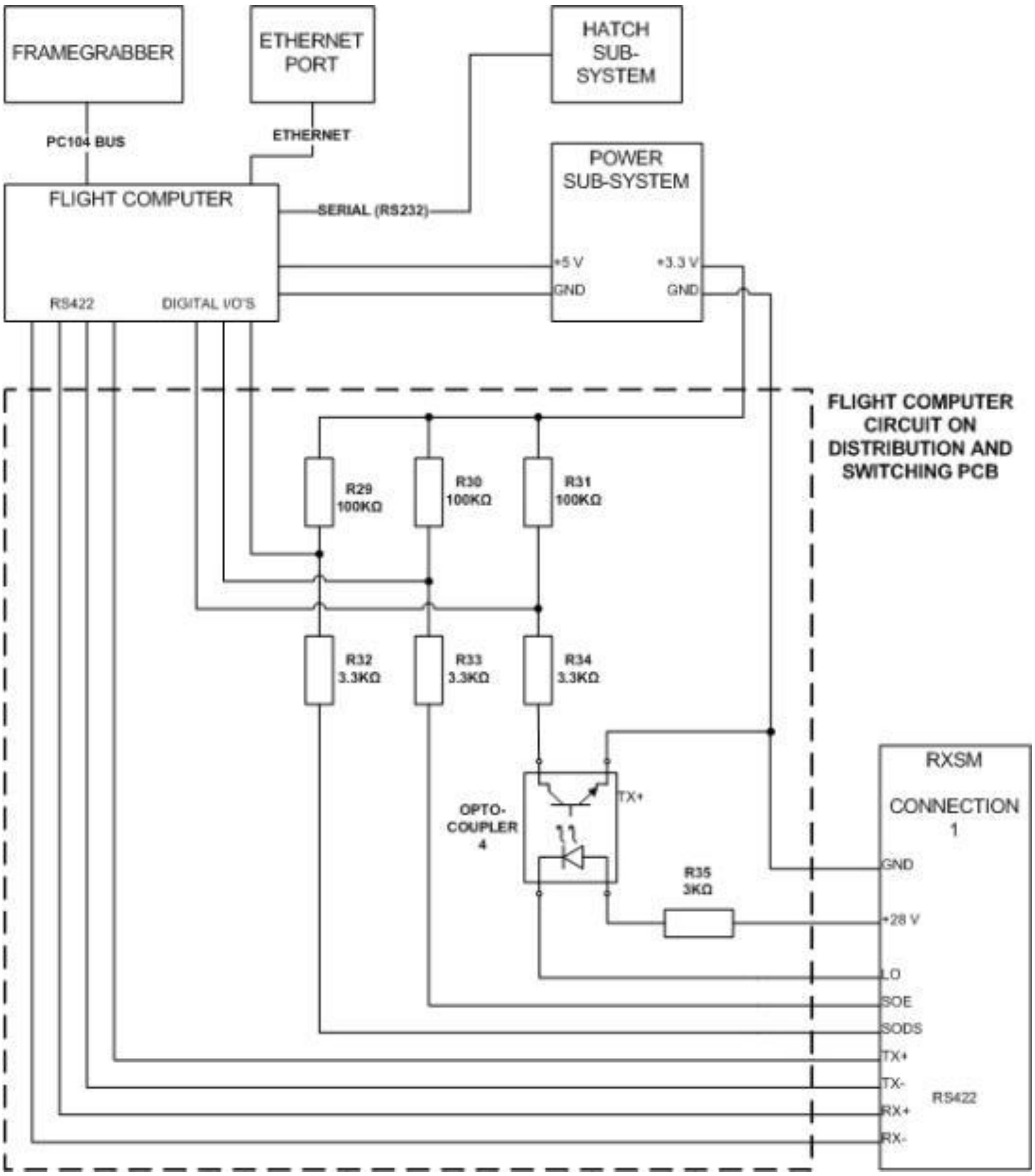


Figure 4-20: Flight computer circuit connection diagram

The frame grabber is a Eurotech CTR-1475, PC/104-Plus type MPEG encoder. It connects directly into the PC/104-Plus bus of the flight computer and draws it power from it. The CTR-1475 has the ability to take images from up to four analogue cameras (only two are used for this experiment), digitise them, compress them into either MPEG4 of AVI format and send them to the flight computer. A connection diagram for the framegrabber is given in Section 4.5.7 (Camera Sub-System).

Further information on the operation of the flight computer and frame grabber is given in section 4.7, Software Design. Further technical information on both boards can be found in the data sheets included in Appendix E.

4.5.4 Pyrotechnic Guillotine Sub-System

Two Cypress pyrotechnic guillotine devices are used to initiate boom deployment and boom jettisoning. When they are subjected to an electrical current of greater than 0.85A for longer than 15ms the pyrotechnic charge inside the devices explodes. The rapidly expanding gases then push on a guillotine which then cuts through a nylon cord passing through the eye of the device. A data sheet for the pyrotechnic guillotines has been included in Appendix D.

Premature firing of the pyrotechnic guillotines would not only cause the experiment to fail but could potentially endanger people working near the experiment at the time. As such, a number of safety features to prevent this, both mechanical and electrical, are incorporated into the experiment. On the mechanical side, two bolts, fitted with remove before integration tags, hold the boom in position, even if the pyrotechnic guillotines have fired. Also, the experiment hatch is closed at all time after integration when the experiment is not in use. If the pyrotechnic guillotines were to fire prematurely during this time the boom would strike harmlessly against the inside of the hatch. This would cause the experiment to fail but would dramatically reduce the like hood of injury to people working in the vicinity.

A connection diagram of the pyrotechnic guillotine firing circuit is shown in Figure 4-21. This circuit has been implemented on two PCB's: the Pyro PCB and the Distribution and Switching PCB. Both of these PCB's are mounted one above the other inside the experiments Electronics Enclosure, with the Pyro PCB being mounted on the bottom. In order to fire the pyrotechnic guillotines the following steps must be taken:

- When power from RXSM connection 1 is switched on, the entire experiment module powers up and power at 3.3 V from the power sub-system is switched on automatically.
- For either of the pyrotechnic guillotines to fire, power from RXSM connection 2 must be switched on and the LO signal from RXSM connection 1 must be switched ON

* Then, switching on the SODS signal from RXSM connection 1 causes the DEPLOY pyrotechnic guillotine to fire.
* Then, switching on the SOE signal from RXSM connection 1 causes the JETTISON pyrotechnic guillotine to fire.

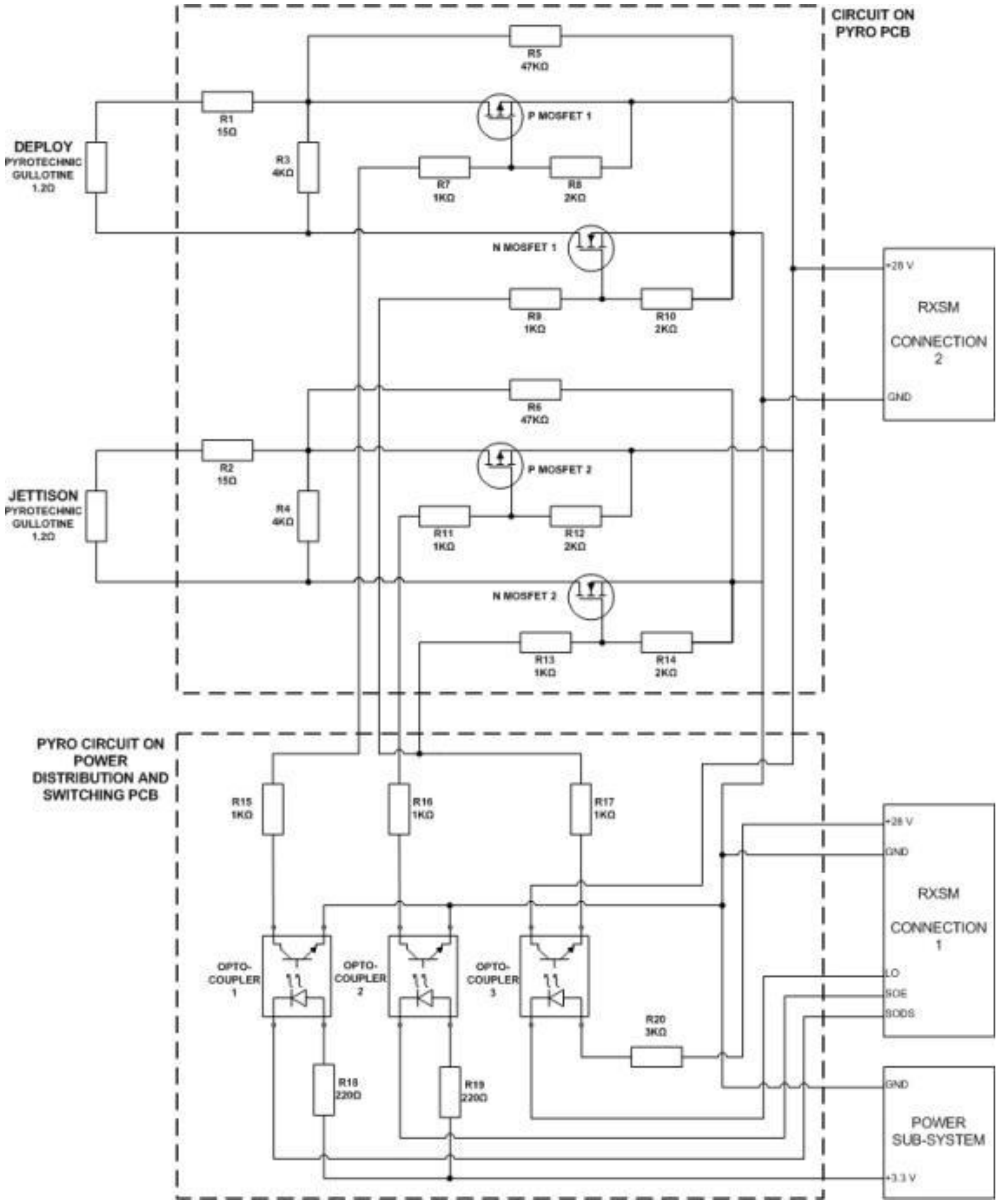


Figure 4-21: Pyrotechnic guillotines circuit connection diagram.

Two 15Ω resistors (R1 and R2) are connected in series with each of the pyrotechnic guillotines and limit the amount of current drawn from the RXSM when the guillotines fire to approximately 1.7A. To cater for this amount of current, 100W power resistors were used (Vishay, LTO100F15R00JTE3). These power resistors were not mounted on a heat sink, which compromises their effectiveness, however, current flows through them for a relatively short time (<1s) each time a pyrotechnic guillotine is fired.

4.5.5 Probe Sub-System

A connection diagram of the probe circuit is shown in Figure 4-22. The circuit is implemented on the Probe PCB, mounted at the distal end of the boom. It consists of an accelerometer, six LED's and assorted passive components.

The accelerometer is an Analog Devices ADXL345. It measures acceleration in three axes. It outputs the acceleration profile of the boom as it is being deployed and is used to determine the frequency of vibration of the end of the boom when it is fully deployed. The accelerometer sends digital acceleration data to the microcontroller in the hatch sub-system through an I^2C bus. The microcontroller then passes the acceleration data on to the main flight computer through a serial port. The six LED's (Thorlab LED661L) and lensed as to direct this light towards the measurement cameras. They emit light at a wavelength of 655nm.

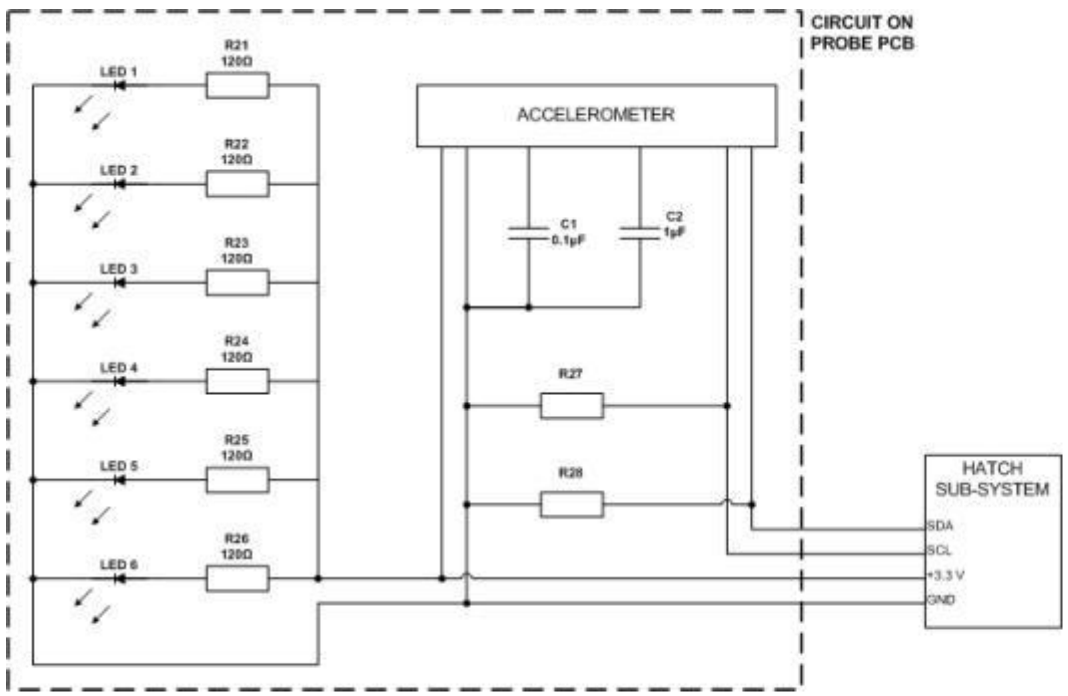


Figure 4-22: Probe circuit connection diagram

Four flexible single core cables connect the Probe PCB with the hatch sub-system through the centre of the boom. Two of these carry power at +3.3V and ground connections for the LED's and accelerometer. The other two carry clock (SCL) and data (SDA) lines for the accelerometers I2C interface.

For further technical information, data sheets of the ADXL345 accelerometer and LED661L LED's have been included in Appendix D.

4.5.6 Hatch Sub-System

The experiment has been fitted with a hatch to allow the boom to deploy through the skin of the rocket but also prevent hot air from entering the experiment during ascent and re-entry and snow from entering the experiment after landing.

A connection diagram for the hatch circuit is shown in Figure 4-23. The majority of the components are implemented on the hatch PCB which is mounted inside the Hatch PCB Enclosure inside the experiment module. The hatch is actuated by an Electronically Commutated (EC) motor (Maxon, EC-Max 22). A motor controller (Maxon, DEC Module 24/2) controls the speed of the motor in closed loop using feedback from three hall sensors imbedded in the EC motor. This motor controller is in turn connected to a microcontroller (Atmel, ATmega328P-PU) via five digital I/O pins and a PWM pin. The PWM signal is sent from the microcontroller to the motor controller and is used to set the desired speed of the EC motor. Three digital outputs from the motor controller send status information to the microcontroller. Two digital outputs from the microcontroller allow it to set the direction of rotation and enable and disable the motor controller. Power from the RXSM is provided at +24-36V. However, the power used by the motor controller cannot be supplied at greater than +28V or the motor controller may be damaged. Therefore, a linear regulator (National Semiconductor, LM350AT/NOPB) is used to provide a power supply at +24V from the RXSM supply for the motor controller and open and closed hall sensors. This linear regulator is mounted on a small heat sink and mounted to the front of the Hatch PCB Enclosure.

Two additional hall sensors have been integrated into the frame mechanism. These detect whether the hatch is open or closed. The output from these hall sensors is at +24V. As such, a set of four resistors act as voltage dividers to reduce this to less than +5V before it is inputted into the microcontroller.

The hatch sub-system also interacts with the probe sub-system. Data from the accelerometer in the probe is read by the hatch microcontroller through an I2C bus. This data, along with status data for the hatch sub-system is then sent to the flight computer and framegrabber sub-system through a RS232 serial connection. Commands for the hatch sub-system from the flight computer are also sent over the same connection. The microcontroller cannot output a serial signal with the required voltage levels for RS232. Therefore, a line driver

(Maxim, MAX233) is used to convert the TTL level signals from the microcontroller to the RS232 standard.

Further details on the software used in the hatch microcontroller are given in Section 4.8.4. Data sheets on several of the hatch components are given in Appendix D and information on the Hatch PCB is provided in Appendix E.

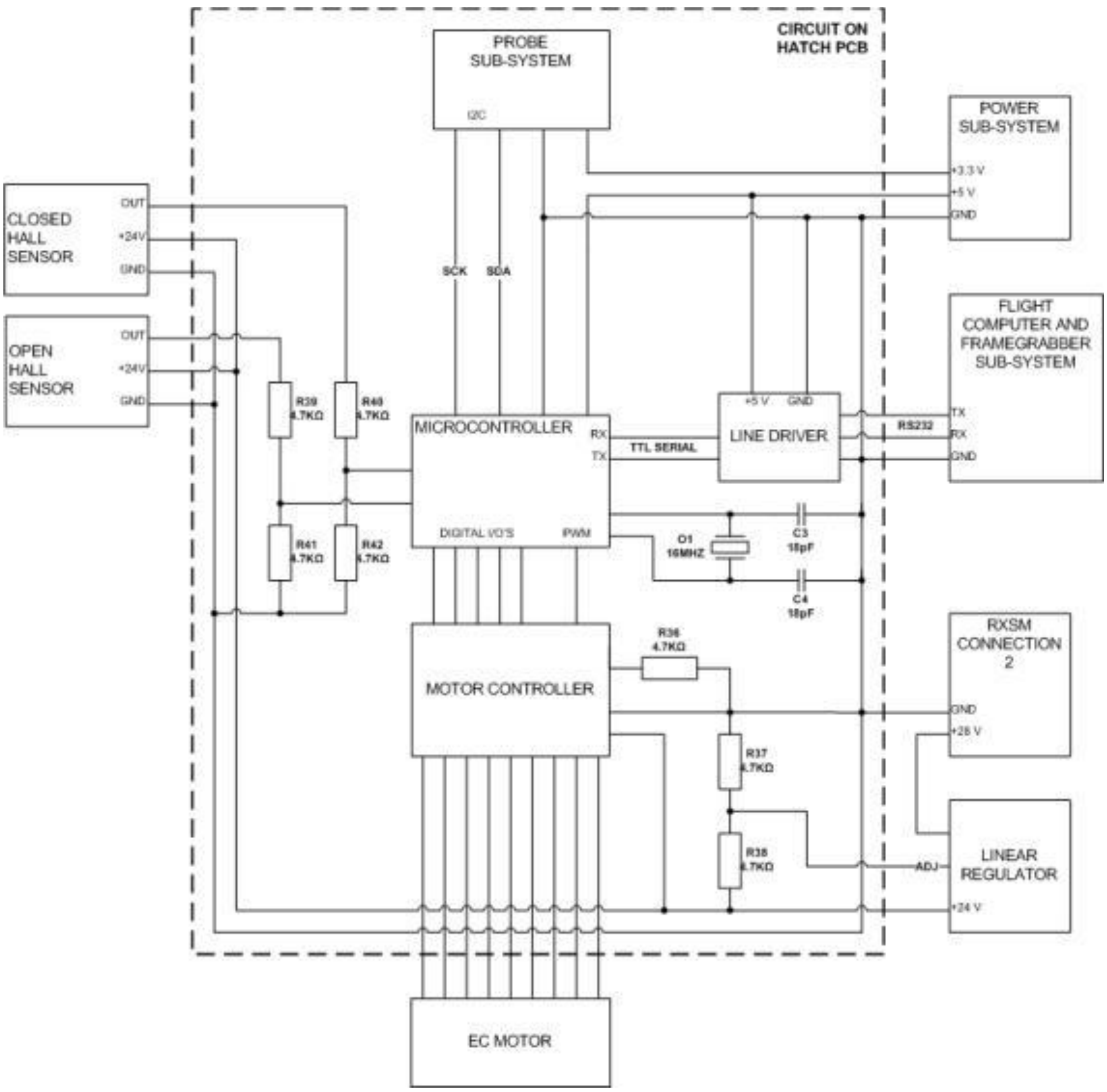


Figure 4-23: Hatch circuit connection diagram

4.5.7 Camera Sub-System

Three cameras are used in the experiment. Two of the cameras are measurement cameras. These are used to precisely measure the length of the boom when it is fully deployed and the magnitude of any boom deflection. The third camera is an observation camera. It is used to send live images of the boom deployment, operation and jettisoning back to the ground station. Figure 4-24 shows how the cameras are connected to the power sub-system, the framegrabber and the TXSM TV channel.

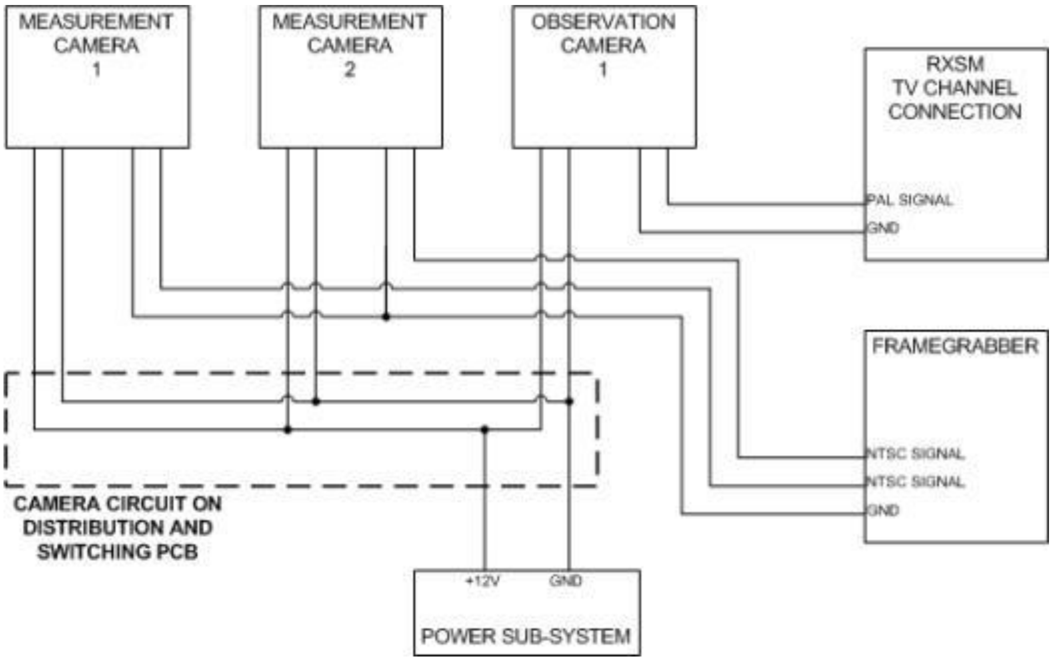


Figure 4-24: Camera circuit connection diagram

The two measurement cameras are Sony XC-ES50 type black and white cameras. These cameras are compact and have excellent vibration and shock characteristics. Each camera is fitted with an Edmund Optics compact fixed focal length lens. A band pass filter is fitted to the end of each lens, which only allows light with a wavelength close to 655nm to pass through it. The LEDs in the probe attached to the end of the boom emit light at 656nm. Filtering out most of the superfluous light allows for better frame compression (in frame grabber) and makes it easier to acquire relevant information from the video frames during post-flight analysis.

In total six LEDs are placed in the probe. This arrangement means that at least three LEDs are seen by each camera at any moment. The position of the probe can then be triangulated from the positions of these LEDs. Further information on how the camera measurement system works is provided in Chapter 7.

Power for the two measurement cameras is provided at +12V by the experiments power sub-system. The video outputs from both cameras are connected to the PC/104 frame grabber board which compresses them into a single MPEG 4 video stream that is then saved to memory by the PC/104 flight computer. For more information on how the data from these cameras is used to measure the position of the probe at the end of the boom please refer to Section 7.1. Also, for more technical information on the XC-ES50 camera, please refer to the data sheet in Appendix D.

The observation camera is a Sony XC-ES30 CE type black and white camera. It has an identical form factor to the XC-ES50 measurement cameras. It is fitted with an Edmund Optics compact fixed focal length lens. The observation camera is used to provide images of the boom deployment, operation and being jettisoning. The video output from the observation camera is connected to the TV transmitter in the RXSM which transmits the images to the ground station where they are monitored to provide live feedback of the experiment operating, particularly to verify if the boom has jettisoned properly. The measurement cameras are unsuitable for this purpose because of their band pass filters and narrow field of view. For more technical information on the XC-ES30 CE camera, please refer to the data sheet in Appendix D.

4.5.8 Printed Circuit Boards (PCB's)

All of the electronic circuits thus far described have been implemented on four PCB's. These are the Pyro PCB, the Distribution and Switching PCB (both mounted in the Electronics Enclosure), the Hatch PCB (mounted inside the Hatch Control Enclosure) and the Probe PCB (mounted inside the probe fixed to the distal end of the boom). All of the PCB's are double sided and implemented on 1.6mm thick fibre-glass board. A combination of KiCAD and EAGLE software was used to develop them and manufacturing was done by PCB Train (www.pcbtrain.co.uk) and PCB Pool (www.pcb-pool.com). Further information on the design of each of these PCB's is given in Appendix E.

4.6 Thermal Design

It is critical that the experiment can withstand the thermal conditions that it is subjected to before, during and after the flight.

Before lift-off and after landing, the REXUS rocket may spend a considerable amount of time on the launch pad. Ambient air temperature at ground level may be as low as -20°C. However, from data obtained from the REXUS 7 rocket, the ambient temperature inside the rocket remains between 0°C and +20°C. This was confirmed by the data obtained from the REXUS 9 flight, seen in Figure 4-25. During the flight, the temperature of the skin reaches approximately +90°C, however, the ambient temperature inside the rocket remained between +5°C and +40°C.

Where possible, experiment components were selected such that they had an extended industrial operating temperature range (-30°C to +85°C), which easily encompasses the range of temperatures experienced by experiment components during the flight. Therefore no insulation was required to thermally protect experiment components.

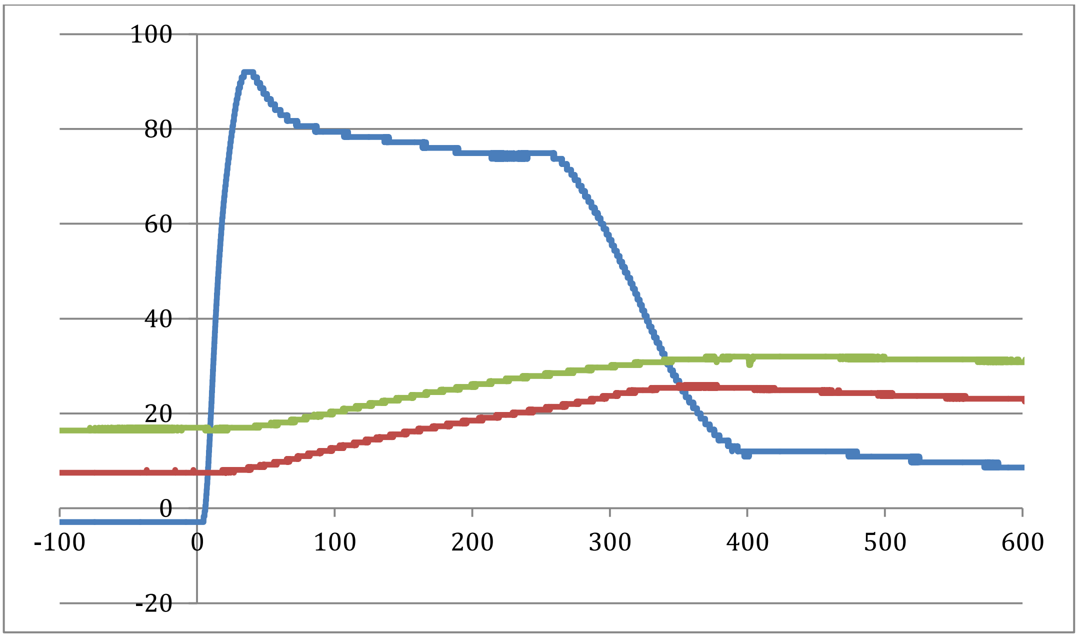


Figure 4-25: Temperature Profile of REXUS 9 Rocket. The blue line represents the skin temperature. The green and red lines represent ambient temperature inside the rocket, measured at two locations.

4.7 Power System

The graph in Figure 4-26 is experiment current consumption against time. Experiment current consumption is steady at approximately 0.7A prior to lift off and during the flight until the second power connection to the RXSM is switched on and the hatch opens, approximately 73 seconds after lift-off. Current consumption then increases to 1A for a period of 2 seconds as the hatch opens before dropping to 0.7A again. The same situation occurs when the hatch is closed, approximately 245 seconds after lift-off. There are two large spikes in the experiment current consumption. The first current spike a few seconds after the hatch has opened and results from the first pyrotechnic guillotine being fired to deploy the boom. The second current spike is when the second pyrotechnic guillotine is fired to jettison the boom. Both of these current spikes do not exceed 2.7A and last for less than 100ms.

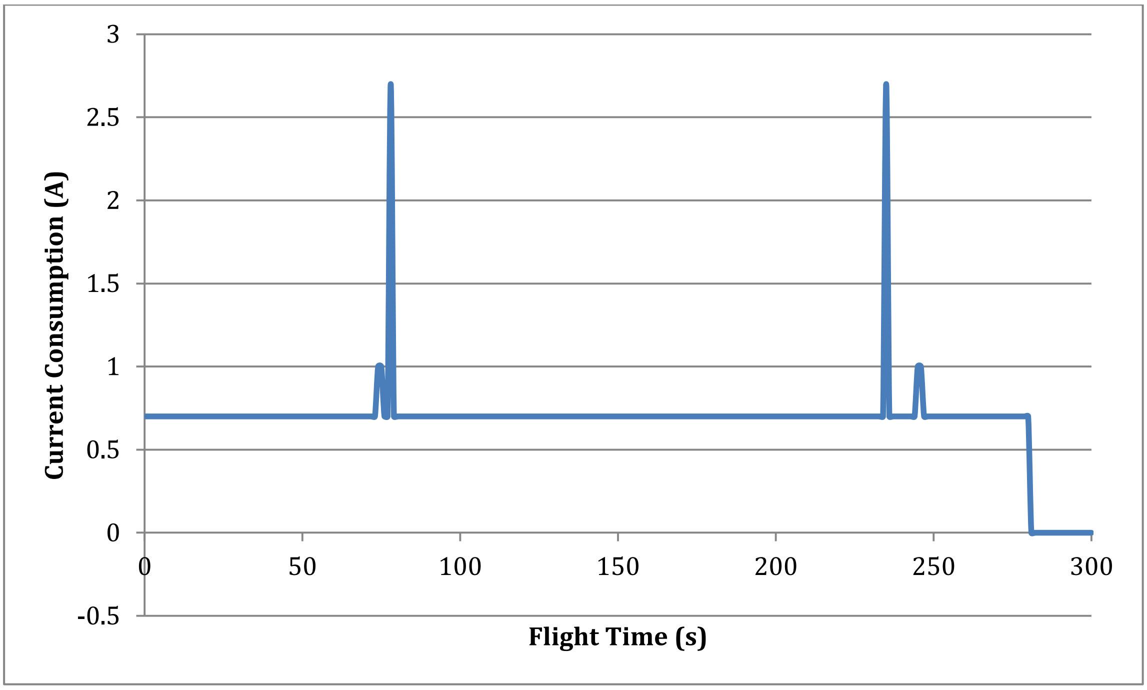


Figure 4-26: Graph of electrical current drawn by the experiment from RXSM versus flight time

4.8 Software Design

4.8.1 Base Operating System

The PC/104 ISIS-XL CPU module used Windows XP Embedded as its base operating system (OS). This stack is the master controller for the various subsystems of the Telescobe 2 module. Communication and control of individual elements is achieved through a number of custom software packages utilising open-source libraries. The OS is configured to initiate the main experiment controller application on system boot so that in the event of a power disruption, the module would come back online to the desired state of operation.

4.8.2 Additional Software

The cameras chosen to monitor boom deployment and deflection (Sony XC-HR58) are controlled by the Eurotech CTR-1475 framegrabber module. This acted as the video compressor, encoder and frame grabber for the measurement cameras. An application for controlling this framegrabber module was provided by Eurotech. Communication with the experiment controller was facilitated using the Python programming language [10].

4.8.3 Experiment Controller

The experiment controller is a custom software application developed in CPython. It runs on the flight computer and handles the control of and communication between all the various parts of the Telescobe 2 experiment. This included functionality for the control and monitoring of subsystems such as the module hatch, boom deployment, boom jettison, data acquisition, communication between the Telescobe 2 module and the RXSM, telemetry communications and data storage. The PySerial module is used to facilitate communication with the hatch controller and probe accelerometer via the flight computers RS232 port. It is also used to facilitate the sending of telemetry to the ground station via the RXSM over the flight computers RS422. The CTypes library was used to interact with any vendor DLLs for accessing hardware such as GPIO ports.

The experiment controller is designed as a variation on the Finite State Machine (FSM) design pattern. As such, the experiment controller is always in one of a number of known states. These are *INIT*, *START*, *ASCENT*, *DEPLOY*, *JETTISON* and *FINALISE*. The state machine uses a combination of the hardware signals received from the RXSM through the GPIO ports as well as custom timers to transition through the states.

The experiment controller can transition through each of the states without activating any of the mission critical sub functions such as boom deployment and boom jettison. During this time all system logs are recorded and telemetry is sent back to the ground station so that the software operation can be verified remotely. In order to preserve memory space, video frames are only stored during the *DEPLOY* state. Mission critical functionality such as boom deployment and jettison pyrotechnic guillotines are controlled by the electronics and are not activated unless the *LO* signal had been received. This means that the system can be tested for a response to the *SODS* and *SOE* signals in a controlled environment, such as on the launch pad.

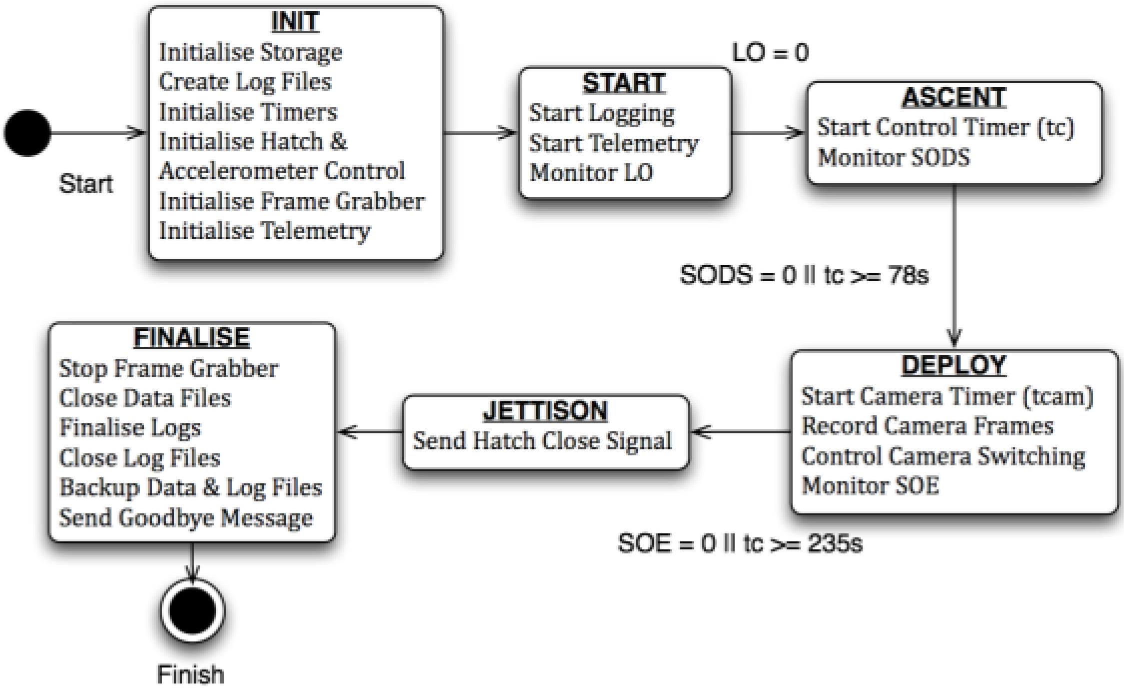


Figure 4-27: Experimental Controller State Diagram

In the unlikely event that there is an unplanned reset of the experiment computer during flight, the presence of the *LO, SODS* or *SOE* signal combinations causes the experiment controller to transition into the correct state on system reboot. A summarised state diagram for the experiment controller can be seen in Figure 4-27. A summary of the operation of each of the states is given in the following sections.

INIT

This is first set of commands executed by the experiment controller on system boot. All initialisation is done it this state, including memory storage areas, data acquisition parameters and communication protocols. Once all parameters and subsystems are set up correctly the system immediately transitions into the *START* state. The flow chart for the *INIT* state can be seen in Figure 4-28.

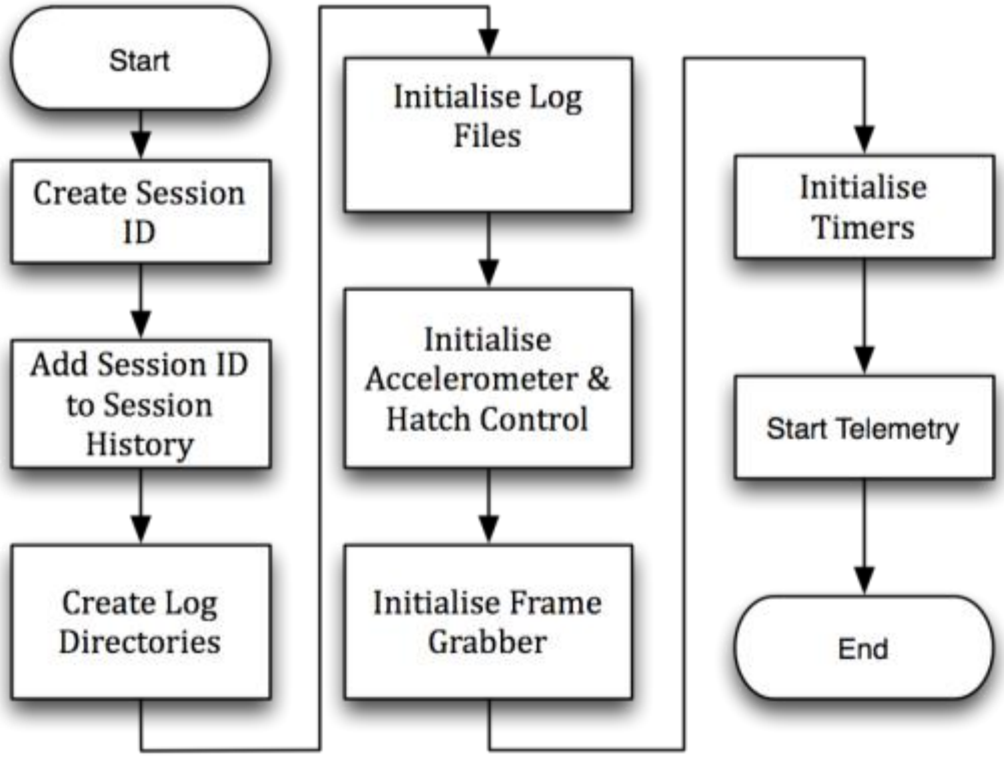


Figure 4-28: INIT State Flow Chart

START

The *START* state is a waiting state in which the system is ready for launch. Systems such as telemetry and logging are active throughout this state. On receipt of the *LO* signal the system logs the lift-off time and transitions into *ASCENT* state.

ASCENT

In *ASCENT* state a control timer, t_c, is started in order to control transition into the next state, (*DEPLOY*), where the camera frames are recorded. The timer is set to trigger state transition at T+78s, 15 seconds before boom deployment. This is so that the actual deployment is captured on camera. As a failsafe the *SODS* signal, which triggers boom deployment at T+93s, is also monitored. On receipt of either the control timer or *SODS* signals, the system transitions into the *DEPLOY* state. This is illustrated in Figure 4-29.

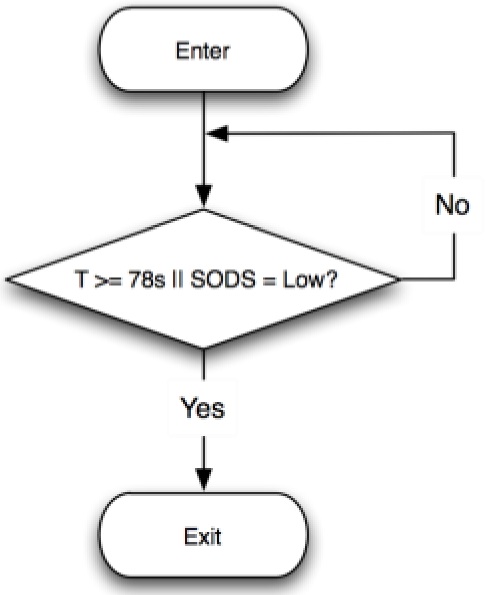


Figure 4-29: ASCENT State Flow Chart

DEPLOY

On entry to the *DEPLOY* state a camera timer, t_{cam}, is started and both measurement cameras start recording frames to on-board storage. As both cameras are recording at this time the boom deployment, (at T+93s), is captured allowing the deployment length to me determined on experiment retrieval. At t_{cam} = *30*s the frame grabber is instructed to record from camera 1 only. At t_{cam} = *70*s the frame grabber is instructed to record from camera 2 only. Switching to single cameras allows frames to be recorded at full resolution so that any deflections can be determined at a higher accuracy during post-flight analysis. At t_{cam} = *110*s the frame grabber is instructed to record from both cameras again so that the deployment length can again be determined and checked against the initial deployment length to make sure there are no changes. Frames continue to be recorded from both measurement cameras until detection of the *SOE* signal, (which in the case of the Telescobe experiment is used to indicate 'Signal of Ejection'), from the RXSM at T+230s. At this point the system transitions into the

JETTISON state. In the event of a hardware failure in the detection of the *SOE* signal, the control timer, t_c, is monitored and the system transitions into the *JETTISON* state at T+235s. The flow chart for this state can be seen in Figure 4-30.

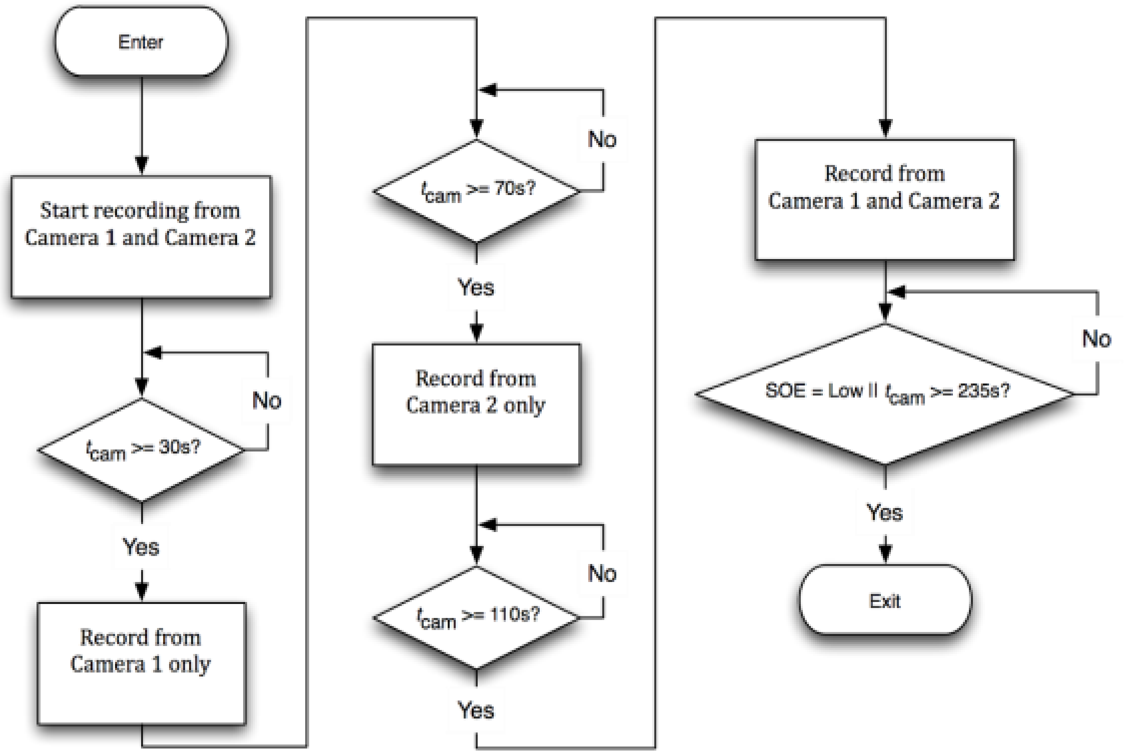


Figure 4-30: DEPLOY State Flow Chart

JETTISON

On entry to the *JETTISON* state, the hatch-close timer is activated and after a period of 5 seconds the close signal is sent to the hatch controller. Once this is complete the system immediately transitions into the *FINALISE* state.

FINALISE

On entry to the *FINALISE* state both cameras are switched off after which a shut-down timer is initialised. After 12 seconds all final log entries are made and all log files are closed. At this point all data files are backed up to the on-board SD card as a safety precaution in the event that the internal memory of the CPU is damaged on landing. Once this is complete the state machine exits the main loop and sends the 'Goodbye' signal to the ground station before execution is stopped. This is illustrated in Figure 4-31.

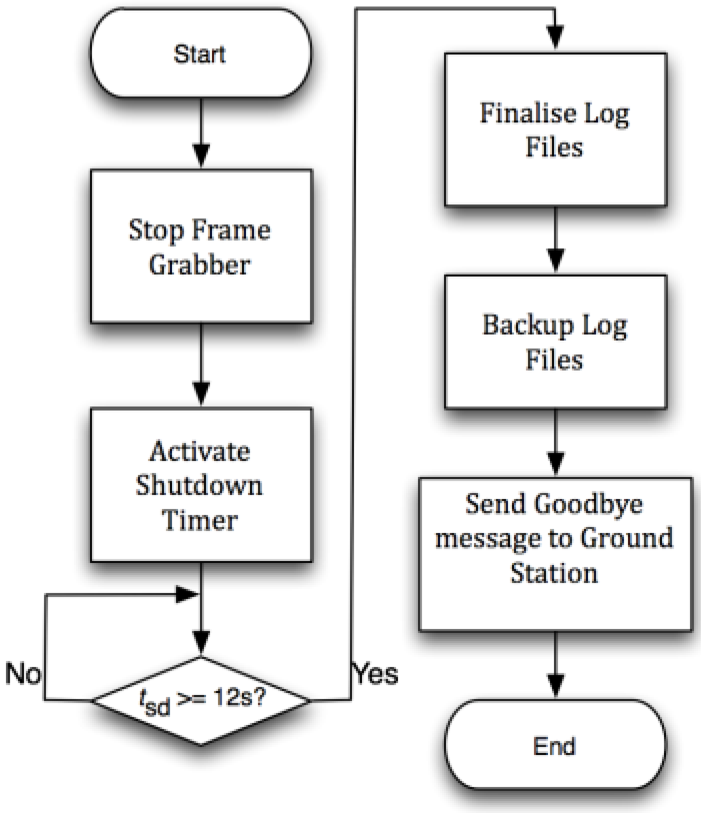


Figure 4-31: FINALISE State Flow Chart

4.8.4 Embedded Sub-Systems

The hatch sub-system and accelerometer are controlled by an AVR Atmage328 microcontroller, configured to use the Arduino [12] boot loader. As such, the microcontroller software was written in AVR C utilising the Arduino open-source libraries. The software is structured as a finite state-machine taking inputs from each of the sensors and sending them back to the experiment controller using the 2nd RS232 port. A handshaking protocol exists between the experiment controller and AVR to control the exchange of sensor data.

The microcontroller runs a finite state machine code structure which consists of five states: WAIT, OPENING, OPEN, CLOSING, and CLOSED. The microcontroller stays in the WAIT state until power from the experiment's second RXSM connection is switched on. This gives power to the motor controller which then sends a ready signal to the microcontroller and causes it to transition to the OPENING state. The microcontroller then sends a command to the motor controller instructing the hatch to open. A timer in the microcontroller then activates such that after a predefined time the microcontroller instructs the motor controller to stop. The microcontroller then transitions to the OPEN state and remains in this state until a close command is received from the experiment flight computer via the RS232 interface. This happens a few seconds after the boom had been jettisoned from the experiment. The code then transitioned to the CLOSING state and a command was sent to the motor controller instructing it to close the hatch. A timer in the microcontroller is again activated such that the motor controller is instructed to stop after a designated time. The microcontroller then transitions to the CLOSED state. In the first four states, accelerometer data is acquired and sent on to the main embedded computer via the RS232 interface. However, in the CLOSED state, the accelerometer was jettisoned from the experiment along with the boom so accelerometer data acquisition was stopped.

4.8.5 Telemetry

Both accelerometer and housekeeping telemetry data are sent to the ground station throughout the experiment. This enables real-time feedback on the performance of the experiment as well allowing events and accelerometer data to be stored by the ground station. The telemetry is handled by a sub module of the main experiment controller; the telemetry controller. It is the job of the telemetry controller to take data passed from the experiment controller, wrap it into packets and send them out through the RXSM telemetry system via the RS422 port. The format of each packet was as follows:

[STX] [PacketTypeID] [Message] [ChkSum]

STX:	Start of packet transmission
PacketTypeID:	Type of packet
	(e.g. Session, Housekeeping, Hatch Status, Accelerometer, Goodbye). The length of the data message can then be inferred from the packet type ID.
Message:	Actual data to be sent packet
ChkSum:	Modulo 256 checksum

Five types of message are sent to the ground station via the telemetry system:

- Session Packet

  The session packet is a 6 Byte packet consisting of a unique random string, or 'Session ID Tag', to differentiate individual invocations of the experiment controller. This is the first type of packet sent to the ground station while still on the launch pad. The Session ID is then recorded by the ground station and used to correlate the ground logs with the flight logs at a later time. This way it is possible to run multiple simulations before launch, each creating their own distinguishable set of log files to be compared with the ground station data at a later time.

- Experiment Controller (EC) Housekeeping Data

  The EC housekeeping data message holds the status information for the entire experiment. It consists of two bytes of data which, when broken down into sets of bits, holds an encoded representation of the state and status information for the experiment controller and related sub-systems. The format of the bits can be broken down as seen in Table 4-5.

Name	Bits	Notes
Mode: Test/Live	0	0=Test, 1=Live
LO signal received	1	0=No, 1=Yes
SODS signal received	2	0=No, 1=Yes
Camera 1 Status	3	0=Off, 1=On
Camera 2 Status	4	0=Off, 1=On
SOE signal received	5	0=No, 1=Yes
Experiment Controller State	6, 7, 8	Binary representation of state
RESERVED	9 - 15	Reserved for additional flags

Table 4-5: Telemetry message for experiment controller housekeeping data

The housekeeping packet, including packet wrapper, is thus 40 bits long. Allowing for a maximum of 10 status packets per second would require 400b/s of the serial channel bandwidth.

- Hatch/Probe (HP) Housekeeping Data

  The HP housekeeping data message holds the status information for the hatch controller and the probe mounted to the distal end of the boom. It consists of one byte of data which, when broken down into bits, holds an encoded representation of the state and status information for the Hatch-Probe controller. The format of the bits can be broken down as seen in Table 4-5.

Name	Bits	Notes
Inductive Sensor 1	0	0=Inactive, 1=Active
Inductive Sensor 2	1	0=Inactive, 1=Active
Motor Enabled	2	0=No, 1=Yes
Close Signal Received	3	0=No, 1=Yes
Accelerometer Status	4	0=No Communication, 1=Communicating
Hatch State	5, 6, 7	Binary representation of state

Table 4-6: Telemetry message for hatch/probe housekeeping data

The housekeeping packet, including packet wrapper, is thus 32 bits long. Allowing for a maximum of 10 status packets per second would require 320b/s of the serial channel bandwidth.

- Accelerometer Data

  The accelerometer data message is a 6 Byte representation of the current sample from each of the x, y and z axes registers. The accelerometer packet, including packet wrapper is thus 72 bits long. Allowing for 100 accelerometer packets per second would require 7.2kb/s of the serial channel bandwidth.

- Goodbye Packet

  The goodbye packet is a static 6 Byte message to signify that the experiment controller and all sub systems have reached their finalise state successfully and are ready for shut down. This is the last message sent to the ground station and is used to indicate that the telemetry is about to stop as expected. The goodbye packet is sent 20 times to ensure that the packet is not missed due to corruption during transmission.

4.8.6 Ground Station

The ground station application is also written in CPython, using TKinter as the graphical user interface (GUI) framework. The job of the ground station is to parse the received telemetry stream and display the real-time status information the experiment. The ground station also logs accelerometer data and event information for off-line analysis at a later time.

4.8.7 Logging

There are a total of ten log files taken during the course of the experiment. Five on-board log files are created by the experiment controller application and stored on the internal flash memory of the ISIS-XL CPU. These are also backed up onto a separate SD card as a safety precaution for retrieval later. Five further logs are also created by the ground station. A brief explanation of the log files is given below:

- Flight Log

  The on-board flight log keeps track of all major events and associated times at which they occur during the experiment. Additional information such as current state are logged during each pass through the main loop of the state machine as a type of 'heart beat' in order to trace and debug events in the case of an unexpected anomaly. A periodic record of the number of telemetry bytes sent is also periodically logged to compare with the number received by the ground station.

- Accelerometer Data Log

  The accelerometer register samples and associated times are logged to a separate file for analysis on retrieval of the experiment.

- EC Housekeeping Flight Log

  The status flags for the experiment controller housekeeping data are logged to a separate file to that event timelines can be plotted and compared to those expected.

- HP Housekeeping Flight Log

  The status flags for the hatch-probe housekeeping controller are also logged to a separate file to that event timelines can be plotted and compared to those expected.

- HP Byte Log

  The raw bytes received from the hatch-probe controller are logged to a separate file as a safety mechanism so that, in the event of an unexpected problem with the parsing of hatch-probe status flags, they may be decoded again on experiment retrieval.

- Ground Event Log

  The ground station event log records the times at which all major events are parsed from the received telemetry. This includes events such as state machine transitions, times at which the RXSM signals are received, camera switching times and a count of corrupt packets vs. total packets received. The 'Session ID Tag' used by the experiment controller for the respective invocation of the experiment is also recorded in the ground event log.

- Accelerometer Ground Log

  As a failsafe in the event that the module cannot be retrieved after the flight or that the on-board storage is damaged, the accelerometer register samples and associated times are also logged by ground station.

- Telemetry Byte Log

  The raw telemetry byte stream is logged to a separate file so that in the case that there is an anomaly in the parsing of individual packets, the telemetry stream can be re-examined at a later time. This also allows for a 'playback' of the telemetry steam through the ground station for post-flight analysis. As with the on-board logger, the EC and HP status bits are logged to separate files as a backup in the case that the experiment cannot be recovered after landing.

4.8.8 Post Flight Analysis

- Data Retrieval

  After the module is recovered and the on-board computer powered up, the video files, accelerometer data and flight logs are transferred from the on-board storage via the network interface. This data can also be retrieved from the on-board SD card on module disassembly.

- Log Parsing

  Both the on-board flight event log and ground station event log can be inspected visually as they are recorded in plain text format. In the case of the housekeeping status logs, Python is used to parse and plot the timeline giving a visual representation of the main events that occurred during the flight. For analysis and processing of the accelerometer data the Python Scipy and MatPlotLib libraries are utilized. The telemetry byte log is also parsed using a custom Python script.

- Deployment and Deflection Analysis - LED Tracking

  The video files recorded from measurement cameras are used to extract the position variation and thus track the movements of the LEDs in the probe. This was achieved using a custom MatLab script. The resulting trajectories are then processed to give deployment and deflection profiles.

- Accelerometer Data Analysis

  The data retrieved from the accelerometer inside the mock-probe at the distal end of the boom is used in conjunction with the deflection profile from the camera measurements to evaluate the boom performance. The accelerometer data processing is achieved using the Python Numpy and Scipy [11] libraries and visualised using MatPlotLib.

4.8.9 Pre-flight Processing

The telemetry data received from the accelerometer inside the probe is used to make sure the probe is working as expected. As the rocket is stationary while on the launchpad, the pre-flight processing consisted of making sure that a force of ~1g could be seen acting down on the probe as well as checking that samples were being received at a sufficient sample rate. If both these criteria are not met a power cycle is requested to reset the experiment.

4.8.10 Storage Requirements

The total on-board flash memory for the ISIS-XL flight computer was 2GB. A further 2GB industrial grade SD card is added for backing up the on-board data in the case that the on-board memory is damaged during re-entry or landing. A breakdown of the actual memory storage used for the experiment data and video files in previous flight simulations is given in Table 4-7

Data	Memory Consumed (Bytes)
Flight Event Log	10395872
EC Housekeeping Log	1117933
HP Housekeeping Log	80528
HP Byte Log	381466
Accelerometer Data Log	1512081
Camera Recordings	12096228
Total Storage Used	**25584108**

Table 4-7: Memory storage used during the experiment flight

It can be seen that the total storage memory required by the experiment was approximately 25.6MB which was well within budget of that available. Accounting for the operating system and pre-existing files on the module before assembly, the extra memory available allowed for many flight simulations to be undertaken while still leaving enough storage space available for an actual flight.

4.9 Ground Support Equipment

One single laptop computer and an RS232 to USB converter is all that is required for the ground support hardware. This runs the ground support software which was written in CPython, using Tkinter for its GUI. For pre-flight testing, this is used to verify that the experiment controller boots up, the telemetry system works and that the experiment is receiving *LO*, *SODS* and *SOE* test signals.

5 Experiment Verification and Testing

5.1 Verification Matrix

Table 5-1 details all of the experiment requirements and the methods used to verify them. Verification procedures were carried out in accordance with ECSS-E-ST-10-02C.

All of the requirements are verified by one or more of four methods:

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

Verification is carried out at five levels:

- Qualification (Qual)
- Acceptance (Acc)
- Pre-launch (Pre-L)
- In-Flight (Fly)*
- Post-launch (Post-L)

Verification is carried out on five experiment models:

- Design (DE)
- Mock-up (MU)
- Structural-Thermal Model (STM)
- Engineering-Qualification Model (EQM)
- Flight Model (FM)

*Flight is sub-orbital, deviation from standard of Orb for in-orbit.

#	Requirement	Level	Verification Methods				
			DE	MU	STM	EQM	FM
F.1	A hatch *shall* open.	Qual	R				
		Acc					T
		Pre-L					T
F.2	The telescopic boom *shall* safely deploy.	Qual	R				
		Acc					T
		Pre-L					T
F.3	Boom deployment *shall* be recorded.	Qual	R				
		Acc					T
		Pre-L					T
F.4	Boom deflection and vibration *shall* be recorded.	Qual	R				
		Acc					T
		Pre-L					T
F.5	Boom deployment, deflection and vibration *should* be monitored and recorded in real time by the ground station.	Qual	R				
		Acc					T
		Pre-L					T
F.6	The boom *shall* be safety jettisoned before re-entry.	Qual	R				
		Acc					T
		Pre-L					T
F.7	Temperature readings *may* be recorded during the flight.	Qual	R				
F.8	The strain on the boom housing *may* be measured	Qual	R				

			DE	MU	STM	EQM	FM
P.5	The telescopic boom *shall* fully deploy in less than 1.5 seconds.	Qual	R				
P.6	The boom *shall* deploy to 1.7m total length.	Qual	R				
		Acc					T
P.7	Boom deployment length accuracy *shall* be such that the distance between the tip of the boom and the REXUS roll axis does not vary by more than 0.5% of max boom length	Qual	R				
		Acc					I
P.8	Boom deflection and vibration amplitude at the distal end of the boom *shall* result in the top of the boom being displaced by an angle of less than 2 degrees from an axis through the boom mounting that is perpendicular to the REXUS roll axis.	Qual	R				
		Acc					I
P.10	Boom deployment *shall* be recorded by a camera system.	Qual	R				
		Acc					I
		Pre-L					I
P.11	Boom deflection *shall* be recorded using the camera system.	Qual	R				
		Acc					I
		Pre-L					I
P.12	The camera system *shall* be capable of recording up to 30 frames per second (FPS).	Qual	R				
P.13	Real time camera data *should* be transmitted to ground station using the RXSM TV transmitter.	Qual	R				
		Acc					T
		Pre-L					T

			DE	MU	STM	EQM	FM
P.15	Data from the measurement system *shall* be stored for post flight analysis.	Qual	R				
		Acc					T
		Pre-L					T
P.16	Boom vibrations *shall* be recorded by accelerometers.	Qual	R				
		Acc					T
		Pre-L					T
P.17	Accelerometers *shall* record data of a sampling rate 20 times the expected maximum boom vibrational frequency.	Qual	R, A				
		Acc					T
P.18	Temperature readings *may* be taken in the “Telescobe” module using thermocouples.	Qual	R				
P.19	Thermocouples *may* sample at a rate of 1 sample per second.	Qual	R				
P.20	Thermocouples *shall* be capable of measuring temperature range 173-473K.	Qual	R				
D.1	The experiment *shall* fit into a module of inside diameter 348.6mm.	Qual	R				
		Acc					I
D.2	The experiment *shall* fit into a module of height 220mm.	Qual	R				
		Acc					I
D.3	The experiment *shall* be capable of withstanding the REXUS temperature profile 173-472K	Qual	R, A				
		Acc		T			
D.4	The experiment *shall* be capable of withstanding the pressures (0.5mBar absolute)	Qual	R, A				
		Acc		T			

			DE	MU	STM	EQM	FM
D.5	The experiment *shall* be capable of withstanding acceleration of up to 20*g*.	Qual	R, A				
		Acc					I
		Pre-L					I
D.6	The experiment *shall* consume less than 28W of power at all times, except during boom deployment and jettison.	Qual	R				
		Acc					T
		Pre-L					T
D.7	The solid state memory device *shall* be capable of withstanding an impact at 8m/s.	Qual	R, A				
D.8	The solid-state memory device *shall* be capable of storing the data stream from the video acquisition system.	Qual	R				
		Acc					T
D.9	The experiment *shall* be capable of withstanding the vibration of the REXUS rocket as described in the REXUS user manual.	Qual	R, A				
		Acc					T
D.10	The experiment *shall* interface with the RXSM through a D-SUB 15 male connector.	Qual	R				
		Acc					I
D.11	The experiment *shall* interface with the RXSM TV transmitter through a BNC connector.	Qual	R				
		Acc					I
D.12	The experimental module *shall* have a mass of less than 55kg.	Qual	R				
		Acc					I
D.13	The experiment *shall* be thermally insulated such that it does not cause a change in temperature in neighbouring modules of more than ±50K.	Qual	R, A				
		Acc					T

			DE	MU	STM	EQM	FM
D.14	All cables used in the experiment *may* be twisted.	Qual	R				
D.15	Cables used in the experiment *may* be shielded.	Qual	R				
D.16	The experiment *shall* not heat feed-through cables to other experimental modules by more than 70K.	Qual	R				
		Acc					T
D.17	The experiment *shall* not induce vibrations greater than a frequency of 25Hz to the rocket.	Qual	R				
		Acc					T
D.18	The experimental systems *shall*survive power cycling.	Qual	R				
		Acc					T
D.19	A foam cap *shall* be used to dampen boom vibrations during the flight.	Qual	R				
		Acc					I
D.20	The experiment module *may* have an umbilical connection	Qual	R				
D.21	All blind holes *shall* be vented	Qual	R				
		Acc					I
O.1	Combustible substances *should* not be used.	Qual	R				
O.2	Compressed fluids *shall* not be used.	Qual	R				
O.3	All systems *shall* be in a secure mode before landing.	Qual	R				
		Acc					R
O.4.	The experiment *shall* be controlled by control lines from the RXSM.	Qual	R				
		Acc					T
		Pre-L					T

			DE	MU	STM	EQM	FM
O.5	The experiment *shall* be designed so it can be safely handled.	Qual	R				
		Acc					I
O.6	The experiment *shall* be able to conduct measurements autonomously in case connection with the ground segment is lost.	Qual	R				
		Acc					R
O.7	The experiment *shall* accept a request for radio silence at any time while on the launch pad.	Qual	R				
O.8	Unless otherwise stated, M4 socket head cap screws and below *shall* use Loctite222 thread locker.	Acc					I
		Pre-L					I
O.9	Unless otherwise stated, M5 and up socket head cap screws *shall* use Loctite243 thread locker.	Acc					I
		Pre-L					I
O.10	Unless otherwise stated, Loctite601 retainer *shall* be used on all dowels.	Acc					I
		Pre-L					I
O.11	All permanent screws *shall* be marked with tamper evident seal.	Acc					I
		Pre-L					I
O.12	If tamper evidence seal is not required (e.g. adjustable brackets) a small dot on the cap *shall* be sufficient to show the screw is properly 'torqued'.	Acc					I
		Pre-L					I
0.13	Pre-launch checks *shall* be devised to ensure that all systems are operational.	Pre-L					R
O.14	All wire connections to screw terminals *shall* be ferruled in accordance with DIN 46228.	Acc					I
		Pre-L					I

			DE	MU	STM	EQM	FM
O.15	The hatch on the outer skin of the module *shall* open fully.	Acc					T
		Pre-L					T
O.16	The hatch *shall* open at least T+75 seconds after launch.	Acc					R
		Pre-L					T
O.17	The hatch *shall* open outwards.	Qual	R				
O.18	The telescopic boom *shall* deploy at at least T+78 seconds after rocket is de-spun at T+63 seconds.	Acc					R
		Pre-L					T
O.19	The boom *shall* be jettisoned away from spacecraft after T+220 seconds.	Acc					R
		Pre-L					T

Table 5-1: Verification Matrix

5.2 Test Plan

The testing practices are based on ECSS-E-ST-10-03A Space Engineering Testing. The experiment as well as the components and materials used were tested under the following headings outlined in ECSS-E-10-03A:

- Vacuum
- Vibration
- Thermal
- Functionality

Details of all requirements which were verified through testing, as well as their associated tests, are presented in Table 5-2. Subsequently, a description of each of the tests is provided.

Requirement	Level	Test Type	Test Number
F.1	Acceptance	Functionality	008, 011
	Pre-launch	Functionality	012, 013
F.2	Acceptance	Functionality	008, 009, 011
	Pre-launch	Functionality	012, 013
F.3	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
F.4	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
F.5	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
F.6	Acceptance	Functionality	009, 011
	Pre-launch	Functionality	012, 013
P.6	Acceptance	Functionality	010
P.13	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
P.15	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
P.16	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
P.17	Acceptance	Functionality	011
D.3	Acceptance	Thermal	007
D.4	Acceptance	Vacuum	001, 002, 003, 004, 005
D.6	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
D.8	Acceptance	Functionality	011
D.9	Acceptance	Vibration	006
D.13	Acceptance	Functionality	011
D.16	Acceptance	Functionality	011
D.17	Acceptance	Functionality	011
D.18	Acceptance	Functionality	011

O.4	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
O.15	Acceptance	Functionality	011
	Pre-launch	Functionality	012, 013
O.16	Pre-launch	Functionality	012, 013
O.18	Pre-launch	Functionality	012, 013
O.19	Pre-launch	Functionality	012, 013

Table 5-2: Details of requirements verified through testing

Test Number: **001**

Test Type: Vacuum test (properties) to 0.2 mbar.

Test Facility: Physics Laboratory, DIT Kevin St.

Tested Item: Shimano Muscle carbon fibre boom (Nexave CX 1150 & ForceMaster)

Test Level: Acceptance

Test Procedure: The carbon fibre fishing pole is cut laterally into eight sections for examination. All samples are first viewed under a microscope to determine their composition before testing.

Half of the samples are control specimens. They can later be compared against samples that undergo vacuum testing. The rest of the samples are placed in the vacuum chamber. The chamber is sealed and, over a period of approximately three minutes, the air pressure inside is reduced to 0.2 mbar. The chamber is then held at this pressure for five minutes before being increased to ambient again.

All of the samples are inspected under an optical microscope to determine if they have been damaged by the testing procedure. The ultimate tensile strength of all of the samples is then determined using a Dartec tensile testing machine.

Test Duration: 30 minutes

Test Campaign Duration: 2 days

Test Number:	**002**
Test Type:	Vacuum test (properties) to 0.2 mbar.
Test Facility:	Physics Laboratory, DIT Kevin St.
Tested Item:	Araldite Bond lock structural epoxy
Test Level:	Acceptance
Test Procedure:	Two steel plates are bonded together with a the adhesive. In total four pairs are created. Two acted as control specimens and two are vacuum tested. Specimens are then subjected to vacuum conditions as per test number 001 and then visually (using a microscope) and physically inspected.
Test Duration:	30 minutes
Test Campaign Duration:	2 days

Test Number:	**003**
Test Type:	Vacuum test (properties) to 0.2 mbar.
Test Facility:	Physics Laboratory, DIT Kevin St.
Tested Item:	Open cell viscoelastic foam (Sunmate Blue, polyurethane, density 60 kg/m^3)
Test Level:	Acceptance
Test Procedure:	Four samples are used. Two are subjected to vacuum conditions as per test number 001. Two act as control samples. Samples are then visually (using a microscope) and physically inspected.
Test Duration:	30 minutes
Test Campaign Duration:	2 days

Test Number:	**004**
Test Type:	Vacuum test (properties) to 0.2 mbar.
Test Facility:	Physics Laboratory, DIT Kevin St.
Tested Item:	Section of rapid prototype material (ABS).
Test Level:	Acceptance
Test Procedure:	Four samples are used. Two are subjected to vacuum conditions as per test number 001. Two act as control

	samples. Samples are then visually (using a microscope) and physically inspected.
Test Duration:	30 minutes
Test Campaign Duration:	2 days

Test Number:	**005**
Test Type:	Vacuum test (functional) to 0.2 mbar.
Test Facility:	Physics Laboratory, DIT Kevin St.
Tested Item:	Electronic equipment (assorted capacitors, PC/104 boards, Sony XC-ES50 and XC-ES30 CE cameras, assorted LED's)
Test Level:	Acceptance
Test Procedure:	All of the equipment is exposed to vacuum conditions as per test number 001. All of the equipment is then visually inspected. Finally, all of the equipment is checked to ensure that it still functions correctly.
Test Duration:	3 hours
Test Campaign Duration:	2 days

Test Number	**006**
Test Type:	Sinusoidal and random vibration
Test Facility:	Zarm, Bremen.
Tested Item	Entire experiment
Test Level:	Acceptance
Test Procedure	The experiment is mounted on a vibration table. Critical parts have accelerometers attached to them. Functional tests on the experiment module are then performed after it is vibrated in each axis of vibration as per the conditions given in Table 5-3.

Frequency	**Level**	**Sweep rate**
(10-50) Hz	0.124 m/s	4 octave per min
(50-2000) Hz	4 g	4 octave per min

Table 5-3: Sinusoidal vibration testing parameters.

The experiment is then repeated to test the effect of random vibrations as per the conditions given in Table 5-4.

Axes	Frequency	Level
Longitudinal	(20-2000) Hz	6 grms
Lateral	(20-2000) Hz	6 grms

Table 5-4: Random vibration testing parameters

Test Duration: 1 day

Test Campaign Duration: 3 days

Test Number **007**

Test Type: Thermal

Test Facility CREST Materials Lab, Dublin

Tested Item Flight boom

Test Level: Acceptance

Test Procedure The boom is cooled to 263 K for to 2 hours. The experiment is then removed from the cooling chamber and tested (Extended multiple times).

Test Duration: 3 hours

Test Campaign Duration: 6 hours

Test Number **008**

Test Type: Functionality test using a spin table to replicate the first phase of the flight.

Test Facility Manufacturing Laboratory, DIT Bolton St.

Tested Item Boom Assembly

Test Level: Acceptance

Test Procedure Boom housing is mounted to a spin table, as shown in Figure 5-1. The spin table is brought up to a spinning frequency of 4Hz. This speed is maintained for greater than 70 seconds to match the flight time of a rocket launch. The spin table is then brought to a stop and the boom retention system is inspected. The boom is then deployed.

Figure 5-1: Boom housing mounted to the spin table.

Test Duration:	3 hours

Test Number	**009**
Test Type:	Functionality test of experiment springs
Test Facility	Manufacturing Laboratory, DIT Bolton St.
Tested Item	Tension springs used for boom deployment and jettison.
Test Level:	Acceptance
Test Procedure	The boom deployment system was loaded and then left for three days. The boom was then deployed and the springs were examined for plastic deformation.
Test Duration:	3.5 days
Test Campaign Duration:	3.5 days

Test Number	**010**
Test Type:	Functionality test of boom deployment system
Test Facility	Manufacturing Laboratory, DIT Bolton St.
Tested Item	The boom assembly
Test Level:	Acceptance
Test Procedure	The boom assembly is loaded and clamped to a fixed structure. The boom is then deployed by manually cutting the retaining cord that holds it in position. The deployed length of the boom is then measured. The lock-out

between each of the boom segments is then inspected to verify that the boom is rigid.

Test Duration:	3 hours

Test Number	**011**
Test Type:	Functionality test of entire experiment module with the RXSM simulator
Test Facility	E-Block, DIT Bolton St., DLR, Bremen.
Tested Item	Entire experiment
Test Level:	Acceptance
Test Procedure	The experiment is assembled as close to flight configuration as possible. The observation camera is connected to a TV monitor. The experiment RXSM connections (1 and 2) are connected to the RXSM simulator. A connection is made from the experiment to the ground station computer through the Ethernet port on the flight computer. A connection for telemetry data is made between the RXSM simulator and the ground station computer through a RS232 to USB converter. The ground station software application is started on the ground station computer. The experiment is then powered on through RXSM connection 1. The power consumption of the experiment is monitored throughout the test. The TV set is observed to verify that the observation camera is sending a video stream. When the experiment computer has booted up (this takes approximately one minute), it is verified that telemetry data is being sent from the experiment to the ground station computer via the RXSM simulator. The experiment is then run in accordance with the flight timeline, presented in Section 6.3. It is verified that the framegrabber application starts and begins recording from both of the measurement cameras before the hatch opens. RXSM connection 2 is powered on manually in accordance with the timeline. It is verified that the hatch opens and that the data being sent in the telemetry stream is correct. The SODS signal is given manually to the experiment in accordance with the timeline using a switch on the RXSM simulator. It is verified that the deployment pyrotechnic guillotine fires, that the boom deploys and that the data being sent in the telemetry stream is correct. The SOE signal is given manually to the experiment in

	accordance with the timeline using a switch on the RXSM simulator. It is verified that the jettison pyrotechnic guillotine fires, that the boom is jettisoned from the experiment and that the data being sent in the telemetry stream is correct. It is also verified that the hatch subsequently closes and that the experiment controller application stops sending telemetry. The experiment is then power-cycled. Microsoft Remote Desktop Connection is used to log into the experiment computer from the ground station computer as soon as the experiment computer restarts. It is verified that the experiment controller software application has terminated. Log files are then transferred from the experiment computer to the ground station computer. These are examined to ensure that accelerometer data and a measurement camera video file have been recorded. The sample rate of the accelerometer data is then analysed. It is also verified that the log files have been duplicated onto the SD card in the flight computer. The size of the log files are noted along with the remaining available space on the flight computer C drive. All log files on the experiment computer are then deleted.
Test Duration:	2 hours

Test Number	**012**
Test Type:	Functionality test of entire experiment module with other REXUS experiments and RXSM simulator.
Test Facility	DLR Bremen, DLR Oberpfaffenhoffen
Tested Item	Entire experiment.
Test Level:	Pre-launch
Test Procedure	As per test number 011 with the only difference being that all of the other experiments for the REXUS payload are also attached to the RXSM simulator at the same time. Also, the boom is not actually deployed or jettisoned (the pyrotechnic guillotines are left disconnected). Fit testing is also carried out to ensure that all of the experiments can fit together in the planned order.
Test Duration:	2 hours
Test Number	**013**
Test Type:	Functionality test of entire experiment module with the complete REXUS payload.

Test Facility	DLR Oberpfaffenhoffen and Esrange Space Centre
Tested Item	Entire experiment. The whole REXUS payload.
Test Level:	Pre-launch
Test Procedure	The experiment is assembled as close to flight configuration as possible. The observation camera is connected to the RXSM. The output from the RXSM is connected to a TV monitor. The experiment RXSM connections (1 and 2) are connected to the RXSM. A connection for telemetry data is made between the RXSM and the ground station computer through a multiplexer and a RS232 to USB converter. The ground station software application is started on the ground station computer. The experiment is then powered on through RXSM connection 1. The power consumption of the experiment is monitored throughout the test by the RXSM. The TV set is observed to verify that the observation camera is sending a video stream. When the experiment computer has booted up (this takes approximately one minute), it is verified that telemetry data is being sent from the experiment to the ground station computer via the RXSM simulator. The experiment is then run in accordance with the flight timeline, presented in Section 6.3. It is verified that the framegrabber application starts and begins recording from both of the measurement cameras before the hatch opens. RXSM connection 2 is powered on automatically by the RXSM in accordance with the timeline. It is verified that the hatch opens and that the data being sent in the telemetry stream is correct. The SODS signal is given automatically to the experiment by the RXSM in accordance with the timeline. It is verified that the deployment pyrotechnic guillotine fires, that the boom deploys and that the data being sent in the telemetry stream is correct. The SOE signal is given automatically to the experiment by the RXSM in accordance with the timeline using a switch on the RXSM simulator. It is verified that the jettison pyrotechnic guillotine fires, that the boom is jettisoned from the experiment and that the data being sent in the telemetry stream is correct. It is also verified that the hatch subsequently closes and that the experiment controller application stops sending telemetry.
Test Duration:	2 hours

5.3 Test Results

Table 5-5 details the results of each of the tests described in Section 5.2.

Test Number	Result	Pass/Fail
001	There is no evidence to suggest that the low pressure conditions affected the epoxy/binder used in the manufacture of the carbon fibre. There appeared to be no changes at this level to the structural composition. This would suggest that the binder did not degas substantially. This was confirmed by the tensile testing. There was no significant difference between any of the samples.	Pass
002	No difference could be found between the control samples and the tested samples at the end of the experiment. The tested item is considered suitable for use in the experiment module.	Pass
003	No difference could be found between the control samples and the tested samples at the end of the experiment. The tested item is considered suitable for use in the experiment module.	Pass
004	No difference could be found between the control samples and the tested samples at the end of the experiment. The tested item is considered suitable for use in the experiment module.	Pass
005	All of the tested items were found to still function correctly at the end of the experiment.	Pass
006	The experiment suffered some power cycling during vibration testing. This was subsequently found to be caused by a damaged connector, which was replaced. Otherwise, the experiment was unaffected by the vibration testing. As the experiment was undamaged mechanically, it was deemed to have passed the test.	Pass
007	Being exposed to prolonged cold conditions had no apparent effect on the performance of the boom.	Pass
008	The boom retention system retained the boom in position during all testing. The boom did not impede the opening of the hatch. The retention system did not impede boom deployment.	Pass

009	There was a small amount of spring plastic deformation however, the boom deployment system performed acceptably.	Pass
010	The boom deployed to its full length. The boom was rigid as all of the boom segments successfully locked out.	Pass
011	This test was conducted in DIT for EAR and was completed without incident. The experiment functioned as expected. All of the correct log data was saved on the flight computer and the SD card. The experiment did not heat up excessively and power consumption was as expected.	Pass
012	This test was first conducted in DLR Bremen immediately after vibration testing (test number 006). Thus, the difficulties that plagued that test also affected this test. The problem was subsequently found to have been caused by a damaged connector, which was replaced. This test was repeated in DLR Oberpfaffenhoffen and the experiment performed as expected.	Partial Pass
013	This test was first conducted in DLR Oberpfaffenhoffen. The experiment performed nominally during this test with the exception that the deployment pyrotechnic guillotine failed to break the electrical circuit after it fired. This did not affect the performance of the experiment but did cause one of the power resistors on the pyrotechnic PCB to burn out. Replacement pyrotechnic PCB's had to be manufactured for the launch campaign. It was afterwards discovered that a change in the manufacturing process of the Cypress pyrotechnic guillotine's means that new batches of these devices are much more susceptible to this type of problem than older batches. This test was repeated at Esrange Space Centre during the launch campaign when the Telescobe experiment was switched from REXUS 12 to REXUS 11. During this test, a previously un-encountered problem arose with the on-board IO ports on the experiment flight computer. This problem appeared progressively more frequently during the launch campaign. It caused all GPIO and serial communication in the experiment to become disabled resulting in a loss of RXSM signals, telemetry, accelerometer data and communication with the hatch controller. As no replacement flight computer was available, this issue had to be managed in the lead up to	Partial Pass

	the launch. All other experiment systems performed nominally during pre-flight tests. The boom deployed and jettisoned and measurement camera data was recorded. As such, it was decided to proceed as planned with the experiment during the flight.	

Table 5-5: Test Results

5.4 Experiment Analysis

5.4.1 Numerical Analysis of Payload Aerodynamic Wake

For an effective Langmuir or E-Field probe deployment system it is required that when the boom is fully deployed, the probe, fitted to the distal end of the boom, is outside the aerodynamic wake of the main payload. A Computational Fluid Dynamics (CFD) analysis was performed to determine if this was the case during the REXUS 11 flight during the boom deployment phase (≈ 60-70 Km).

A STEP file of the rocket was imported into ANSYS CFX software and the appropriate boundary conditions were applied. The solid rocket model was subtracted from the surrounding field which left a void with zero velocity along its boundary. The velocity of the fluid at this phase of the flight was extracted from the REXUS manual (≈ 900 m/s). Appropriate information on air viscosity, pressure and air temperature at this altitude was also found [13]. The model was meshed and solved. A mesh convergence was then performed. It was found that the turbulent aerodynamic wake at this altitude is approximately 30 mm thick (shown in Figure 5-2). The deployed length of the boom outlined in requirement P.6 was substantially larger than this.

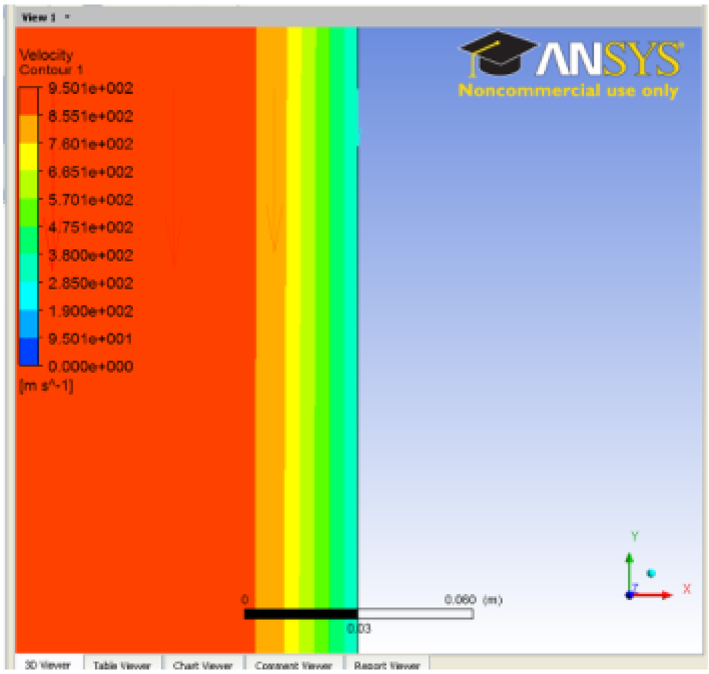


Figure 5-2: CFX analysis of rocket boundary layer during boom deployment

5.4.2 Numerical Analysis to Find Boom Harmonic Response

In response to requirement F.4., vibrations at the distal end of the boom were recorded during the flight. However, in order to design an effective vibration measurement system it was first necessary to know the frequencies of vibration that the boom would experience during the flight. As such, the harmonic response of the deployed boom was investigated using finite element analysis (FEA) in order to discover the frequencies at which the deployed boom would resonate. Ansys 12.0 software was used for this analysis. The boom geometry was drawn using the Ansys drawing package and a mesh was created and then refined with a higher concentration of nodes at the areas where the boom sections overlap after lock-out when deployed. A wide range of frequencies were tested for, with particular attention to the range of 0 to 2000 Hz, to simulate the range of vibrations during launch. The result of this analysis is shown in Figure 5-3, which is a graph of boom deformation versus frequency. From this graph it can be seen that maximum boom deformation occurs at a frequency of around 1760Hz.

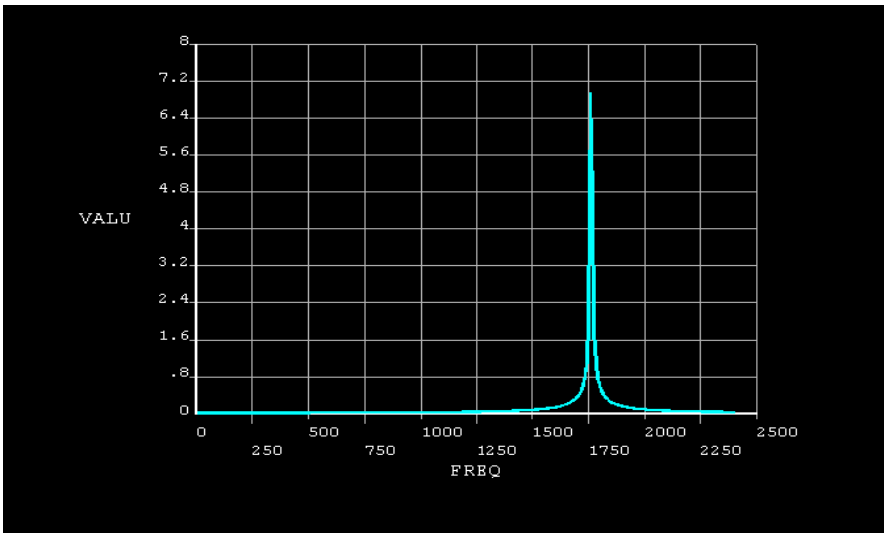


Figure 5-3: Resonant frequency of boom

5.4.3 Boom Impulse Force Calculation

Other experiments that shared the REXUS 11 payload with the Telescobe experiment module may have been sensitive to the impulse force generated by the boom when it deploys. Also, if sufficiently large, the impulse from boom deployment may have altered the trajectory of the payload during the flight. As such, the boom deployment impulse force was calculated.

The boom deployment and jettison system contained two springs which were tensioned when the boom was loaded. The stored energy in each spring changed to kinetic energy as the first pyro-cutter was triggered to cut the deployment cord. When the boom was deployed, the spring travelled 100mm until it was stopped by the jettison retention cord which initially started slack. The impulse force, velocity and time taken for this deployment were calculated using the parameters given in Table 5-6.

Mass of boom assembly (M)	0.94 kg
Spring constant (K)	434 N/m
Total spring extension (L)	0.16 m
Spring deployment length (X)	0.1 m

Table 5-6: Impulse force calculation parameters

The potential energy (available for boom deployment) in the springs was calculated as follows:

$$P.E. = \frac{1}{2}(K + K)x^2 = \frac{1}{2}(434 + 434)(0.1)^2 = 4.34 joules$$

It was then approximated that all of this potential energy was transformed into kinetic energy as the boom deployed.

$$P.E. = K.E. = 4.34 = \frac{1}{2}mv^2 = \frac{1}{2}0.94v^2$$

Therefore:

$$v = 3.03 m/s$$

When the boom had travelled through 0.1m, the slack in the jettison retention cord was taken up and brought the largest section to a stop. The impulse for this is calculated below.

$$impulse = M.\Delta v = 0.94(3.03 - 0) = 2.84 N.s$$

6 LAUNCH CAMPAIGN PREPARATION

The Telescobe 2 experiment was launched on the REXUS 11 sounding rocket from Esrange Space Centre in Sweden in November 2012. The following section outlines the preparations made for this launch campaign.

6.1 Input for the Campaign/Flight Requirement Plans

6.1.1 Dimensions and Mass

Experiment mass (kg):	12 (including Bulkhead and skin) 5 (experiment only)
Experiment dimensions (mm):	220 x 347.6
Experiment footprint area (m^2):	0.001092
Experiment volume (m^3):	0.000240240
Experiment expected Centre Of Gravity (COG) position (mm):	X=81.13, Y=-9.76, Z= -10.05

Table 6-1: Experiment Mass and Volume

6.1.2 Safety Risks

The unpacking and assembly procedures for the experiment posed no risks to any team member or Esrange personnel. Additionally, no safety risks were foreseen during normal testing and simulation procedures of the measurement systems. However, as the mechanical aspects of the experiment included the use of a spring loaded deployment system, it was recommended that caution should be taken during the following times:

- **Boom Loading**

  Possible Risk: Accidental release of springs causing abrasion

  The loading of the boom deployment mechanism required two experienced personnel. As this involved the extension and mounting of powerful tension springs, the immediate vicinity of the experiment was to be kept clear in case any part or mounting became loose. Safety goggles were to be worn by both team members loading the springs. Once the boom was loaded, two

Remove Before Flight (RBF) bolts were to be screwed in the safety mounts and only removed before payload integration or before any deployment tests were carried out.

- **Deployment & Jettison Testing**

  Possible Risk: Unexpected deployment causing injury

  Testing of the deployment mechanism required the release of the tensioned deployment and jettison springs, and in turn, the deployment of the boom. These tests required at least two experienced personnel to carry out correctly. Since this involved the deployment of a 1.6m boom at high speed, the area in immediate vicinity of the experiment was to be kept clear and the area in front of the hatch kept unobstructed up to a distance of at least 3m from any personnel apart from a designated Telescobe team member. Safety goggles were to be worn by the two team members carrying out such tests.

- **Experiment Arming**

  Possible Risk: Accidental firing of pyrotechnic devices causing premature deployment

  The release of the deployment and jettison mechanisms involved the firing of two pyrotechnic guillotines to sever the boom retaining chords. As a precaution against any accidental firing of these devices, the RBF bolts were to be installed and a safety strap was to be fixed around the module to cover the hatch opening in the skin. The hatch door was to be in the closed position preventing the boom form deploying through the hatch opening.

- **Payload Integration**

  Possible Risk: Accidental deployment causing injury

  During payload integration as well as any subsequent bench testing and communication checks, the experiment was in the armed state with the internal RBF bolts removed. From this point up until the final roll-out for launch, the safety strap was to remain fixed around the module covering the hatch opening. The hatch door was to be in the closed position preventing the boom from deploying through the opening.

- **Roll-out & Transport to Launching Site**

  Possible Risk: Accidental deployment causing injury

  During roll-out and transport to the launching site the experiment was armed and the internal RBF bolts were removed. During this time the safety strap was to remain fixed around the module covering the hatch opening. The hatch door was to be in the closed position preventing the boom form deploying through the opening in the module.

- **Experiment Recovery**

  Possible Risk: Un-deployed boom mechanism activation causing injury

  In the event of a failed deployment it was possible that the loaded boom could still be inside the module during recovery. As a precaution against any accidental deployment during this time the recovery team was to be given an instruction leaflet detailing procedures for attaching the safety strap around the module to cover the hatch opening during transport.

6.1.3 Electrical Interfaces

REXUS Electrical Interfaces		
Service module interface required? Yes		
	Number of service module interfaces:	2
	TV channel required?	Yes
Up-/Downlink (RS-422) required? Yes/No	Yes (Downlink)	
	Data rate - downlink:	14.3Kb/s
	Data rate - uplink	N/A
Power system: Service module power required? Yes		
	Peak power consumption:	52.4W
	Average power consumption:	20.4W
	Total power consumption after lift-off (until T+800s)	4.07Wh
	Power ON/OFF control	N/A
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO:	Yes
	SODS:	ON: T+86s OFF: T+225s
	SOE:	ON: T+225s

Table 6-2: Electrical Interfaces Applicable To REXUS

6.1.4 Launch Site Requirements

Provision of the following was required at Esrange:

- A work area with enough space to test boom deployment (min $4m^2$).
- A workbench and bench top power supply.
- Access to standard engineering tools.
- Use of a solder station.
- Requisite storage for four pyro cutters.
- Anti-static strips for each team member to guard against unwanted discharges.
- Facility to test downlink capabilities of experiment.

6.2 Preparation and Test Activities at Esrange

The experiment module was in good working order following the postponed REXUS 11 launch campaign in March 2012. A fault with the flight computer GPIO ports, which occurred during this launch campaign, meant that the SODS OFF and SOE were both given at the same point in the experiment timeline. SOE fired the jettison pyrotechnic guillotine but SODS OFF was used to simulate SOE in terms of the operation of the flight computer. Before the Telescobe team departed Esrange, the boom deployment system was unloaded and the experiment was stored in preparation for the re-scheduled launch campaign, which takes place in November 2012. Two team members travelled to Esrange for this re-scheduled launch campaign. The work plan for the launch campaign was as follows:

- **DAY 1**

  Unpacking of experiment and visual inspection of the assembly

  Wiring check

  Mechanical & Structural Checks

  Post unpacking assembly

  Power-up Check

  RXSM signal checks

- **DAY 2**

  Functional tests of control software

Functional tests of sensing devices

Pre-integration launch simulations with RXSM Simulator

Boom deployment & jettison test preparation.

- **DAY 3**

  Boom deployment & jettison tests, (see Appendix H).

  Analysis of simulation data

  Boom preparation for loading

  Flight simulations with RXSM

- **DAY 4**

  Experiment preparation for final integration

  Measurement camera calibration

  Reserved time for unforeseen delays

- **DAY 5**

  Bench tests

  Integration tests

  Communications Check

  Reserved time for unforeseen delays

- **DAY 6**

  Possible Launch

6.3 Timeline for Countdown and Flight

Table 6-3 highlights the main stages of the experiment in the context of the REXUS 11 flight plan. The most significant times to note from this table are boom deployment from the experiment module at T+86s and boom jettison at T+225s.

	Event	Time (s)	Altitude (km)
1	Experiment Main Power On	T-600	0.3
2	Experiment Computer Booted Up	T-540	0.3
3	Telemetry Data Starts Sending	T-540	0.3
4	All Experiment Checks Complete	T-300	0.3
5	Ignition	T+0.0	0.3
6	Lift-off (LO Received)	T+0.4	0.3
7	Burn-Out	T+26.0	21.0
8	Yo-Yo Despin	T+70.0	59.0
9	Nosecone Ejection	T+74.0	62
10	Motor Separation	T+77.0	64.0
11	TV Channel to Telescobe Observation Camera	T+80.0	NA
12	Experiment Hatch Power On	T+80.0	NA
13	Boom Deployment (SODS On)	T+86.0	NA
14	TV Channel to CARU Observation Camera	T+105	NA
15	Apogee	T+139.0	82.31
16	TV Channel to Telescobe Observation Camera	T+220.0	NA
17	Boom Jettisoned (SOE On, SODS Off)	T+225.0	NA
18	Experiment Hatch Closes	T+232.0	NA
19	TV Channel to other Experiment	T+247.0	NA
20	Experiment Hatch Power Off	T+240.0	NA
21	Experiment Main Power Off	T+600.0	NA

Table 6-3: Experiment events

6.4 Post-Flight Activities

The following workplan was devised for immediately after the REXUS11 payload was recovered disassembled and the individual experiment modules returned to the teams:

- Visually inspect the experiment module for any damage. Take photographs where necessary.
- Remove the boom housing from the experiment module.
- Remove the skin from the experiment module.

- Remove the PC104 enclosure from the experiment module.
- Remove the flight computer from the PC104 module.
- Remove the SD card from the flight computer.
- Inspect the SD card to ensure it has not been damaged
- Possible drying time in the event of snow entering the module
- Copy all experiment data from the SD card.
- Re-assemble the experiment module and power it up.
- Verify that flight computer boots up.
- Log into flight computer to inspect experiment data and flight logs.
- Copy all experiment data from flash memory.
- Perform initial analysis of the data and draw initial conclusions of experiment success.
- Perform complete analysis of flight data.

Due to the problems experienced with the experiment computer during the flight, the hatch did not close and a quantity of snow entered the experiment upon landing. Therefore, the experiment was left to dry overnight before any power was applied to the any part of the experiment during the post-flight activities outlined above. Also as a result of the issues with the flight computer, it was decided that no attempt would be made to remove any flight data from the experiment in Esrange. Instead, the flight computer was removed from the experiment module and transported separately back to Dublin where all data retrieval was performed. This data was then analysed according to the procedure outlined in Section 7.1.1.

7 DATA ANALYSIS PLAN AND EXPERIMENT REPORTS

7.1 Data Analysis Plan

7.1.1 Boom Deployment Analysis

Two cameras were used to measure the deflection and final length of the boom when it was fully deployed. A technical description of the camera measurement system is provided in Section 4.5.7 and a basic layout of the system is shown in Figure 7-1. The layout dimensions are provided in Table 7-1.

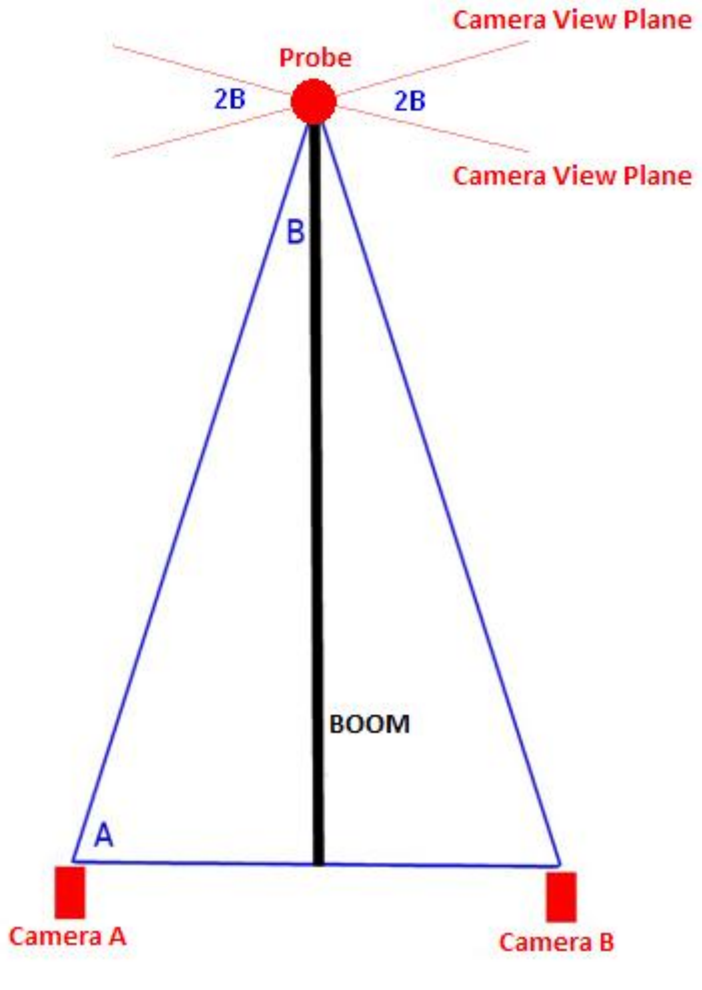


Figure 7-1: Camera Measurement System Layout

Distance between two measurement cameras (mm)	265
Angle A (Degrees)	85.2
Angle B (Degrees)	4.8
Angle 2B (Degrees)	9.6
Camera field of view width at camera view plane (mm)	100

Table 7-1: Camera Measurement System Details

From Figure 7-1, as the length of the boom increases, the probe moves to the left, as seen by camera A. Similarly, the probe moves to the right as seen by the camera B. The opposite occurs if the length of the boom decreases. On the other hand, if the boom deflects to the left, the probe will move to the left as seen by both cameras. Similarly, if the boom deflects to the right, the probe will move to the right as seen by both cameras.

It was desired to measure the length of the boom to a resolution of ±6mm during the flight. To achieve this, calibration data was required. This calibration data consisted of images of the probe taken by the measurement cameras when it was at two known positions relative to a point at the intersection between the roll axis of the REXUS payload and an axis through the centre of the boom housing (i.e. approximately the centre of the experiment). This calibration data was recorded during the launch campaign using a custom calibration rig. The experiment module was aligned with one end of the calibration rig and a calibration probe, identical to the probe used in the experiment, was located at a known position at the opposite end. An X-Y stage equipped with vernier callipers was then used to move the probe to a number other positions required for the calibration test. Table 7-2 details the calibration data gathered during the REXUS launch campaign.

Distance from centre of the experiment (mm)	**Camera A (Relative position)**		**Camera B (Relative position)**	
	X-axis (px)	**Y-axis (px)**	**X-axis (px)**	**Y-axis (px)**
1570	0	0	0	0
1670	-9	28	-63	26

Table 7-2: Camera measurement system calibration data gathered during REXUS launch campaign.

The distance between the centre points of each of the LEDs was 19mm. Using this figure, a boom deflection calibration factor was generated such that a movement of 1 pixel as seen by the measurement cameras was equivalent to an average movement of 0.34mm in a plane parallel to the front face of the boom housing. Given the calibration data in Table 7-2, and using the deflection calibration factor to compensate for any misalignment in the calibration rig, it was determined that a movement of 1 pixel as seen by the measurement cameras is equivalent to an average movement of 3.7mm along an axis through the centre of the boom housing.

When the measurement camera video was recorded by the experiment, it was first duplicated and copied to another computer for processing. To process the video, it was first required to split it into its individual frames. Open-source software called VirtualDub [14] was used to split this video (in AVI format at 30 frames per second) into individual bitmap images, numbered sequentially beginning at zero. A typical example of this type of image is shown in Figure 7-2. Over a thousand such images were generated from a typical run through of the experiment. These images were then manually analysed discarding any frames before boom deployment and after boom jettison.

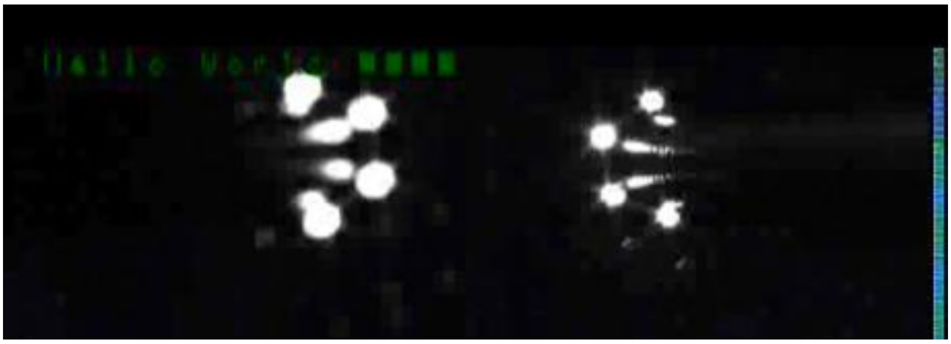


Figure 7-2: A frame extracted from a measurement camera video file. The left half **of the image was recorded by Camera A and the** right half **was recorded by Camera B.**

To determine the deployed length of the boom, a small number of frames were selected from different points during the flight timeline. The centre point co-ordinates, in pixels, of three of the LEDs seen by Camera A and three of the LEDs seen by Camera B were determined manually. An error of one pixel was allowable for the measurement accuracy to be below the desired measurement tolerance (±6mm). An Excel spread sheet was created such that when these co-ordinates were entered into the spread sheet, the deployed length of the boom at that point in the timeline is given. This was done by calculating the co-ordinates of the centre point of the probe from the co-ordinates of the three LEDs. The probe co-ordinates were then compared to the calibration data. The established relationship between distance and pixels (3.7mm/pixel) was then used to determine the absolute length of the boom.

For measuring boom deflection, a custom Python application was developed to extract the deflection data from the measurement camera video frames. A flow diagram of this application is shown in Figure 7-3. The data extracted by this Python application was saved to a CSV format log file. This data was then copied to a spread sheet where the calibration data (0.34mm/pixel) was applied to it and the boom deflection was plotted.

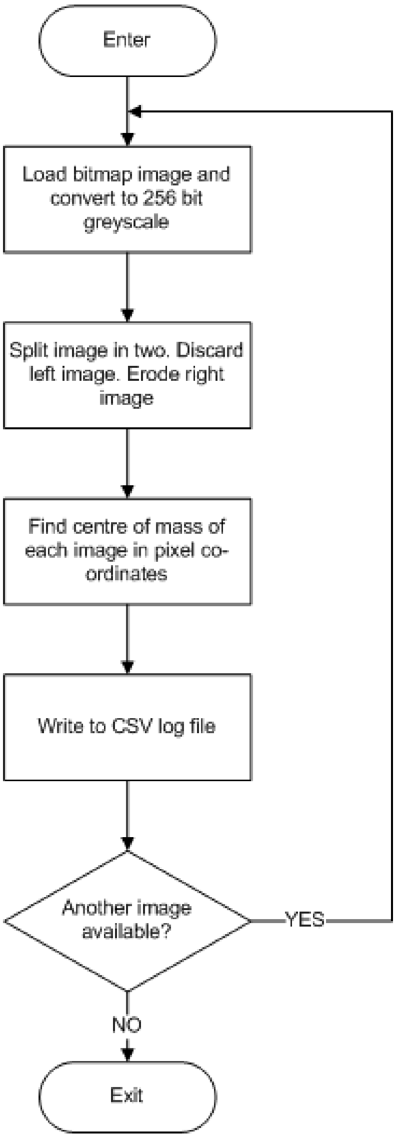
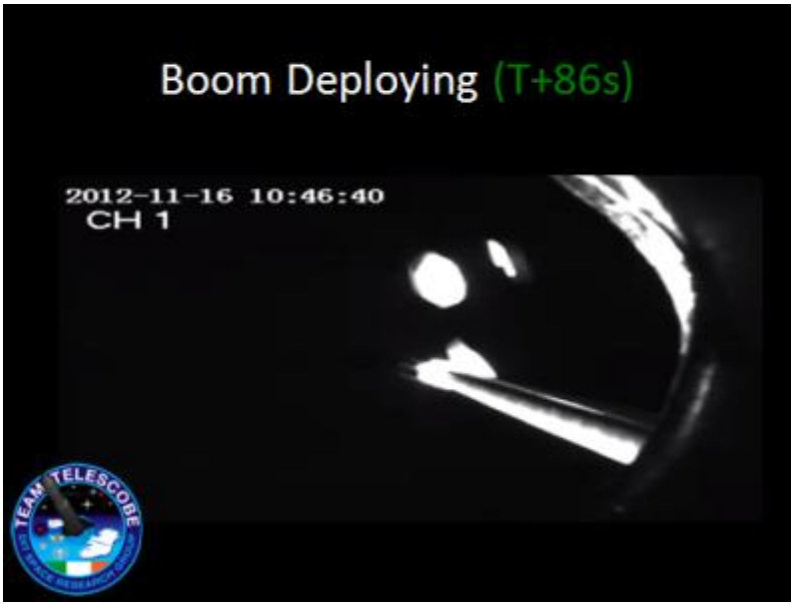


Figure 7-3: Flow diagram of the Python application for extracting boom deflection data from measurement camera images.

7.2 Experiment Reports

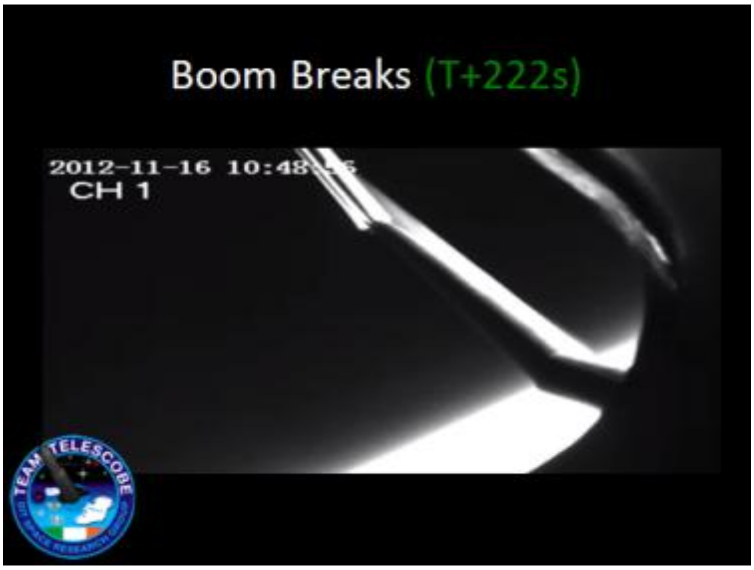
7.2.1 Presentation during Post-Flight Meeting

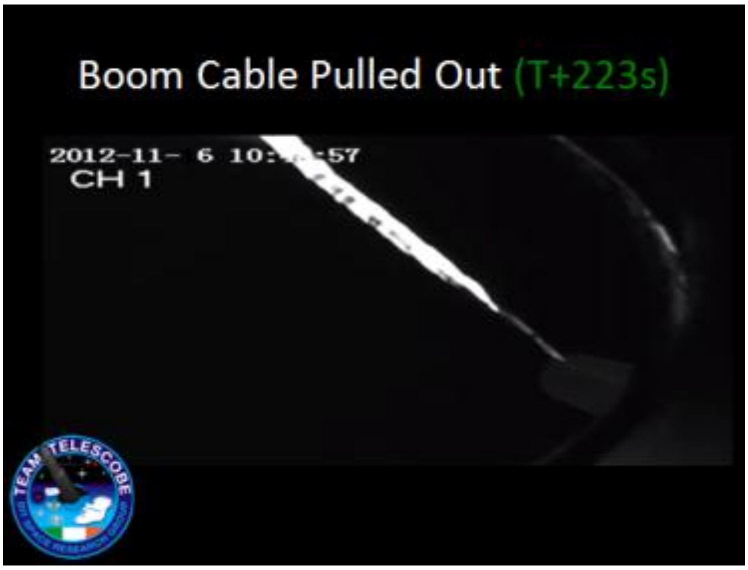
The following presentation was given during the RX11 launch campaign post-flight meeting.




Boom Deployed (T+98s)
2012-11-16 10:46:52
CH 1
TEAM TELESCOBE


Boom Deflecting (T+221s)
2012-11-16 10:48:55
CH 1
TEAM TELESCOBE


Boom Breaks (T+222s)
CH 1
TEAM TELESCOBE

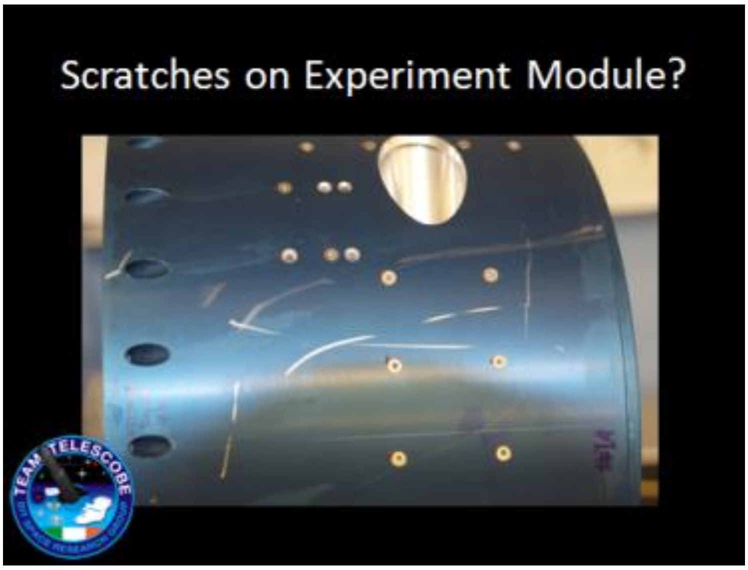

Boom Cable Pulled Out (T+223s)
CH 1

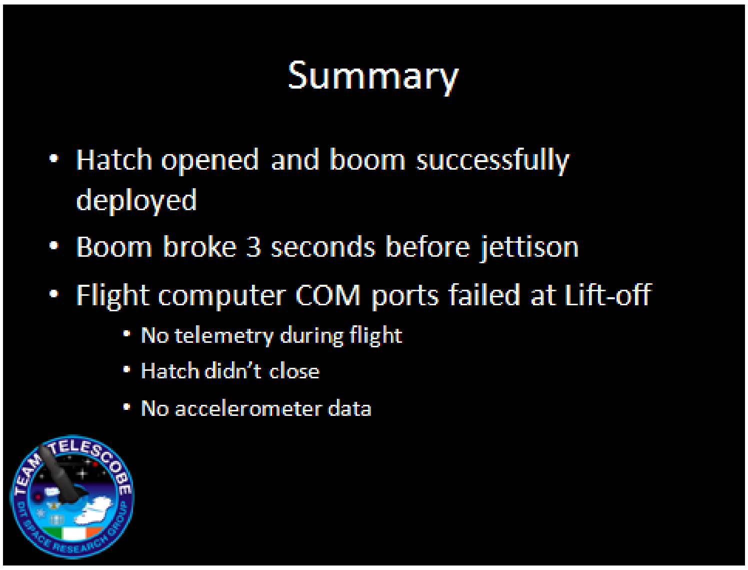

Boom Stump (T+227s)
2012-11-16 10:49:00
CH 1

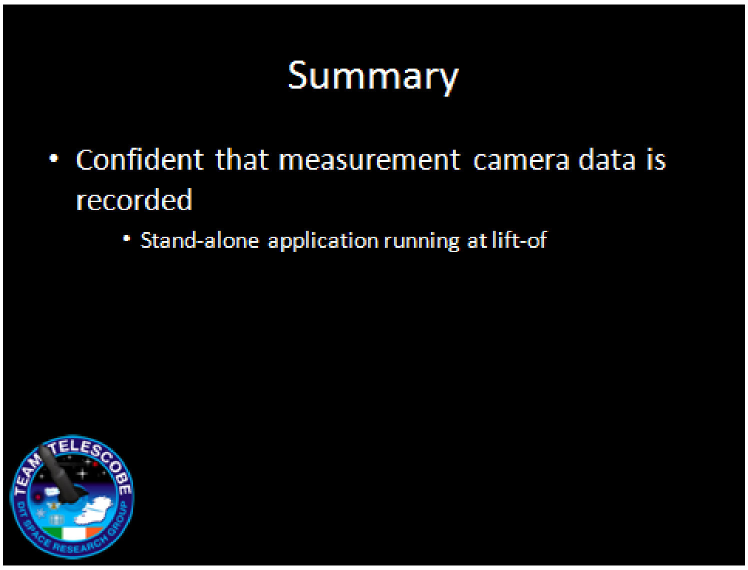

Boom Breaks a 2nd Time (T+237s)
2012-11-16 10:49:12
CH 1


Last Boom Section Still in Module
TEAM TELESCOBE


Boom Guide Tube was Loose
Boom
Guide
TEAM TELESCOBE


Scratches on Experiment Module?
TEAM TELESCOBE


Summary
• Hatch opened and boom successfully deployed
• Boom broke 3 seconds before jettison
• Flight computer COM ports failed at Lift-off
• No telemetry during flight
• Hatch didn't close
• No accelerometer data
TEAM TELESCOBE
DIT SPACE RESEARCH GROUP


Summary
• Confident that measurement camera data is recorded
• Stand-alone application running at lift-of
TEAM TELESCOBE
DIT SPACE RESEARCH GROUP

7.2.2 Final Experiment Report

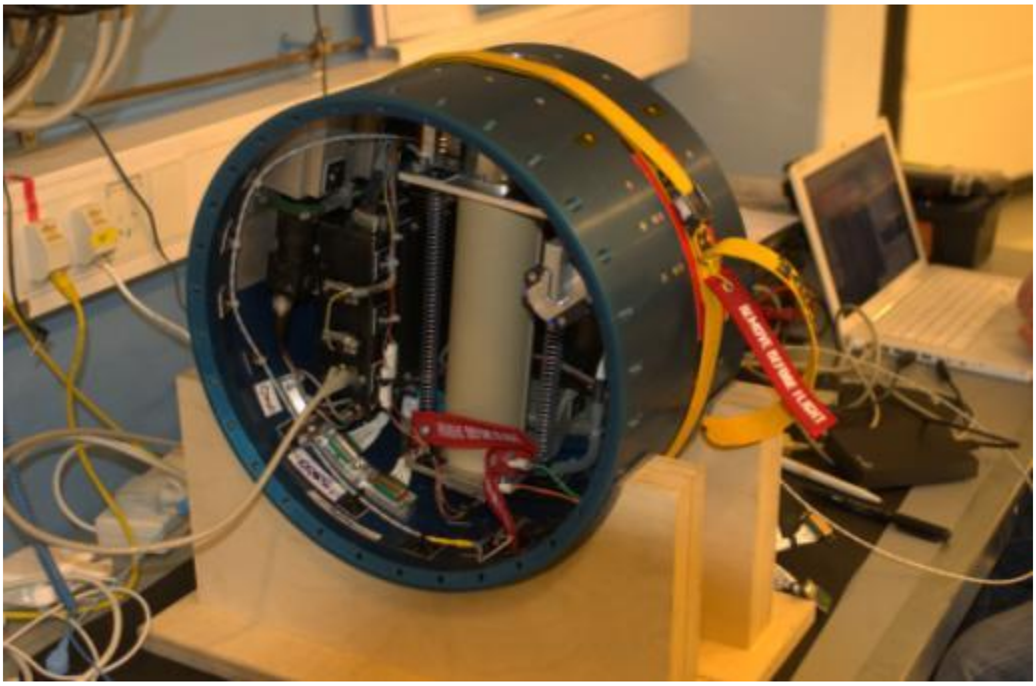


Figure 7-4: The Telescobe 2 experiment module fully armed and ready for final integration. Remove Before Flight (RBF) covers over the camera windows keep them clean and dry. Two RBF bolts inside the experiment module and a RBF strap around the experiment module protect against accidental boom deployment.

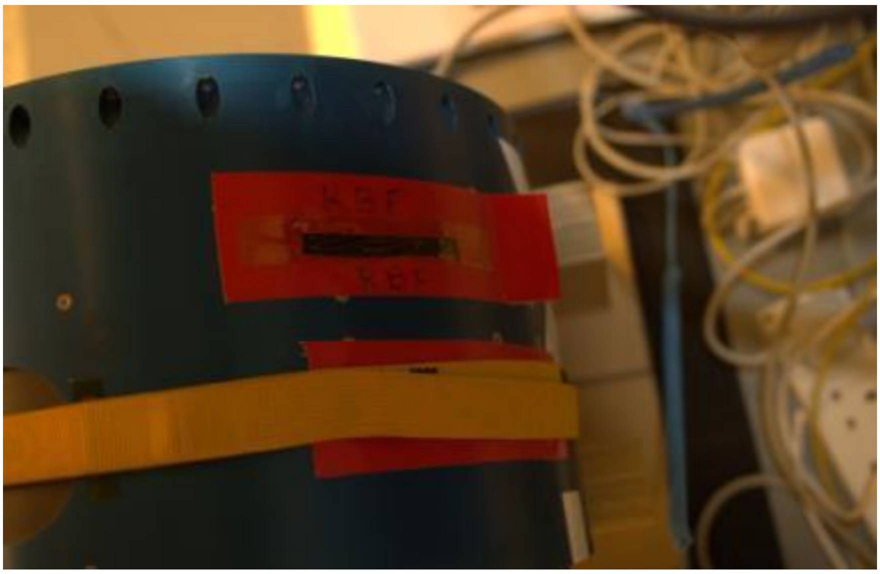


Figure 7-5: The Remove Before Flight (RBF) covers over one of the measurement camera windows and the observation camera window. A slit covered in Kapton tape in the RBF cover over the observation camera cover was used to make sure the observation camera was operational and to ensure the RFB camera covers were removed before launch.

Figure 7-6: The fully assembled REXUS 11 payload. The ‘X’ in REXUS is on the Telescobe 2 experiment module.

Launch Campaign

During the launch campaign, a previously un-encountered problem arose with the on-board IO ports on the experiment flight computer. This caused all GPIO and serial communication in the experiment to become disabled resulting in a loss of RXSM signals, telemetry, accelerometer data and communication with the hatch controller. As no replacement flight computer was available, this issue had to be managed in the lead up to the launch. All other experiment systems performed nominally during pre-flight tests.

Due to the presence of these new problems affecting the flight computer, the Telescobe 2 experiment was not powered up for communication checks during the countdown and so was powered for the first time twenty minutes before launch. The telemetry system then performed nominally during the countdown phase but ceased operation at lift-off, indicating that the serial ports on the flight computer had stopped working. As a result, no telemetry data was received at the ground station during the flight. From this point onwards, the only feedback available during the flight was through the live TV channel. Observation of the TV channel confirmed that the boom successfully deployed and subsequently broke approximately 2 seconds before it was due to be jettisoned.

After recovery, the experiment was in good overall condition as expected. There were some scratches on the outside of the module but these were most likely caused during landing or recovery. The hatch was open, but this was expected as a result of the flight computer serial port problem. It was known that the boom had broken during the flight but on recovery of the experiment it was found that the last section of the boom was still inside the boom housing, as shown in Figure 7-7. The guide tube fixed to the front of the boom housing was also loose, as depicted in Figure 7-8. Two of the four screws that secured it to the boom housing were missing and the two remaining screws were both loose. As evidenced by the payload TV channel, the boom began oscillating with a very high amplitude in the period after T+180s. Much of the force from these oscillations would have been transmitted through the guide tube and this is the most likely explanation for why it became loose during the flight. Indentations discovered on the interior of the guide tube provided further evidence for this. These lateral forces acting on the boom are also the most likely reason why the boom jettison system was unable to eject the last section of the boom from the experiment module.

All other experiment systems functioned nominally. Video recordings from the two measurement cameras were retrieved from the flight computer and the flight video file totalled 139MB. The failure of the hatch to close had no visible negative effect on the experiment except that a small quantity of snow entered the module after landing. Power consumption was also in line with expectations with the exception that the boom jettison pyrotechnic guillotine failed to break the electrical circuit when it fired, resulting in the experiment drawing additional current of approximately 1A between T+225s and T+240s. The possibility of this problem occurring during the flight had been identified prior as it had happened during bench testing in Oberpfaffenhofen. It was known that while a reoccurrence of this problem during the flight could potentially inhibit the reuse of the Pyrotechnic PCB and increase the power consumption, it would not affect the functionality of the experiment nor increase the power consumption to a level which would affect the performance of the RXSM.

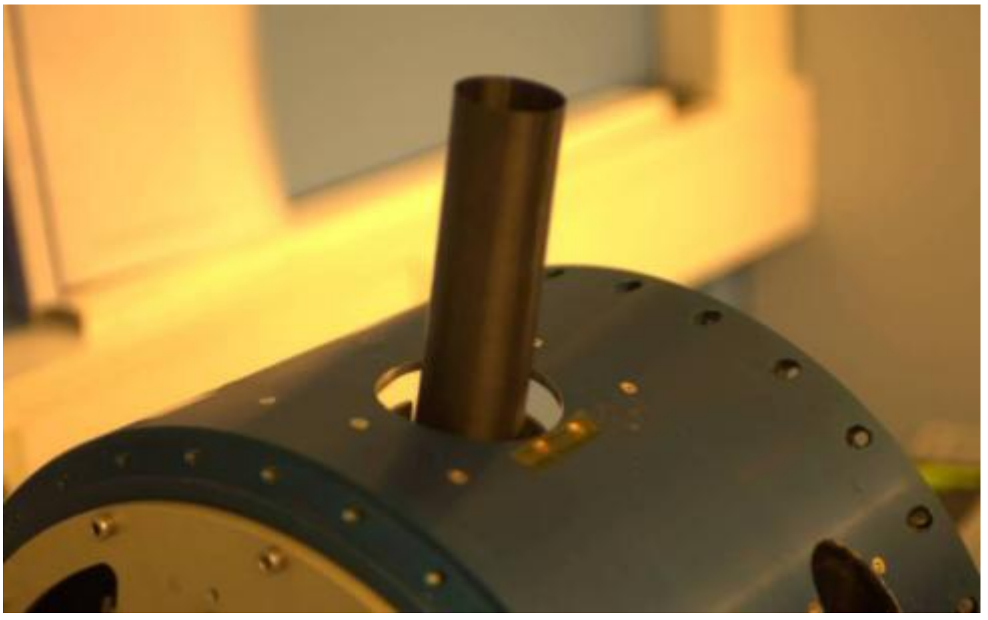


Figure 7-7: The last section of the boom inside the boom housing on experiment recovery.

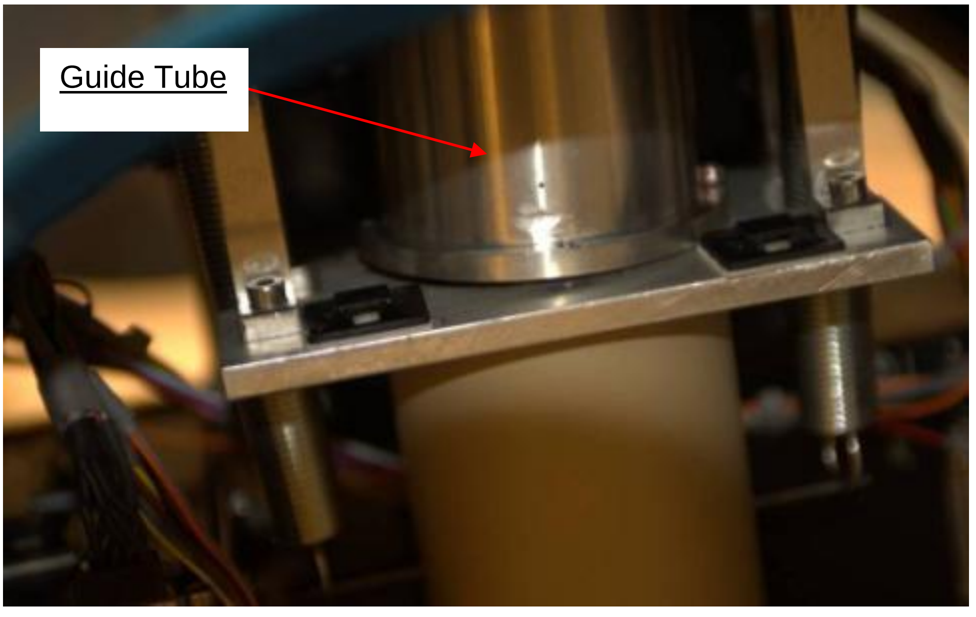


Figure 7-8: The guide tube was loose when the experiment was recovered.

Results

The boom was deployed successfully from the experiment module, as shown in Figure 7-9 and Figure 7-10. The video file recorded from the measurement cameras during the flight was analysed using the method discussed in Section 7.1.1. The boom was found to have deployed in less than 1 second to a length of 1708.3 (±6mm) during the flight and remained within the confines of the measurement resolution (±6mm) for as long as it was possible to verify (i.e. until 100s after boom deployment). This indicates that all of the boom sections locked out correctly and that the boom was rigid.

Figure 7-9: A screenshot of the boom deploying at T+86s taken from the observation camera feed. The image shows that the three section of the probe protector were successfully thrown clear of the boom during deployment.

Figure 7-10: A screenshot of the telescopic boom deployed from the experiment module taken from the observation camera feed at T+98s (12 seconds after boom deployment).

Boom deflection data was also extracted from the measurement camera recordings. Figure 7-11 shows the deflection of the distal end of the boom in an axis parallel to a plane between the X-axis and Y-axis of the payload (i.e. left-right). Figure 7-12 shows the deflection of the boom in an axis parallel to the Z-axis of the payload (i.e. up-down). From both graphs it can be seen that the maximum deflection of the probe at the distal end of the boom did not exceed 5mm in any direction during the first 90s after boom deployment. In fact, for most of this period boom deflection did not exceed 2mm. There are small gaps in both graphs between 20.0s and 22.4s and between 26.1s and 27.5s. These were periods when the measurement cameras were pointing towards the sun and no clear picture was available. It was not possible to obtain deflection data for these periods.

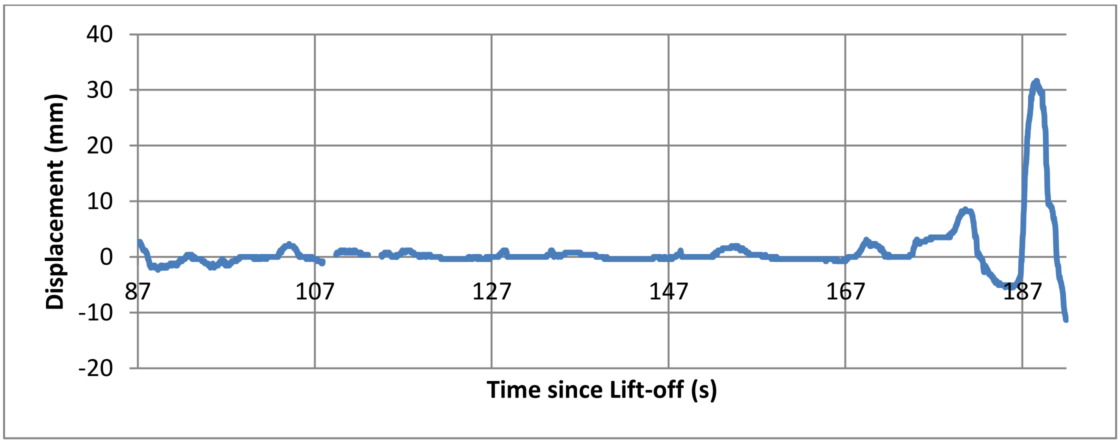


Figure 7-11: Displacement of the distal end of the boom in an axis parallel to a plane between the payload X-axis and Y-axis during the first 105 seconds after boom deployment.

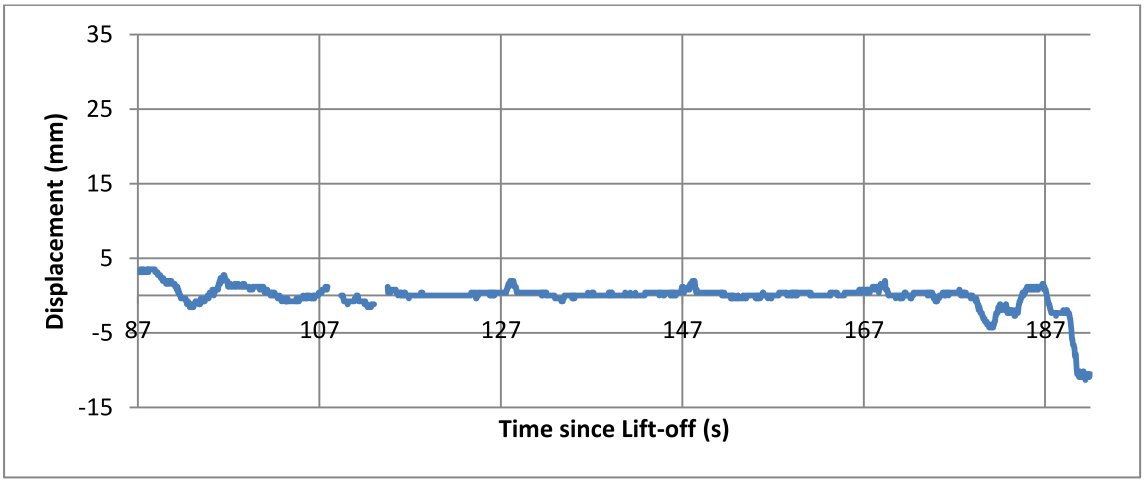


Figure 7-12: Displacement of the distal end of the boom in an axis parallel to the payload Z-axis during the first 105 seconds after boom deployment.

From ~T+175s onwards it can be observed from both graphs that the magnitude of boom deflection began increasing significantly. This deflection was such that the probe began to move outside the field of view of the measurement cameras after T+192s, hence making it impossible to measure boom deflection after that point. However, it is known that boom deflection eventually increased to such an amount that the boom finally fractured two seconds before it was due to be jettisoned at T+225s. Figure 7-13, Figure 7-14 and Figure 7-15 depict images taken from the observation camera feed during this time.

Figure 7-13: A screenshot of the boom deflecting at T+221s taken from the observation camera feed.

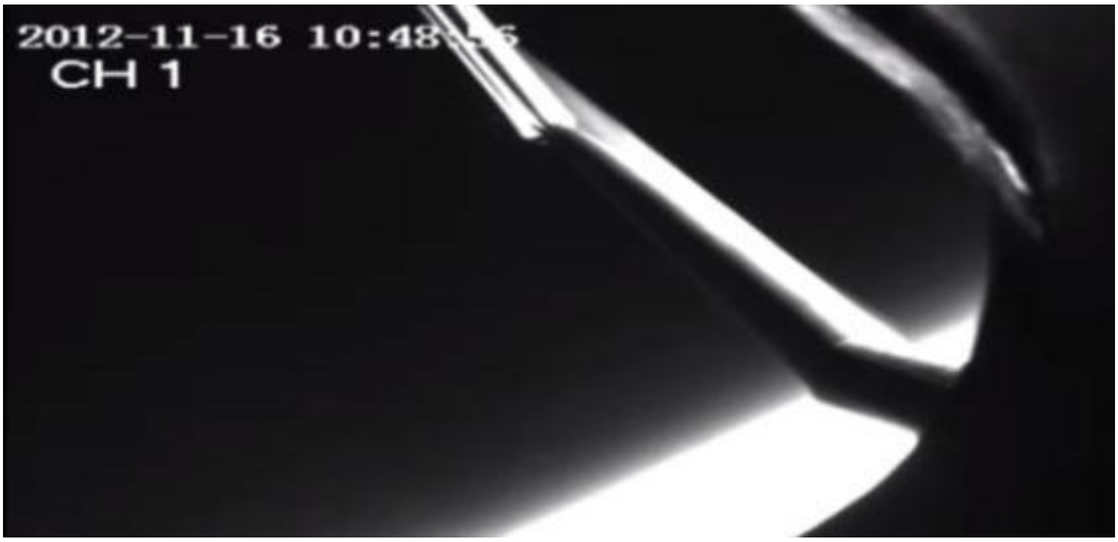


Figure 7-14: A screenshot of the boom breaking at T+222s taken from the observation camera feed.

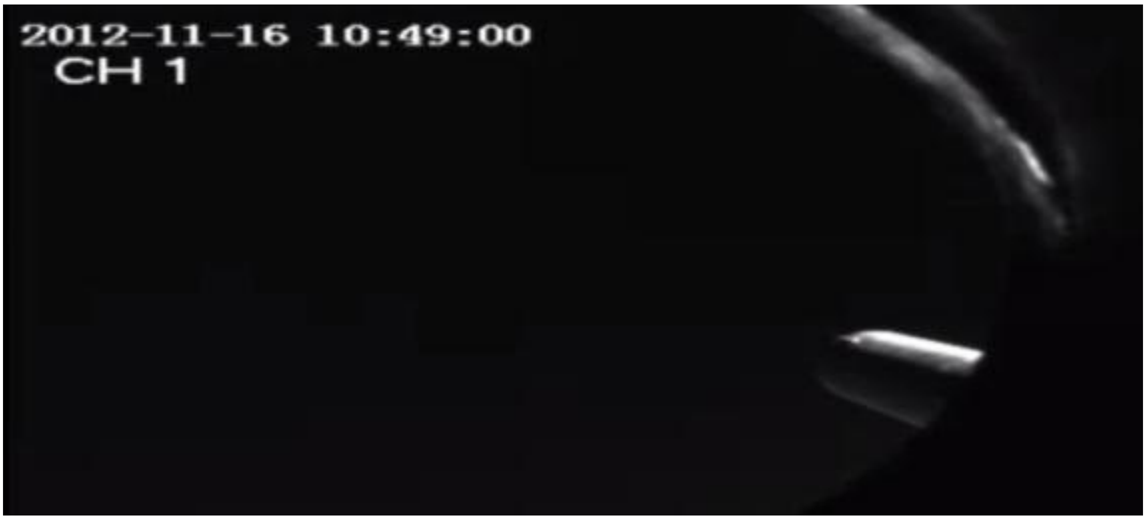


Figure 7-15: A screenshot showing the remaining boom stump at T+225s taken from the observation camera feed.

Conclusion

Overall the experiment can be deemed a success. The problems encountered during the launch of the original Telescobe experiment on REXUS 9 (namely the non-functional hatch and poor image quality captured by the monitoring camera) were successfully overcome. However, it is fair to say that an optimum solution to either problem was not achieved. The motor used to actuate the hatch in Telescobe 2 was chosen to ensure a successful hatch opening in any circumstance, except electrical power failure. As such, one may be able to use a motor in future that is less of burden on power, mass and financial budgets. Similarly, the limited budget available for Telescobe 2 meant that we were unable to replace the monitoring camera. Instead the camera aperture settings were changed and a more intense neutral density filter was used to help reduce ‘white out’. While this provided a much improved image the use of a camera with an auto-aperture feature would have yielded further improved results.

While some problems with the flight computer were experienced during the flight, measurement camera data was recovered successfully for post flight analysis. The carbon fibre, telescopic boom performed well during the flight. It deployed and settled quickly at T+86s and remained stable until T+177s, a period of time that took it through the apogee of the flight. Had the boom been jettisoned during this period the eventual breaking of the boom due to aerodynamic forces would have been avoided. Reinforced lock-out sections on the boom along with a more tightly toleranced boom guide tube may have helped the boom survive intact and be jettisoned successfully from the module.

This boom system is particularly suited for use on sounding rockets where the fast deployment time lends itself to the short payload flight time.

Lessons Learned

- Special experiences and problems

  All of the Telescobe 2 team members greatly enjoyed their time working on the project. The most significant lesson that the team will take away from the project is that while bad things happen, it is how you deal with them that is important. A lot of technical issues were experienced with Telescobe 2 throughout the project and during the launch campaign. Of these, most were relatively minor in nature and simple to fix. A large number were simply due to wear and tear on the experiment. The launch of Telescobe 2 on REXUS 11 was the second flight for most of the components in the experiment. In addition, most of these components had been through two vibration tests and had been shipped extensively around Europe. This took a significant toll on many of the experiment components. However, neither the budget nor the time to remake/redesign all of the experiment components was available so these issues had to be managed as far as was practical.

- Identified Failures and Mistakes

  One area where problems were experienced with the experiment was in the use of black box technology, namely the flight computer. The same flight computer was flown in the original Telescobe experiment without any problems. However, for Telescobe 2, when issues were experienced with the flight computer after vibration testing in Bremen and in the lead up to the launch, the causes of problems were very difficult to diagnose. The expense of the flight computer meant that there was insufficient finance available to purchase an alternative and lead times were also quite long. A custom designed flight computer, possibly based on a microcontroller, would have been much cheaper to manufacture and spares would have been readily available.

  A number of problems also occurred with both the original Telescobe experiment and with Telescobe 2 due to last minute changes. In the original Telescobe experiment, the hatch failure can be directly attributed to the hatch system being integrated into the experiment at a very late stage in the project (i.e. after bench testing in Oberpfaffenhoffen). In the aborted launch campaign of REXUS 11 in March 2012, problems were also experienced when Telescobe 2 was moved from REXS 12 to REXUS 11. While the experiment had no problems communicating with the REXUS 12 service module it could not detect the control signals from the REXUS 11 service module. In repairing this problem the GPIO port for detection of the SOE signal on the flight computer was damaged. The Telescobe 2 experiment controller software and the flight timeline then had to be modified so that SODS off signal was used instead of SOE to transition between software states. From a hardware point of view, the SOE signal was still sufficient to fire the jettison pyrotechnic guillotine.

- Possible Experiment Improvements

  Some issues with the boom system were also highlighted that should be rectified in future iterations of the design. As the payload descended back to ground, the increasing air resistance resulted in oscillations which caused the boom to fracture at T+223s. The boom stump then failed to jettison at T+225s. Therefore, in any future flight, the boom should be jettisoned much earlier since the measurement phase would be complete before re-entry. In the case of this flight, T+177s would appear to have been the ideal time to jettison the boom. Consideration should also be given to increasing the amount of force available for jettisoning the boom. Also, as the failure of the experiment hatch to close had no negative effect on the experiment, future iterations of the design could include a much simpler hatch that is part of the boom deployment system i.e. the hatch would be jettisoned as the boom is deployed. This would reduce the size of the experiment as well as reducing the number of moving parts. Such a design would greatly increase the reliability of the deployment system (the failure of the hatch mechanism caused the failure of the original Telescobe experiment).

  A number of other general design improvements for the experiment could also be considered.

  - A camera with automatic exposure controls for the experiment observation camera would have been a much better choice and would have greatly improved image quality.
  - A means of switching off the current to the pyrotechnic guillotines should have been included to overcome any issues caused by the failure in the guillotine circuit breaker after firing.
  - The boom loading procedure should be simplified.

- Internal team management

  Internal team management generally worked quite well through the course of the Telescobe 2 project. No significant team issues were experienced and the experiment was ready on-time for all of the major milestones throughout the project.

8 REFERENCES

Note:

The *REXUS User Manual* is referenced extensively throughout the document and forms the basis for many of the design choices made.

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9 ABBREVIATIONS

AC	Alternating Current
AIT	Assembly, Integration and Test
ASAP	As Soon As Possible
AVI	Audio Visual Interleave
BNC	Bayonet Neill-Concellman
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CDR	Critical Design Review
COG	Centre of gravity
DC	Direct Current
DIT	Dublin Institute of Technology
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
EC	Electronically Commutated
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	European Sounding Rocket Launching Range
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
EU	European Union
FAR	Flight Acceptance Review
FEA	Finite Element Analysis
FER	Final Experiment Report
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
FSM	Finite State Machine
GPIO	General Purpose Input Output
GSE	Ground Support Equipment
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document
I/F	Interface

IPR	Interim Progress Review
LED	Light Emitting Diode
LO	Lift Off
LT	Local Time
LOS	Line of sight
LUG	Local User Group
Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
MPEG	Moving Picture Experts Group
N/A	Not Applicable
OP	Oberpfaffenhofen, DLR Center
OS	Operating System
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
RBF	Remove Before Flight
RX11	REXUS 11
SED	Student Experiment Documentation
SER	Short Experiment Report
SNSB	Swedish National Space Board
SODS	Start of Data Storage
SOE	Start of Experiment
SSC	Swedish Space Corporation (EuroLaunch)
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or –
TeaPOT	TeaPOT's Existence Advances People Oriented Technology
TBC	To be confirmed
TBD	To be determined
WBS	Work Breakdown Structure

APPENDIX A – EXPERIMENT REVIEWS

REXUS / BEXUS

Experiment Acceptance Review

Flight: REXUS 12

Payload Manager: EuroLaunch

Experiment: TELESCOBE

Location: Dublin **Date:** 09-11-2011

1. Review Board

Mark Uitendaal **SSC, EuroLaunch**

2. Participating Payload Team members:

- Stephen Curran
- Paul Duffy
- Johnalan Keegan
- Dinesh Vather
- Mark Nolan
- Mark Wylie
- Sean Ludlow
- Keelan Keogh
- Ronan Byrne

3. General Comments

The Telescobe experiment is a re-flight from the campaign of 2010. At the previous flight the interaction of the boom and the hatch jammed to the whole experiment. This year, the experiment is modified to prevent the same outcome.
Furthermore, the team has been added with 3 new team members, which are referred to as "the lads".

4. Panel Comments and Recommendations

- Organization and project planning
  - Since this is a re-flight, the project planning is finished. The experiment has been retrofitted with a new hatch motor with a lot more torque than the previous version. Some parts for this new mechanism are still under construction at the workshop of the university.
- Mechanics
  - Mechanical finished experiment.
  - Lever and motor for hatch operation modified.
  - Retention system for the boom build, finished and tested on a custom build spintable.
- Electrical / electronics
  - The experiment was connected with success with the RXSSS, system still running as expected.
  - Cameras are modified to prevent whiteout.

- Software
  - A complete flight sequence has been done. Software still performed nominally. The ground software is also performing as expected.
- Others
  - Experiment as good as operational. The final lever needs to be placed and the system can be shipped.

5. Final remarks

- Summary of actions for the experiment team
  - Install hatchlever.
  - Ship experiment to Bremen for integrationweek.
- Summary of actions (major / minor) for EuroLaunch/ESA
  - None
- Other recommendations
  - No comments

Outcome:
EAR passed.


APPENDIX B – OUTREACH AND MEDIA COVERAGE

B.1 Web Presence

The main point of contact with the public is through an online presence. This consists of a number of portals through which members of the public can communicate and keep up to date with our progress. The main components of the internet outreach approach are:

- **Facebook:**

Regular status updates keep the public informed of our progress. There was also a gallery, video and posts section. The posts section was updated automatically as a new entry is posted in our online blog.

B-1: Telescobe Facebook Page. http://www.facebook.com/TelescobeTeam

- **Twitter:**

The twitter account is updated automatically from our blog posts. The title and a link to the original post were included automatically in the tweets.

- **Space Research Website:**

A dedicated website has been created as part of our outreach program. This facilitates content management for individual project info pages, team member profiles, integrated blogging functionality, news feeds, search functionality, individual post comments and a team contact form.

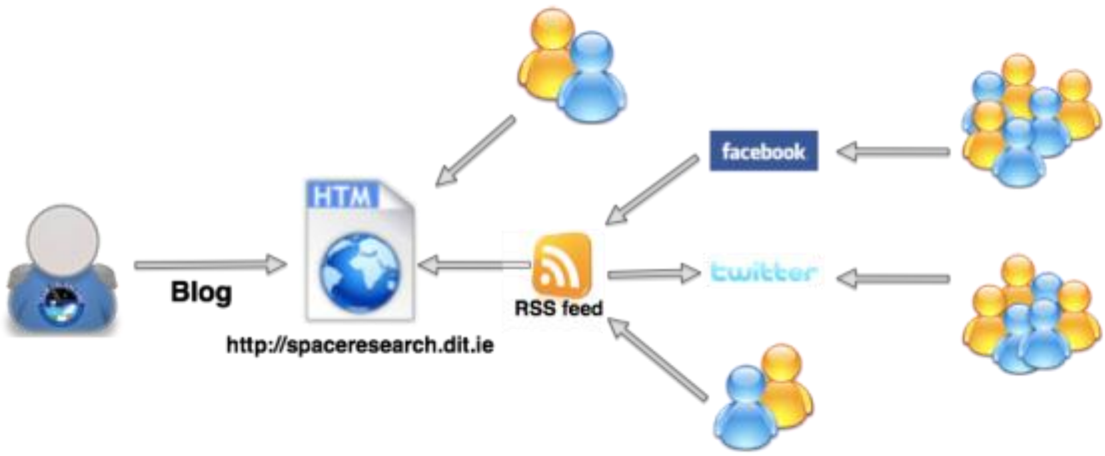
When a blog is posted to the website, it becomes available to subscribers to the RSS feed. Once this happens it gets automatically posted to the Twitter account with the title of the post and a link back to the original post on the website.

The Facebook account was also configured to automatically poll the RSS feed and import news posts as they become available. This makes the blog posts available to TeamTelescobe's Facebook friends automatically, without the requirement that they sign up to the news feed.

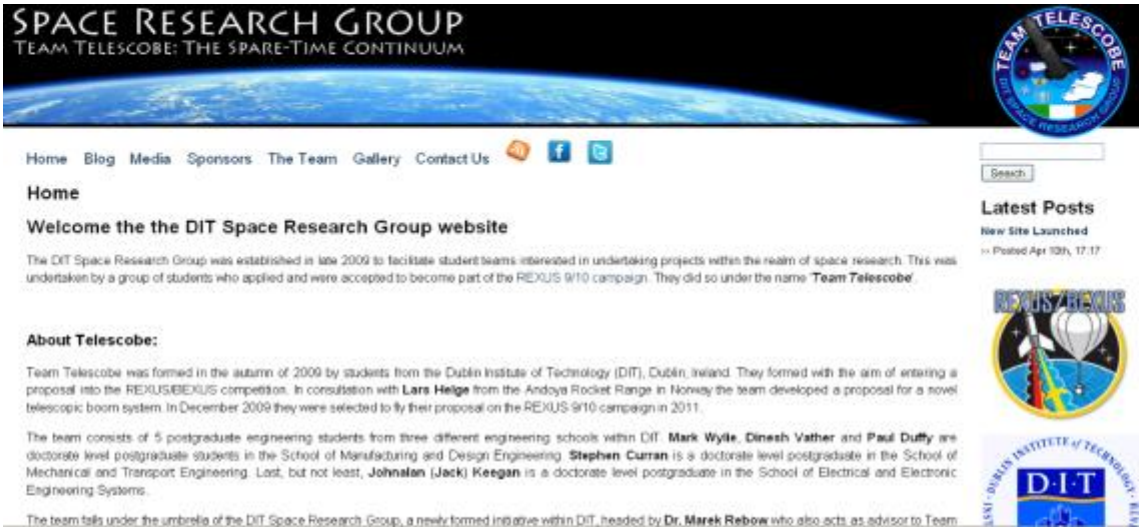
The result is that the Telescobe blog acts as a single Internet outreach portal which facilitates communication with our RSS (Blog), Twitter and Facebook subscribers as well as any members of the public who are directed to our website from any other articles/links or news items. This setup is illustrated in Figure B-1.

In order to facilitate future teams who wish to conduct experiments under the umbrella of the DIT space research group, the website was setup to be accessible a sub-domain of the main DIT website under the umbrella of the DIT Space Research Group. Any future teams will be given access to this functionality as a sub URL of http://spaceresearch.dit.ie. The Team Telescobe website is permanently reachable via the sub URL:

http://spaceresearch.dit.ie/telescobe



B-2: Automated web outreach setup



B-3: Website Homepage: http://spaceresearch.dit.ie

B.2 Media Coverage

- Feature article on Irish national broadcaster website:

  Available at: http://www.rte.ie/news/2010/0114/rexusdit.html

- Featured on Dublin Institute of Technology website main page:

  Available at: http://dit.ie/news/archive2010/spaceexperiment/

- Featured on Dublin Institute of Technology website research page:

  Available at: http://www.dit.ie/researchandenterprise/

- Featured in DIT UPADATE Newsletter:

  Available at: http://update.dit.ie//2010/11-01-10/news-briefs-space.php

- Featured on DIT Graduate Research School Facebook page:

  Available at: http://www.facebook.com/pages/Rathmines-Ireland/DIT-Graduate-Research-School/

- Featured on Union of Students in Ireland's Facebook page:

  Available at: http://www.facebook.com/notes/union-of-students-in-ireland-usi/dit-students-win-rexus-competition/257734039820

- Article in the Engineers' Ireland Journal:

  'Irish Engineers Rocket to Success'

- Article in Irish Independent Newspaper, the largest selling broadsheet in Ireland

  'Boom Time for Irish Engineers'

- Article in DIT Research News Magazine

  'DIT Engineering Students Win European Space Agency's REXUS Competition'

B.3 Outreach Activities

- Presentation and Q & A session with 4th, 5th and 6th year students in Oatlands Secondary School

- Presentation and Q & A session with 4th, 5th and 6th year students in St. Mary's College

- Presentation and Q & A session with 4th, 5th and 6th year students in Belvedere College S.J.

- Presentation and Q & A session with 4th, 5th and 6th year students in Skerries Community College

- Presentation and guest speakers at Galway Education Symposium, June 2011.

- Presentation to 3rd year students resulting in:

- Student undergraduate thesis for academic year 2010/2011:

  'Design, build and test of a spin table capable of replicating the flight profile of a sounding rocket'.

- Student undergraduate thesis for academic year 2010/2011:

  'Investigation into the effectiveness of **LabView** for processing telescopic boom performance data gathered during a near space flight'

- Student undergraduate thesis for academic year 2010/2011:

  Investigation into the effectiveness of **MatLab** for processing telescopic boom performance data gathered during a near space flight'

- Student undergraduate thesis for academic year 2011/2012:

  Development of a spin table and boom retaining mechanism for use in Telescobe 2.0 testing and flight

- Student undergraduate thesis for academic year 2011/2012:

  Module hatch mechanism redesign for Telescobe 2.0 flight.

- Student undergraduate thesis for academic year 2011/2012:

  Upgrading of resolution of camera measurement system for Telescobe 2.0 through the use of more advanced post processing.

B.4 Seminars

The DIT Space Research Group and The REXUS Project with guest expert Mr. Lars Helge from Andoya Rocket Range, Norway.

- Held on Friday 30th of April in Dublin Institute of Technology, Bolton Street

The Implementation of Lean Six Sigma with guest expert Ms. Laurie Peterson from NASA Johnson Space Centre.

- Held on Wednesday 4th of August in Dublin Institute of Technology, Bolton Street

B.5 Conference Papers

- **Matrib Conference, Croatia, June 2010**

A NOVEL TELESCOPIC BOOM DEPLOYMENT SYSTEM FOR USE IN UPPER ATMOSPHERE RESEARCH

Paul Duffy[1], Mark Wylie[1], Stephen Curran[1], Dinesh Vather[1] and Johnalan Keegan[1]

1 - DIT Space Research Group, Dublin Institute of Technology, Bolton St, Dublin 1, Ireland

ABSTRACT

Typical probe deployment systems on spacecraft employ hinged booms which extend the probes away from the rocket. With restrictions on mass and volume, this configuration often requires considerable amount of the rocket's payload volume which in turn offers poor flexibility with respect to flight profiles. In an effort to reduce both mass and volume, the DIT Space Research Group has designed a novel light weight carbon fibre telescopic boom deployment system, compatible with probes commonly used in upper atmosphere research. Our design has been selected to be tested on a suborbital space flight onboard the REXUS 9 sounding rocket in March 2011. The purpose of this test is to characterise the boom system in-situ and increase its Technology Readiness Level (TRL). The system is capable of deploying a boom with a mock E- Field probe to a length of 1.63m ±0.5%. The mock probe attached to the distal tip of the boom will house six LEDs which emit light at a wavelength of 620 nm. A filtered camera measurement system will gather this light allowing both boom deployment length and amplitudes of vibrational displacement to be measured and recorded. An accelerometer mounted in the probe will also monitor this vibration. The boom will then be jettisoned from the rocket before re-entry. A third camera will be used to monitor boom jettison. All data will be stored on solid state drives and recovered for post flight analysis. A downlink to a ground station will provide a live TV feed of boom deployment and jettison. The entire system has a mass budget of less than 4kg and can be contained in a rocket module of 348 mm diameter and 220 mm height.

KEYWORDS: Aerospace, Engineering, Sounding Rocket, Booms

1.0 INTRODUCTION

This project is part of the REXUS/BEXUS programme. The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through collaboration with the European Space Agency (ESA) EuroLaunch, a cooperation between the Esrange Space Centre of the Swedish Space Corporation (SSC) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from ESA, SSC and DLR provide technical support to the student teams throughout the project. Funding for the project is being provided by the Dublin Institute of Technology, Enterprise Ireland and Acra Control Ltd.

1.1 Overview of the REXUS/BEXUS Project

The REXUS/BEXUS project allows students from universities across Europe an opportunity to carry out scientific and technological experiments on sounding rockets and high altitude balloons. Two rockets and two balloons are launched each year from the Esrange space centre in northern Sweden, carrying a total of up to twenty experiments. The Telescobe experiment will fly onboard the REXUS 9 sounding rocket which is due to be launched in March 2011.

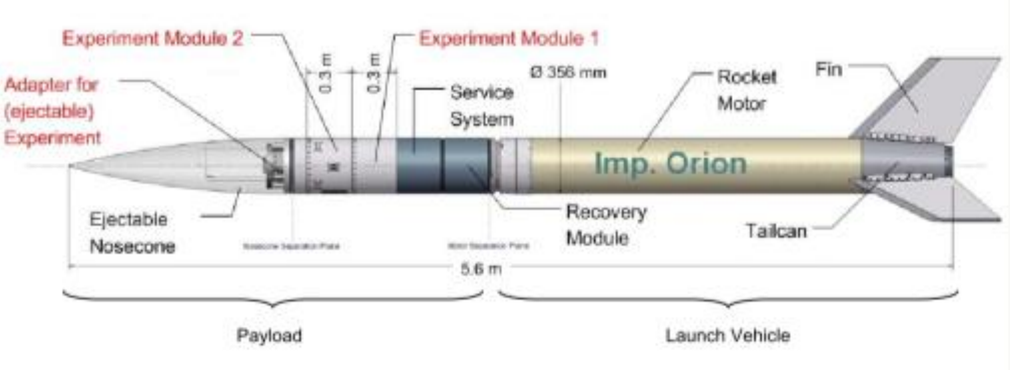


Figure 9-1: REXUS Standard Configuration

The REXUS vehicle is an unguided, spin-stabilized, solid-propellant single stage rocket shown above in Figure 1. The total mass of the rocket is around 515 Kg comprising a propellant mass of 290 Kg, motor and vehicle hardware of around 125 Kg and a payload mass of around 100 kg. The total rocket vehicle has a length of approximately 5.6 m and the diameter is 356 mm. The standard configuration of the payload comprises the recovery module, the service system, an ejectable nosecone and two or three experiment modules. After liftoff, the motor will burn out at an altitude of about 25 Km. The motor will then separate from the payload, with the payload continuing up to an altitude of approximately 100 Km before descending again. A parachute then deploys from the recovery module before the payload hits the ground. The flight profile can be seen below in Figure 2.

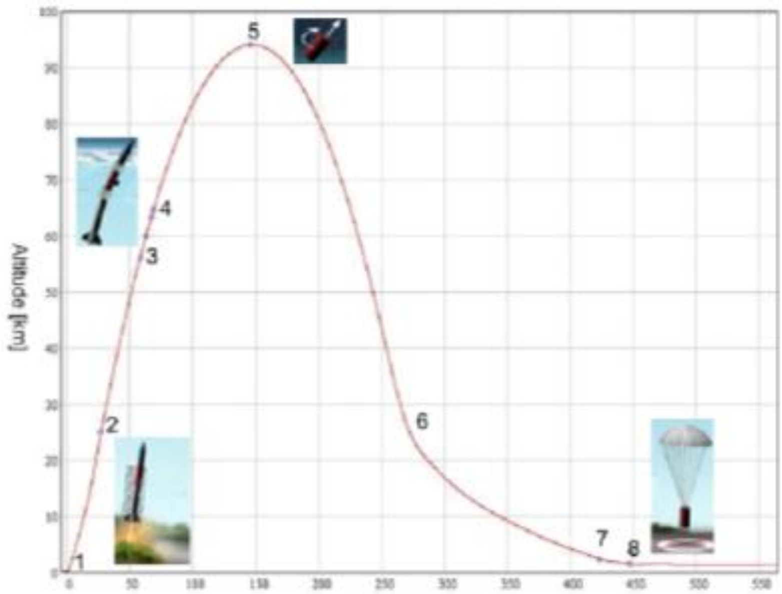


Figure 9-2: Graph of Experiment Altitude

V Flight Time Showing Major Flight Events.

(1 = lift off, 2 = motor burnout, 3 = nose cone ejection, 4 = motor separation, 5 = apogee, 6 = max. deceleration, 7 = stabilising parachute deployment, 8 = main parachute deployment).

2.0 TECHNICAL BACKGROUND

Upper atmosphere research is a valuable tool in better understanding the effects of both Earth based pollution and solar weather on our planet. High altitude balloons, sounding rockets and satellites are all employed to conduct measurements at altitudes ranging from tens to thousands of kilometres. High altitude balloons offer a relatively cheap and simple method of conducting this research. Experimental payload design and testing is also relatively quick but the maximum attainable altitude is usually no more than 45km. Sounding rockets provide a method for conducting upper atmospheric research at much greater altitudes, typically between an altitude of 45km and 160km. However, some sounding rockets can reach altitudes of over 1500 km. The minimum altitude for satellite research is about 160km. The advantage of satellite experiments is that they can take measurements in the space environment for much longer periods of time. Satellites can also conduct similar research on other celestial bodies. However, payload design and testing takes much longer and overall costs are much higher than for the other options.

The Earth's magnetic field and atmospheric plasma electron density are typically measured by Electric Field and Langmuir probes. Electric field, or E-Field, probes as their name suggests, are used to measure the magnitude of electric fields in the atmosphere. They can be split into two main classifications: active or passive probes and are usually deployed in pairs. Langmuir probes are used to measure the ionisation energy and electron temperature of plasma. Measurements can be made using one probe however as many as five probes have been used with certain configurations. In order to take their measurements these probes have to be extended out from the balloon/rocket/satellite payload bay. The altitude of the probes must be known at all times for accurate measurements. It is also necessary to extend the measurement probes clear of any wake turbulence or electromagnetic fields created by the main vehicle. As such, a number of different boom systems have been developed to deploy these probes.

Probes extended from the spacecraft by wires are compact; however the vehicle must be spinning in order to take advantage of centrifugal forces which are used to deploy the probes. These probes are prone to oscillation (as they lack rigidity) in turn effecting measurement accuracy. Single rigid booms can support larger probes and are less prone to oscillation; however, they require a large amount of storage space in the main vehicle. Folding booms may require less storage space than single rigid booms but typically weigh more due to the extra joints in their design.

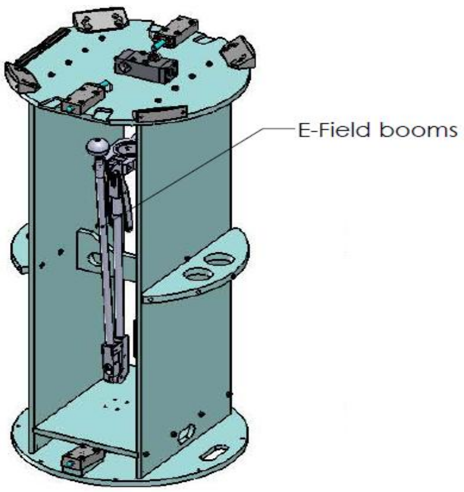


Figure 9-3: Typical folded E-Field boom configuration [1].

Screw driven telescopic booms can require less storage space than either folding or rigid booms. However they can take time to deploy and cannot take advantage of the centrifugal force generated by spin stabilized craft to deploy. It is clear from the above descriptions that each boom system has both advantages and disadvantages. Figure 9-4 below shows some of the different systems mentioned above. In this case the probes are deployed from a sounding rocket (left) and a satellite (right).

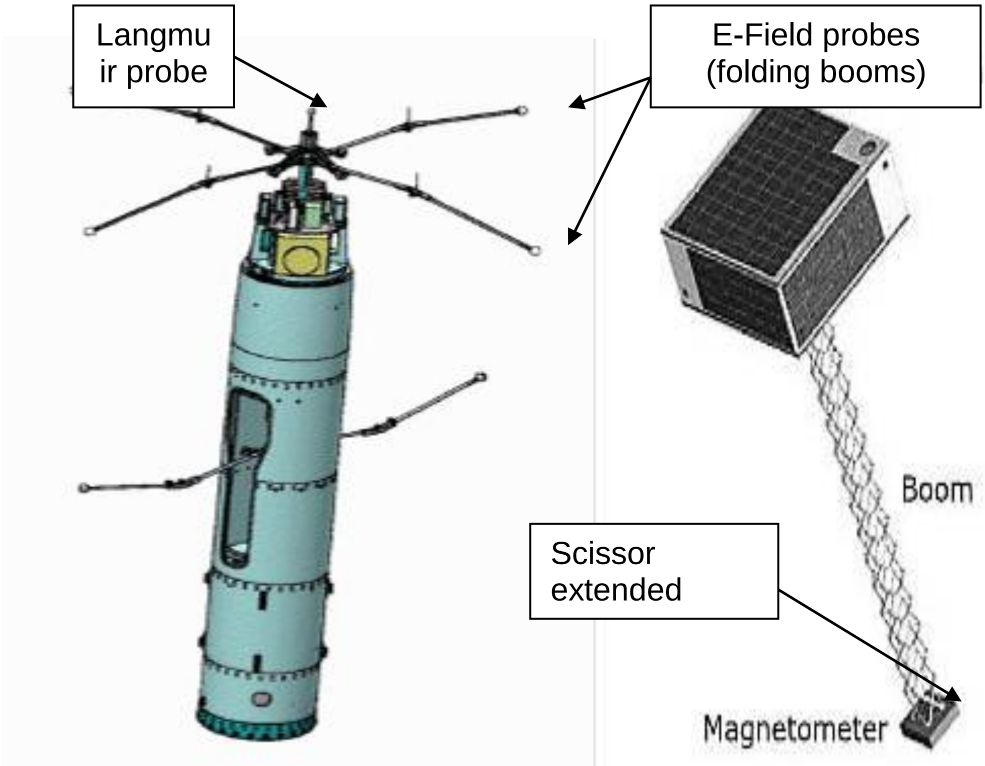


Figure 9-4: Various Sounding Rocket and Satellite Boom Systems [2].

A spring loaded telescopic boom system offers storage advantages (similar to screw driven telescopic boom). It can also take advantage of the centrifugal force generated by spin stabilized spacecraft to deploy. The lack of a mechanical drive system in its design also results in both mass and cost savings compared to a screw driven boom. The quick deployment time of a spring loaded boom system means that it is suited to sounding rocket flights where data acquisition times may be limited to a short period of time due to the flight plan in place. A spring loaded telescopic boom would have potential applications in other ways too. This type of boom could be used to deploy antennae, solar panels or other types of measurement probes.

3.0 EXPERIMENT OVERVIEW

The aim of the Telescobe project is to develop and fly a novel, carbon fibre, telescopic boom system on a sounding rocket. While the carbon fibre boom is being tested extensively on the ground, the aim of the flight is to verify the performance of the boom when it is subjected to the harsh conditions that will be experienced during the flight. These harsh conditions include acceleration forces of up to 21*g*, high vibration levels, vacuum, low gravity and harsh thermal conditions. Figure 5 shows an exploded view of the experiment payload. At lift-off, the boom will be stowed in the rocket in a non-extended state. It will be retained in position using pins and cables, open cell foam will be used to prevent the booms smaller sections from shaking during launch. It is intended to deploy the telescopic boom at an altitude of approximately 70 km. A hatch in the skin of the rocket will be opened using pyrotechnic explosives and the boom will deploy through the skin to a total length of 1.63m. The boom will then be jettisoned during descent to ensure that it doesn't become entangled in the parachute which deploys from the REXUS rockets recovery module. The rocket will be de-spun prior to the boom being deployed so centrifugal force will be unavailable to assist in boom deployment. As a result, spring based boom deployment and jettison systems have been developed. These different stages are shown in Figures 5 & 6.

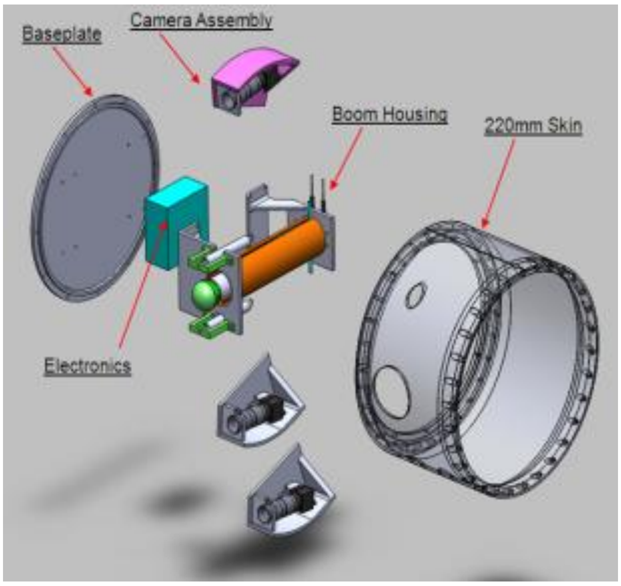


Figure 5: Exploded view of experiment during flight

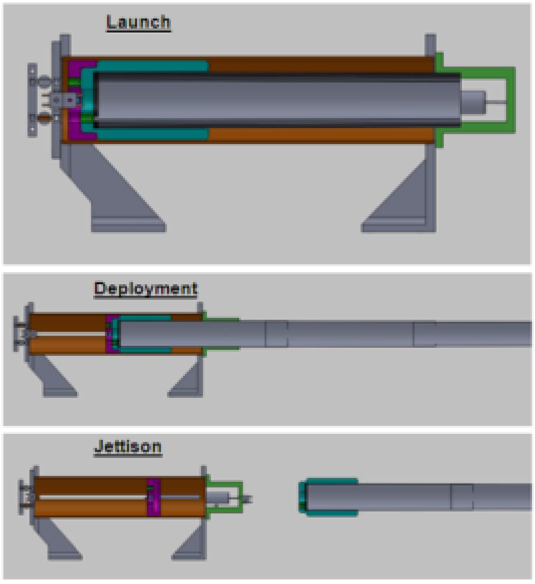


Figure 6: Main boom stages

Data will be gathered to determine the performance of the boom during the flight. Two filtered cameras, looking out through windows in the skin of the rocket will be used to determine the exact position of the mock probe fitted to the end of the boom. Six LEDS will be mounted in the mock probe, as shown in Figure 7. A total of six LEDS are required to ensure the camera system has a line of sight to a minimum of two LEDS at all times regardless of any possible boom rotation or excessive deflection during flight. The 620 nm wavelength light emitted by them will be detected by the camera system and ambient light blocked by the filtering system allowing precision imaging and reduction of data which needs to be processed. These cameras will allow the deployment length of the boom to be measured to an accuracy of 0.5% and will also be used to measure the amplitude of vibrational displacement. The principal behind this technique is shown in Figure 8. A digital accelerometer will be placed in the mock probe fitted to the end of the boom. This accelerometer will provide data on the frequency of vibration of the mock probe. A third camera will be used to monitor boom deployment and jettison, providing a live TV feed to a ground station. All of this data will be sent to an onboard computer, consisting of a PC104 stack (Eurotech ISIS-XT), which will save it to a flash memory card. After the rocket payload lands and is recovered, the memory card will be removed. The data stored on it will then be analysed to determine if the telescopic boom performed appropriately. MatLab software will be used during this analysis. This computer system also controls the experiment during flight, using signals from the REXUS service module to trigger the main experiment events.

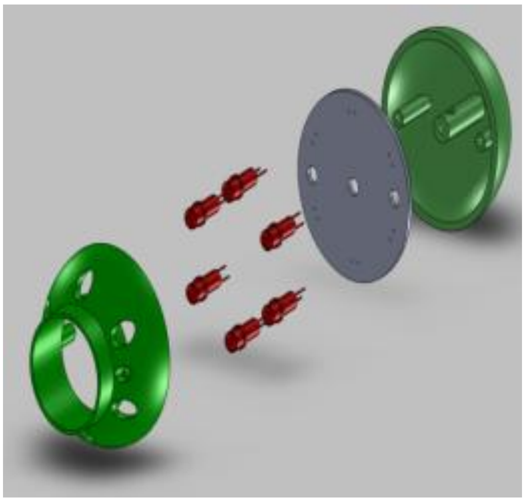


Figure 7: Exploded view of mock probe camera

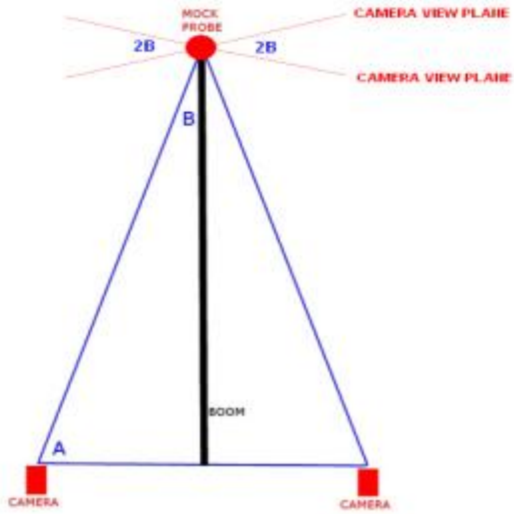


Figure 8: Principle of operation for system

4.0 TELESCOPIC BOOM

The telescopic boom used in the Telescobe experiment is made from commercially available carbon fibre fishing poles produced by Shimano Inc. Fishing poles were used because they provide an affordable and readily available source of tapered carbon fibre sections. The fishing pole was cut into a series of 230mm long sections. After some experimentation the use of a rotary tool and grinding disc was found to be the best technique for cutting the boom sections. Figure 9 shows the cutting setup. The pole sections were first mounted in a lathe. The cutting disk of the rotary tool was then positioned using the lathe carriage, allowing an accuracy of 0.001mm.The tool was then switched on and the lathe turned by hand until the cut was complete. The high speed of the cutting disc allowed each section end to be ground to a smooth finish. The quality of the cut is extremely important as carbon fibre is quite brittle and tends to crack if there are imperfections on any of the edges. Eight sections were cut in this way, with the maximum diameter of the largest section being 45mm and the minimum diameter of the smallest section being 20mm. When the sections are placed one inside the other the length of this non-extended boom is 230mm, shown in Figure 10. Then, when the boom is extended, all of the sections lock into each other, with a 30mm overlap between the sections, giving a total extended boom length of 1.63m.

Figure 9: Boom Manufacture

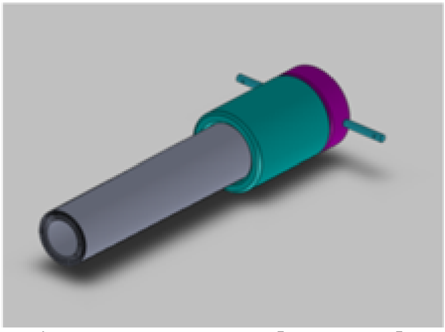


Figure 10: Boom, sleeve and retaining cup

A precise specification of the type of carbon fibre that the fishing poles were made from was unavailable. As such, various tests were carried out to the carbon fibre to prove its suitability for use in the experiment. First, the carbon fibre was submitted to a vacuum test. It was placed in a vacuum chamber and the pressure inside was lowered to below that which is expected during flight. The carbon fibre was then examined under a microscope and found to have no ill effects. A tensile test was also carried out on sections of the carbon fibre which determined that the tensile strength of the carbon is suitable for use on the experiment. Tests were also carried out to determine the strength of the interference fit between the sections and the rigidity of the boom. The results of all these tests were acceptable. The most important performance characteristic of the boom is that it deploys to its designed deployment length during the flight within a tolerance of 0.5%. To test this, a prototype of the boom deployment system that will be used on board the experiment during the flight has been built. For this, a PEEK (Polyether ether ketone) sleeve and an aluminium (2024 T3) base plate were bonded to the largest section of the boom. The PEEK sleeve sits inside an aluminium housing where it can move up and down but is well supported so that there is no lateral movement. The base plate, with boom, is then pulled back against two tension springs (K = 0.434N/mm) on either side of the boom housing and secured with cable to retaining posts. These cables pass through pyro-guillotines (Cypress Cutters) which will be activated to cut the cable and initiate the boom deployment. The entire boom is accelerated forward approximately 100mm until the boom sleeve is suddenly stopped by a second longer cable. The forces produced by the sudden deceleration provide each boom section with a sufficient amount of energy to deploy the boom its extended state. This system was also designed to be capable of deploying all associated wiring that would be used with actual E-Field probes. This wiring will be stored outside of the boom housing but will pass through the inside of the boom as it deploys. For this purpose, a four core shielded cable is required. For this experiment this wire will provide power to the LED array and accelerometer in the mock probe and well as carry data signals from the accelerometer back to the experiment computer. Extensive testing has been carried out on this deployment system and it has been shown to accurately deploy the boom as long as the deployment spring is sufficiently large to ensure a good interference lock between the carbon fibre sections. A similar mechanism will be used for boom jettison. The cable which retained the boom sleeve after boom deployment will be severed. The remaining stored energy in the two tension springs will be used to jettison the boom through the hatch. It is necessary therefore to detach all physical connections (i.e. the wiring), to do this, a Winchester pull plug will be used which will separate under the forces generated by the jettison sequence. Figure 11 shows an exploded view of the boom deployment and jettison system.

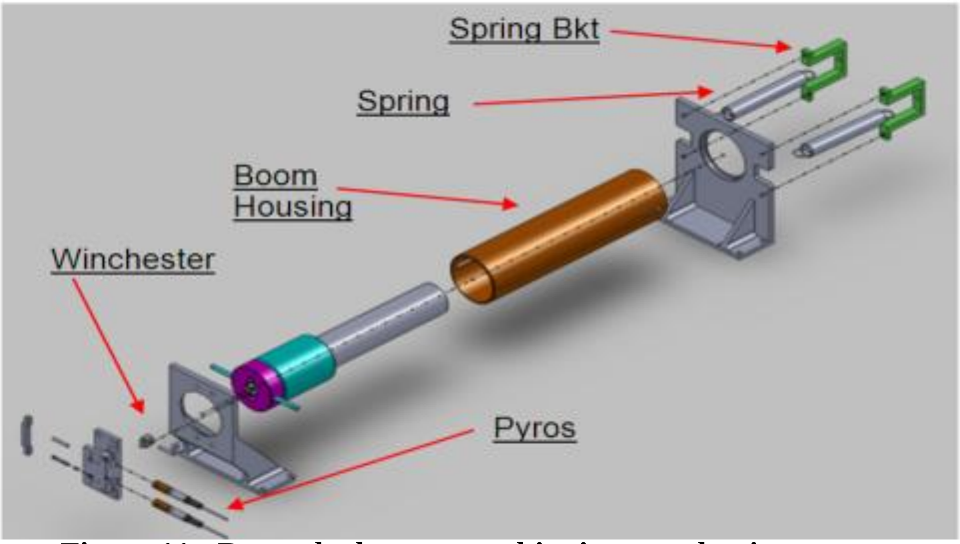


Figure 11: Boom deployment and jettison mechanisms

5.0 CONCLUSION

The commercially available tapered carbon fibre sections being used to construct the telescopic boom for the Telescobe experiment are fit for purpose. The prototype boom has performed well in tests to date. However, all laboratory testing can, at best, only an approximate the environmental conditions that will be experienced during the REXUS rocket flight, where the experiment will be subjected to high g-forces, high vibration levels, low gravity, vacuum and extreme thermal conditions. The final test of this approach to sounding rocket boom development will therefore only come from the satisfactory performance of this telescopic boom during the REXUS flight. The Telescobe experiment is expected to fly on board the REXUS 9 sounding rocket which will take off from the Esrange space centre in Northern Sweden in March 2011.

6.0 REFERENCES

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- **Internatioanal Manufacturing Conference 27, Ireland. October 2010**

Developing a Carbon Fibre, Telescopic Boom for the Telescobe REXUS Project

Stephen Curran, Dinesh Vather, Paul Duffy, Mark Wylie, Johnalan Keegan

Dublin Institute of Technology (D.I.T)
Dublin 1, Ireland

Abstract

Telescobe is an experiment module for a REXUS (Rocket EXperiment for University Students) sounding rocket being developed by a group of five postgraduate engineering students at D.I.T. It involves the design, build and testing of a novel telescopic boom system which can be used to deploy probes from a sounding rocket for atmospheric research. Current booms require a large amount of storage space in rockets. The amount of space required can be greatly reduced through the development of a telescopic boom system. An experiment control system and a data acquisition system to verify the performance of the boom during the flight are also being developed. The Telescobe experiment will be launched on the REXUS 9 rocket from Esrange space centre in northern Sweden in March 2011.

The objective of this paper is to verify the suitability of commercially available, off the shelf carbon fibre as a material from which to construct the telescopic boom. The telescopic boom is made from tapered carbon fibre sections, which are commonly used, for example, in fishing equipment. From a retracted length of 230mm, the boom deploys to a length of 1600mm within a tolerance of ±1mm. An interference fit between the carbon fibre sections holds the boom in position once it has been deployed. A mock probe is fitted to the end of the boom. A cable passes through the hollow carbon fibre sections and connects to electronic devices in the mock probe. Inside the rocket, the boom is mounted in a housing made from aluminium alloy and polyether ether ketone (PEEK). Spring based systems have been developed to deploy the boom at an altitude of 70km and then to jettison it before landing. During its flight, the REXUS 9 rocket is expected to reach an altitude of approximately 95km and have a total flight time of about 10 minutes. During this time the carbon fibre boom will be subjected to vacuum, low gravity and harsh thermal conditions. It will also experience large acceleration forces as well as strong vibrations from the rocket. This paper will present the results of tests to determine the ability of a carbon fibre boom to withstand these conditions and perform within the desired specifications.

The REXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European

countries through collaboration with the European Space Agency (ESA). Funding to develop the Telescobe REXUS experiment has been provided by D.I.T and Enterprise Ireland.

Keywords: Telescopic boom, sounding rocket, carbon fibre

Introduction

This paper outlines the development process of the Telescobe telescopic boom and the results of testing to date. The aim of the Telescobe project is to develop and then fly a novel carbon fibre, telescopic boom system for sounding rockets. Booms are commonly used for upper atmosphere research for probes such as electromagnetic field probes and Langmuir probes. However, most of the booms being used presently are relatively heavy and take up a lot of valuable space inside the rocket. By developing a carbon fibre, telescopic boom system from commercially available components the mass of the boom as well as the space it occupies inside the rocket can be potentially significantly reduced, leaving more space for other equipment and experiments on board the rocket, resulting in more cost effective flights.
The Telescobe experiment is being developed by five post-graduate students in DIT as part of the DIT space research group. Advice on developing the project is being provided by Lars Helge who works at the Andoya rocket range in Norway. Funding to develop the experiment has been provided by DIT, Enterprise Ireland and ACRA Control ltd.

Overview of the REXUS/BEXUS project

The REXUS/BEXUS project allows students from universities across Europe an opportunity to carry out scientific and technological experiments on sounding rockets and high altitude balloons. Two rockets and two balloons are launched each year from the Esrange space centre in northern Sweden, carrying a total of up to twenty experiments. The Telescobe experiment will fly onboard the REXUS 9 sounding rocket which is due to be launched in March 2011.

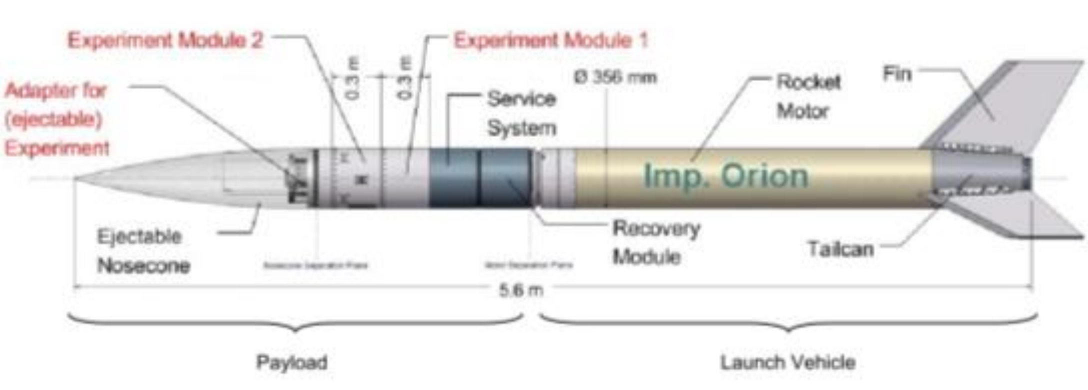

Figure 9-5: REXUS standard configuration

The REXUS vehicle is an unguided, spin-stabilized, solid-propellant single stage rocket. The total mass of the rocket is around 515 Kg comprising a propellant mass of 290 Kg, motor and vehicle hardware of around 125 Kg and a payload mass of around 100 kg. The total rocket vehicle has a length of approximately 5.6 m and the diameter is 356 mm. The standard configuration of the payload comprises the recovery module, the service system, an ejectable nosecone and two or three experiment modules. After liftoff, the motor will burn out at an altitude of about 25 Km. The motor will then separate from the payload, with the payload continuing up to an altitude of approximately 100 Km before descending again. A parachute then deploys from the recovery module before the payload hits the ground.

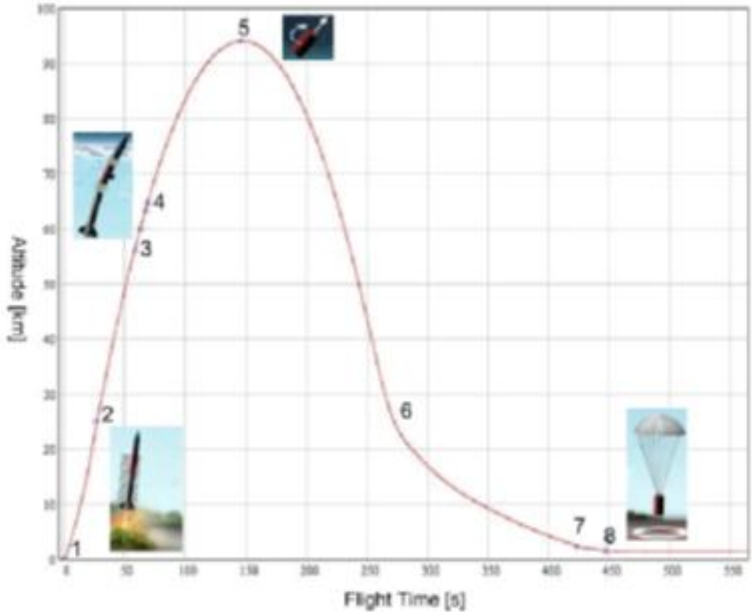

Figure 9-6: Graph of experiment altitude against flight time showing major flight events.

(1 = lift off, 2 = motor burnout, 3 = nose cone ejection, 4 = motor separation, 5 = apogee, 6 = max. deceleration, 7 = stabilising parachute deployment, 8 = main parachute deployment)

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through collaboration with the European Space Agency (ESA).

Boom Systems - Technical Background

Upper atmospheric research provides many valuable insights to scientists. Information on the composition of the atmosphere and magnetosphere can be studied. In doing so, the effects of both solar weather and pollution on our atmosphere can be better understood. Upper atmospheric research can be carried out using a number of methods, such as, high altitude balloons, sounding rockets and satellites. High altitude balloons offer a relatively cheap and simple method of conducting this research. Experimental payload design and testing is also relatively quick but the maximum attainable altitude is usually no more than 45km. Sounding rockets provide a method for conducting upper atmospheric research at much greater altitudes, typically between an altitude of 45km and 160km. However, some sounding rockets can reach altitudes of over 1500 km. The minimum altitude for satellite research is about 160km. The advantage of satellite experiments is that they can take measurements in the space environment for much longer periods of time. Satellites can also conduct similar research on other celestial bodies. However, payload design and testing takes much longer and overall costs are much higher than for the other options.
The Earth's magnetic field and atmospheric plasma electron density are typically measured by Electric Field and Langmuir probes. Electric field, or E-Field, probes as their name suggests, are used to measure the magnitude of electric fields in the atmosphere. They can be split into two main classifications: active or passive probes and are usually deployed in pairs. Langmuir probes are used to measure the ionisation energy and electron temperature of plasma. Measurements can be made using one probe however as many as five probes have been used with certain configurations. In order to take their measurements these probes have to be extended out from the balloon/rocket/satellite payload bay. The altitude of the probes must be known at all times for accurate measurements. It is also necessary to extend the measurement probes clear of any wake turbulence or electromagnetic fields created by the main vehicle. As such, a number of different boom systems have been developed to deploy these probes.
Probes extended from the spacecraft by wires are compact; however the vehicle must be spinning in order to take advantage of centrifugal forces which are used to deploy the probes. These probes are prone to oscillation (as they lack rigidity) in turn effecting measurement accuracy. Single rigid booms can support larger probes and are less prone to oscillation than is the case for wire deployment. However, they require a large amount of storage space in the main vehicle. Folding booms may require less storage space than single rigid booms but typically weigh more due to the extra joints in their design.

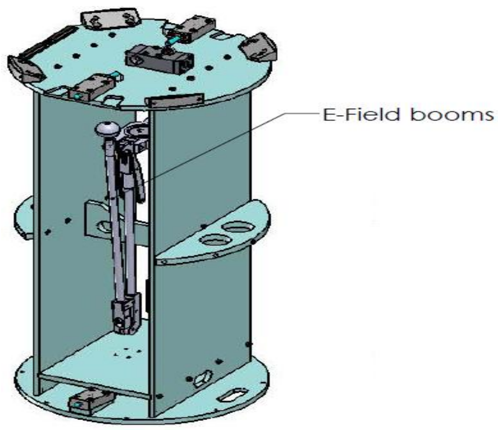

Figure 9-7: Typical folded E-Field boom configuration

Screw driven telescopic booms can require less storage space than either folding or rigid booms. However they can take time to deploy and cannot take advantage of the centrifugal force generated by spin stabilized craft to deploy. It is clear from the above descriptions that each boom system has both advantages and disadvantages. Figure 9-4 below shows some of the different systems mentioned above. In this case the probes are deployed from a sounding rocket (left) and a satellite (right).

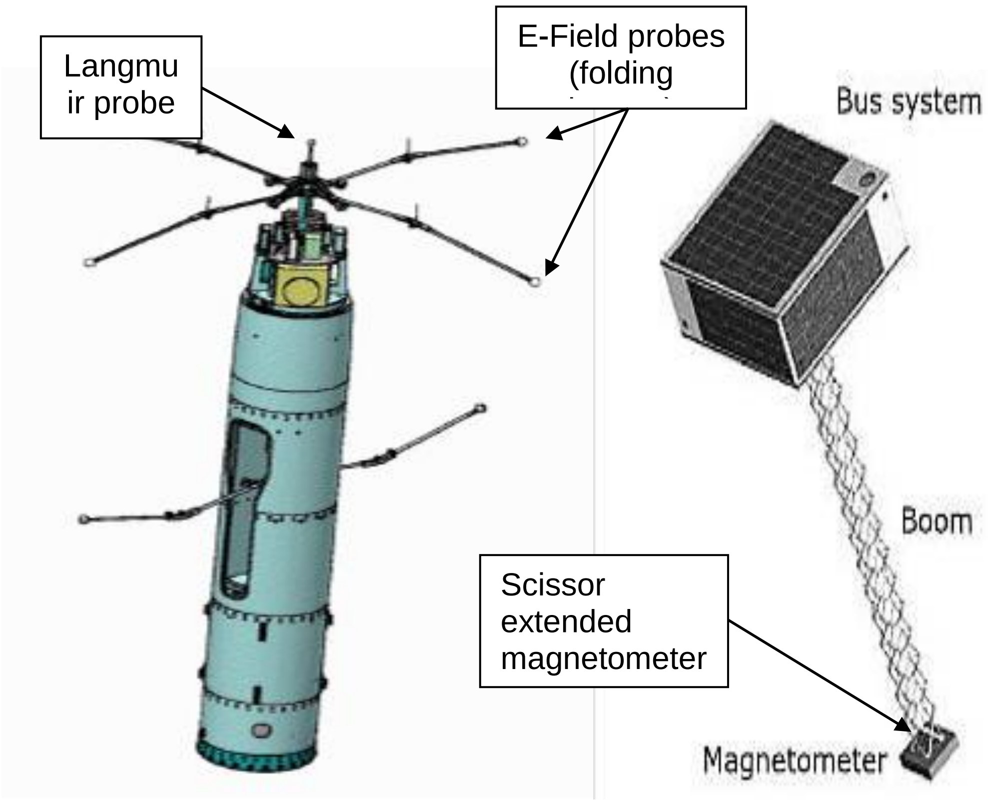

Figure 9-8: Various sounding rocket and satellite boom systems

A spring loaded telescopic boom system offers storage advantages (similar to screw driven telescopic boom). It can also take advantage of the centrifugal force generated by spin stabilized spacecraft to deploy. The lack of a mechanical drive system in its design also results in both mass and cost savings compared to a screw driven boom. The quick deployment time of a spring loaded boom system means that it is suited to sounding rocket flights where data acquisition times may be limited to a short period of time due to the flight plan in place. A spring loaded telescopic boom would have potential applications in other ways too. This type of boom could be used to deploy antennae, solar panels or other types of measurement probes.

Overview of the Telescobe Experiment

The aim of the Telescobe project is to develop and fly a novel, carbon fibre, telescopic boom system on a sounding rocket. While the carbon fibre boom is being tested extensively on the ground, the aim of the flight is to verify the performance of the boom when it is subjected to the harsh conditions that will be experienced during the flight. These harsh conditions include acceleration forces of up to 21*g*, high vibration levels, vacuum, low gravity and harsh thermal conditions.

At lift-off, the boom will be stowed in the rocket in a non-extended state. It will be retained in position using pins and open cell foam will be used to stop the smaller sections rattling. It is intended to deploy the telescopic boom at an altitude of approximately 70 Km. A hatch in the skin of the rocket will open and the boom will deploy out through it to a total length of 1600mm. The boom will then be jettisoned during descent to ensure that it doesn’t become entangled in the parachute that deploys from the REXUS rockets recovery module. The rocket will be de-spun prior to the boom being deployed so centrifugal force will be unavailable to assist in boom deployment. As a result, spring based boom deployment and jettison systems have been developed.

Data will be gathered to determine the performance of the boom during the flight. Two cameras will look out through windows in the skin of the rocket. These cameras will be used to determine the exact position of the mock probe fitted to the end of the boom. These cameras will allow the deployment length of the boom to be measured to an accuracy of 1mm. These cameras will also be used to measure the magnitude of any boom deflection. An accelerometer will also be placed in the mock probe fitted to the end of the boom. This accelerometer will provide data on the frequency of vibration of the mock probe.

All of this data will be sent to an onboard computer which will save it to a flash memory card. After the rocket payload lands and is recovered, the memory card will be removed. The data stored on it will then be analysed to determine if the telescopic boom performed appropriately.

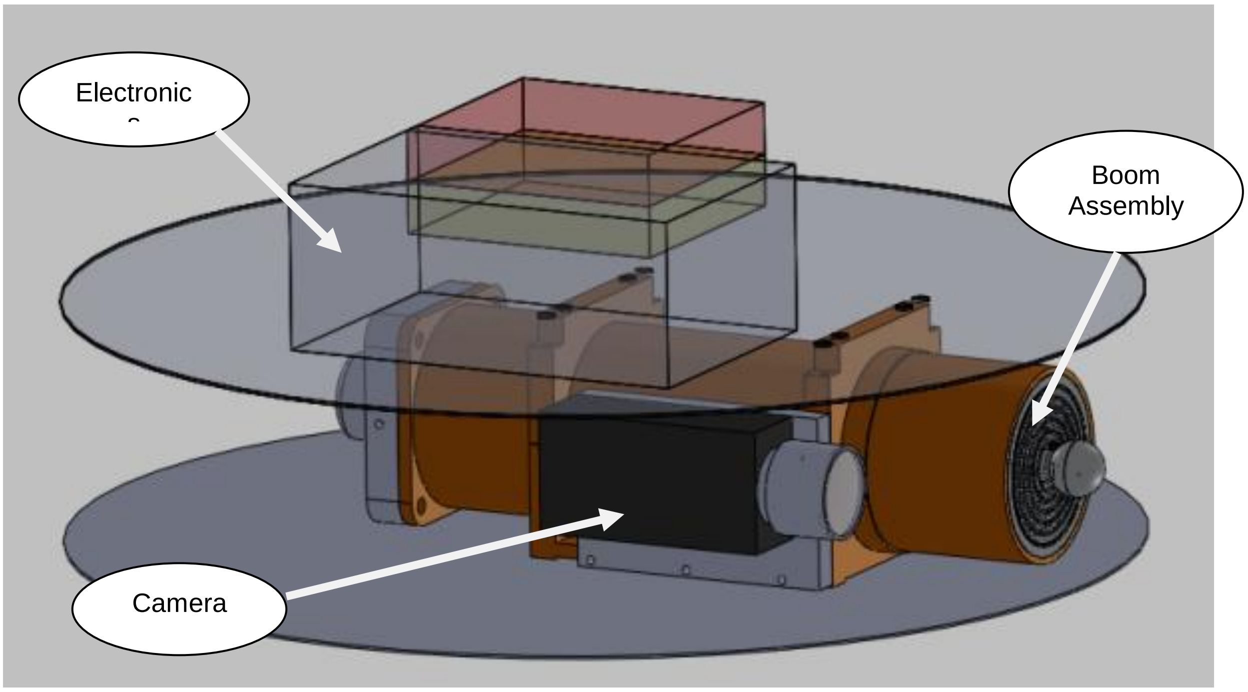

Figure 9-9: Provisional Schematic of the Telescobe experiment

Telescobe: Carbon Fibre, Telescopic Boom

The telescopic boom used in the Telescobe experiment is made from commercially available carbon fibre fishing poles made by Shimano Inc. Fishing poles are used because they provide an affordable and readily available source of tapered carbon fibre sections. The fishing pole can then be cut into a series of 230mm long sections. It has been found that the best way to do this is using a Dremel saw with a flexible chuck, clamped to a lathe. The cutting disk of the Dremel saw cuts into the carbon fibre and then the lathe is manually turned very slowly, cutting the carbon fibre cleanly, without any splinters. The quality of the cut is extremely important as carbon fibre is quite brittle and tends to crack if there are imperfections on any of the edges.

Figure 9-10: Manufacturing the boom sections

Eight sections are cut in this way, with the maximum diameter of the largest section being 45mm and the minimum diameter of the smallest section being 20mm. When the sections are placed one inside the other the length of this non-extended boom is 230mm. Then, when the boom is extended, all of the sections lock into each other, with a 30mm overlap between the sections, giving a total extended boom length of 1600mm.

A precise specification of the type of carbon fibre that the fishing poles were made from was unavailable. As such, various tests were carried out to the carbon fibre to prove its suitability for use in the experiment. First, the carbon fibre was submitted to a vacuum test. It was placed in a vacuum chamber and the pressure inside was lowered to below that which is expected during flight. The carbon fibre was then examined under a microscope and found to have no ill effects. A tensile test was also carried out on sections of the carbon fibre which determined that the tensile strength of the carbon is suitable for use on the experiment. Tests were also carried out to determine the strength of the interference fit between the sections and the rigidity of the boom. The results of all these tests were acceptable.

The most important performance characteristic of the boom is that it deploys to its designed deployment length during the flight within a tolerance (currently ±1mm). To test this, a prototype of the boom deployment system that will be used on board the experiment during the flight has been built. For this, a PEEK (Polyether ether ketone) sleeve and an aluminium base plate were bonded to the largest section of the boom. The PEEK sleeve sits inside an aluminium housing where it can move up and down but is well supported so that there is no lateral movement. The base plate is then pushed back against a spring inside the aluminium housing and held in position using a retaining pin. When this pin is pulled, the entire boom is accelerated forward until the sleeve impacts against another pin in the aluminium housing. With this impact, the momentum of all of the other sections, with the mock probe attached to the smallest section, keeps them travelling forward, deploying the boom. Extensive testing has been carried out on this deployment system and it has been shown to accurately deploy the boom as long as the deployment spring is sufficiently large to ensure a good interference lock between the carbon fibre sections.

It is necessary that a cable passes through the carbon fibre boom to the mock probe. For the Telescobe experiment this cable will provide power to the LED array and accelerometer in the mock probe and well as carry data signals from the accelerometer back to the experiment computer. For this purpose, four core shielded cable is required. However, if measurement probes such as E-field probes or Langmuir probes were fitted to the end of the boom a co-axial cable would have to be used. As such, the cable that will be used with the Telescobe experiment has been selected such that it diameter and bend radius are similar to the diameter and bend radius of the high-flex co-axial cable that would typically be used with these measurement probes.

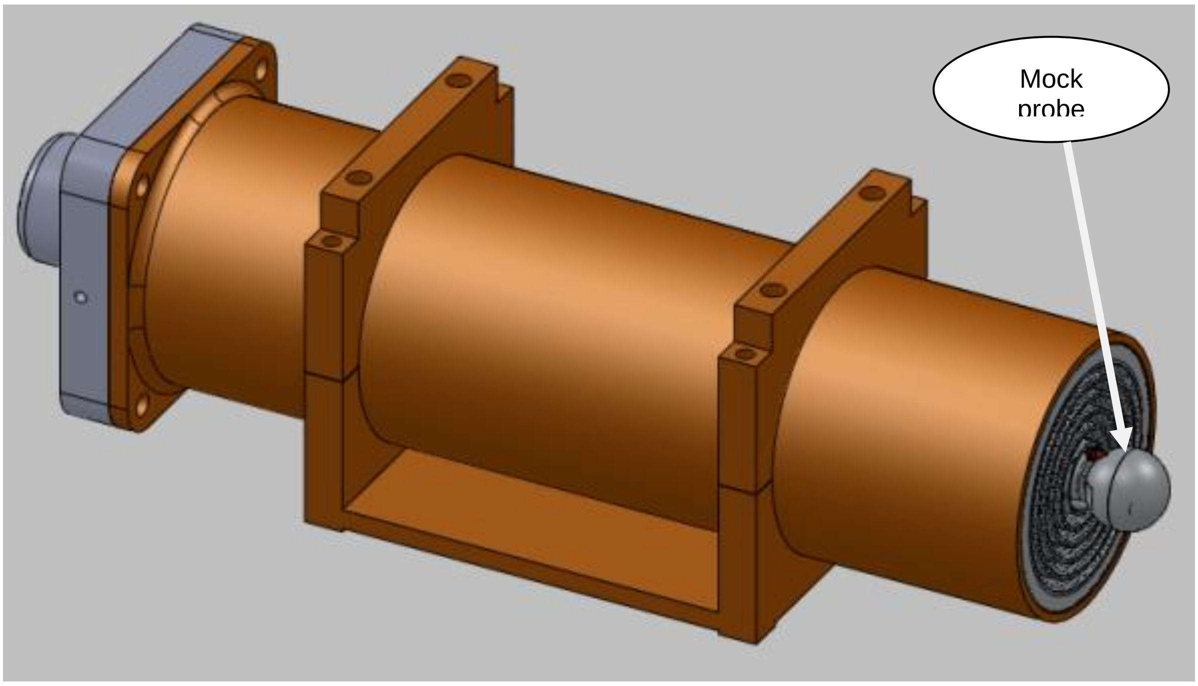

Figure 9-11: The non-extended boom inside its housing

Conclusion

The commercially available tapered carbon fibre sections being used to construct the telescopic boom for the Telescobe experiment are fit for purpose. The prototype boom has performed well in tests to date. However, all laboratory testing can, at best, only an approximate the environmental conditions that will be experienced during the REXUS rocket flight, where the experiment will be subjected to high g-forces, high vibration levels, low gravity, vacuum and extreme thermal conditions. The final test of this

approach to sounding rocket boom development will therefore only come from the satisfactory performance of this telescopic boom during the REXUS flight.
The Telescobe experiment is expected to fly on board the REXUS 9 sounding rocket which will take off from the Esrange space centre in Northern Sweden in March 2011.

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- **ESA-PAC Symposium, France. May 2011**

DEPLOYMENT AND CHARACTERISATION OF A TELESCOPIC BOOM FOR SOUNDING ROCKETS

Johnalan Keegan(1), Mark Wylie(2), Stephen Curran(2), Dinesh Vather(2), Paul Duffy(2)

(1) Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland, Email: spaceresearch@dit.ie
(2) Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland, Email: spaceresearch@dit.ie

1. ABSTRACT

In any sounding rocket, volume and mass are at a premium. Payload designers strive towards smaller, lighter and cheaper mechanisms which can achieve the same goals. This project aims to reduce the mass and volume for probe deployment booms and their deployment mechanisms. An experiment (Telescobe) to test a low cost novel method of boom deployment using telescopic carbon fibre poles was developed.

A custom camera measurement system was also developed to measure boom length and harmonic deflection. This experiment was flown onboard the REXUS 9 sounding rocket [1] in February 2011 from Esrange space centre, Sweden. The experiment functioned as expected in all pre-flight tests. However, an unexpected malfunction in the experiment hatch door was experienced during flight which prevented the boom from being extended through the hatch. Despite this, it was found that the carbon fibre sections, all mechanisms and hardware, survived the flight and functioned as expected as far as possible. It is hoped that with a redesigned hatch, the experiment can be re-launched onboard a future REXUS rocket.

2. INTRODUCTION

Telescobe is an experiment, developed by postgraduate and undergraduate engineering students from the Dublin Institute of Technology (DIT), Ireland. The aim of the Telescobe project was to design, build and fly a telescopic boom system capable of being used to deploy E-Field and Langmuir probes for use in upper atmospheric research. A telescopic boom system potentially makes more efficient use of the available space and mass onboard a sounding rocket when compared with other boom systems.

The Telescobe experiment was developed as part of the REXUS/BEXUS programme. The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through collaboration with the European Space Agency (ESA). Funding for the project was provided by the Dublin Institute of Technology, Enterprise Ireland and Acra Control Ltd. The campaign began in January 2010 and ran until the launch in February 2011.

3. SCIENTIFIC BACKGROUND

Measurements of the Earth's magnetic field and the atmospheric plasma electron density are typically taken using E-Field and Langmuir probes respectively. To take accurate measurements, these probes are extended out from the spacecraft so that they are clear of any wake turbulence or electromagnetic fields created by the rocket. They can be used in single probe and multiple probe configurations. When used in a multiple probe configuration the relative positions of all the probes must be known for accurate measurements to be taken.

There are a number of different systems available to deploy these probes. Probes extended from spacecraft by wires are compact and light weight. However the spacecraft must be spinning as centrifugal force is utilised for deployment. These probes are also prone to oscillation as they extend. Single rigid booms extended from spacecraft can support larger probes and are less prone to oscillation. However, this design does not lend itself to efficient use of the payload volume available.

Folded booms are another option. However, they can also require a significant amount of storage space and the addition of hinges and motors also adds further mass and volume. A typical configuration using folded booms is shown in Fig. 1.

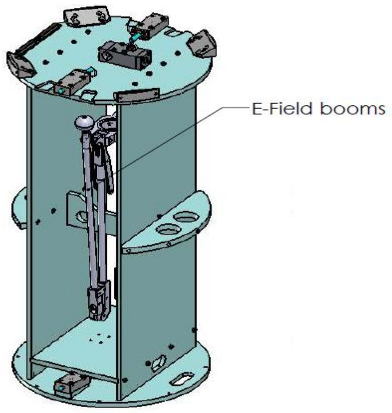


Figure 9-12: Typical folded boom sections for E-Field probes [2].

An effective telescopic boom system offers a more efficient use of the storage space and potentially a reduction in the overall mass. It can also take advantage of the centrifugal force generated by a spinning spacecraft to deploy, but it does not solely rely on this for deployment. By using a spring loaded configuration, the deployment time of such boom configurations is greatly reduced. This is ideal for short flight sounding rockets.

4. PROJECT AIMS

The primary objectives of the Telescobe project were:

- To design and build a telescopic boom, boom deployment and boom jettison system.
- To safely test this system on a near-space flight aboard the REXUS 9 sounding rocket [1].
- To monitor and record boom deployment length, boom vibration characteristics and boom jettison.
- To collate, analyse and disseminate experiment data via presentations and publications.
- To promote the activities of the Telescobe team, DIT and the REXUS/BEXUS program through an outreach program.

Performing electric field measurements did not fall within the scope of the experiment. Instead a mock probe, housing an accelerometer and six LEDs, was fitted to the end of the telescopic boom. This probe was used as the datum point for measurement.

5. EXPERIMENT OVERVIEW

The Telescobe module, shown in Fig. 2, is 220 mm in height and has an internal diameter of 348 mm. An exploded view of the experiment can be seen in Fig. 3. The boom is made from tapered carbon fibre sections and, during the flight it is stored in a PEEK housing inside the experiment. A foam cap is used to prevent the boom from being damaged by excessive vibrations during lift-off.

At a designated time during the flight, a hatch in the skin of the rocket opens. Three seconds later, a pyrotechnic guillotine fires, cutting a nylon cable that retains the boom in its stored position. Two tension springs on either side of the boom housing then deploy the boom out through the hatch. The foam cap is pushed out with the boom and then falls away from it as it is in three sections.

When the boom is deployed, cameras are used to measure its length and an accelerometer is used to quantify any vibrations. After the payload has gone past the flight apogee, a second pyrotechnic guillotine fires, cutting a nylon cable that secures the base of the boom to the experiment. The remaining tension in the two springs then jettisons the boom from the experiment. The boom falls to ground and the hatch closes, preventing hot air from entering the module during re-entry. The timeline for the experiment during the flight is shown in Tab. 1.

Figure 12: The complete experiment module

#	Event	Time (s)	Altitude (km) Approx.
1	Lift-off	0.0	0.332
2	Motor Separation	77.0	~ 64.7
3	Hatch Opens	80.0	~ 67.0
4	Boom Deploys	84.0	~ 69.0
50	Apogee	136.5	80.6
6	Boom Jettisons	210.0	~ 61.0
7	Hatch Closes	215.0	~ 58.0
8	Power Switched Off	600.0	~ 35.0

Table 1: Experiment timeline

6. EXPERIMENT DESIGN

6.1. Boom

The boom is manufactured from tapered carbon fibre sections. The sections are stored one inside the other when the boom is in its stowed position. The largest section has a maximum outer diameter of 55 mm and an average wall thickness of 1.5 mm. The smallest section has a maximum outer diameter of 20 mm and an average wall thickness of 0.5 mm. When extended, the boom locks out with a 20 mm interference fit between each section. The largest boom section is bonded into a cylindrical aluminium sleeve which slides in the boom housing, shown in Fig. 4. Pre-flight, all of the boom sections are collapsed and retained in the boom housing.

6.2. Boom deployment and jettison mechanism

Two pyrotechnic guillotines are used to initiate boom deployment and boom jettisoning. When they are subjected to an electrical current of greater than 0.85A for longer than 15ms the pyrotechnic charge inside the devices detonates. The rapidly expanding gases then push the guillotine which cuts through a nylon cord (Cypress parachute cord).

Two tension springs, shown in Fig. 4, attach to the pushing cup shown in Fig. 5A. When the boom is loaded it is held in position by a nylon cord as shown in Fig. 5A. This cord passes through a pyrotechnic guillotine and is anchored to the boom housing.

When the first pyrotechnic guillotine is activated it cuts this nylon cord. The boom sleeve and boom sections are then accelerated forward by the springs. After they have travelled 100 mm, the slack in a second nylon cord is taken up and the boom sleeve and largest boom section come to a dead stop. However, all of the other boom sections keep moving and lock out into one another, fully extending the boom. This is shown in Fig. 5B.

To jettison the boom, the second guillotine is activated. This cuts the second nylon cord. The remaining tension in the springs then jettisons the boom from the experiment module as shown in Fig. 5C. Four, highly flexible cables also pass up through the boom. They are connected with rest of the experiment module through a Winchester plug at the back of the boom housing. When the boom is jettisoned, this disconnects so that the cables are jettisoned along with the boom and there is no risk of any short circuits occurring inside the experiment.

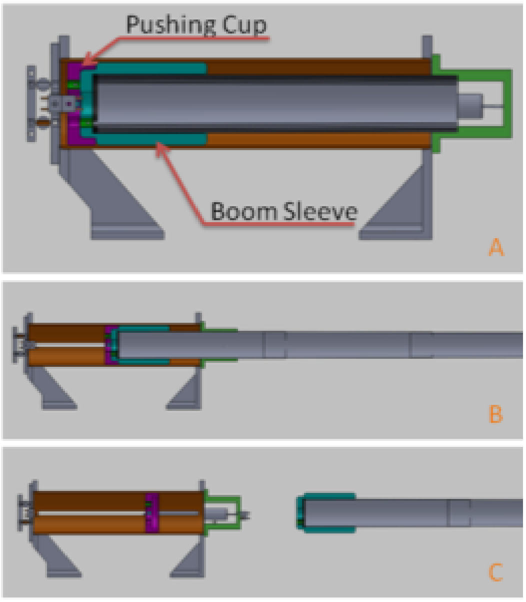


Figure 9-13: (A) Boom in stowed position, (B) Boom is deployed, (C) Boom is jettisoned.

6.3. Probe

A three axis accelerometer (Analog Devices ADXL345) and an array of six LEDs are mounted on a printed circuit board (PCB) that is placed in the probe fitted to the distal end of the boom. It measures the acceleration profile of the boom during deployment and is used to determine the frequency of vibration of the boom when it is deployed. The LEDs (Thorlabs LED661L) emit light at a wavelength of 655 nm and are lensed to direct this light towards the measurement cameras. Four flexible single core cables pass through the boom. Two of which carry 3.3 V and the ground signal connections for the LEDs and accelerometer. The other two facilitate the transmission of the clock and data signals for an I^2C bus.

6.4. Cameras

Three cameras are used in the experiment. They are mounted on custom designed camera brackets. The camera brackets mount directly to the inside skin of the module. A float glass window with an extended temperature range is mounted in the camera bracket parallel to the camera lens. This allows the camera to gather light from outside the rocket while preventing hot air from entering the module through the hole in the skin. This assembly can be seen in Fig. 6.

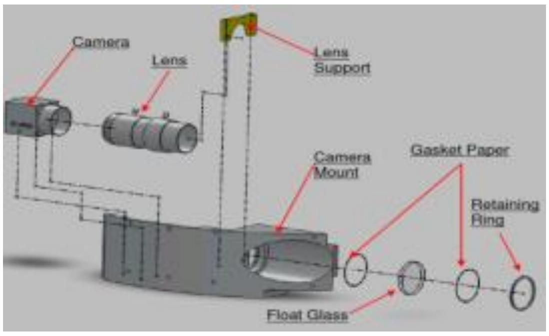


Figure 6: Camera and camera bracket

Two of the cameras are measurement cameras (SONY XC-ES50) and are used to precisely measure the length of the boom when it is fully deployed, as well as the magnitude of any boom deflection. They are both fitted with a compact fixed focal length lens. A narrow band pass filter is fitted to each lens. The filters will only allow light with a wavelength of 655 nm to pass through it. Filtering out most of the superfluous light allows for better frame compression and makes it easier to acquire relevant information from the video frames during post-flight analysis. An image of the probe captured by one of the measurement cameras is shown in Fig. 7.

The third camera is an observation camera (SONY XC-ES30 CE). It is fitted with an Edmund Optics compact fixed focal length lens. It is used to provide images of the boom deployment, operation and jettison. The video output from the observation camera is connected to the TV transmitter in the rocket service module. From here they are transmitted to the ground station where they are monitored in real time.

Figure 7: The LEDs in the probe, as seen by one of the measurement cameras

6.5. Hatch

The experiment has been fitted with a hatch to allow the boom deploy through the skin of the rocket and prevent hot air from entering the experiment during ascent and re-entry. The hatch consists of guide rails, a door and a spring return rotary solenoid. The solenoid is connected to the door using a link arm. The hatch is powered from the same power source as the pyrotechnic guillotines. A pulse width modulation (pwm) solenoid driver is used to control the flow of electrical current to the solenoid. When power to the solenoid is switched on, 2.2 A flows into it, opening the hatch. Because of power consumption limitations, after 1 second, pwm mode begins and the current flowing into the solenoid is reduced to a 350 mA “holding” current.

6.6. Flight computer and frame grabber

The flight computer is a PC/104-plus CPU module (Eurotech ISIS XT). It is a fanless design that instead incorporates a large heatsink which is in contact with the aluminium skin of its enclosure. This dissipates the waste heat generated. The computers operating system, all the flight telemetry and images acquired from the two measurement cameras are stored in the internal 2 GB memory. For additional security, the flight telemetry and camera images are also stored on a 2 GB industrial grade SD card. The ISIS-XT has an I^2C bus interface which is used for interaction with the accelerometer. The built in RS422 port is used during flight to transmit selected telemetry information, through the rocket service module's telemetry system, to a ground station. It also has digital I/O ports available which are used to read the status of control signals from the rocket service system.

The framegrabber is a PC/104-Plus type MPEG encoder module (Eurotech CTR1475). It connects directly into the PC/104-Plus bus of the flight computer from which it draws its power. The frame grabber has the ability to take images from up to four analogue cameras, digitise them, and compress them into MPEG4 format.

6.7. Power management and distribution

Power is supplied to the experiment at 24-36 V from the Rocket Service module. However, the various experiment sub-systems require power to be provided at 12 V, 5 V or 3.3 V. To achieve this, a power management board is used (Eurotech ACS5151). Power is supplied at 12 V, 5 V and 3.3 V to the power distribution and switching PCB for use by the other experiment sub-systems.

Power for the pyrotechnic guillotines, as well as the hatch, is supplied from an independent rocket service module interface to that of the rest of the experiment. This power is only switched on at a designated time during the flight. The experiment receives three control signals from the rocket service module. The first of these is received at lift-off. If the LO signal is not received, guillotines cannot fire. The other two control signals, (SODS and SOE), are switched on at pre-programmed times during the flight. Each of these control signals is linked to one of the pyro guillotines and is used as the final trigger for initiating boom deployment or jettison.

6.8. Experiment Control Software

The flight computer runs Windows Embedded as its base operating system. The experiment controller application was written in Python 2.6. The experiment controller is implemented as a modified state machine with states for initialization, start, ascent, deployment, jettison and finalisation. A graphical representation can be seen in Fig. 8.

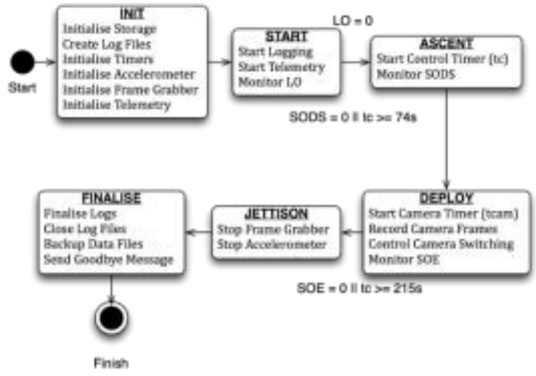


Figure 9-14: Experiment controller state machine

A summary of the states is given below:

- *INIT*
  This is first set of commands executed by the experiment controller on system boot. All initialisation is done in this state including memory storage, data acquisition parameters and communication protocols. Once all parameters and subsystems are set up correctly the system immediately transitions to the START state.
- *START*
  This is a waiting state. The system is ready for launch. Telemetry and logging are active throughout this state. On receipt of the lift-off signal from the rocket service module the system transitions to the ASCENT state.
- *ASCENT*
  In this state a control timer is started to control transition into the next state in which the camera frames are recorded. The timer is set to trigger state transition at T+74 seconds, 10 seconds before boom deployment. As a failsafe the SODS signal from the rocket service module, which triggers boom deployment at T+84s, is also monitored. On receipt of either the timer signal or SODS signal, the system transitions into the DEPLOY state.
- *DEPLOY*
  On entry to the DEPLOY state a camera timer is started and both onboard measurement cameras start recording frames to onboard storage. This data is subsequently used to determine the deployed length of the boom. Frames continue to be recorded from both measurement cameras until detection of the SOE signal from the rocket service

module at T+210s. At this point the system transitions into the JETTISON state.

- *JETTISON*
  On entry into this state both cameras and accelerometer acquisition is switched off. Once this is complete the system immediately transitions into the FINALISE state.
- *FINALISE*
  In the FINALISE state the final log entries are made and all log files are closed. At this point all data files are backed up to the SD card as a safety precaution in the event that the internal memory of the CPU is damaged on landing. Once this is complete the state machine exits the main loop and sends a 'Goodbye' signal to the ground station before execution is stopped.

6.9. Telemetry

The telemetry is sent to the ground station via the rocket service module through an on-board RS422 connection.
Throughout the experiment, four types of telemetry messages are sent in the packets to the ground station. The ***Session*** packet contains a 6 byte code to signify a uniqie session string for each run of the experiment. This is used to correlate different sets of data files with those received at the ground station during pre-filght tests and the actual flight. The ***Housekeeping*** packet holds the status information for the entire experiment. It wraps a message consisting of two bytes of data which encode the states and status information of the experiment controller and related sub-systems. The ***Accelerometer*** packet wraps a 6 byte representation of the current sample from each of the x, y and z axes registers. The ***Goodbye*** packet contains a 6 byte message to signify that the experiment controller and all sub systems have reached their finalised state successfully and are ready to shut down. This is the last message sent to the ground station and is used to indicate that the telemetry is about to stop.

6.10. Ground Station:

The ground station software is again written in Python 2.6. The job of the ground station is to parse the telemetry stream received from the rocket and display the current status of the experiment as well as a realtime display of the accelerometer samples.

7. THE FLIGHT

The Telescobe experiment was launched on 22nd February 2011, on the REXUS 9 sounding rocket. All experiment systems passed pre-flight checks and were deemed operational pre-launch. However, an unforeseen event occurred during the ascent phase of the flight which caused one of the experiments components (i.e. the hatch) to malfunction. This prevented the telescopic boom from deploying. During the flight, all of the experiments software and electronic systems functioned as expected and telemetry data was received at the experiment ground station. Data was obtained from the accelerometer and images from the two experiment measurement cameras were recorded. Mechanically, the boom deployment system worked, as in, the pyrotechnic guillotines fired, cutting the deployment cable and firing the boom forward. This was also true for the jettison. When the payload was retrieved after landing, the experiment was still operational and data was obtained from the onboard SD card. Ultimately the hatch failure was deemed responsible for the experiments failure.

8. POST-FLIGHT ANALYSIS

8.1. Hatch failure

A foam cap supported one end of the telescopic boom to prevent it from being damaged by vibrations during the launch. Friction held it in position. During the ascent stage of the flight, the centrifugal forces generated by the spinning rocket caused the cap to move towards the hatch door. After rocket was de-spun, the foam cap was still in contact with the hatch. Then, when power was switched on to open the hatch, the hatch door only half opened, jammed by the foam cap.

When the signal for deploying the boom was subsequently received the boom deployed against the hatch door. This problem may have been prevented if the foam cap was retained more robustly but this issue was not anticipated before the flight. Most crucially, the late design and assembly of the hatch meant that the experiment was not spin tested with a loaded boom and a fully assembled hatch.

Other issues may also have contributed to the malfunction. The electronics for controlling the hatch were short-circuited before the launch by an incorrect cable. The experiment was partially disassembled to repair this. This caused the plastic foam cap to move 2-3mm from its normal position towards the hatch door. This was never seen before but was deemed acceptable by the team at the time. Also, an issue during the countdown meant that the rocket was unexpectedly elevated outside for approximately two hours. This caused the temperature inside the rocket to drop well below 0^{o}C. While many parts of the experiment were tested in a sub zero environment, the hatch and foam cap were never tested at these temperatures and the effect that this might have had on it is unknown. Finally, during post-flight tests it was discovered that cycling the power to the hatch so that it would receive more than one initial current spike would most likely have fully opened the hatch. Therefore, putting in a sensor to detect if the hatch was fully opened and, if not, to cycle the power to the hatch, may also have avoided the failure.

8.2. Analysing camera images

Images recorded by the experiments measurement cameras, such as that shown in Fig. 7, are read into Matlab to be analysed. They are then filtered and eroded to give an image similar to that shown in Fig. 9. The position of the centroid of each of the white areas is then found and, from this, the co-ordinates of the centre point of the probe are found. This can then be compared with a set of calibration data to give the co-ordinates of the centre point of the probe relative to the rockets co-ordinate system. However, as the boom did not deploy during the flight there were no images to perform useful post-flight analysis on.

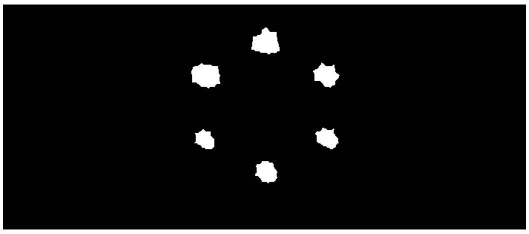


Figure 9-15: A filtered and eroded image obtained from one of the measurement cameras

8.3. Other post-flight analysis

Both the onboard flight log and ground station event log can be inspected visually as they are recorded in plain text format. For analysis of the accelerometer data the python Scipy and MatPlotLib libraries are utilised. The telemetry byte log is parsed using Python.

9. RESULTS

Although the boom did not deploy fully as expected, examination of the accelerometer data shows that, had the hatch not obstructed the boom deployment, it would have deployed as expected. Fig. 10 shows the acceleration profile of the probe during the flight.

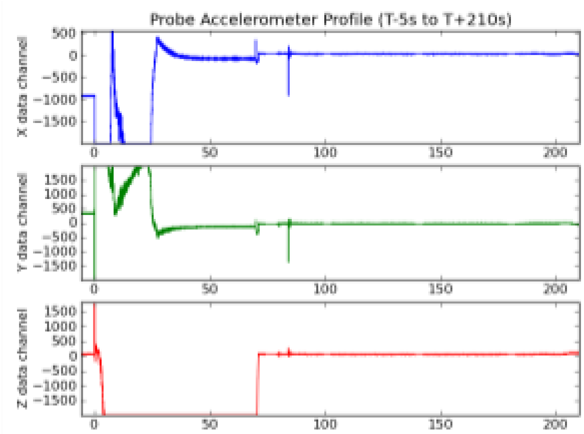


Figure 9-16: Probe Accelerometer Data from T-5s to T+210s

A magnified view of the accelerometer data from T+65s to T+88s is shown in Fig. 11. It can be seen that there are acceleration spikes at T+69.8s, T+80.15 and T+84s. These times correspond to nosecone ejection, hatch opening and boom deployment respectively.

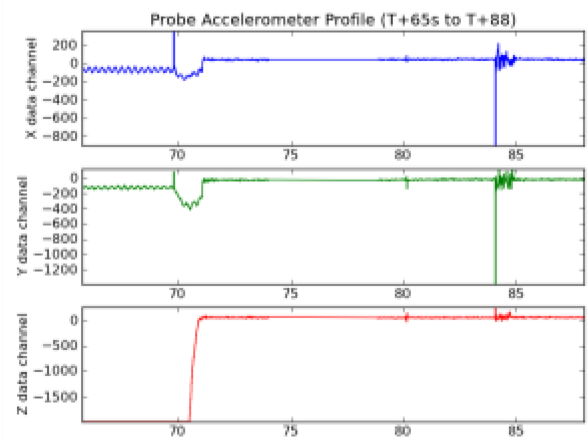


Figure 9-17: Section of Probe Accelerometer Profile from T+65s to T+88s

The fact that there is an acceleration spike at hatch opening verifies that the probe must have been in contact with the hatch door at this time. Acceleration spikes at boom deployment and boom jettison verify that the boom pusher cup was still held in the required positions prior to the firing of the pyros and moving forward each time each of the pyros were activated.

10. CONCLUSION

The hatch on the experiment module failed to open fully during the flight. This was ultimately responsible for the failure of the boom to deploy. A thorough and careful post flight analysis was carried out to determine the cause of this failure. The conclusion was that foam cap that protected the probe during lift-off moved against the hatch door during the flight and caused it to jam. This could have been avoided by better retaining the foam cap or by incorporating active feedback into the hatch that would detect if it was not fully open and then take corrective action such as cycling the power supply to it.

All of the other experiment systems functioned as expected, as far as possible, during the flight. Accelerometer and telemetry data was retrieved from the experiment and, from this data, it is believed that the experiment would have performed as expected had the hatch failure not occurred.

The experiment was retrieved completely intact after the flight. As such, it is intended to apply for a re-flight onboard a future REXUS sounding rocket with a modified hatch.

11. REFERENCES

[1]. Eurolaunch. “REXUS User Manual v7”. December 2011. Available at:
http://www.rexusbexus.net/index.php?option=com_content&view=article&id=47&Itemid=59

[2]. Helge, L,.Hansen, G,. “*New flight qualified payload by Andoya Rocket Range*”. ESA-PAC 19th Symposium, Bad Reichenhall, Germany, June 2009

APPENDIX C – PART NUMBERING SYSTEM

Part No.	Code	Description
0001-XXXX	Product	Overall Assembly.
0002-XXXX	Sub Ass.	Mechanical Sub Assembly
0003-XXXX	Electrical Ass.	Electrical Assembly (e.g. Control Panel)
0004-0XXX	Cable Ass.	Cable Assembly (Power Cable)
0004-1XXX	Cable Ass.	Cable Assembly (Signal Cable)
0004-2XXX	Cable Ass.	Cable Assembly (Safety Cable)
0004-5XXX	Cable Ass.	Cable Groups
0004-6XXX	Cable Ass.	Cable Assembly (Signal Cable)
0010-XXXX	Software	Software Release
0020-XXXX	Std. M/ced. Pt	Standard Machined Parts
0021-XXXX	Mod Parts	Modified Parts (e.g. modified bought in parts)
0030-XXXX	Frame Fab.	Frame Fabrication
0031-XXXX	Sheet Metal	Sheet metal Fabrication
0032-XXXX	Safety Fab.	Safety Guarding Fabrication
0033-XXXX	Plas-parts	Plastic Parts
0040-XXXX	Elect. Draw	Electrical Drawings (e.g. Circuits etc.)
0050–XXXX	Circu. Draw	Mechanical Circuit Drawings
0050 -1XXX		Pneumatic Circuit Drawings
0050 -2XXX		Vacuum Circuit Drawings
0050 -3XXX		Extraction Circuit Drawings
0050 -3XXX		Water Circuit Drawings
0060-XXXX	Des. Draw	Descriptive Drawings
0070-XXXX	Mech. Assy. Draw	Mechanical Assembly drawings

0100-0XXX	Standard Metric Fasteners.	Standard Metric Fasteners. Socket Head Cap Screws (SHC), Counter Sink Screws (C / Sink), Button Head Screw(Button), Grub Screws (Grub)
0100-00XX		Shoulder Bolts, Tie Rods
0100-01XX		Fasteners less than M2
0100-02XX		Fasteners from M2 less than M3.
0100-03XX		Fasteners from M3 less than M4.
0100-04XX		Fasteners from M4 less than M5.
0100-05XX		Fasteners from M5 less than M6.
0100-06XX		Fasteners from M6 less than M8.
0100-07XX		Fasteners from M8 less than M10.
0100-08XX		Fasteners greater than M10.
0100-09XX		Metric Grub Screws (Grub)
0100-1XXX	Standard Imperial Fasteners.	Standard Imperial Fasteners. Socket Head Cap Screws (SHC), Counter Sink Screws (C / Sink), Button Head Screw(Button), Grub Screws (Grub)
0100-10XX		Shoulder Bolts, Tie Rods.
0100-11XX		Fasteners Size 0, 1 and ¼ - Inch, ½ .
0100-12XX		Fasteners Size 2.
0100-13XX		Fasteners Size 3 and 3/8 – Inch, ¾ .
0100-14XX		Fasteners Size 4.
0100-15XX		Fastener Size 5, and 5/8 – Inch, 5/16.
0100-16XX		Fasteners Size 6.
0100-17XX		Fasteners 7/16 – Inch, 7/8 – Inch.
0100-18XX		Fasteners Size 8, 10, 12 and 1, 1 ¼, 1 ½ .
0100-19XX		Imperial Grub Screws
0100-2XXX	Non-Std Metric Panel Fast	Non-Standard Metric Panel Fasteners, Tinement Clips & studs, ¼ Turn Captive Screws, etc
0100-3XXX	Non-Std Imperial Panel Fast	Non-Standard Imperial Panel Fasteners, Tinement Clips & studs, ¼ Turn Captive Screws, etc
0100-4XXX	Metric Nuts and Receptacles.	Nuts and Receptacles. Pem nuts- PEM, Press in threads - Press, Weld Studs- Stud, Standard Nuts- Nut, Non-Standard Nuts - Nut,
0100-5XXX	Metric Washers.	Washers. Flat Washers- Flat, Spring Washers - Spring, Crinkle Washers- Crinkle.

0100-6XXX	Special Metric Fasteners.	Special Metric Fasteners (i.e. dowels, rivets, split pins, circlips)
0100-7XXX	Imperial Nuts and Receptacles.	Nuts and Receptacles. Pem nuts- PEM, Press in threads - Press, Weld Studs- Stud, Standard Nuts- Nut, Non-Standard Nuts - Nut,
0101-XXXX	Std. Mech	Standard mechanical parts, e.g. Handles, catches, bearings, gear boxes.
0101-0XXX	Std. Mech	Bearings, bearing surfaces, slides. Shafts
0101-1XXX		Standard Metal parts, extrusions, metal enclosures.
0101-2XXX		Cable management, Cable chains, trunking, cable ties, cable cleats, cable glands.
0101-3XXX		Standard parts, handles, latches, levers, hinges, knobs, feet, fans. Sealing profiles, Sound Absorbing material
0101-4XXX		Springs, Shock Abs.
0101-5XXX		Locating Pins and Bushes
0101-6XXX		Purchased Tooling
0101-7XXX		Gaskets, Seals, O-Rings etc
0102-XXXX	Gen. Elec	General Electrical e.g. Terminal blocks, junction box
0102-0XXX		Power Sockets, Legends, E-stop Legend, labels, signs.
0102-1XXX		Bulbs, fuses, indicating devices.
0102-2XXX		Connectors.
0102-20XX		D shell connectors, 9, 15, 25, 37, etc.
0102-21XX		Circular connectors, 4, 9, 14, etc.
0102-22XX		Other connectors, IDC, Mains inlet,
0102-23XX		Connector accessories; back shells.
0102-24XX		Ethernet Sockets, BNC , Networking parts

0102-3XXX		Cable terminators.
0102-30XX		Ferrules, crimps, eyelets, and solder pins.
0102-36XX		Heat shrink, solder.
0102-4XXX		Terminals.
0102-40XX		2.5 sq. terminals.
0102-41XX		4.0 sq. terminals.
0102-42XX		6.0 sq. terminals.
0102-43XX		10 sq. terminals.
0102-44XX		16 sq. terminals.
0102-45XX		Busbars, commoning bars, end caps, covers
0102-46XX		Terminal Blocks
0102-5XXX		Discrete comps, resistors, capacitors, diodes, transistors.
0102-6XXX		Single / Multicore Cable.
0102-60XX		0.25 sq.
0102-61XX		0.5 sq.
0102-62XX		0.75 sq.
0102-63XX		1.0 sq.
0102-64XX		1.5 sq.
0102-65XX		2.5 sq.
0102-66XX		4.0 sq.
0102-67XX		6.0 sq.
0102-68XX		10 sq.
0102-69XX		16 sq.
0102-70XX		25 sq.
0102-75XX		0.14 and less Multicore Cables
0102-76XX		0.2 Multicore Cable
0102-77XX		0.25 Multicore Cable
0102-78XX		0.5 Multicore Cable
0102-79XX		0.75 Multicore Cable
0102-80XX		1.0 Multicore Cable

0102-81XX		1.25 Multicore Cable
0102-82XX		1.5 Multicore Cable
0102-83XX		2.5 and Greater, Multicore Cable
0102-85XX		Other Cables, co-axial, ribbon, CAT 5.
0102-90XX		Bought in assembled cables
0103-XXXX	Pneu.	Pneumatics, e.g. Solenoids, piping, manifolds
0103-0XXX		Tubing & Fittings
0103-1XXX		Cylinders
0103-2XXX		Valves & Manifolds
0103-3XXX		Air Flow Controllers
0103-4XXX		Filters, Regulators, Gauges, Silencers
0103-5XXX		Nozzles, Aerators
0103-6XXX		Pneumatic brackets and panel mounts
0103-7XXX		Pumps and Cooling Equipment
0103-8XXX		Vacuum Pumps
0103-9XXX	Water	Heaters
0104-XXXX	Elec. Brake	Electrical breakers, MCB's, ELCB's, relays, contact.
0105-XXXX	Power Supp.	Power supplies, e.g. 24VDC PSU, DC-DC convert. UPS
0106-XXXX	Switch	Switches, Contacts, Pushbuttons, and Actuators. Pressure and Vacuum Switches
0107-XXXX	Sensor	Sensors, e.g. Reed switch, capacitance sensor. Sensor Amplifiers
0108-XXXX	Opto	Opto 22 components, e.g. rack, cable, modules.
0109-XXXX	Traffo	Transformers.
0110-XXXX	Elec. Con.	Electrical Controllers, Timers, Counters, e.g. Omron

0111-XXXX	Motion	Motion products, motors, encoders, gears, timing belts, motion controller's etc.
0111-0XXX		Belts, conveyor and timing belts.
0111-1XXX		Motors.
0111-2XXX		Encoders, tachos, resolvers, feedback dev.
0111-3XXX		Gears and pulleys.
0111-4XXX		Misc, Motor couplings etc.
0111-5XXX		Stages
0111-6XXX		Robots, Tilt Stations, Prealigners
0112-XXXX	PC Card	PC cards, e.g. Ethernet, VGA.
0113-XXXX	PC comp.	PC components, e.g. CDROM, HDD, FDD, PSU.
0114-XXXX	PC Cables	Standard cables, e.g. keyboard exten, serial cable
0115-XXXX	PC Ancillary	PC Ancillary products, monitors, keyboard, mice.
0116-XXXX	Optics	Optics
0116-0XXX		Cameras
0116-1XXX		Lenses
0116-2XXX		Lasers
0116-3XXX		Ancillary Optics
0118-XXXX	Labels	Labels, e.g. Hazard or warning label, CE label
0119-XXXX	Solvents	Solvents, greases, adhesives, oils, cleaning fluids, paint, thread lock, bearing, lock, etc.
0120-XXXX	Pack	Packaging. Shipping crates etc.
0121-XXXX	Manuals	Manuals, e.g. Installation, maintenance.
0122-XXXX	Office Sup.	Office Supplies

0160-XXXX	Paint specs	Paint Specifications
0170-XXXX	Chemicals	Solutions, liquids, chemicals

Table C-1 Part Numbering System

APPENDIX D – DATA SHEETS

The following data sheets are included in this appendix.

- D.1 PC/104 CPU Module
- D.2 PC/104 MPEG Module
- D.3 PC/104 Digital I/O Module
- D.4 PC/104 Power Module
- D.5 Cameras
- D.6 Probe LEDs
- D.7 Accelerometer
- D.8 Cypress Cutters
- D.9 ATmega328 Microcontroller
- D.10 MAX233 Line driver
- D.11 EC Motor
- D.12 Planetary Gearbox (690:1)
- D.13 Motor Controller

D.1 PC/104 CPU Module

ISIS XL

PC/104+ Module with Intel® Atom™ processor

Features

Features:

- Intel® Atom™ Processor up to 1.33GHz
- High performance x86 compatibility in a fanless design
- Atmel Trusted Platform Module Device
- 20-channel GPS receiver
- Extended temperature range

Supported Operating Systems:

- Windows® XP
- Windows® XP Embedded
- Linux

The ISIS XL processor board provides all the benefits of Intel's new Atom LPIA architecture in a PC/104+ form factor; comprising of a processor module and carrier board.

Using Intel's Hi-K 45nm technology the Intel Atom Z5xx series processor delivers the benefits of Intel's x86 architecture in a robust, ultra-small package with exceptional performance-per-watt. The processor is matched with an Intel System Controller Hub (SCH) US15W which is a highly integrated device combining a graphics memory controller and an I/O controller. The ISIS XL offers high-performance x86 compatibility in a fanless design that requires only a fraction of the power previously needed for comparable systems.

A full range of on board peripherals are provided including 8 x USB 2.0 ports, VGA, LVDS, HD-Audio, RS232/422/485, Ethernet, GPIO and IDE. Expansion requirements are well covered by a combination of PC/104 (ISA), PC/104+ (PCI) and PCI Express MiniCard, so interfacing to real-world I/O or the latest wireless technology is easy. Requiring less than 5W of power and running at 1.1GHz or 1.33GHz the ISIS XL has all the functionality and connectivity previously associated with much larger and more power-hungry systems.

The ISIS XL comes with up to 1GB of DDR2 RAM and 4GB of soldered-down Flash for security and durability. Further solid-state Flash expansion is available via an SDIO socket.

ISIS XL is compatible with all major desktop operating systems, and is also available with pre-installed, ready to run, embedded operating systems including Windows XP, XP Embedded and Linux.

Having all this performance in such a small package is a truly compelling offering that makes the ISIS XL ideally suited to applications such as infotainment, interactive kiosks, in-vehicle systems where mains power is not readily available, HMI, medical, mobile access routers and industrial control.

EUROTECH

ISIS XL

Technical Specifications

PROCESSOR	Intel® Atom™ processor options (13mm x 14mm BGA)
	1.33GHz (2.3W)
	1.1GHz (2W)
CHIPSET	System Controller Hub US15W (22mm x 22mm BGA)
	2.3W (industrial temperature)
SUPPORTED OS	Windows XP, XP Embedded and Linux
MEMORY	System memory: DDR2 SDRAM
	Up to 1GB (400/533MHz)
	Flash: 2GB or 4GB solid-state drive (NAND Flash on board)
BIOS	InsydeH2O
	SPI Flash (proprietary)
TPM (optional)	Atmel Trusted Platform Module device, TCG v1.2 compatible
TEST SUPPORT	JTAG interface (Intel XDP)
STACKING CONNECTORS	High density board to board connector supporting:
	Video ports (LVDS, SDVO)
	Intel high definition audio
	I/O connectivity (8 x USB 2.0, 2 x PCIe (x1), LPC, PATA)
	Power connector
EXPANSION	PC/104+ (PCI 32-bit)
	PC/104 (ISA 16-bit)
	PCI Express MiniCard socket
	SDIO socket (4-bit)
	I²C interface
GRAPHICS	VGA interface
	Single-channel LVDS 24-bit interface
AUDIO	HD audio digital interface
USB SUPPORT	USB 2.0 supporting low/full/high speed modes
	8 x user accessible ports (on pin headers)
ETHERNET	1 x fast Ethernet port supporting 10/100 BaseT
SUPER I/O	SMSC SCH3114 SuperIO device
	GPIO
	3 High speed serial ports 16C550 compatible
	- 2 x user accessible ports (RS232/RS485/RS422 & RS232)
	- 1 x port used to connect to onboard GPS receiver
	PS/2 keyboard and mouse support
IDE SUPPORT	Parallel ATA interface - single channel (Master/Slave)
GPS RECEIVER	iTrax300 20-channel GPS receiver with full position/ velocity/time functionality
POWER SUPPLY	5V only (+/-5%)
	4 - 4.5W power consumption (average per typical application)
DIMENSIONS	ISIS XL carrier board PC/104+ form factor, 96mm x 90mm
	ISIS XL processor module 100mm x 67mm
OPERATING TEMPERATURE	Industrial: -40°C to +85°C

Development Kit

- 8.4" 800 x 600 LCD with touchscreen
- HD audio breakout with line in, line out and mic in connections
- 80GB hard drive
- Windows XP, XP Embedded and Linux
- 10/100 Ethernet port
- 4 x USB 2.0 ports
- 2 x serial ports
- Other features (VGA port, SDIO, PS/2 keyboard/mouse)

About EUROTECH

EUROTECH delivers embedded computer systems for high capability and low power applications, networking and wearable computing solutions, and application framework middleware for multimedia, industrial, transportation, medical, and wireless applications. EUROTECH platforms allow OEM and enterprise customers to focus on their core revenue-generating products and services and get to market quickly.

ETH_ISIS_XL_ME280709

EUROTECH

www.eurotech.com

D.2 PC/104 MPEG Module

DATASHEET - PC/104-PLUS PERIPHERAL MODULES

EUROTECH

CTR-1475

MPEG-4 VIDEO COMPRESSOR WITH 4 INPUTS

Features

Encoding Processor:
Integrated RISC Microcontoller
(to offload compression overhead from system CPU)

Video Input:
4 Analog Video Input Channels
(Up to 16 concurrent cameras can be supported with four CTR-1475 in a single PC/104Plus stack)

Video Output (Analog):
1 Analog Video Output Channel
(for Monitoring)

Audio Input:
4 Audio Input Channels
(PCM, ADPCM Audio Compression)

Video Quality Control:
Programmable Quantization Values - Picture Size, Position, Panning, Tilting, Freeze

Bit Rate Control:
Supports Variable Bit Rate (VBR), Constant Bit Rate (CBR) and Hybrid Bit Rate (HBR)

General Purpose Digital I/O:
8 Digital I/O Channels

General Description

The CTR-1475 is a real-time MPEG-4 video compressor, encoder and frame grabber module designed to capture up to four concurrent high-quality analog video and audio streams, encode them in compressed MPEG-4 or AVI formats, and send them to an embedded computer over the 32-bit PCI bus.

Featuring an onboard RISC microcontroller dedicated to handling the computationally intensive video compression procedure, this PC/104-Plus form factor module supports up to four cameras at a time, enabling a lower-end system processor or up to four CTR-1475 modules to be used in a single system (supporting up to 16 cameras). Because of its compact size and rugged design, the board is especially suited for live video surveillance applications where rugged environmental conditions (vibration/extreme temperatures) and space constraints exist (i.e. in transportation, industrial and defence systems).

Featuring 4-channel NTSC/PAL/SECAM video decoders with composite video (CVBS) inputs, this modular MPEG-4 encoder provides dedicated hardware and rate control algorithms to produce a high quality MPEG-4 video stream. It can capture video (from PAL/NTSC cameras, VCR, and other video sources) in any of three modes: up to 30 frames/sec on one camera at full screen; up to 30 frames/sec on two cameras at 1/2 screen; or up to 30 frames/sec on four cameras at 1/4 screen. The board also provides an analog video output channel to perform real-time monitoring of the recording sequence.

EUROTECH
E-MAIL: SALES@EUROTECH.IT
HTTP://WWW.EUROTECH.IT

ETH_CTR-1475_DS121206

CTR-1475 DATASHEET

Specifications

Static Gain Control:
Programmable or automatic static gain control for each CVBS channel

Motion Detection:
Programmable detection windows, motion velocity, motion sensitivity and Blind Camera Detection

Software:
Drivers, Source Code and Demonstration Software (IP Streaming and Capabilities Demo);

Hardware:
Compatible with Linux, Windows XPE/CE

Video Processing:
MPEG-4 (ISO/IEC 14496-2), MPEG-4 SOP @LEVEL3

Audio Processing:

- Supports ISO/IEC 11172-3 MPEG-1 Audio Layer 2
- Supports u-Law PCM and IMA-ADPCM for speech quality 48/44.1/32 Samplings Supported

NTSC Compression Capabilities:
352x240 @ 120fps, 720x480 @ 30fps

PAL Compression Capabilities:
352x288 @ 100fps, 720x576 @ 25 fps

System File Formats:
AVI, MP-4

Video Compression Modes:
Supports I, P, B Frame Compression

Scaling:
Built-in High Quality Scalar (1/2, 1/3, 2/3, 1/4)

Zoom:
Random-position high-quality linear Zoom (2X~4X)

Minimum System Requirement:
586 Class Processor

Bus Connectors:
PCI and ISA buses PC/104-Plus compliant

Potential Applications

Live video surveillance applications in rugged environmental conditions and space constraints (transportation, industrial and defence systems)

Physical Characteristics

Operating Temperature Range:
0°C to +60°C; (Extended range as option)

Storage Temperature:
-40° to +85°C

Power Input:
+5 Vdc

Power Consumption:
7W (typical), 10W (maximum)

Dimensions:
90 x 96 mm (3.550" x 3.775")

Architecture:
PCI Compatible

RoHS:

- RoHS (2002/95/CE) Compliant
- Replacement for CTR-1472

Options

- Conformal Coating
- Extended Operating Temperature Range (-40°C to +85°C)
- Custom Connectors

EuroTecH
Tel. +39 0433 485 411
Fax. +39 0433 485 499
E-mail: sales@eurotech.it
URL: www.eurotech.it

ETH_CTR-1475_DS121206

D.4 PC/104 Power Module

ACS-5151

50 Watt PC/104 Automotive Power Supply Module
Vin = 8 ~ 40VDC

Features

General Features:

Architecture
- PC/104 compliant

Voltage Input:
- VIN=+8 VDC to +40 VDC
- High transient voltage margin (50V 1ms)

Voltage Output:
- +5V, +12V, +3.3VDC

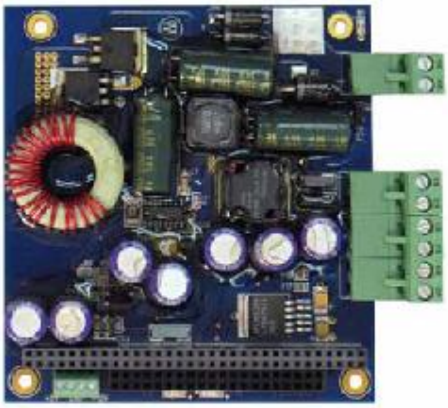
Power Output:
- Up to 50 Watts Combined (+5V@10A, +3.3V@2A, +12V@2A)

Input Protection:
- Reverse over-voltage and load-dump protection
- Input protected with automotive transient voltage suppressor (6600W 10/1000us)
- Suitable for 12 or 24 V battery installations

EMI Input Filter:
- Onboard input filter designed to comply with MIL-STD-461, CE, and EN-55022 class B conducted and radiated emissions

Power Connectors:
- PC/104 Bus
- Screw Clamp Terminal Blocks;
- HDD Terminal Block

RoHS:
- Fully RoHS (2002/95/CE) Compliant
- RoHS replacement for ACS-5150



The ACS-5151 vehicle power supply is designed to meet the system design requirements of vehicle, machine, industrial, and mobile installations. It offers resistance to high levels of shock and vibration and has a rugged mechanical design. All heavy components are glued to the board.

Reverse protection up to -45VDC and short-term tolerance of spikes up to 50V (1ms) make this power supply the ideal choice for battery operated +12V or +24V systems. A dedicated high power automotive voltage suppression circuitry will dissipate up to 6KW of transient energy (10/1000us waveform) meeting the ISO7637-2 surge specification. The onboard input filter and protection circuitry is designed to meet the requirements of the EC low voltage directives for CE compliance EN55022-B and EN61000 and MIL-STD-461 for radiated and conducted emissions. Emissions are reduced by optimal layout, as well as EMI filtering of all the board outputs including the power applied into the PC/104 computer bus.

The output voltages are supplied into the PC/104 bus as well as can be accessed from the terminal blocks on the board. The +3.3V output can be used to power other low voltage peripheral devices in the system such as LCD panels, GPS receivers or wireless communication devices. LEDs indicate the status of the +5V and +12V power outputs.

EUROTECH

ACS-5151

Applications

- High Reliability Systems
- Vehicle and mobile computers
- Industrial controllers
- Ship and airborne systems

About Eurotech

Eurotech delivers embedded computer systems for high capability and low power applications, networking and wearable computing solutions, and application framework middleware for multimedia, industrial, transportation, medical, and wireless applications. Eurotech platforms allow OEM and enterprise customers to focus on their core revenue-generating products and services and get to market quickly.

Specifications

EFFICIENCY	88% typical on 5V (at full load)
MTBF Calculated per: MIL-HDBK-217F @ 40°C	• 997079 hours (GB, Controlled) • 157971 hours (Airborne Inhabit Fighter)
DIMENSIONS	90 x 96 mm (3.6" x 3.8")
OPERATING TEMPERATURE	-40 ~ +85°C (-40 ~ +185°F)

ETH_ACS-5151_DS181108

Americas

EUROTECH Inc
e-mail: sales-us@eurotech.com
tel: +1 301.490.4007
toll free: +1 888.941.2224

Western Europe

EUROTECH UK
e-mail: sales-uk@eurotech.com
tel: +44 (0) 1223 403.410

EUROTECH France
e-mail: sales-fr@eurotech.com
tel: +33 04.72.89.00.90

Central & Southern Europe

EUROTECH Italy
e-mail: sales-it@eurotech.com
tel: +39 0433.485.411

Northern & Eastern Europe

EUROTECH Finland
e-mail: sales-fi@eurotech.com
tel: +358 9.477.888.0

www.eurotech.com

D.5 Cameras

SONY

B/W Video Camera Module
XC-E Series

The XC-E Series are compact, light-weight one-piece black and white cameras incorporating the latest 1/2 and 1/3 type Interline (IT) CCD which produces new levels of picture detail. With dimensions of 29 x 29 x 30 mm*, these cameras can easily be installed in places where installation was previously difficult for other larger cameras.

The XC-E Series offer three different model ranges that only differ in spectral sensitivity as to suit various application environments. The XC-ES Series (XC-ES50/ES50CE, XC-ES50L/ES50LCE, XC-ES51/ES51CE and XC-ES30/ES30CE) are standard models for general use under visible light conditions. The XC-EI Series (XC-EI50/EI50CE and XC-EI30/EI30CE) offer excellent near-infrared sensitivity. Under low light conditions or when used with IR LED illumination systems, these cameras provide clear images. The XC-EU Series (XC-EU50/EU50CE) offer near-ultraviolet sensitivity in the i-line, or 365 nm, range. The short wavelength allows the XC-EU Series to capture very fine detail. All models have identical dimensions and controls, making them easy to interchange. A variety of settings are available for differing subject and lighting conditions. All camera control switches are accessible from the outside of the camera. Excellent vibration and shock characteristics make these cameras ideal for demanding machine vision applications.

* The XC-ES50L/ES50LCE, which are L-type versions of the XC-ES50/ES50CE, measure 29 (W) x 42.5 (H) x 43.8 (D) mm.

Features

- XC-ES50/ES50CE/ES50L/ES50LCE/ES51/ES51CE/EI50/EI50CE/EU50/EU50CE: 1/2 type IT CCD
- XC-ES30/ES30CE/EI30/EI30CE: 1/3 type IT CCD
- Compact and light weight: 29 (W) x 29 (H) x 30 (D) mm, 50 g except for XC-ES50L/ES50LCE:
  29 (W) x 42.5 (H) x 43.8 (D) mm, 110 g
- Near-infrared sensitivity: XC-EI50/EI50CE, XC-EI30/EI30CE
- Near-ultraviolet sensitivity: XC-EU50/EU50CE
- Minimum illumination at F1.4:
  0.3 lx: XC-ES50/ES50CE/ES30/ES30CE
  3.0 lx: XC-ES50L/ES50LCE
  0.1 lx: XC-EI50/EI50CE
  0.2 lx: XC-ES51/ES51CE/EI30/EI30CE
- High S/N Ratio: 60 dB
- Electronic shutter function:
  1/100 to 1/10,000 s: EIA, 1/120 to 1/10,000 s: CCIR
- Flexible trigger shutter function
- Scanning system: 2:1 interlaced
- Frame/field exposure
- Restart/reset function
- Synchronization: internal/external (HD/VD)
- High shock and vibration tolerance
- Lead-free products

Standard model

XC-ES50/ES50CE
XC-ES50L/ES50LCE
XC-ES51/ES51CE
XC-ES30/ES30CE

Applicable wavelength range
400-770 nm

Near IR model

XC-EI50/EI50CE
XC-EI30/EI30CE

Applicable wavelength range
400-770 nm

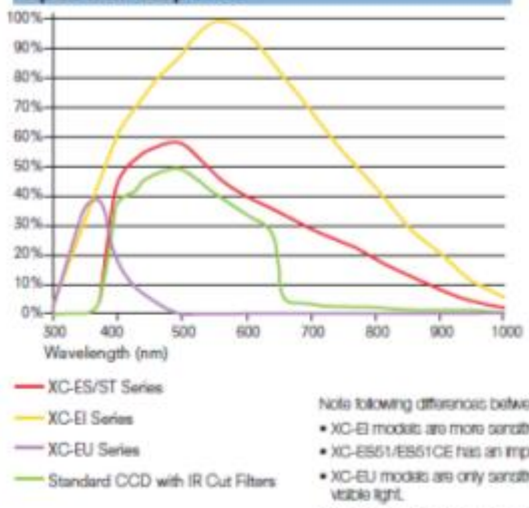
UV model

XC-EU50/EU50CE

Applicable wavelength range
300-420 nm

The XC-EU50/EU50CE models are compact and light-weight cameras that have near-ultraviolet sensitivity in the i-line, or 365 nm, range. Examples of typical application areas are PCB and solder inspection, document proofing, microscopy, medical and cosmetics applications. Using UV lighting, the short wavelength allows the XC-EU50/EU50CE models to capture clearly very fine detail and surface structures, which cannot be detected using visible or IR lighting, including very small scratches, dust or blemishes, as well as special fluorescent materials.

Spectral response



Accessories

Compact camera adaptor
DC-700/700CE
- Compact, lightweight (700 g, 1 lb 8 oz)
- External sync IN/OUT
- Trigger input / WEN output
- New EIAJ standard 12 pin connector
- Dimensions: 110 (W) x 53 (H) x 160 (D) mm (4 3/8 x 2 1/8 x 6 3/8 inches)

12 pin camera cable (CE standard)
- CCXC-12P02N (2 m)
- CCXC-12P05N (5 m)
- CCXC-12P10N (10 m)
- CCXC-12P25N (25 m)

Tripod adaptor
VCT-333I
- ABS
- Approx. 6.1 g (0.2 oz)
- Dimensions: 18 (W) x 6 (H) x 27 (D) mm (23/32 x 1/4 x 1/8 inches)

Note following differences between models:
- XC-EI models are more sensitive than XC-ES models, not only in near-IR range but in visible range as well.
- XC-ES51/ES51CE has an improved sensitivity over XC-ES50/ES50CE.
- XC-EU models are only sensitive in near-UV range and are not susceptable to disturbance from surrounding visible light.
- XC-ES50L/ES50LCE include an IR Cut Filter.

XC-E Series Specifications

	XC-ES50	XC-ES50L	XC-ES51	XC-ES30	XC-EI50	XC-EI30	XC-EU50
Image device	1/2 type IT CCD			1/3 type IT CCD	1/2 type IT CCD	1/3 type IT CCD	1/2 type IT CCD
Effective picture elements	768 (H) x 494 (V)						
Signal system	EIA (standard)						
Horizontal frequency	15.734 kHz						
Vertical frequency	59.94 Hz						
Cell size (µm)	8.4 x 9.8			6.35 x 7.4	8.4 x 9.8	6.35 x 7.4	8.4 x 9.8
Lens mount	C mount						
Flange back	17.526 mm						
Sync system	Internal/External (auto)						
External sync system	HD/VD (2 to 5 Vp-p)						
External sync frequency	± 1 %						
Jitter Less than	± 50 nsec						
Scanning system	2:1 Interlaced						
Video output	1.0 Vp-p, negative, 75 Ω unbalanced						
Horizontal resolution	570 TV lines						
Sensitivity (Gamma ON, MIN GAIN, No IR cut filter)	400 lx F5.6	400 lx F4	400 lx F8	400 lx F4	400 lx F11	400 lx F8	–
Minimum illumination*	0.3 lx	3.0 lx	0.2 lx	0.3 lx	0.1 lx	0.2 lx	–
S/N ratio	60 dB						
Gain	AGC/Manual selectable						
Gamma	ON/OFF selectable						
Normal shutter	1/100 to 1/10,000 s						
External trigger shutter**	1/4 to 1/10,000 s						
Power requirements	DC 12 V (+9 to +16 V)						
Power consumption	1.6 W			1.4 W	1.6 W	1.4 W	1.6 W
Dimension (W) x (H) x (D)	29 x 29 x 30 mm	29 x 42.5 x 43.8 mm	29 x 29 x 30 mm				
Mass	50 g (2 oz)	110 g (4 oz)	50 g (2 oz)				
Operating temperature	-5 to +45 °C (23 to 104 °F)						
Operating humidity	20 to 80 %						
Storage temperature	-30 to +60 °C (-22 to +140 °F)						
Storage humidity	20 to 95 %						
Vibration resistance	10 G (20 to 200 Hz)						
Shock resistance	70 G						
MTBF	126,000 hrs.						
Regulatory compliance	UL1492, FCC Class B Digital Device, CE (EN61326/97 + A1/98), AS4251.1 + AS4252.2						
Supplied accessories	Lens mount cap (1), Operating instructions (1)						

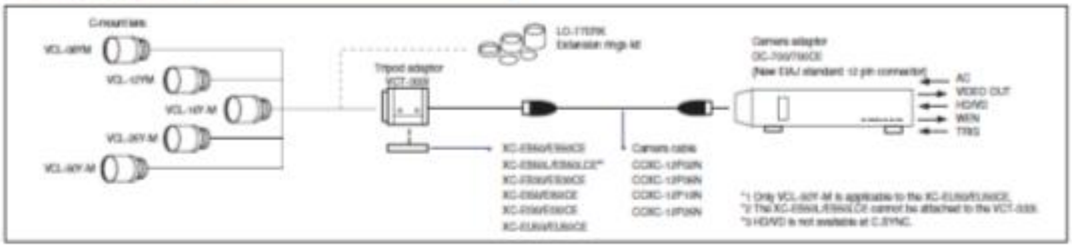
* (F1.4, AGC ON, without IR cut filter) ** Using Dip switch on the rear panel or Using trigger pulse width

	XC-ES50CE	XC-ES50LCE	XC-ES51CE	XC-ES30CE	XC-EI50CE	XC-EI30CE	XC-EU50CE
Image device	1/2 type IT CCD			1/3 type IT CCD	1/2 type IT CCD	1/3 type IT CCD	1/2 type IT CCD
Effective picture elements	752 (H) x 582 (V)						
Signal system	CCIR (standard)						
Horizontal frequency	15.625 kHz						
Vertical frequency	50 Hz						
Cell size (µm)	8.6 x 8.3			6.5 x 6.25	8.6 x 8.3	6.5 x 6.25	8.6 x 8.3
Lens mount	C mount						
Flange back	17.526 mm						
Sync system	Internal/External (auto)						
External sync system	HD/VD (2 to 5 Vp-p)						
External sync frequency	± 1 %						
Jitter Less than	± 50 nsec						
Scanning system	2:1 Interlaced						
Video output	1.0 Vp-p, negative, 75 Ω unbalanced						
Horizontal resolution	560 TV lines						
Sensitivity (Gamma ON, MIN GAIN, No IR cut filter)	400 lx F5.6	400 lx F4	400 lx F8	400 lx F4	400 lx F11	400 lx F8	–
Minimum illumination*	0.3 lx	3.0 lx	0.2 lx	0.3 lx	0.1 lx	0.2 lx	–
S/N ratio	60 dB						
Gain	AGC/Manual selectable						
Gamma	ON/OFF selectable						
Normal shutter	1/120 to 1/10,000 s						
External trigger shutter**	1/4 to 1/8,000 s						
Power requirements	DC 12 V (+9 to +16 V)						
Power consumption	1.6 W			1.4 W	1.6 W	1.4 W	1.6 W
Dimension (W) x (H) x (D)	29 x 29 x 30 mm	29 x 42.5 x 43.8 mm	29 x 29 x 30 mm				
Mass	50 g (2 oz)	110 g (4 oz)	50 g (2 oz)				
Operating temperature	-5 to +45 °C (23 to 104 °F)						
Operating humidity	20 to 80 %						
Storage temperature	-30 to +60 °C (-22 to +140 °F)						
Storage humidity	20 to 95 %						
Vibration resistance	10 G (20 to 200 Hz)						
Shock resistance	70 G						
MTBF	126,000 hrs.						
Regulatory compliance	UL1492, FCC Class B Digital Device, CE (EN61326/97 + A1/98), AS4251.1 + AS4252.2						
Supplied accessories	Lens mount cap (1), Operating instructions (1)						

* (F1.4, AGC ON, without IR cut filter) ** Using Dip switch on the rear panel or Using trigger pulse width

XC-E Series

Connection Diagram



Dimensions & Rear Panel

XC-ES50/ES50CE/ES51/ES51CE/ES30/ES30CE
XC-EI50/EI50CE/EI30/EI30CE/EU50/EU50CE

Unit: mm

XC-ES50L/ES50LCE

Factory setting mode of rear panel

No.	Switch name		Factory setting mode
①	Shutter speed/Mode setting DIP switch	Dip switch 1-4: Shutter speed	OFF
		Dip switch 5: FRAME/FIELD	FRAME
		Dip switch 6-8: External trigger shutter mode, restart/reset mode	Normal
		Dip switch 9: Gamma ON/OFF	OFF
		Dip switch 0: GAIN	Manual
②	Manual GAIN (M GAIN) control knob		Twelve o'clock position
③	HD/VD signal input/output switch		EXT
④	75 Ω termination switch		ON

12-pin multi-connector

Pin No.	External sync (HD/VD)	Internal sync (HD/VD)
[illegible]	GND	GND
[illegible]	+12 V	+12 V
[illegible]	GND	GND
[illegible]	VIDEO output	VIDEO output
[illegible]	GND	GND
[illegible]	External HD input	Internal HD output
[illegible]	External VD input*	Internal VD output
[illegible]	GND	GND
[illegible]	-	-
[illegible]	WEN output*	WEN output*
[illegible]	TRIG input	TRIG input
[illegible]	GND	GND

*1 HD/VD input is required when using restart, reset mode.
*2 WEN output works only when in external trigger shutter mode.

Sony Contacts

[illegible]

D.6 Probe LEDs

THORLABS LED661L

Part 1. Introduction: LED661L Ultra Bright Red LED

The LED661L emits light with a spectral output centered at 655 nm. This LED is composed of heterostructures (HS) grown on an AlGaAs substrate. The diode is packaged in a TO-18 stem and hermetically sealed with a glass ball lens.

Part 2. Specifications for an LED661L

2.1. *Electrical Specifications*

	Typical	Maximum Ratings
Power Dissipation		120 mW
Reverse Voltage		5.0 V
DC Forward Current		50 mA
Forward Voltage @ 20 mA	1.9 V	2.2 V
Pulsed Current (1 ms pulse with 10% duty cycle)		75 mA
Operating Temperature		-30 °C to 85 °C
Storage temperature Range		-30 °C to 100 °C

Note: All maximum measurements specified are at 25 °C.

2.2. *Optical Specifications*

	Typical
Center Wavelength	655 nm ±10 nm
FWHM	20 nm
Half Viewing Angle	6°
Total Optical Power	1.7 mW @ 20mA

2.3. *Soldering Specifications*

	Conditions
Manual Soldering	295 °C ± 5 °C , for less than 3 seconds
Wave Soldering	260 °C ± 5 °C , for less than 5 seconds
Reflow Soldering	**Preheating:** 70 °C to 80 °C , for 30 seconds **Soldering:** 245 °C ± 5 °C , for less than 5 seconds

2.4. *Cleaning Solvents*

Solvent	Ethyl Alcohol	Isopropyl Alcohol	Propanol	Acetone	Chloroseen	Tricloroethylene	MKS
Approved	Yes	Yes	Yes	No	No	No	No

THORLABS LED661L

2.5. Physical Specifications

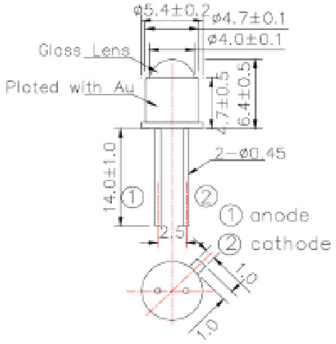
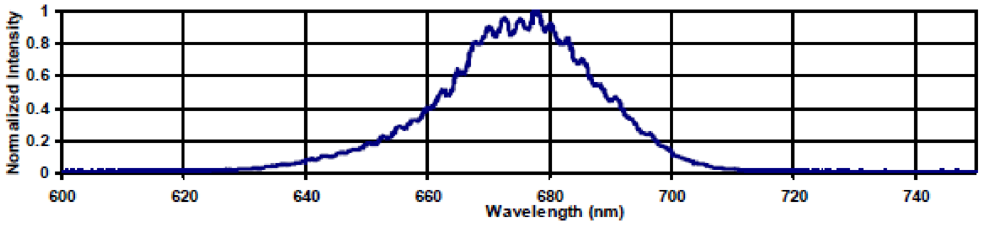
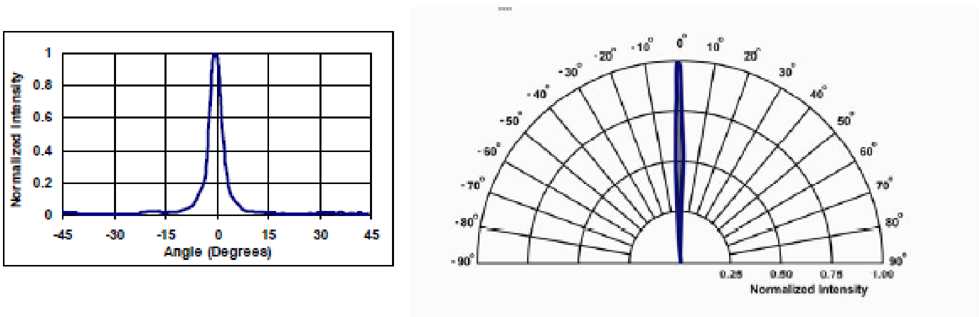


Figure 1: LED661L. All dimensions in mm.

2.6. Typical Spectral Intensity Distribution



2.7. Typical Radial Intensity Distribution



D.7 Accelerometer

ANALOG DEVICES

3-Axis, ±2 *g*/±4 *g*/±8 *g*/±16 *g* Digital Accelerometer

ADXL345

FEATURES

Ultralow power: as low as 40 µA in measurement mode and 0.1 µA in standby mode at V_S = 2.5 V (typical)
Power consumption scales automatically with bandwidth
User-selectable resolution
- **Fixed 10-bit resolution**
- **Full resolution, where resolution increases with *g* range, up to 13-bit resolution at ±16 *g* (maintaining 4 m*g*/LSB scale factor in all *g* ranges)**

Embedded, patent pending FIFO technology minimizes host processor load
Tap/double tap detection
Activity/inactivity monitoring
Free-fall detection
Supply voltage range: 2.0 V to 3.6 V
I/O voltage range: 1.7 V to V_S
SPI (3- and 4-wire) and I²C digital interfaces
Flexible interrupt modes mappable to either interrupt pin
Measurement ranges selectable via serial command
Bandwidth selectable via serial command
Wide temperature range (−40°C to +85°C)
10,000 *g* shock survival
Pb free/RoHS compliant
Small and thin: 3 mm × 5 mm × 1 mm LGA package

APPLICATIONS

Handsets
Medical instrumentation
Gaming and pointing devices
Industrial instrumentation
Personal navigation devices
Hard disk drive (HDD) protection
Fitness equipment

GENERAL DESCRIPTION

The ADXL345 is a small, thin, low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I²C digital interface.

The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (4 mg/LSB) enables measurement of inclination changes less than 1.0°.

Several special sensing functions are provided. Activity and inactivity sensing detect the presence or lack of motion and if the acceleration on any axis exceeds a user-set level. Tap sensing detects single and double taps. Free-fall sensing detects if the device is falling. These functions can be mapped to one of two interrupt output pins. An integrated, patent pending 32-level first in, first out (FIFO) buffer can be used to store data to minimize host processor intervention.

Low power modes enable intelligent motion-based power management with threshold sensing and active acceleration measurement at extremely low power dissipation.

The ADXL345 is supplied in a small, thin, 3 mm × 5 mm × 1 mm, 14-lead, plastic package.

FUNCTIONAL BLOCK DIAGRAM

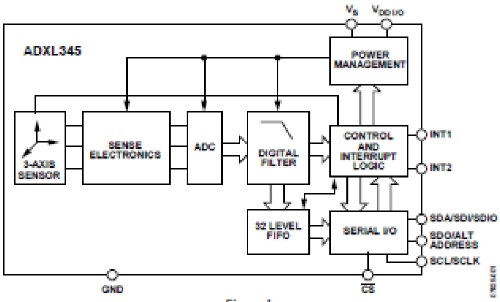


Figure 1.

Rev. 0

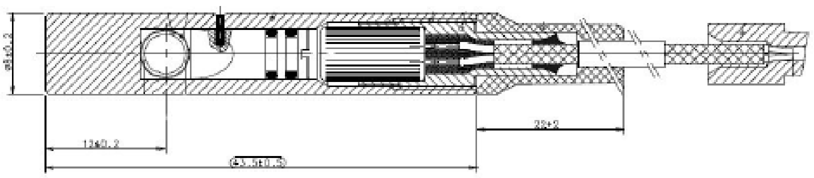
One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113

D.8 Cypress Cutters

Technical Data
for the CYPRES Cutter

Shielding	≤	0,5	Ohm
Insulating resistance white	>	20	MOhm
Insulating resistance black	>	20	MOhm
Internal resistance		1,10 – 1,80	Ohm
No fire		0,18 A / 10 s	
Fire		0,85 A / 15 ms	

Lifetime is 12.5 years (un-activated)
One-time use device
The plug and socket connector, which is in the cutter cable is a propriety waterproof system that was developed for use with the CYPRES.
For non-CYPRES use, we can supply with or without the plug.



Airtec GmbH & Co. KG
Mittelstr. 69
33181 Bad Wünnenberg
Germany

March, 2010

D.9 ATmega328 Microcontroller

Features

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 4/8/16/32K Bytes of In-System Self-Programmable Flash progam memory (ATmega48PA/88PA/168PA/328P)
  - 256/512/512/1K Bytes EEPROM (ATmega48PA/88PA/168PA/328P)
  - 512/1K/1K/2K Bytes Internal SRAM (ATmega48PA/88PA/168PA/328P)
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
    Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips I^{2}C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.8 - 5.5V for ATmega48PA/88PA/168PA/328P
- Temperature Range:
  - -40°C to 85°C
- Speed Grade:
  - 0 - 20 MHz @ 1.8 - 5.5V
- Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega48PA/88PA/168PA/328P:
  - Active Mode: 0.2 mA
  - Power-down Mode: 0.1 µA
  - Power-save Mode: 0.75 µA (Including 32 kHz RTC)

8-bit AVR® Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash

ATmega48PA
ATmega88PA
ATmega168PA
ATmega328P

Rev. 8161D–AVR–10/09

D.10 MAX233 Line Driver

+5V-Powered, Multichannel RS-232 Drivers/Receivers

MAX220–MAX249

ABSOLUTE MAXIMUM RATINGS—MAX223/MAX230–MAX241

V_{CC} ....-0.3V to +6V
V+ ....(V_{CC} - 0.3V) to +14V
V- ....+0.3V to -14V
Input Voltages
T_{IN} ....-0.3V to (V_{CC} + 0.3V)
R_{IN} ....±30V
Output Voltages
T_{OUT} ....(V+ + 0.3V) to (V- - 0.3V)
R_{OUT} ....-0.3V to (V_{CC} + 0.3V)
Short-Circuit Duration, T_{OUT} ....Continuous
Continuous Power Dissipation (T_A = +70°C)
14-Pin Plastic DIP (derate 10.00mW/°C above +70°C)....800mW
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)....842mW
20-Pin Plastic DIP (derate 11.11mW/°C above +70°C)....889mW
24-Pin Narrow Plastic DIP
(derate 13.33mW/°C above +70°C) 1.07W
24-Pin Plastic DIP (derate 9.09mW/°C above +70°C)......500mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C).........762mW
20-Pin Wide SO (derate 10 00mW/°C above +70°C).......800mW
24-Pin Wide SO (derate 11.76mW/°C above +70°C).......941mW
28-Pin Wide SO (derate 12.50mW/°C above +70°C) 1W
44-Pin Plastic FP (derate 11.11mW/°C above +70°C) 889mW
14-Pin CERDIP (derate 9.09mW/°C above +70°C)..........727mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C)........800mW
20-Pin CERDIP (derate 11.11mW/°C above +70°C) 889mW
24-Pin Narrow CERDIP
(derate 12.50mW/°C above +70°C) 1W
24-Pin Sidebraze (derate 20.0mW/°C above +70°C)..........1.6W
28-Pin SSOP (derate 9.52mW/°C above +70°C).............762mW
Operating Temperature Ranges
MAX2 _ _ C _ _....................0°C to +70°C
MAX2 _ _ E _ _....................-40°C to +85°C
MAX2 _ _ M _ _ ....-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX223/MAX230–MAX241

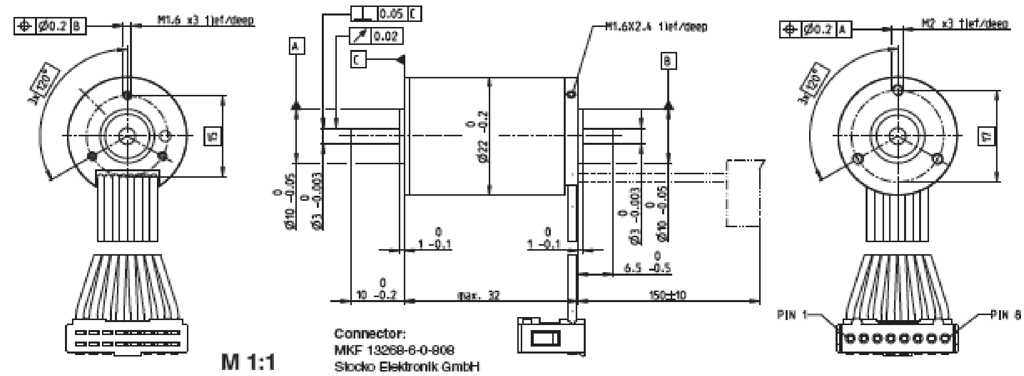
(MAX223/230/232/234/236/237/238/240/241, V_{CC} = +5V ±10; MAX233/MAX235, V_{CC} = 5V ±5%, C1–C4 = 1.0µF; MAX231/MAX239, V_{CC} = 5V ±10%; V+ = 7.5V to 13.2V; T_A = T_{MIN} to T_{MAX}; unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to ground		±5.0	±7.3		V
V_{CC} Power-Supply Current	No load, T_A = +25°C	MAX232/233		5	10	mA
		MAX223/230/234–238/240/241		7	15	
		MAX231/239		0.4	1	
V+ Power-Supply Current		MAX231		1.8	5	mA
		MAX239		5	15	
Shutdown Supply Current	T_A = +25°C	MAX223		15	50	µA
		MAX230/235/236/240/241		1	10	
Input Logic Threshold Low	T_{IN}; EN, $\overline{SHDN}$ (MAX233); $\overline{EN}$, SHDN (MAX230/235–241)				0.8	V
Input Logic Threshold High	T_{IN}		2.0			V
	EN, $\overline{SHDN}$ (MAX223); $\overline{EN}$, SHDN (MAX230/235/236/240/241)		2.4			
Logic Pull-Up Current	T_{IN} = 0V			1.5	200	µA
Receiver Input Voltage Operating Range			-30		30	V

D.11 EC Motor

maxon *EC*-max

EC-max 22 ∅22 mm, brushless, 12 Watt



- Stock program
- Standard program
- Special program (on request)

Order Number		283837	283838	283839	283840	283841
Motor Data						
Values at nominal voltage						
1 Nominal voltage	V	6.0	12.0	18.0	24.0	36.0
2 No load speed	rpm	11400	12100	12100	12100	12100
3 No load current	mA	282	155	103.0	77.3	51.6
4 Nominal speed	rpm	7300	8060	8260	8260	8210
5 Nominal torque (max. continuous torque)	mNm	10.4	10.1	10.9	10.8	10.6
6 Nominal current (max. continuous current)	A	2.37	1.25	0.878	0.657	0.432
7 Stall torque	mNm	30	31.3	35.4	35.1	34.1
8 Starting current	A	6.23	3.47	2.60	1.94	1.25
9 Max. efficiency	%	63	63	65	65	65
Characteristics						
10 Terminal resistance phase to phase	Ω	0.963	3.46	6.93	12.4	28.7
11 Terminal inductance phase to phase	mH	0.0343	0.121	0.275	0.488	1.09
12 Torque constant	mNm / A	4.81	9.02	13.6	18.1	27.2
13 Speed constant	rpm / V	1990	1060	701	526	352
14 Speed / torque gradient	rpm / mNm	397	406	356	360	371
15 Mechanical time constant	ms	9.36	9.56	8.39	8.47	8.75
16 Rotor inertia	gcm²	2.25	2.25	2.25	2.25	2.25

Specifications

	Thermal data	
17	Thermal resistance housing-ambient	13.5 K / W
18	Thermal resistance winding-housing	1.72 K / W
19	Thermal time constant winding	1.82 s
20	Thermal time constant motor	567 s
21	Ambient temperature	-40 ... +100°C
22	Max. permissible winding temperature	+155°C
	Mechanical data (preloaded ball bearings)	
23	Max. permissible speed	18000 rpm
24	Axial play at axial load < 5.0 N	0 mm
	> 5.0 N	14 mm
25	Radial play	preloaded
26	Max. axial load (dynamic)	4.5 N
27	Max. force for press fits (static)	53 N
	(static, shaft supported)	1400 N
28	Max. radial loading, 5 mm from flange	16 N
	Other specifications	
29	Number of pole pairs	1
30	Number of phases	3
31	Weight of motor	83 g

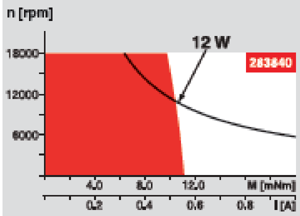
Values listed in the table are nominal.

Connection (Cable AWG 24)

brown	Motor winding 1	Pin 1
red	Motor winding 2	Pin 2
orange	Motor winding 3	Pin 3
yellow	V_{Hall} 3 ... 24 VDC	Pin 4
green	GND	Pin 5
blue	Hall sensor 1	Pin 6
violet	Hall sensor 2	Pin 7
grey	Hall sensor 3	Pin 8

Wiring diagram for Hall sensors see p. 27

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

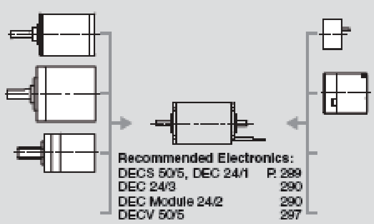
Assigned power rating

maxon Modular System Overview on page 16 - 21

Planetary Gearhead
∅22 mm
0.5 - 3.4 Nm
Page 223 / 224

Koaxdrive
∅32 mm
1.0 - 4.5 Nm
Page 235

Spindle Drive
∅22 mm
Page 247 / 248



Encoder MR
128 / 256 / 512 CPT,
2 / 3 channels
Page 261

Brake AB 20
24 VDC
0.1 Nm
Page 316

Recommended Electronics:

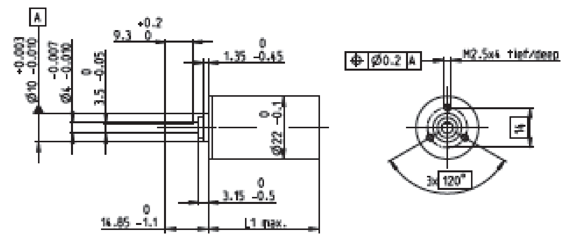
DECS 50/5, DEC 24/1	P. 289
DEC 24/3	290
DEC Module 24/2	290
DECV 50/5	297
DES 50/5	298
EPOS2 Module 36/2	304
EPOS2 24/1	304
EPOS2 24/5, EPOS2 50/5	305
EPOS2 P 24/5	308
Notes	20

164 maxon EC motor

May 2011 edition / subject to change

D.12 Planetary Gearbox (690:1)

Planetary Gearhead GP 22 C ∅22 mm, 0.5 - 2.0 Nm
Ceramic Version



M 1:2

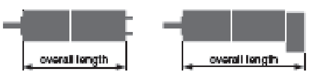
Technical Data	
Planetary Gearhead	straight teeth
Output shaft	stainless steel, hardened
Bearing at output	ball bearing
Radial play, 10 mm from flange	max. 0.2 mm
Axial play	max. 0.2 mm
Max. radial load, 10 mm from flange	70 N
Max. permissible axial load	100 N
Max. permissible force for press fits	100 N
Sense of rotation, drive to output	=
Recommended input speed	< 8000 rpm
Recommended temperature range	-40 ... +100°C

maxon gear

Stock program
Standard program
Special program (on request)

Order Number												
		143971	143974	143980	143986	143990	143996	144002	144004	144011	144017	144023
Gearhead Data												
1 Reduction		3.8 : 1	14 : 1	53 : 1	104 : 1	198 : 1	370 : 1	590 : 1	742 : 1	1386 : 1	1996 : 1	3189 : 1
2 Reduction absolute		15/4	225/16	3375/64	87723/845	50625/256	10556001/28561	59049/100	759375/1024	[illegible]	[illegible]	[illegible]
3 Max. motor shaft diameter	mm	4	4	4	3.2	4	3.2	4	4	3.2	3.2	4
Order Number		143972	143975	143981	143987	143991	143997	144003	144006	144012	144018	144024
1 Reduction		4.4 :1	16 : 1	62 : 1	109 : 1	231 : 1	389 : 1	690 : 1	867 : 1	1460 : 1	2102 : 1	3728 : 1
2 Reduction absolute		57/13	855/52	12825/208	2187/20	192375/832	263169/676	1121931/1625	[illegible]	[illegible]	[illegible]	[illegible]
3 Max. motor shaft diameter	mm	3.2	3.2	3.2	4	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Order Number		143973	143976	143982	143988	143992	143998	144005	144007	144013	144019	144025
1 Reduction		5.4 : 1	19 : 1	72 : 1	128 : 1	270 : 1	410 : 1	850 : 1	1014 : 1	1538 : 1	2214 : 1	4592 : 1
2 Reduction absolute		27/5	3249/169	48735/676	41553/325	731025/2704	6561/16	531441/625	[illegible]	[illegible]	177147/80	[illegible]
3 Max. motor shaft diameter	mm	2.5	3.2	3.2	3.2	3.2	4	2.5	3.2	4	4	2.5
Order Number			143977	143983	143989	143993	143999		144008	144014	144020	
1 Reduction			20 : 1	76 : 1	157 : 1	295 : 1	455 : 1		1068 : 1	1621 : 1	2458 : 1	
2 Reduction absolute			81/4	1215/16	19683/125	18225/64	[illegible]		273375/256	[illegible]	[illegible]	
3 Max. motor shaft diameter	mm		4	4	2.5	4	3.2		4	3.2	3.2	
Order Number			143978	143984		143994	144000		144009	144015	144021	
1 Reduction			24 : 1	84 : 1		316 : 1	479 : 1		1185 : 1	1707 : 1	2589 : 1	
2 Reduction absolute			[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
3 Max. motor shaft diameter	mm		3.2	3.2		3.2	3.2		3.2	3.2	3.2	
Order Number			143979	143985		143995	144001		144010	144016	144022	
1 Reduction			29 : 1	89 : 1		333 : 1	561 : 1		1249 : 1	1798 : 1	3027 : 1	
2 Reduction absolute			729/25	4617/52		69255/208	[illegible]		[illegible]	[illegible]	[illegible]	
3 Max. motor shaft diameter	mm		2.5	3.2		3.2	3.2		3.2	3.2	3.2	
4 Number of stages		1	2	3	3	4	4	4	5	5	5	5
5 Max. continuous torque	Nm	0.5	0.6	1.2	1.2	1.8	1.8	1.8	2.0	2.0	2.0	2.0
6 Intermittently permissible torque at gear output	Nm	0.8	0.9	1.9	1.9	2.7	2.7	2.7	3.0	3.0	3.0	3.0
7 Max. efficiency	%	84	70	59	59	49	49	49	42	42	42	42
8 Weight	g	42	55	68	68	81	81	81	94	94	94	94
9 Average backlash no load	°	1.0	1.2	1.6	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10 Mass inertia	gcm²	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
11 Gearhead length L1*	mm	25.4	32.2	39.0	39.0	45.8	45.8	45.8	52.6	52.6	52.6	52.6

*for EC-max 16 L1 is - 2.8 mm



maxon Modular System														
+ Motor	Page	+ Sensor / Brake	Page	Overall length [mm] = Motor length + gearhead length + (sensor / brake) + assembly parts										
EC 16, 60 W	147			81.5	88.3	95.1	95.1	101.9	101.9	101.9	108.7	108.7	108.7	108.7
EC 16, 60 W	147	MR	261	92.2	99.0	105.8	105.8	112.6	112.6	112.6	119.4	119.4	119.4	119.4
EC 22, 40 W	149			70.0	76.8	83.6	83.6	90.4	90.4	90.4	97.2	97.2	97.2	97.2
EC 22, 40 W	149	MR	261	76.0	82.8	89.6	89.6	96.4	96.4	96.4	103.2	103.2	103.2	103.2
EC 22, 100 W	151			88.2	95.0	101.8	101.8	108.6	108.6	108.6	115.4	115.4	115.4	115.4
EC 22, 100 W	151	MR	261	94.2	101.0	107.8	107.8	114.6	114.6	114.6	121.4	121.4	121.4	121.4
EC-max 16, 8 W	163			58.7	65.5	72.3	72.3	79.1	79.1	79.1	85.9	85.9	85.9	85.9
EC-max 16, 8 W	163	MR	261	66.0	72.8	79.6	79.6	86.4	86.4	86.4	93.2	93.2	93.2	93.2
EC-max 22, 12 W	164			57.5	64.3	71.1	71.1	77.9	77.9	77.9	84.7	84.7	84.7	84.7
EC-max 22, 12 W	164	MR	261	67.2	74.0	80.8	80.8	87.6	87.6	87.6	94.4	94.4	94.4	94.4
EC-max 22, 12 W	164	AB 20	316	93.1	99.9	106.7	106.7	113.5	113.5	113.5	120.3	120.3	120.3	120.3
EC 20 flat, 3 W, A	183			33.1	39.9	46.7	46.7	53.5	53.5	53.5	60.3	60.3	60.3	60.3
EC 20 flat, 3 W, B	183			32.5	39.3	46.1	46.1	52.9	52.9	52.9	59.7	59.7	59.7	59.7
EC 20 flat, 5 W	184			36.7	43.5	50.3	50.3	57.1	57.1	57.1	63.9	63.9	63.9	63.9
EC 20 flat, IE, IP 00	185			39.7	46.5	53.3	53.3	60.1	60.1	60.1	66.9	66.9	66.9	66.9
EC 20 flat, IE, IP 40	185			40.8	47.6	54.4	54.4	61.2	61.2	61.2	68.0	68.0	68.0	68.0
EC 20 flat, IE, IP 00	186			43.7	50.5	57.3	57.3	64.1	64.1	64.1	70.9	70.9	70.9	70.9
EC 20 flat, IE, IP 40	186			44.8	51.6	58.4	58.4	65.2	65.2	65.2	72.0	72.0	72.0	72.0
EC 32 flat, 6 W	187			39.8	46.6	53.4	53.4	60.2	60.2	60.2	67.0	67.0	67.0	67.0

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maxon gear 223

D.13 Motor Controller

2 Technical Data

2.1 Electrical data

Nominal supply voltage $+V_{CC}$ .... 8 … 24 VDC (optional 5 VDC[1])
Absolute minimum supply voltage $+V_{cc\ min}$ .... 8 VDC (optional 5 VDC[1])
Absolute maximum supply voltage $+V_{cc\ max}$ .... 28 VDC
Max. output voltage .... $+V_{CC}$
Continuous output current I_{cont} .... 2 A
Max. output current I_{max} .... 3 A
Switching frequency .... 46.8 kHz
Max. speed (motor with 1 pole pair) .... 80 000 rpm

2.2 Inputs

«Set value speed» .... Analogue input (0 ... 5 V); Resolution: 1024 steps
«Enable» .... +2.4 … +28 V (R_i = 100 kΩ) or switch against V_{CC}
«Direction» .... +2.4 … +28 V (R_i = 100 kΩ) or switch against V_{CC}
Speed range «DigIN1 » .... +2.4 … +28 V ($R_{pull-up}$ = 15 kΩ at 5 V) or switch against Gnd
Speed range «DigIN2 » .... +2.4 … +28 V ($R_{pull-up}$ = 15 kΩ at 5 V) or switch against Gnd
«Set current limit» .... external resistor ($^1/_{16}$ W) against Gnd
Hall sensors .... «Hall sensor 1», «Hall sensor 2», «Hall sensor 3»

2.3 Output

Status indication «Ready» .... Digital output signal, 5 V (R_i = 10 kΩ)

2.4 Voltage output

+5 VDC output voltage «V_{CC} Hall» .... +5 VDC, max. 35 mA

2.5 Motor connections

Motor connections .... «Motor winding 1», « Motor winding 2», « Motor winding 3»

2.6 Ambient temperature

Operation .... -10 ... +45°C
Storage .... -40 ... +85°C

2.7 Humidity range

Non condensating .... 20 ... 80 %

2.8 Protective functions

Current limitation (cycle-by-cycle) .... adjustable up to maximum 3 A
Blockage .... Motor current limitation if motor shaft is blocked for longer than 1.5 s
Undervoltage shutdown .... shutdown if V_{CC} < 6.5 VDC
Overvoltage shutdown .... shutdown if V_{CC} > 30 VDC
Thermal overload protection of power stage .... shutdown if $T_{power\ stage}$ > 95°C

2.9 Mechanical data

Weight .... approx. 4 g
Dimensions (LxWxH) .... 24.2 x 20.38 x 12.7 mm
.... 0.95 x 0.8 x 0.5 Inch

2.10 Terminals

Pin header 1 .... 9 poles
.... single row, pitch 2.54 mm (0.1 Inch)
Pin header 2 .... 8 poles
.... single row, pitch 2.54 mm (0.1 Inch)

1 5V operating see chapter «10.8.2 Low Voltage +5V operation»

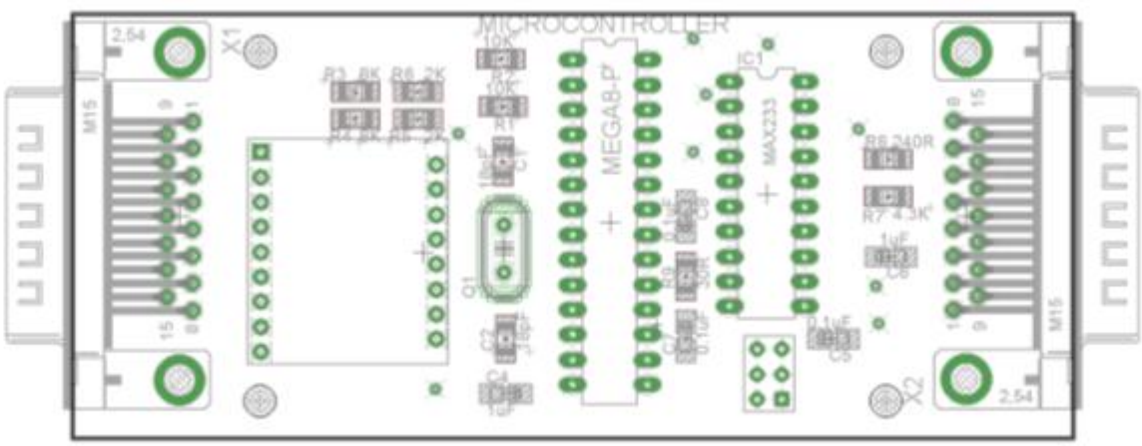
APPENDIX E – PRINTED CIRCUIT BOARD (PCB) LAYOUT

- E.1 Hatch PCB
- E.2 Power Distribution and Switching PCB
- E.3 Pyrotechnic PCB
- E.4 Probe PCB

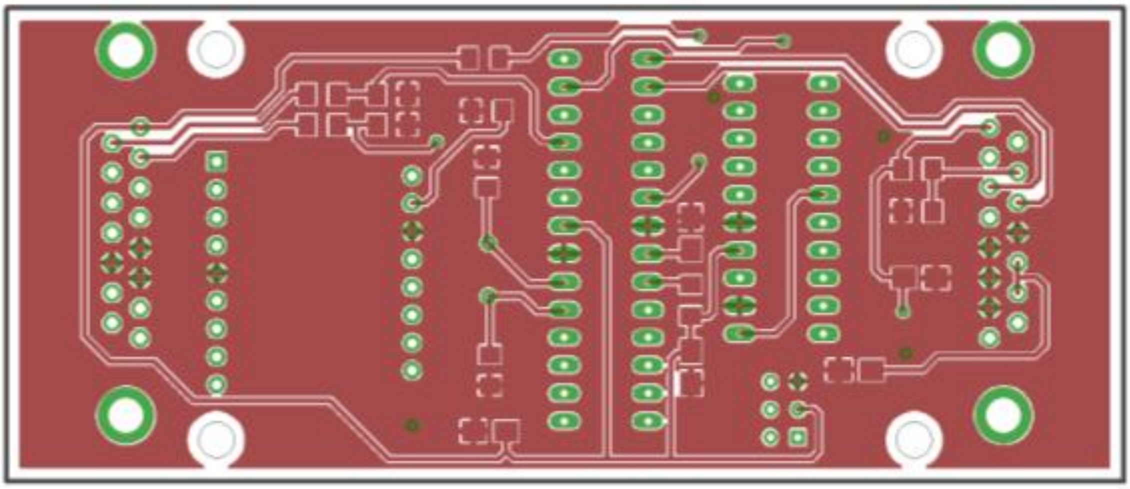
E.1 Hatch PCB

- Schematic

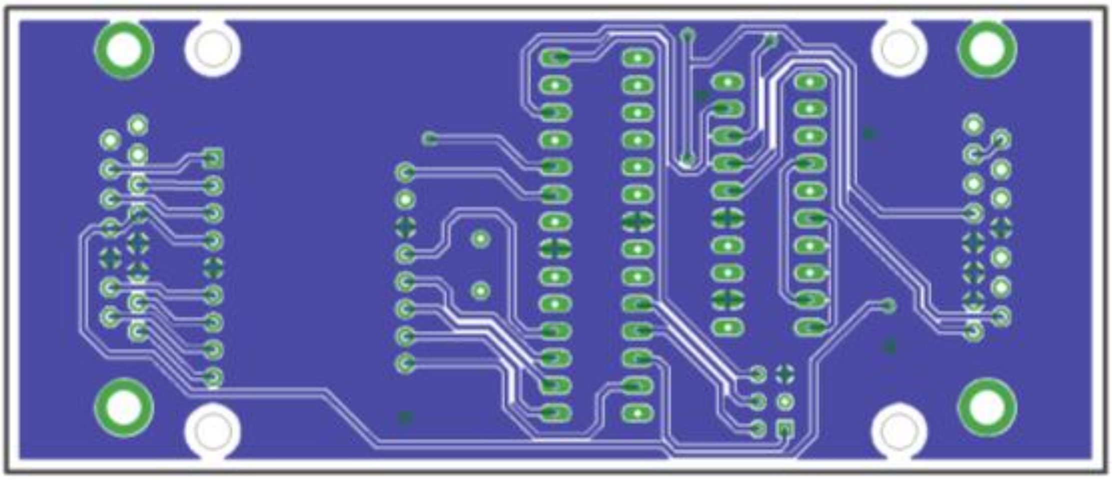
- PCB Component View



- PCB Top layer

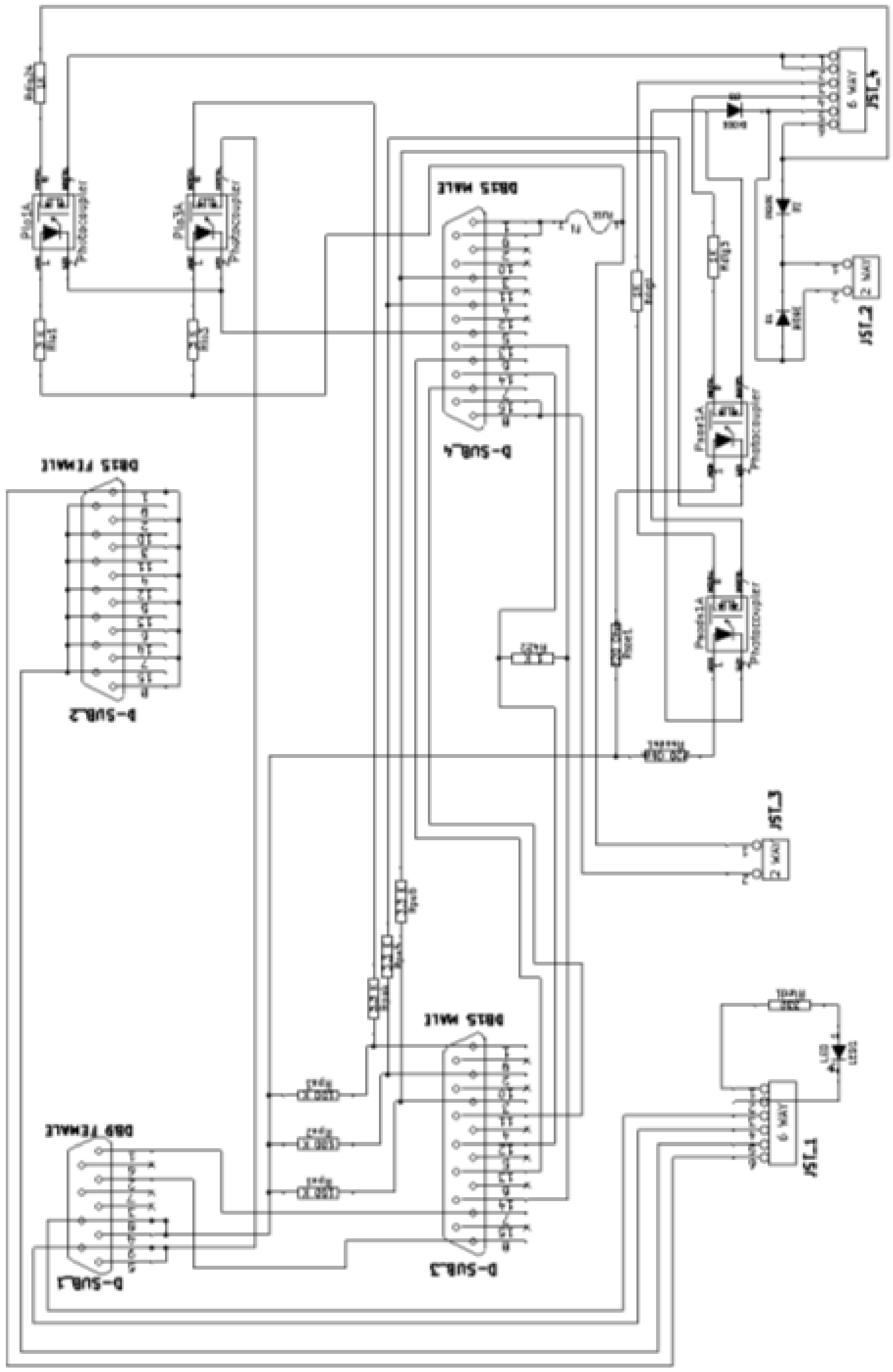


- PCB Bottom layer

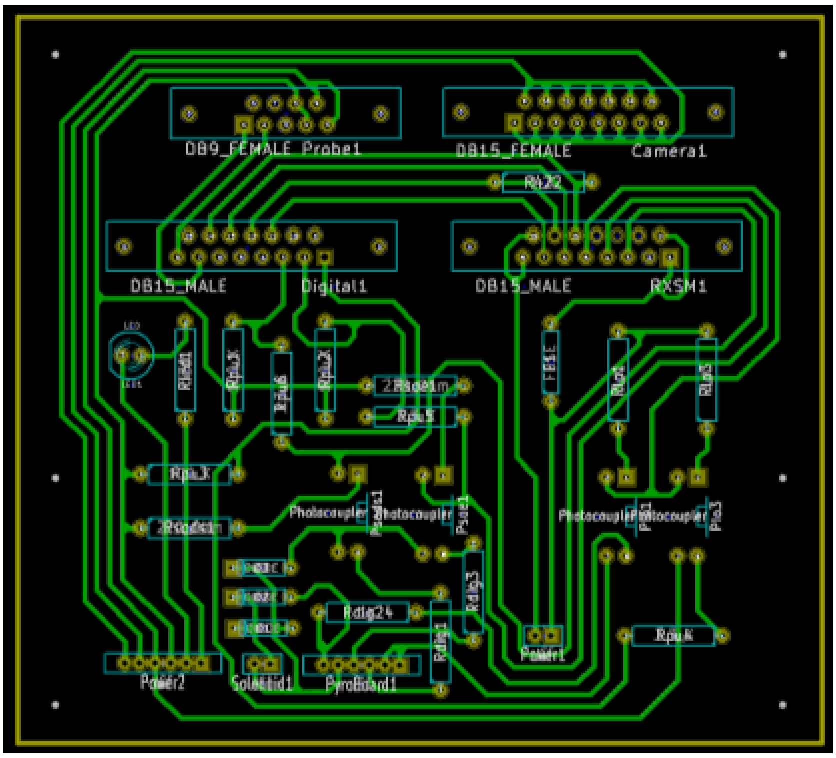


E.2 Power Distribution and Switching PCB

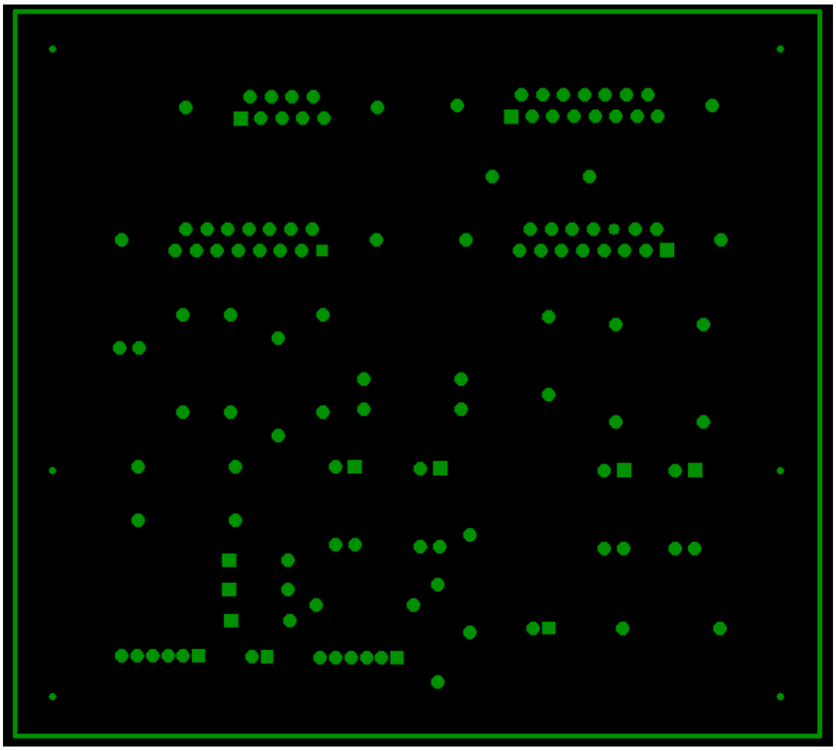
- Schematic



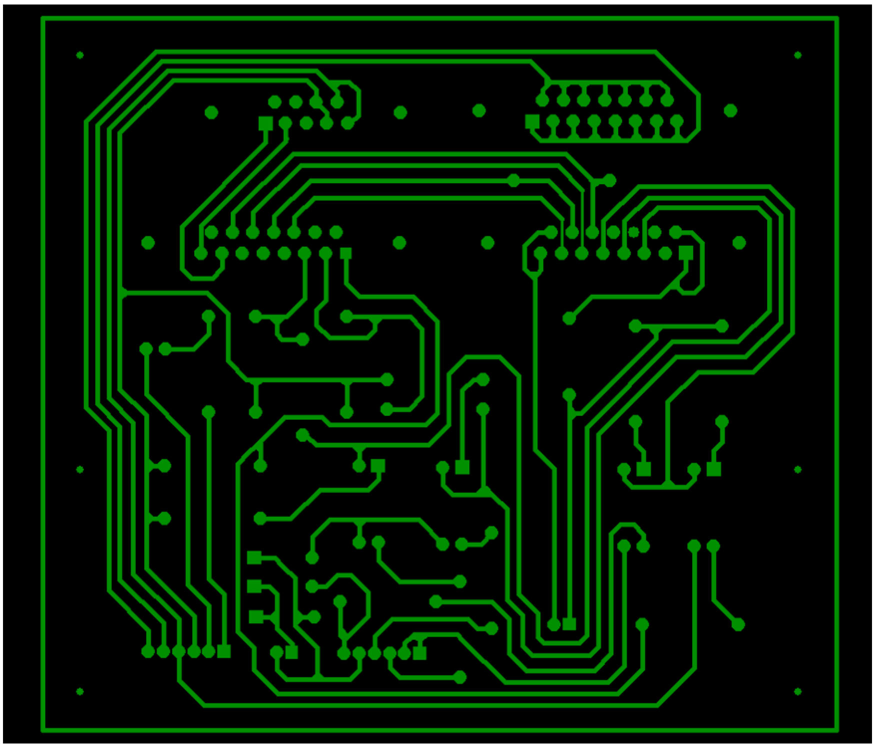
- PCB layout



- PCB Gerber format image – Top Layer

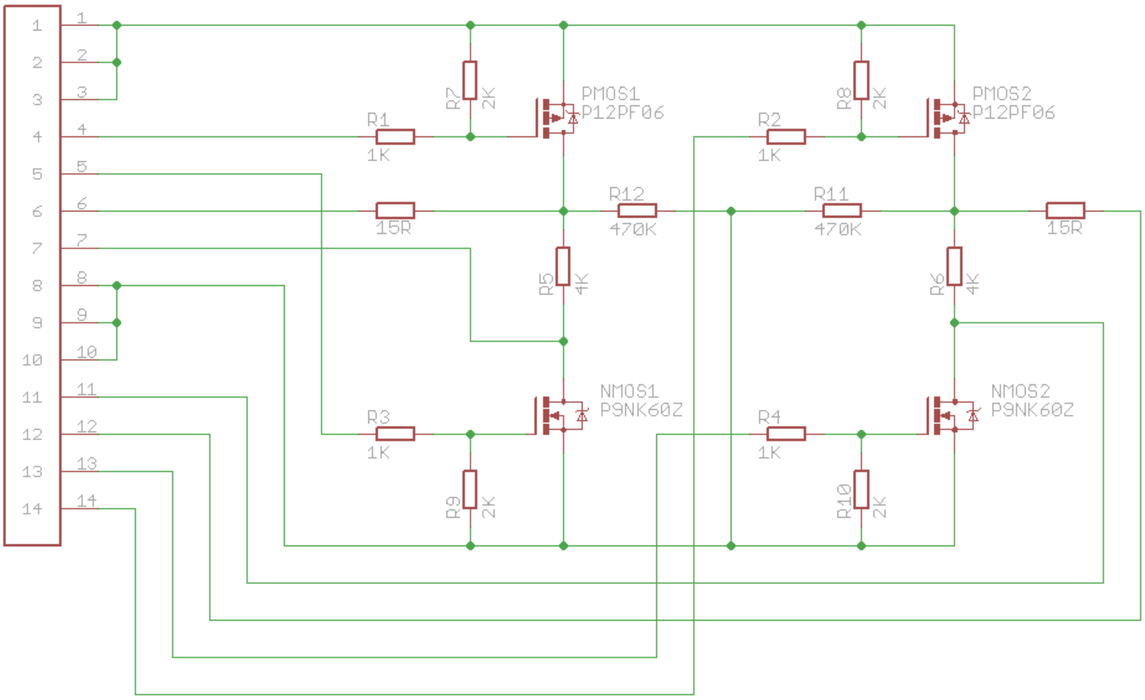


- PCB Gerber format image – Bottom Layer

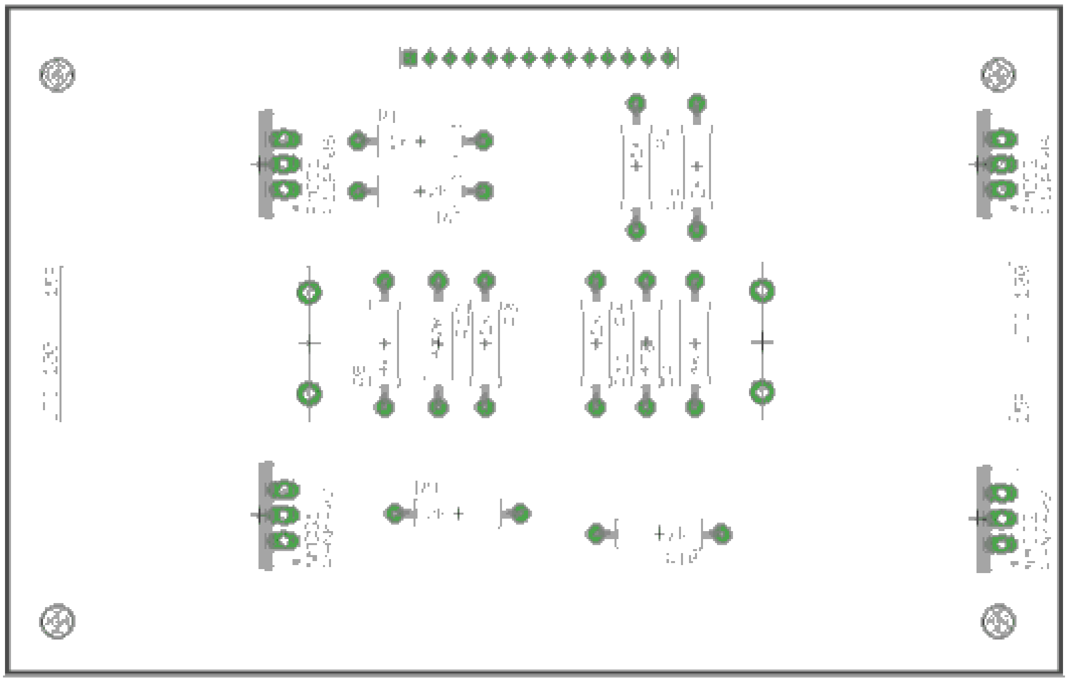


E.3 Pyrotechnic PCB

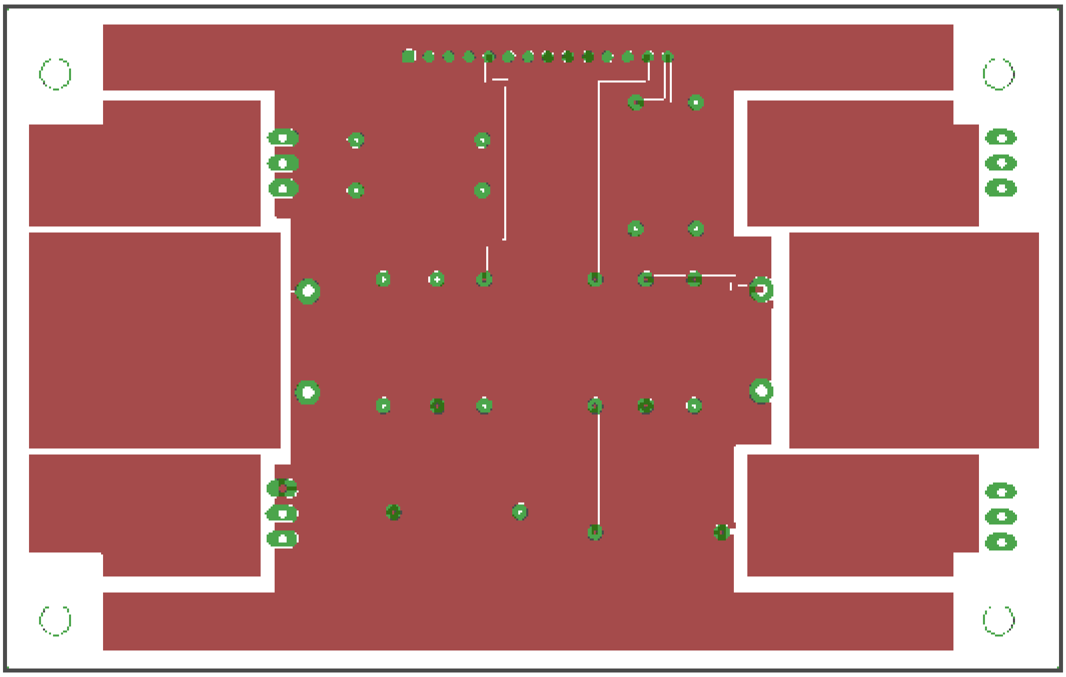
- Schematic



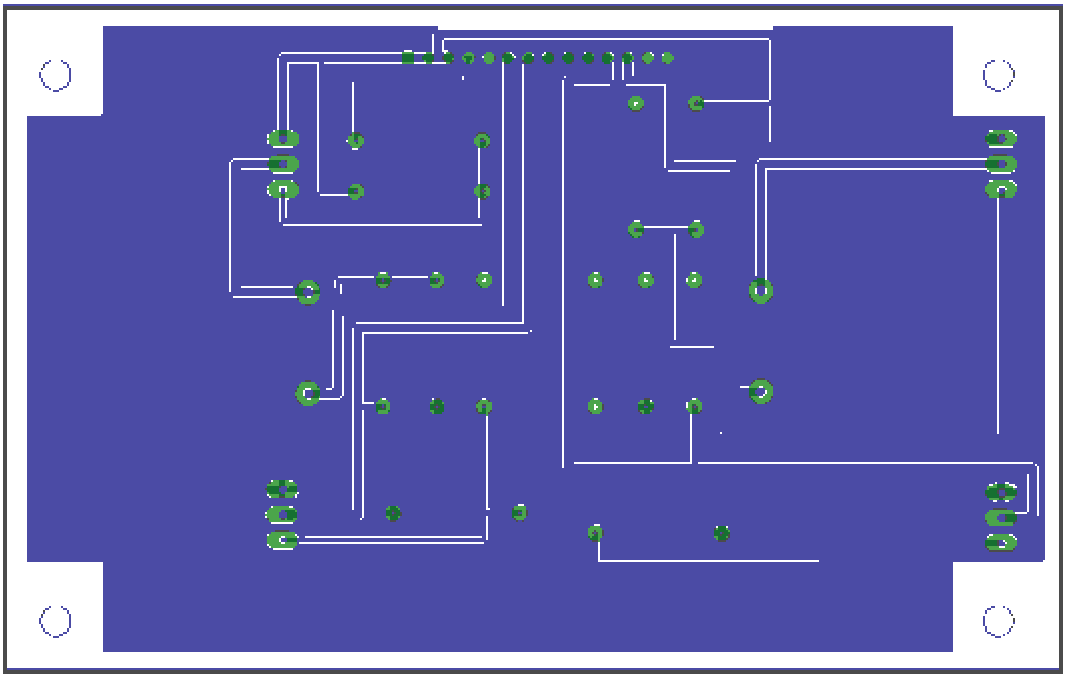
- PCB Component View



- PCB Top Layer

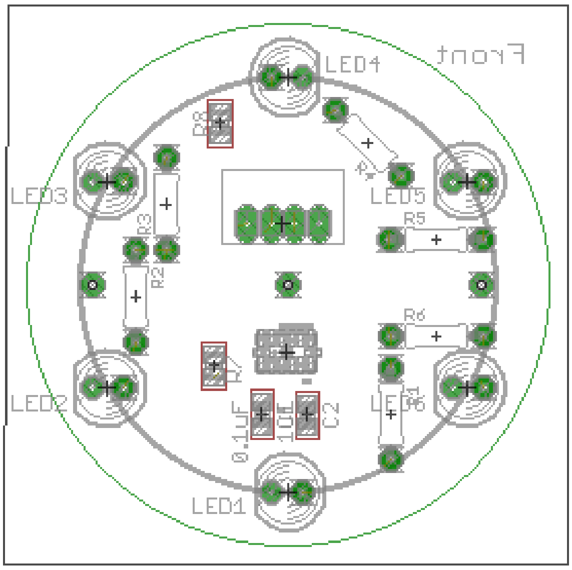


- PCB Bottom Layer

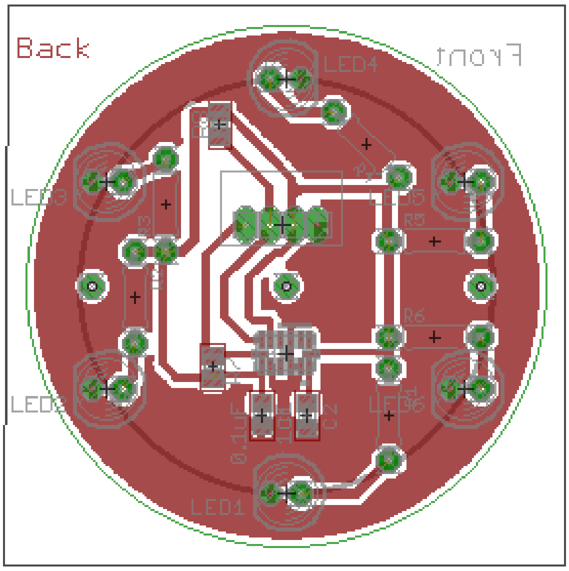


E.4 Probe PCB

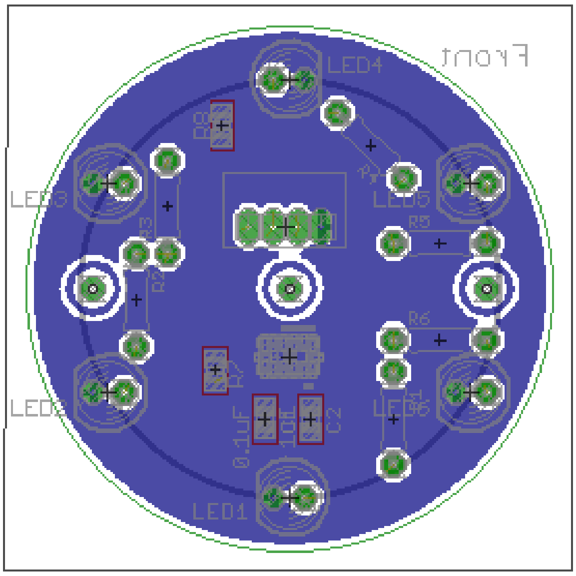
- PCB Component View



- PCB Top Layer



- PCB Bottom Layer



APPENDIX F – WBS AND RISK REGISTER

- F.1. Work Breakdown Structure (WBS)
- F.2. Risk Register

F.1 Work Breakdown Structure (WBS)

- **Documentation**

  Primary Responsibility: Stephen Curran

  Assisted By: Johnalan Keegan, Paul Duffy, Dinesh Vather, Keelan Keogh, Sean Ludlow and Ronan Byrne.

- **Outreach**

  Primary Responsibility: Paul Duffy

  Assisted By: Johnalan Keegan, Stephen Curran and Dinesh Vather.

- **Project Management**

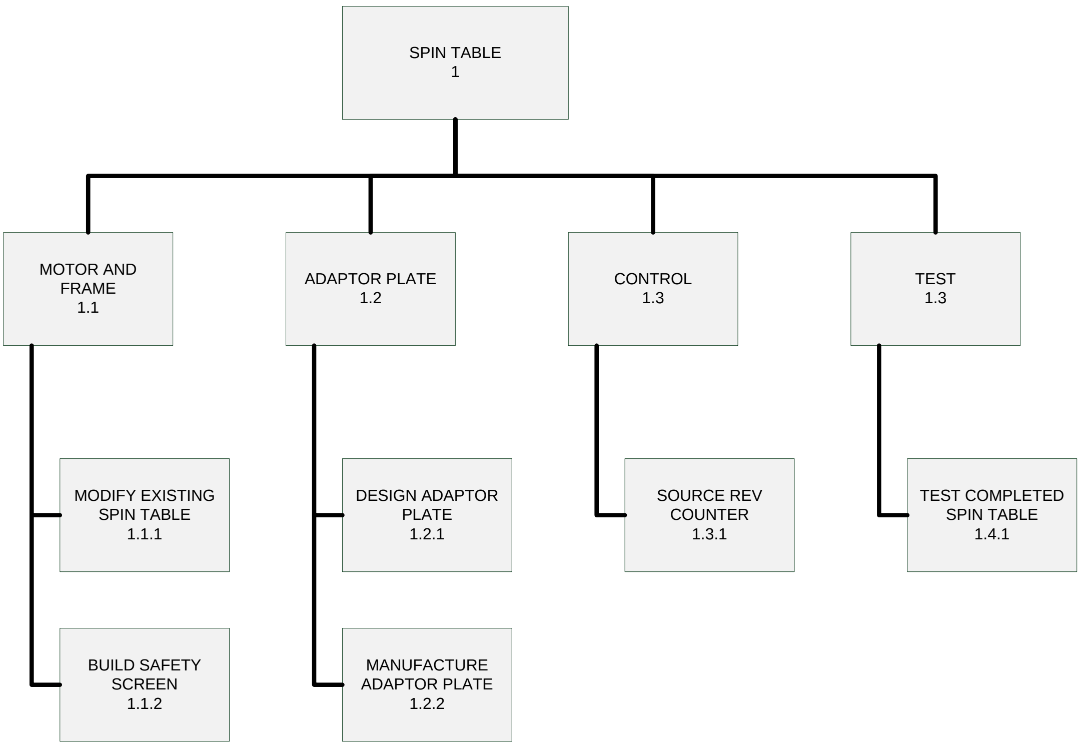
  Primary Responsibility: Stephen Curran

  Assisted By: Johnalan Keegan

- **Spin Table**

  Primary Responsibility: Sean Ludlow

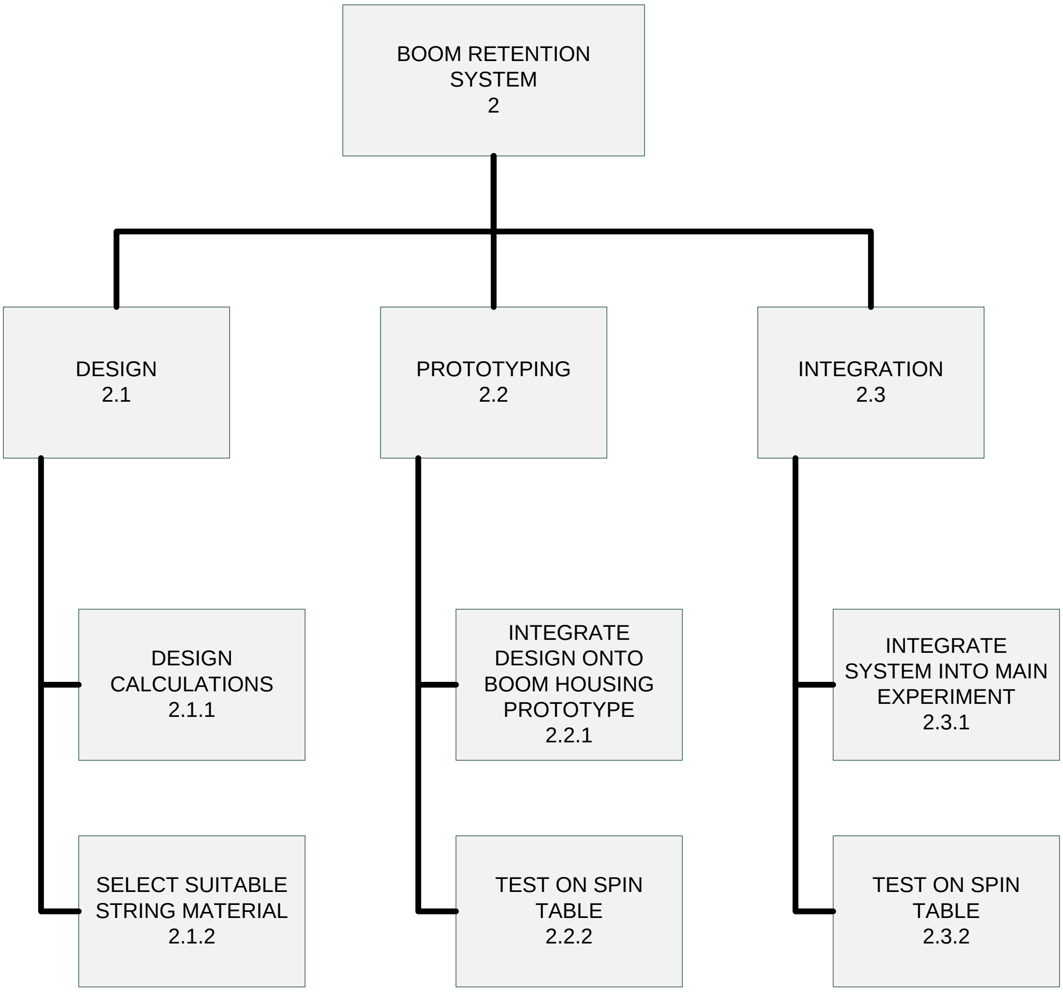
  Assisted By: Paul Duffy, Dinesh Vather, Stephen Curran



- **Boom Retention System**

  Primary Responsibility: Sean Ludlow

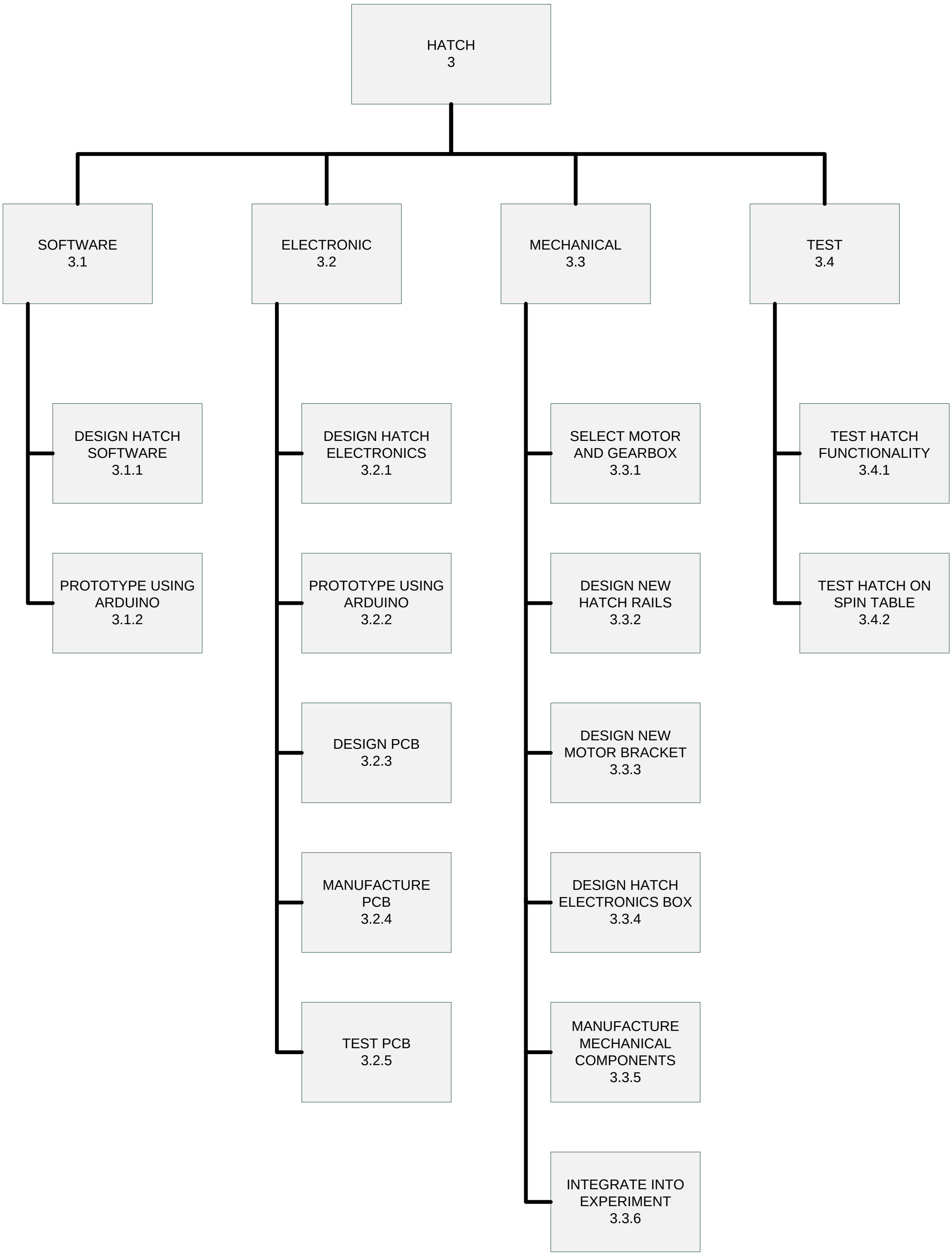
  Assisted By: Paul Duffy, Dinesh Vather, Stephen Curran



- **Hatch System**

  Primary Responsibility: Keelan Keogh

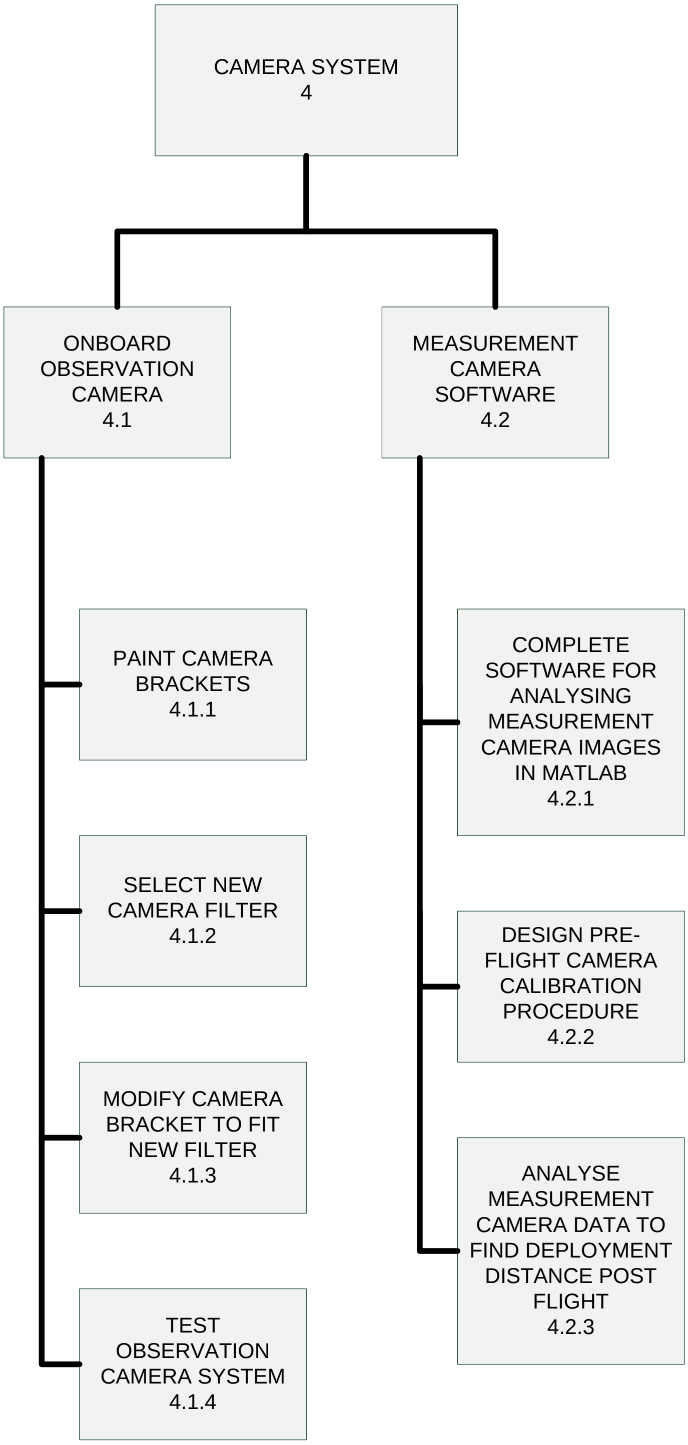
  Assisted By: Paul Duffy, Dinesh Vather, Stephen Curran, Mark Nolan



- **Camera System**

  Primary Responsibility: Ronan Byrne

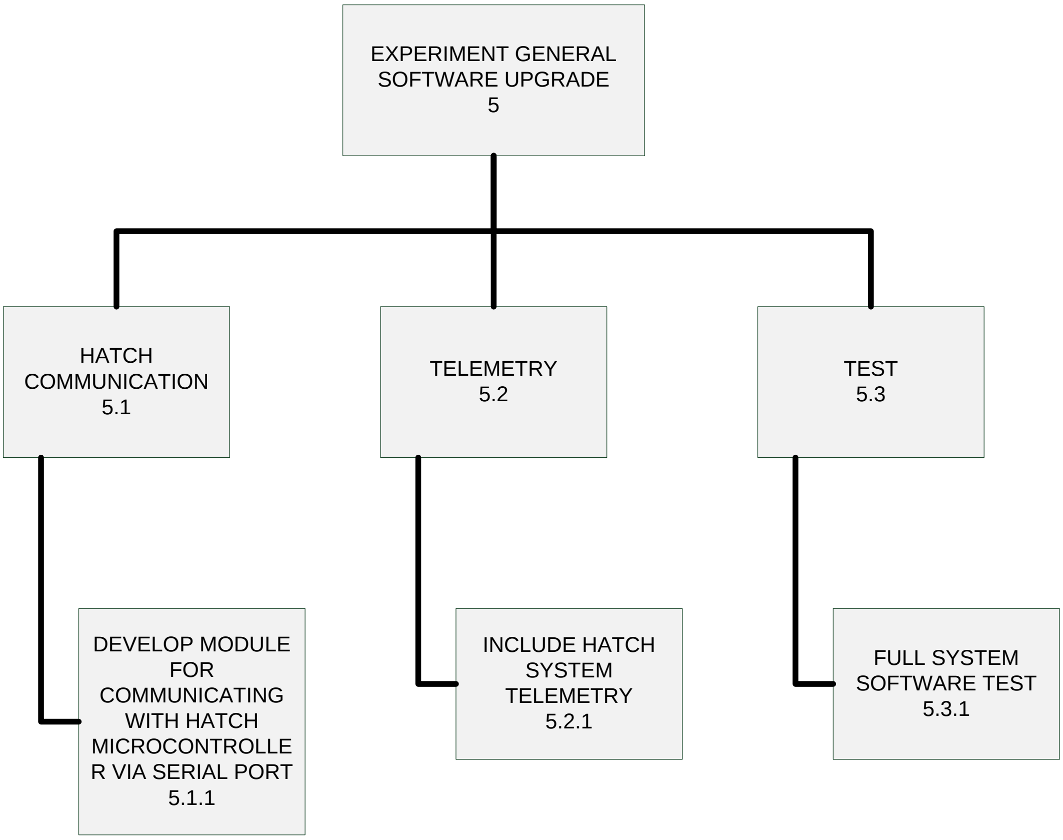
  Assisted By: Paul Duffy, Dinesh Vather



- **Experiment General Software Upgrade**

  Primary Responsibility: Johnalan Keegan

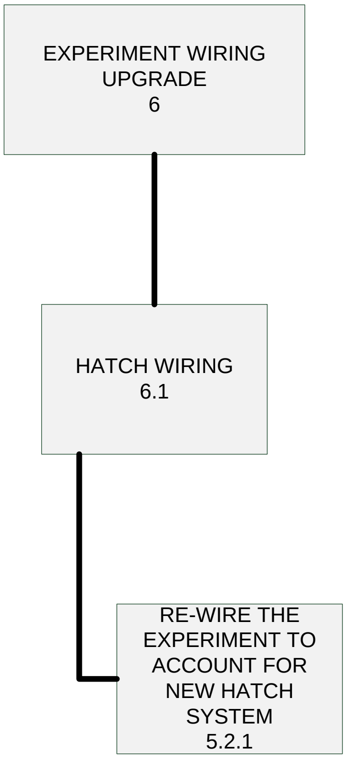
  Assisted By: Stephen Curran



- **Experiment General Electrical Upgrade**

  Primary Responsibility: Stephen Curran

  Assisted By: Johnalan Keegan



F.2 Risk Register

Item Number	Risk Description	Risk Index	Risk magnitude	Proposed Action
	TECHNICAL			
TC10	Boom design flawed	***B4***	**Low**	Stringent design review by advisors
TC20	Boom deployment system flawed	***B4***	**Low**	Stringent design review by advisors
TC30	Boom jettison system flawed	***B4***	**Low**	Stringent design review by advisors
TC40	Mounting design flawed	***B4***	**Low**	Stringent design review by advisors
TC50	Inaccurate numerical models	***C4***	**Medium**	Validation by previous experimental results, mesh convergence and reviewed by experts in this field
TC60	Failure to adequately specify components	***B3***	**Low**	Stringent design review by advisors Include Factor of Safety (FOS)
TC70	Inaccurate bench top experimental results	***C4***	**Medium**	Review test designs and protocols, comparison with similar tests from literature. Perform multiple tests.
MS10	Boom doesn’t deploy as required	***A5***	**Low**	Extensive testing will be performed to ensure reliable deployment.
MS20	Boom breaks off during flight	***B4***	**Low**	A suitable material with a high strength to mass ratio, such as carbon fibre, will be used to construct the booms. Analysis will be performed on the booms to

				ensure they have sufficient strength to survive forces up to 100% higher those that would normally expected during the course of a flight.
MS30	Excessive vibration in booms	***B3***	**Low**	The mass and dimensions of the booms will be engineered to reduce their natural frequency of vibration.
MS40	Deployment system failure	***B5***	**Medium**	Contingency will be built in where possible to ensure that boom will deploy
MS50	Jettison system failure	***B5***	**Medium**	Contingency built in to release booms regardless of system failure. Drag forces may pull boom out of rocket if released. A manual override from the ground station will be implemented.
MS60	Timing system failure from RXSM	***B3***	**Low**	Timing signals are provided by RXSM, so failure is unlikely. However in case of such an event occurring the embedded computer shall be able to provide a redundancy signal.
VE10	Heat radiation from module interfaces	***D2***	**Medium**	Module can be fully tested to ensure we stay within our requirements
MS70	Failure of components due to vibration	***A5***	**Low**	All components will be tested to withstand 2 kHz vibration on all axes.
MS80	Failure of system components due to G-Forces	***A5***	**Low**	All electrical components and mechanical components shall be bought as space qualified.
MS90	Temporary loss of power from	***B3***	**Low**	System will be able to automatically reboot.

	RXSM			
MS100	Permanent loss of power from RXSM	***B3***	**Low**	Highly unlikely scenario. No action can be taken.
MS110	Effect of background light (or lack of it) on camera measurement system	***C3***	**Low**	An L.E.D. that emits light in a narrow band may be used in conjunction with a filter to remove light of different wavelengths from other sources placed over the lens of the high quality camera.
MS120	Failure of system components due to temperature	***B5***	**Medium**	Experiment module will be tested for the temperature profile of the flight. Additional features to enhance heating/cooling will then be incorporated into the design if necessary.
MS130	Failure of components due to impact of rocket on descent	***B5***	**Medium**	The expected impact velocity is 8m/s. The experiment module will be tested at an impact velocity of 12m/s. If this proves to be problematic then additional features will have to be designed and incorporated into the experiment module to ensure that all vital components survive impact.
MS140	Failure of DAQ to enter landing stable mode.	***B2***	**Very Low**	DAQ will be extensively tested. Back up off switch may be included in the system
VE20	Hatch in rocket	***A5***	**Low**	Boom deployment/jettison

	skin doesn't open			system will be prevented from arming.
VE30	Rocket chute failure	***A5***	**Low**	Low resolution data may be transmitted to ground station prior to chute release.
~~**TC80**~~	~~Unable to source carbon fibre fishing booms~~	~~***C3***~~	~~**Low**~~	~~Get manufactured by outsourcing (Eirecomposities) or make in house.~~
MS150	High resolution camera fails to record useful information	***A4***	**Very Low**	Live TV feed will provide some information on this experiment if this happens. Other methods of determining if boom is deployed can be used (e.g. accelerometers, low resolution camera)
MS160	Boom fails to deploy to desired length	***C4***	**Medium**	Information will still be recorded on the effectiveness of the boom deployment length (accelerometers & T.V live feed). We can ensure reliable deployment through testing
MS170	Boom proximal end collides with rocket as it is jettisoned	***B5***	**Medium**	Booms shall be deployed at such a velocity to ensure that they clear the rocket in a timely manner.
SF10	Boom jettison is delayed and damages chute as it is jettisoned late.	***A5***	**Low**	Back up boom jettison system.
MS180	Carbon fibre boom delaminate	***A4***	**Very Low**	Testing materials in bench top vacuum experiments

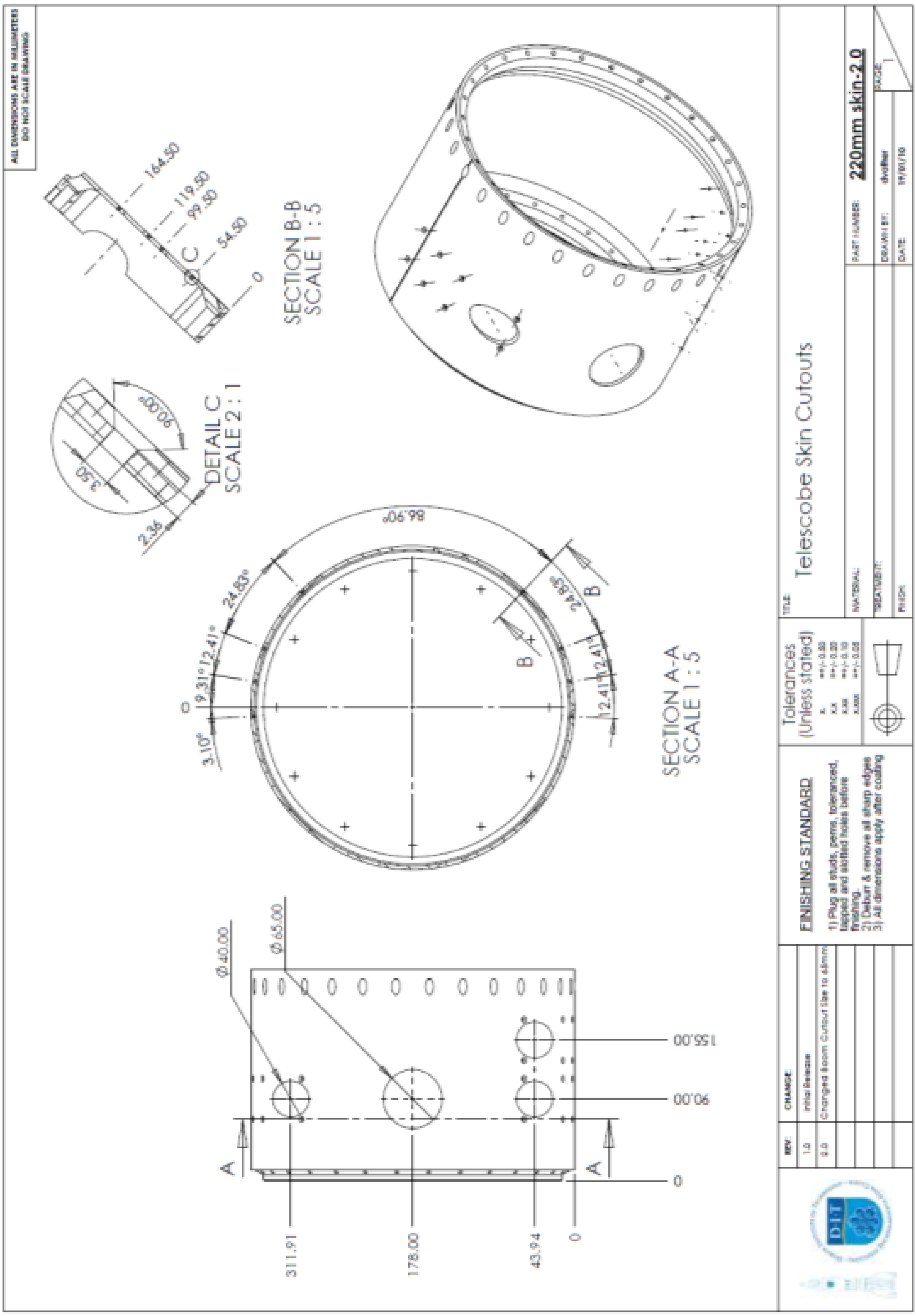
	in vacuum, integrity is compromised			
TC90	Restriction/limited access to workshop to build or test experiment	***C3***	**Low**	Project manager shall contact relevant heads to assign times or outsource manufacturing
TC100	No useable results from bench top testing	***A5***	**Low**	Have clearly defined testing procedures. Have a number of testing methods.
MS190	Wire and cables for LED/probe may prematurely sever on deployment	***B3***	**Low**	Test wire and cables for successful deployment
MS200	Wire and cables for LED/probe may not deploy, preventing boom deployment.	***B5***	**Medium**	Have contingency disconnection means.
MS210	Wire and cables for LED/probe may not disconnect on jettison	***B5***	**Medium**	Have contingency disconnection means.
TC110	Critical component is destroyed in testing	***B3***	**Low**	Order spare components and keep them available
MS220	Software programme failure during flight	***C3***	**Low**	Watchdog checks for crashes and resets if necessary

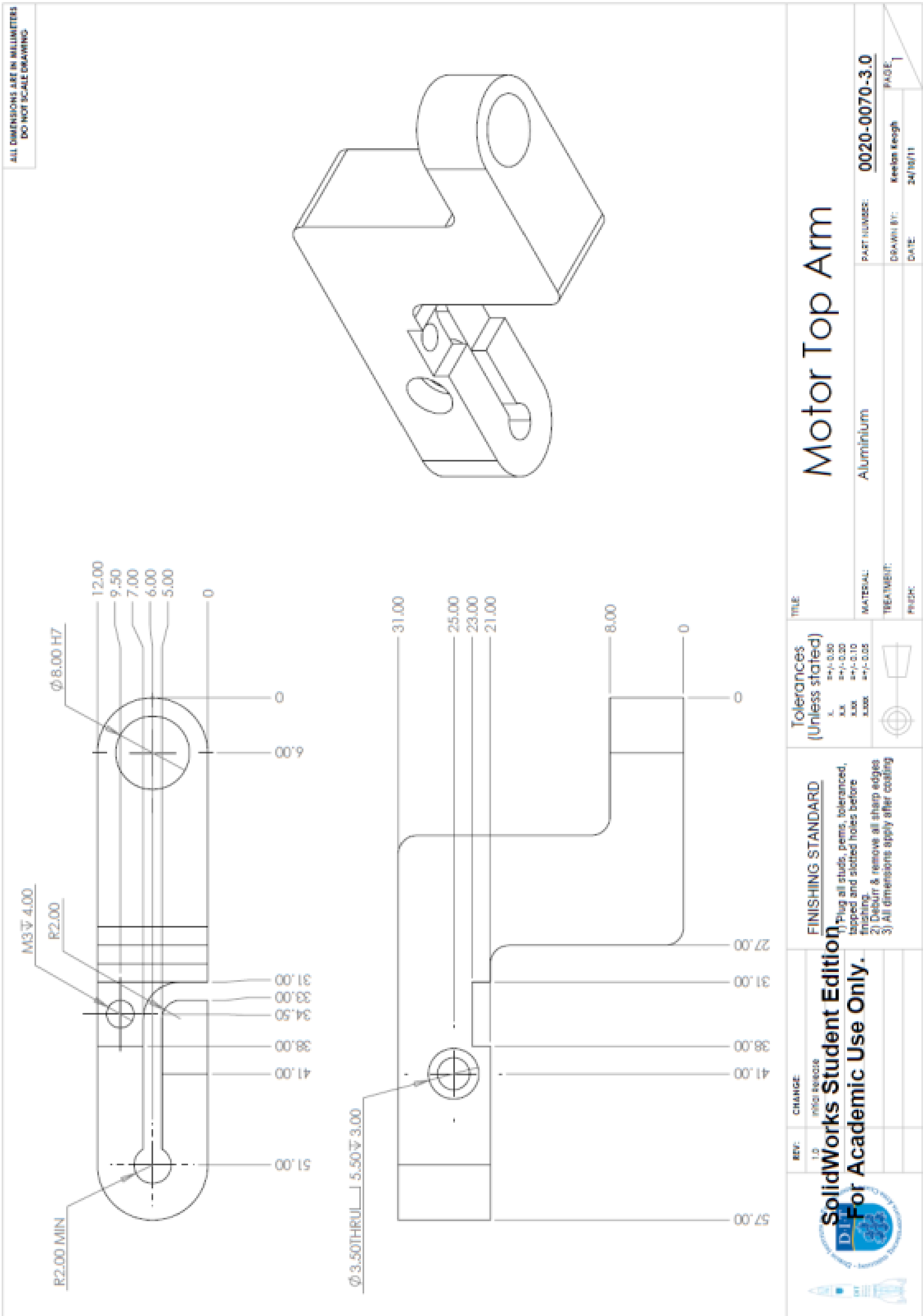
MS221	(residual of MS220)	***B3***	**Low**	'Power-on-reset' sequence brings system to safe state
MS230	Failure to remove retaining mechanisms before flight	***C3***	**Low**	Removal step included in pre-flight check list. Check list completed using 'buddy" system.
	COST			
TC110	Cannot source components or material within our budget	***B5***	**Medium**	Get multiple quotes from sources, use commercially off the shelf (COTS) materials and components where possible. Manufacture or produce in house
TC120	Unavailable funding, funding terminated	***A5***	**Low**	Have multiple sources of funding. Seek formal commitment of funding. Seek legal action
TC130	Over spending	***C3***	**Low**	Purchases must be signed off by project manager
TC140	Unexpected costs	***D2***	**Low**	Seek a flexible budget, revise budget and make appropriate corrections
TC150	Costs incurred by outsourcing production due to schedule overruns	***B2***	**Very Low**	Have comprehensive Gantt chart, highlight any possible outsourcing early and adjust budget
TC160	Buying replacement materials and components (faulty, broken accidently or change in design)	***D3***	**Medium**	Carefully monitor all stock, buy better grade components. Develop storage and handling protocol, return broken items and seek replacements
	SCHEDULE			

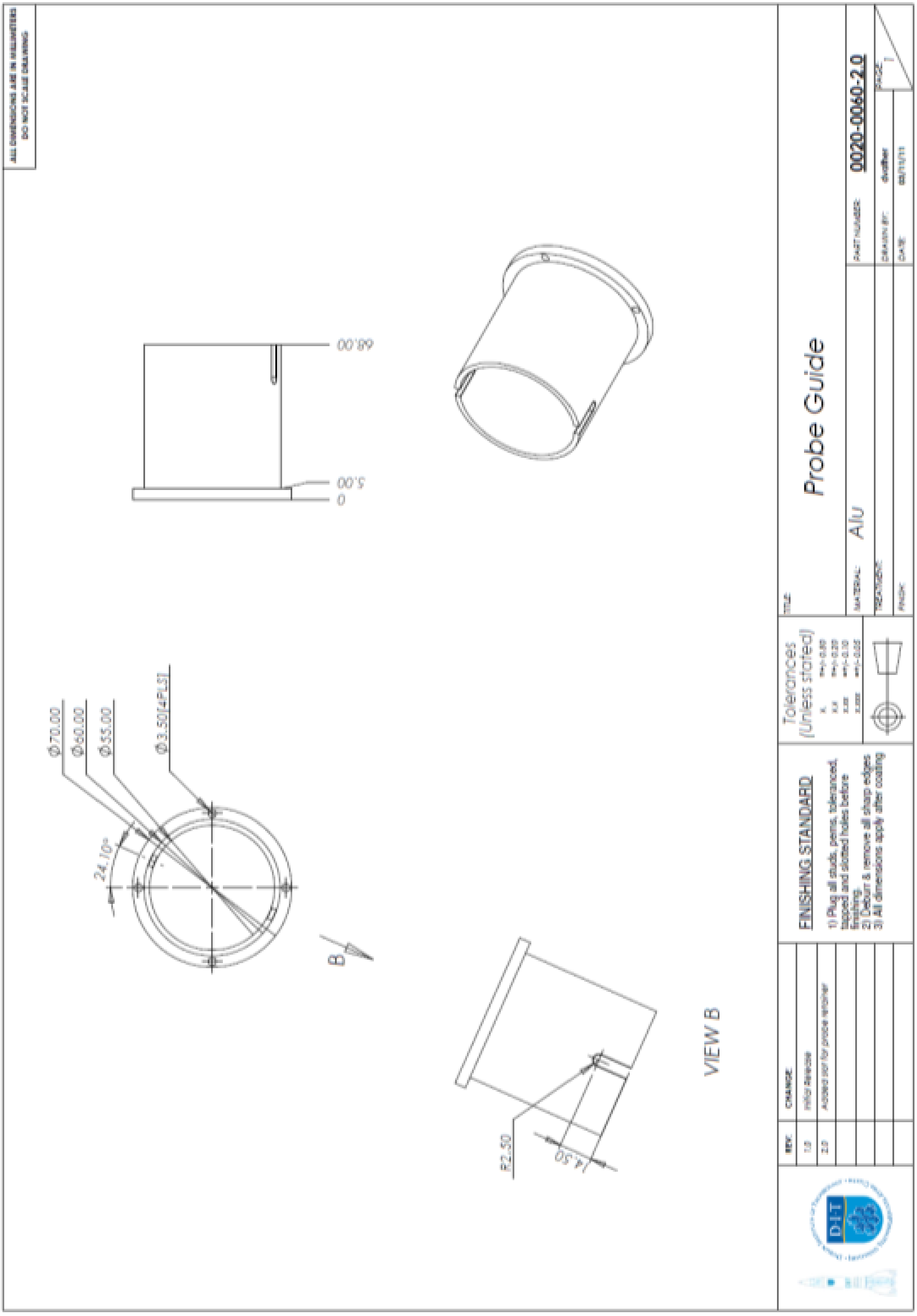
TC170	Extended lead time of materials	***E2***	**Medium**	Have alternate source
TC180	Extended lead time of components	***E2***	**Medium**	Have alternate source, manufacture in house
TC190	Project is running behind schedule due to poor project planning.	***C3***	**Low**	Regular oversight of project management by project advisor
TC200	Delays in manufacturing of experiment	***D3***	**Medium**	Keep design simple, use standard manufacturing techniques
TC210	Delays in bench top testing of experiment	***D3***	**Medium**	Have comprehensive testing timetable, outsource testing to industry, perform numerical analysis
TC220	Unforeseen design revisions	***B3***	**Low**	Design oversight by advisors
VE40	Launch delayed or postponed	***C3***	**Low**	Specify that experiment can maintain functionality for a longer period of time.
PE10	Delay in project due to illness	***B3***	**Low**	Spread work load between other team members, draft new team members
TC230	Damage to finished experimental module in transit to launch	***A5***	**Low**	Disassemble and package experiment sufficiently.
	OTHERS			
PE20	Sickness or death of team member	***A5***	**Low**	Draft new team member/s

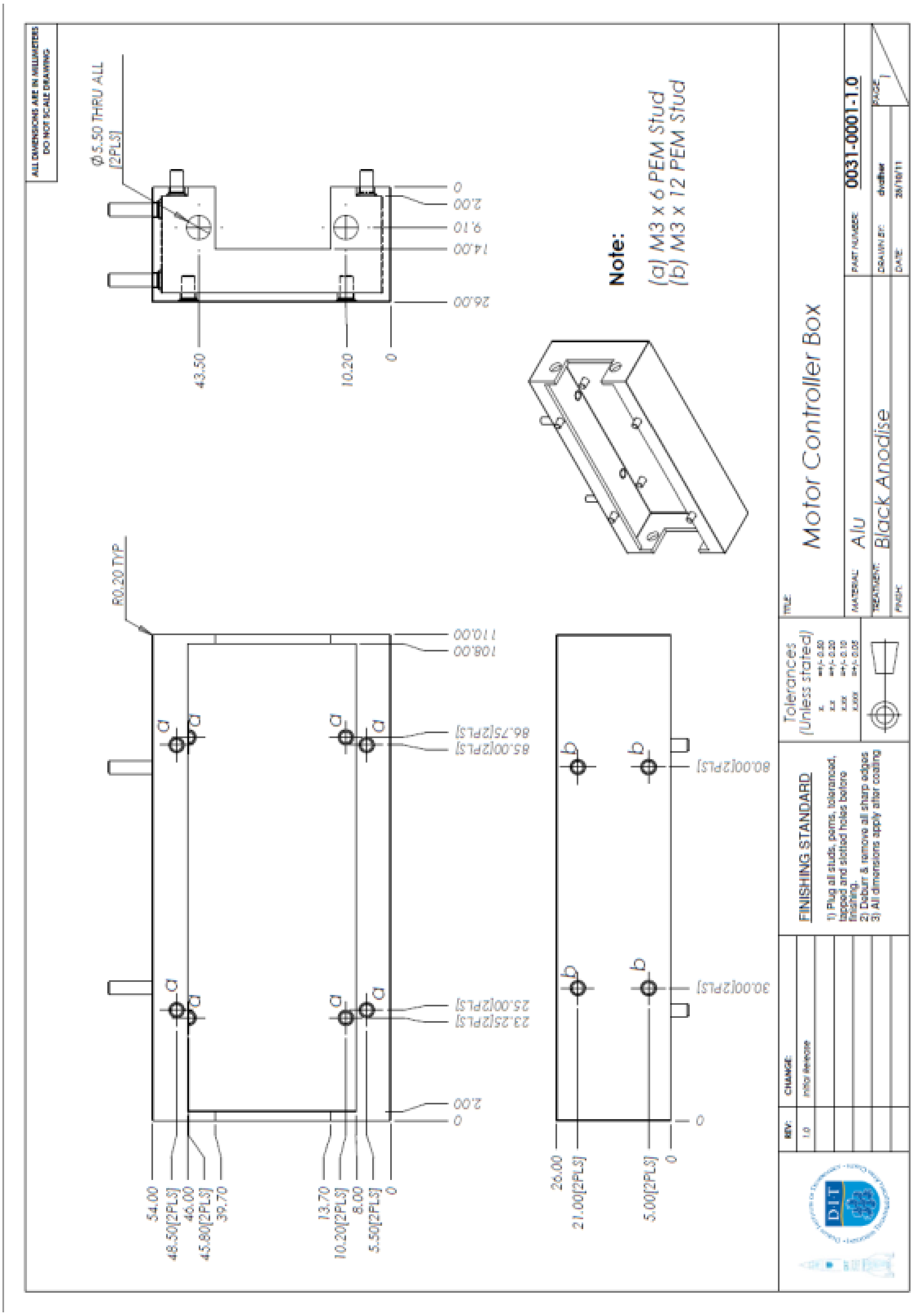
SF20	Boom injures someone as they descend through the atmosphere	***A5***	**Low**	Boom jettison before re-entry
VE50	Rocket is not recovered intact	***A5***	**Low**	Design DAQ system to withstand large shock loads.
VE60	Rocket explodes on lift-off	***A5***	**Low**	N/A
VE70	Other modules damage our experiment	***B4***	**Low**	Insulate and isolate our experimental module from surrounding modules
PE30	Team members can no longer partake in the project	***A5***	**Low**	Draft other team members, spread the work load amongst other team members
SF30	Boom injures team member during bench top experiment	***A5***	**Low**	Safe testing procedures.
PE40	Lack of necessary skills to produce experiment in a timely manner	***B5***	**Medium**	Seek additional support from advisors
Item Number	**Risk Description**	**Risk Index**	**Risk magnitude**	**Proposed Action**

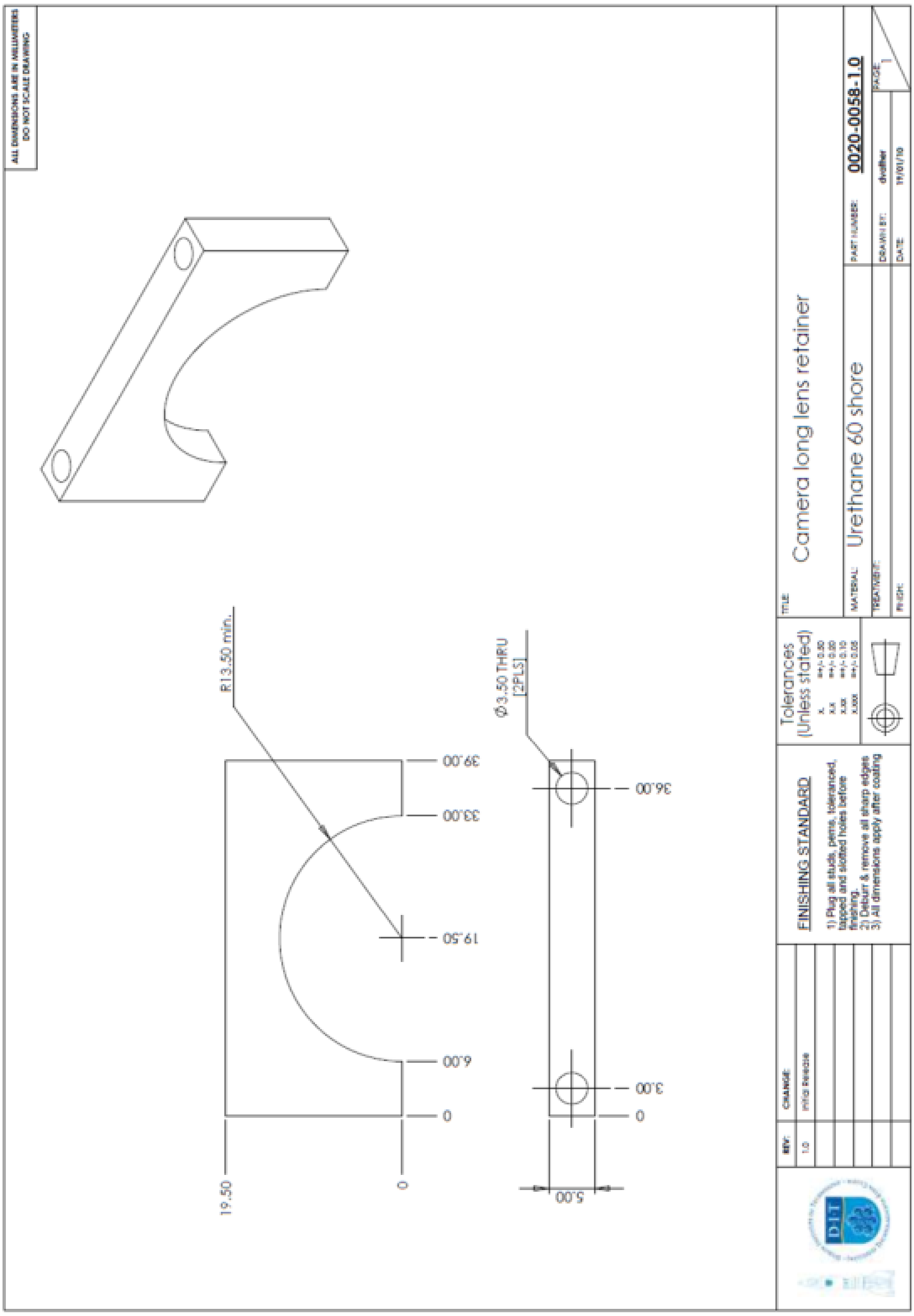
APPENDIX G – MECHANICAL DRAWINGS

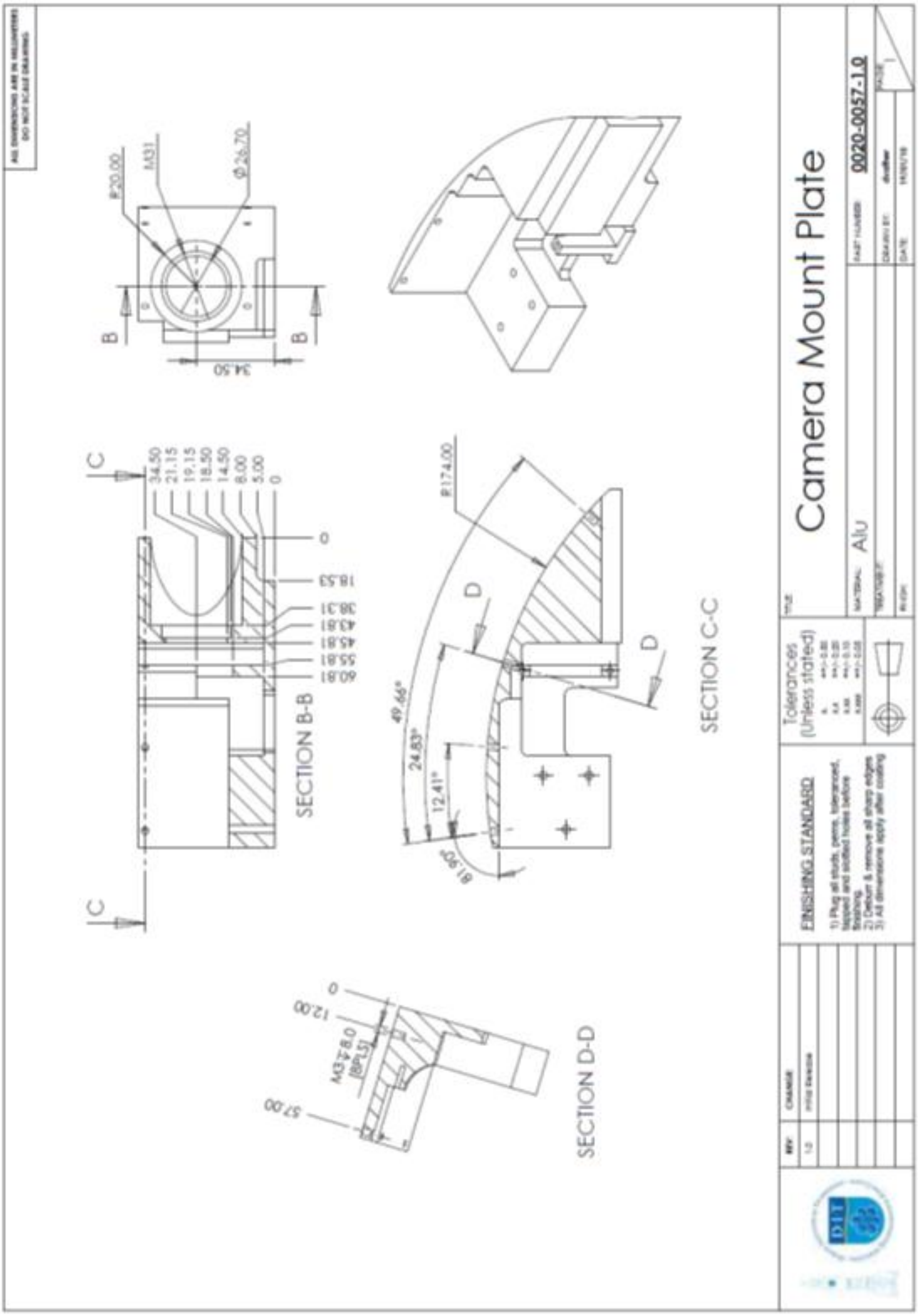


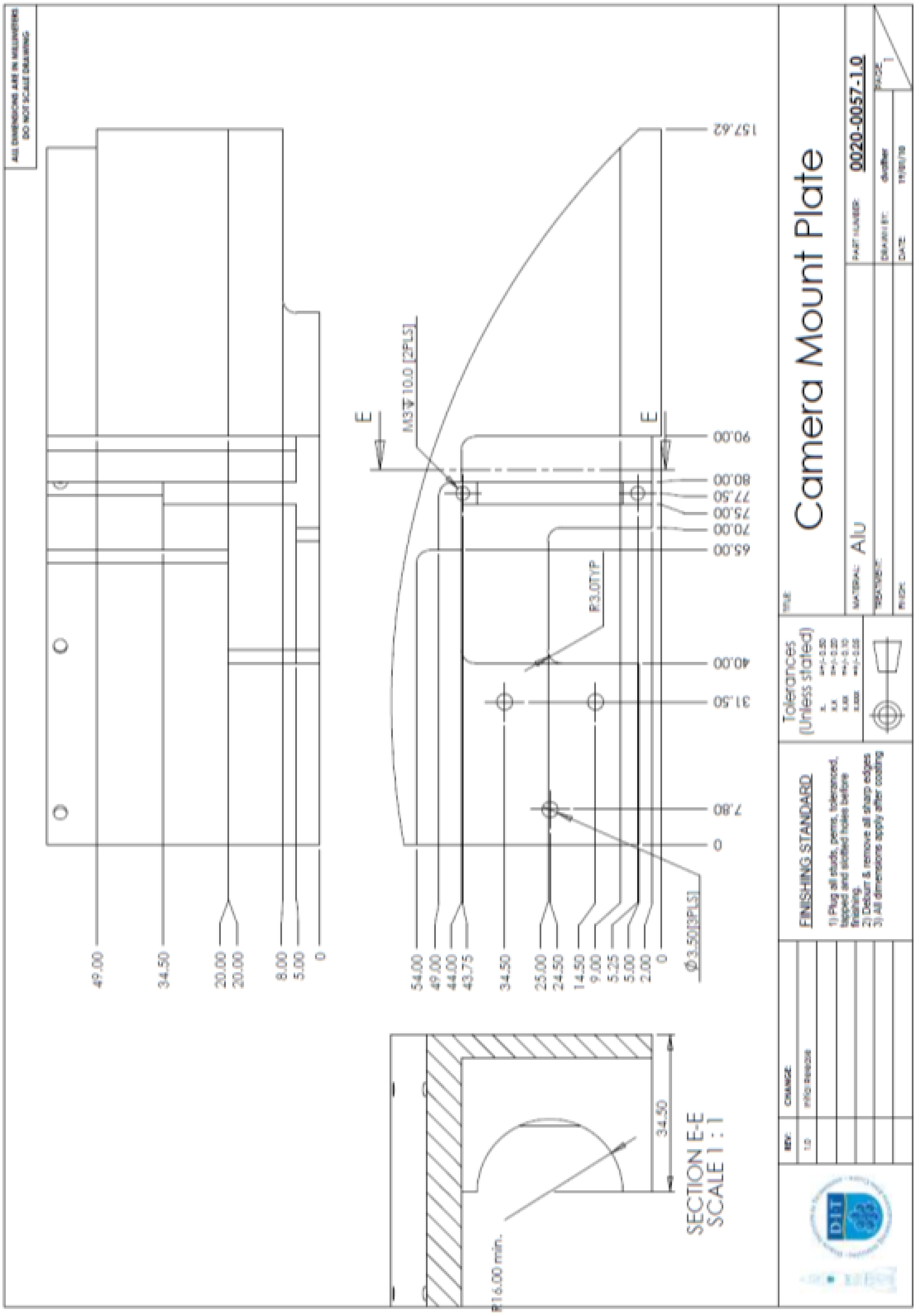

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
Motor Top Arm
Aluminium
0020-0070-3.0
Keelan Keogh
FINISHING STANDARD
Tolerances
(Unless stated)
SolidWorks Student Edition.
For Academic Use Only.

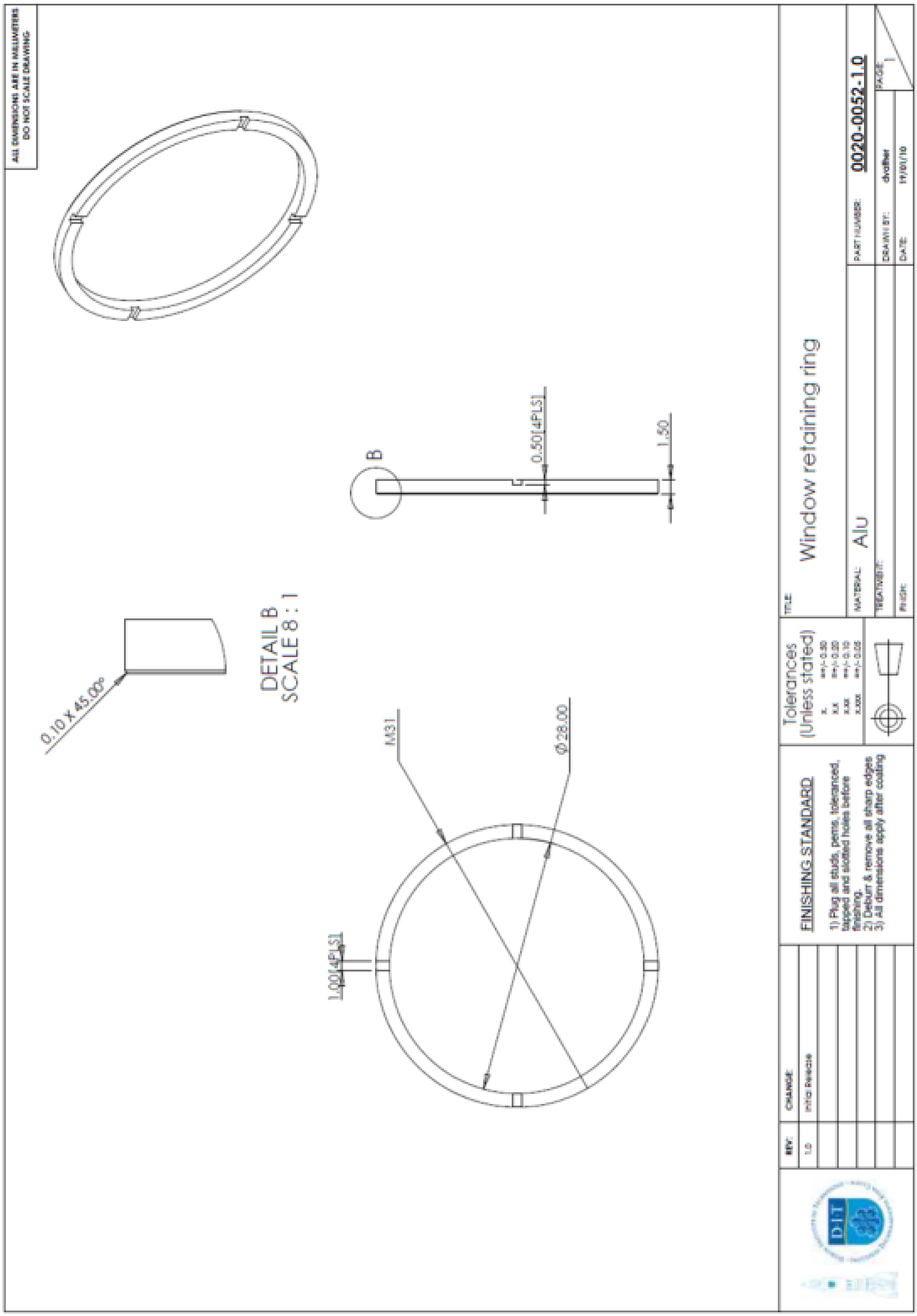

Probe Guide
Alu
0020-0060-2.0
FINISHING STANDARD
Tolerances
(Unless stated)
VIEW B
Ø70.00
Ø60.00
Ø55.00
Ø3.50[4PLS]
24.10°
68.00
5.00
0
R2.50
4.50
B

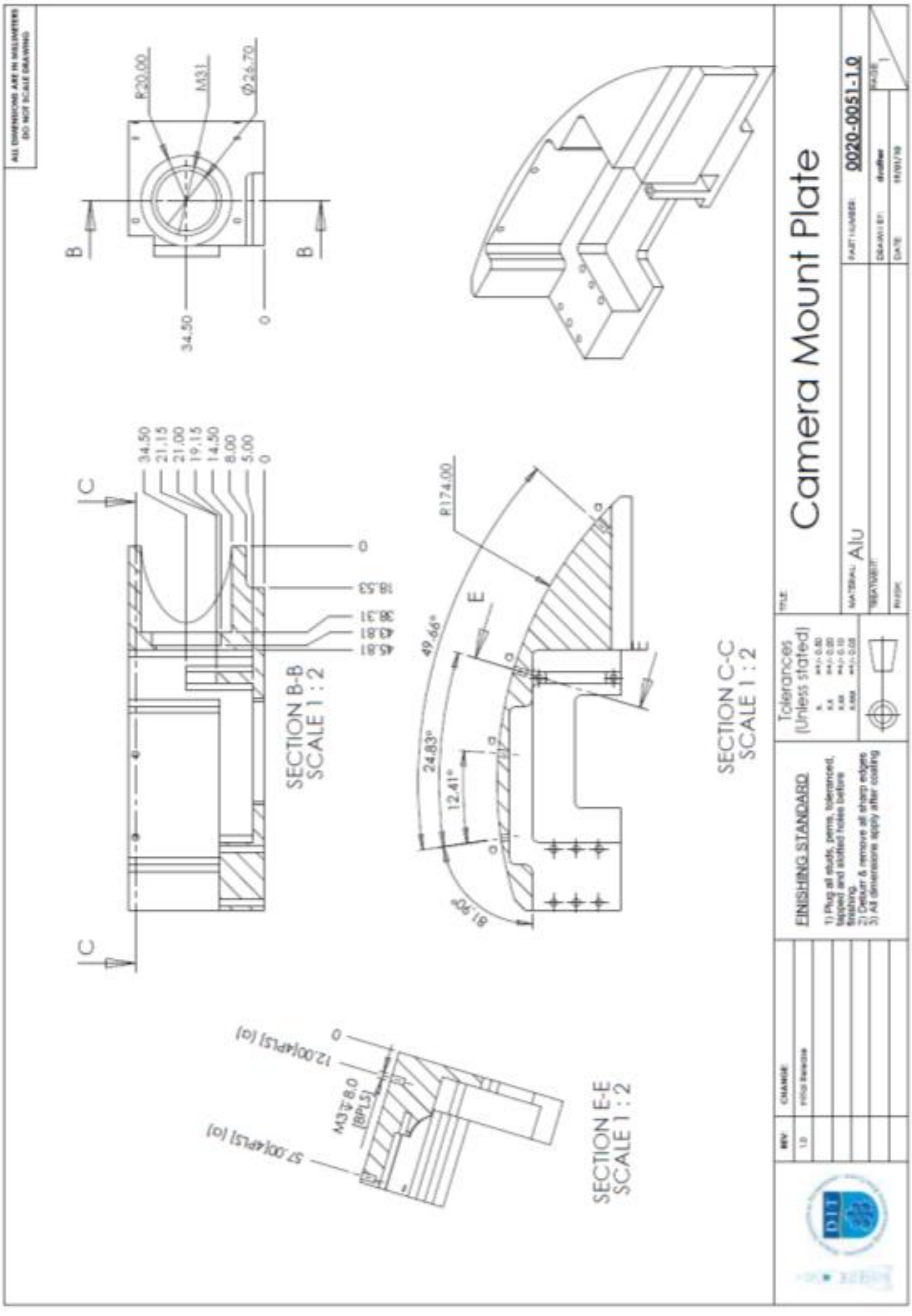

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
Ø5.50 THRU ALL
[2PLS]
R0.20 TYP
Note:
(a) M3 x 6 PEM Stud
(b) M3 x 12 PEM Stud
Motor Controller Box
Alu
Black Anodise
0031-0001-1.0
Tolerances
(Unless stated)
FINISHING STANDARD
1) Plug all studs, pems, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Initial Release
DIT


ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
R13.50 min.
Ø3.50 THRU
[2PLS]
39.00
33.00
19.50
6.00
0
36.00
3.00
5.00
FINISHING STANDARD
1) Plug all studs, pems, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Tolerances
(Unless stated)
TITLE:
Camera long lens retainer
MATERIAL:
Urethane 60 shore
TREATMENT:
FINISH:
PART NUMBER:
0020-0058-1.0
DRAWN BY:
DATE:
PAGE:
1
REV:
CHANGE:
1.0
Initial Release
DIT

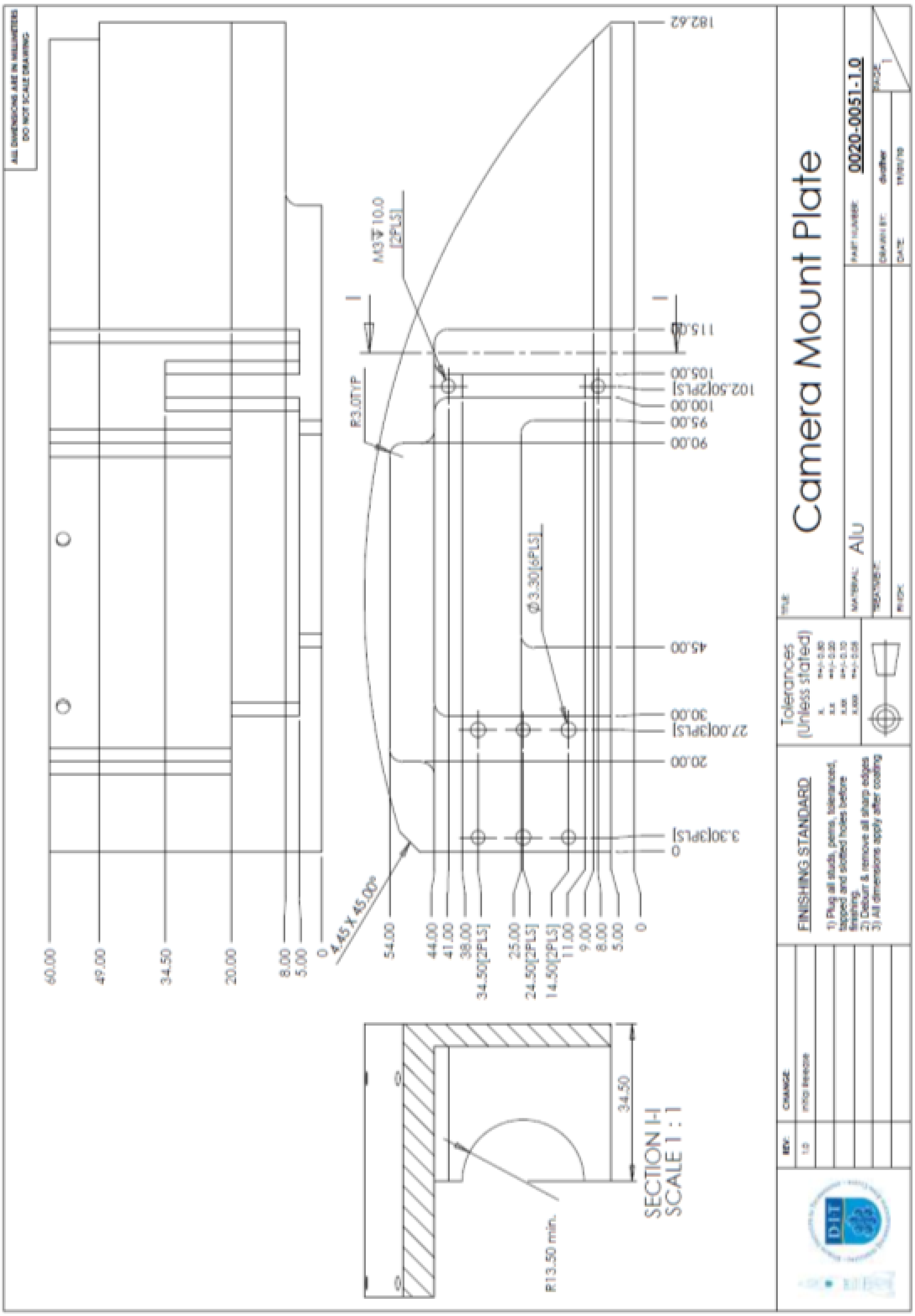

Camera Mount Plate
0020-0057-1.0
Alu
SECTION B-B
SECTION C-C
SECTION D-D
FINISHING STANDARD
Tolerances (Unless stated)
R174.00
R20.00
M31
Ø26.70
34.50

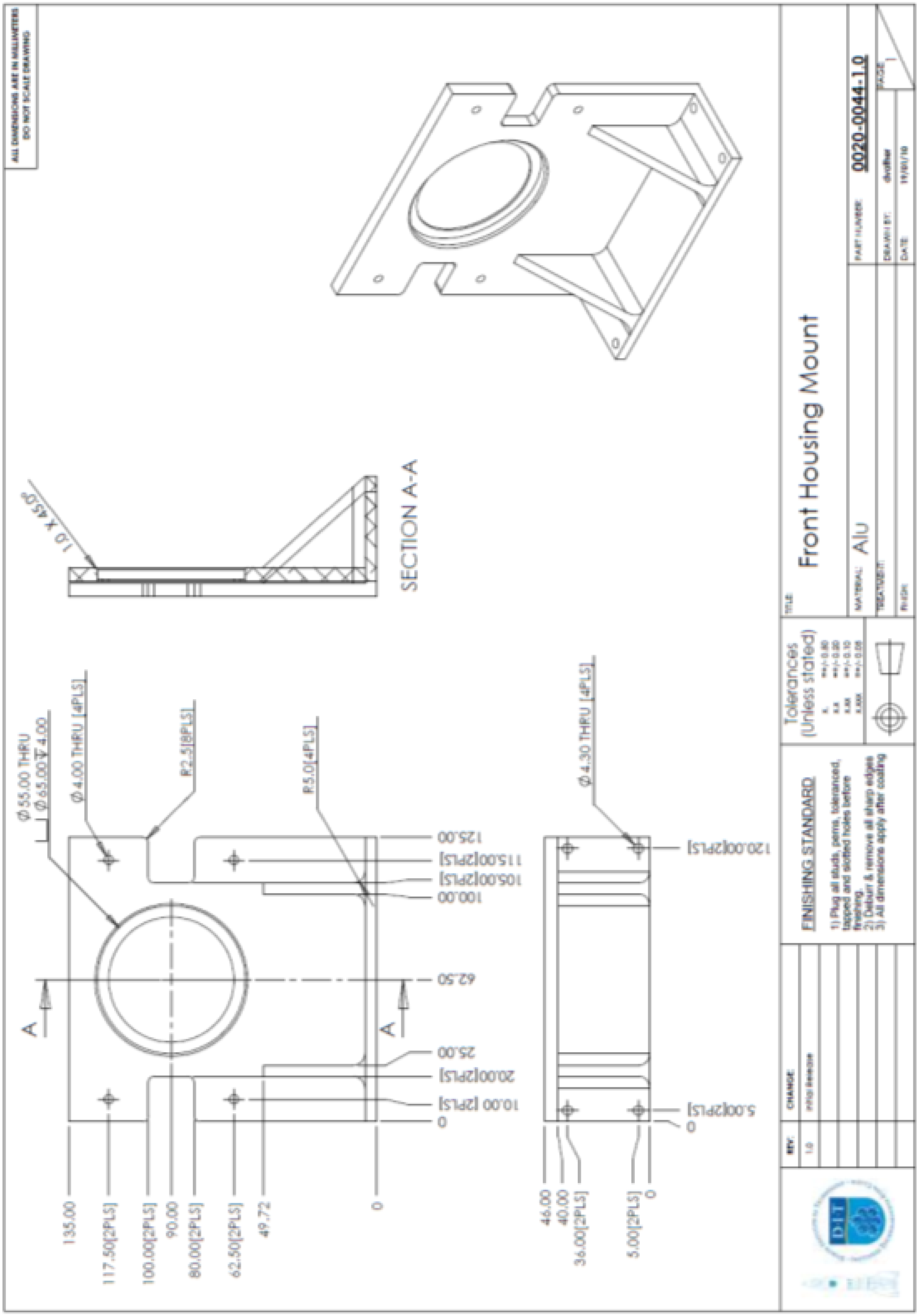

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
Camera Mount Plate
0020-0057-1.0
MATERIAL: Alu
Tolerances
(Unless stated)
FINISHING STANDARD
1) Plug all studs, pems, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
SECTION E-E
SCALE 1 : 1
R16.00 min.
34.50
M3 ⊽ 10.0 [2PLS]
R3.0TYP
Ø3.50[3PLS]
E
E
157.62
90.00
80.00
77.50
75.00
70.00
65.00
40.00
31.50
7.80
0
49.00
34.50
20.00
20.00
8.00
5.00
0
54.00
49.00
44.00
43.75
34.50
25.00
24.50
14.50
9.00
5.25
5.00
2.00
0

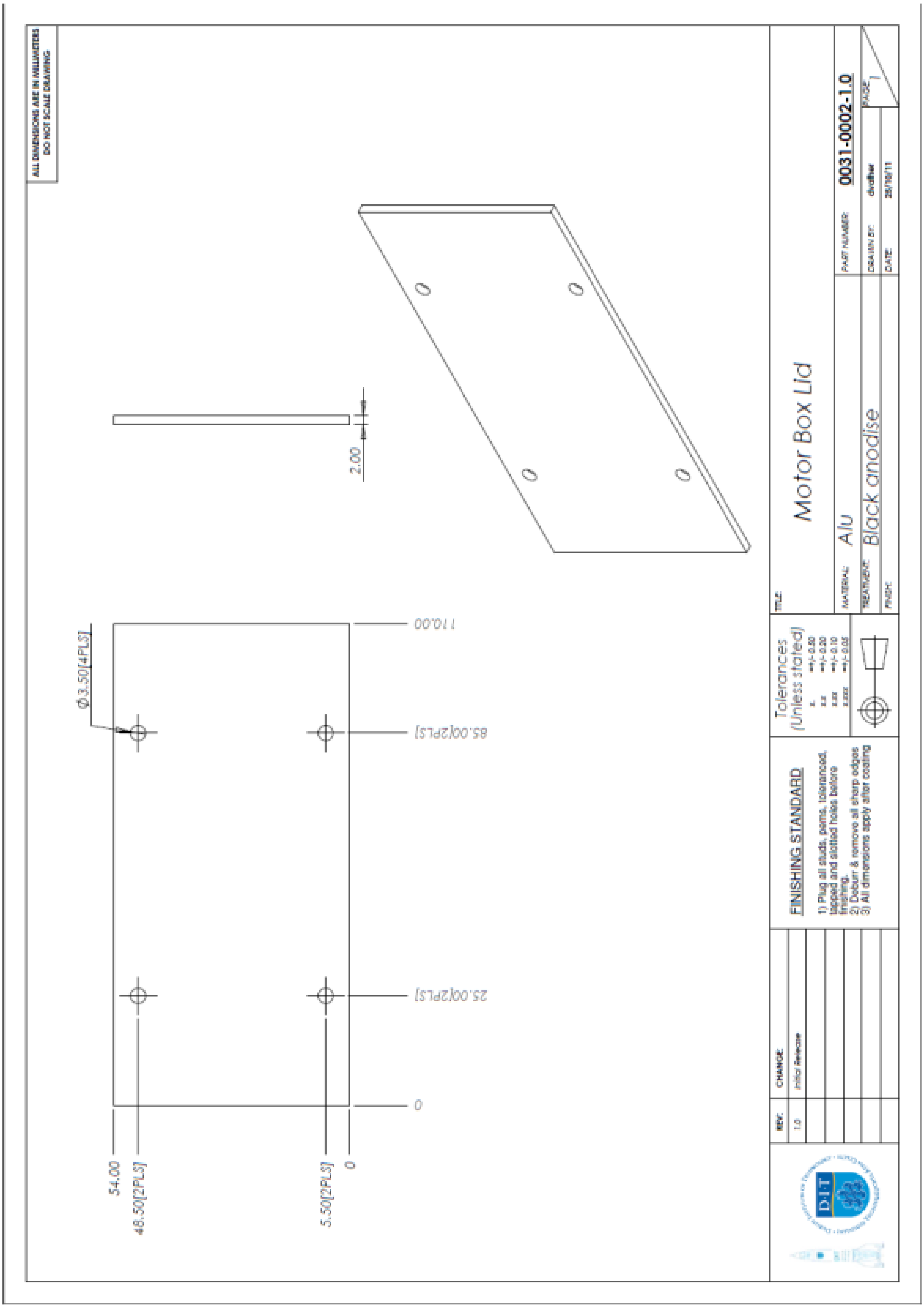

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
0.10 X 45.00°
DETAIL B
SCALE 8 : 1
B
0.50[4PLS]
1.50
M31
Ø28.00
1.00[4PLS]
FINISHING STANDARD
Tolerances (Unless stated)
TITLE:
Window retaining ring
MATERIAL:
Alu
TREATMENT:
FINISH:
PART NUMBER:
0020-0052-1.0
DRAWN BY:
DATE:
PAGE:
REV:
CHANGE:
1.0
Initial Release

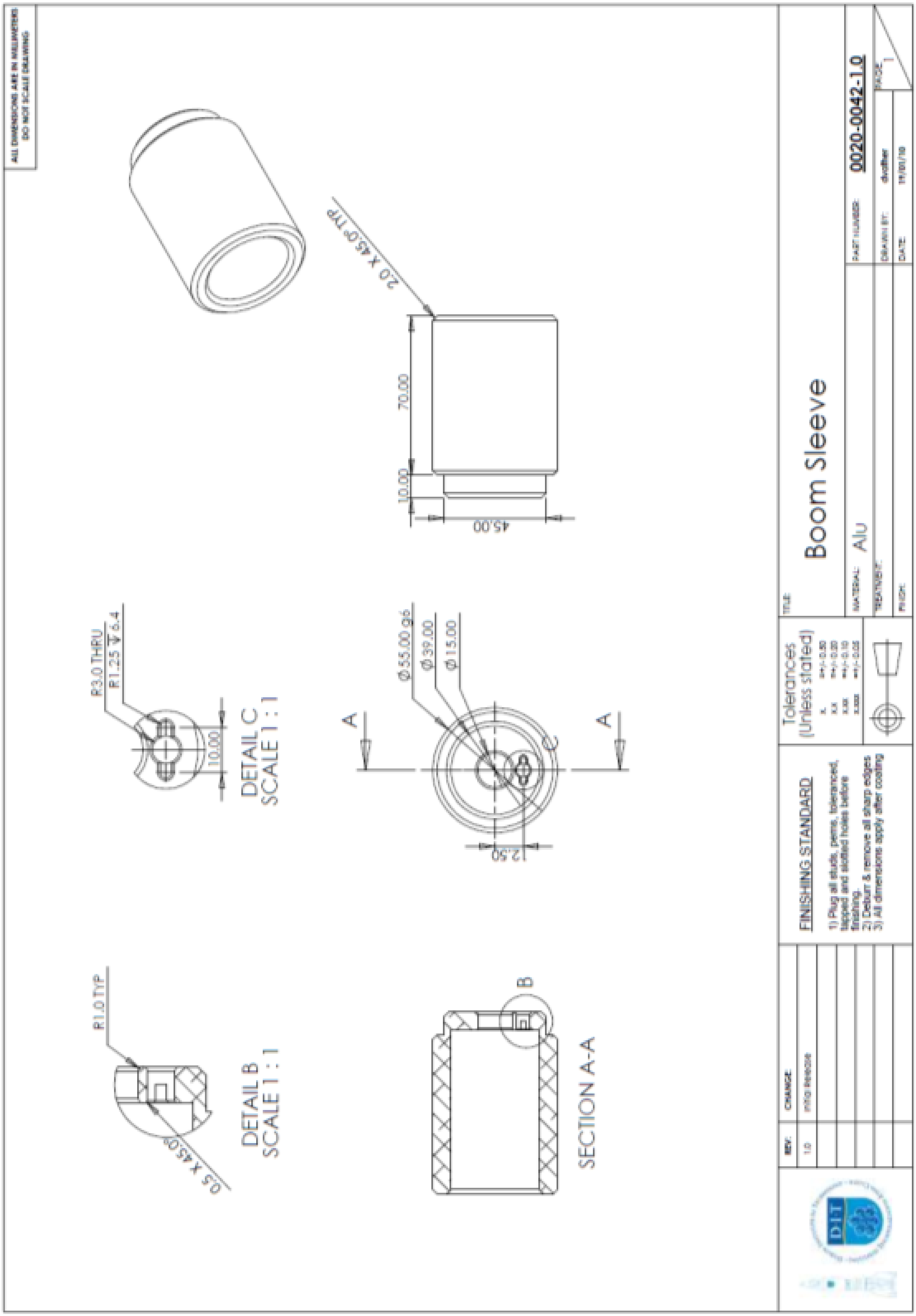


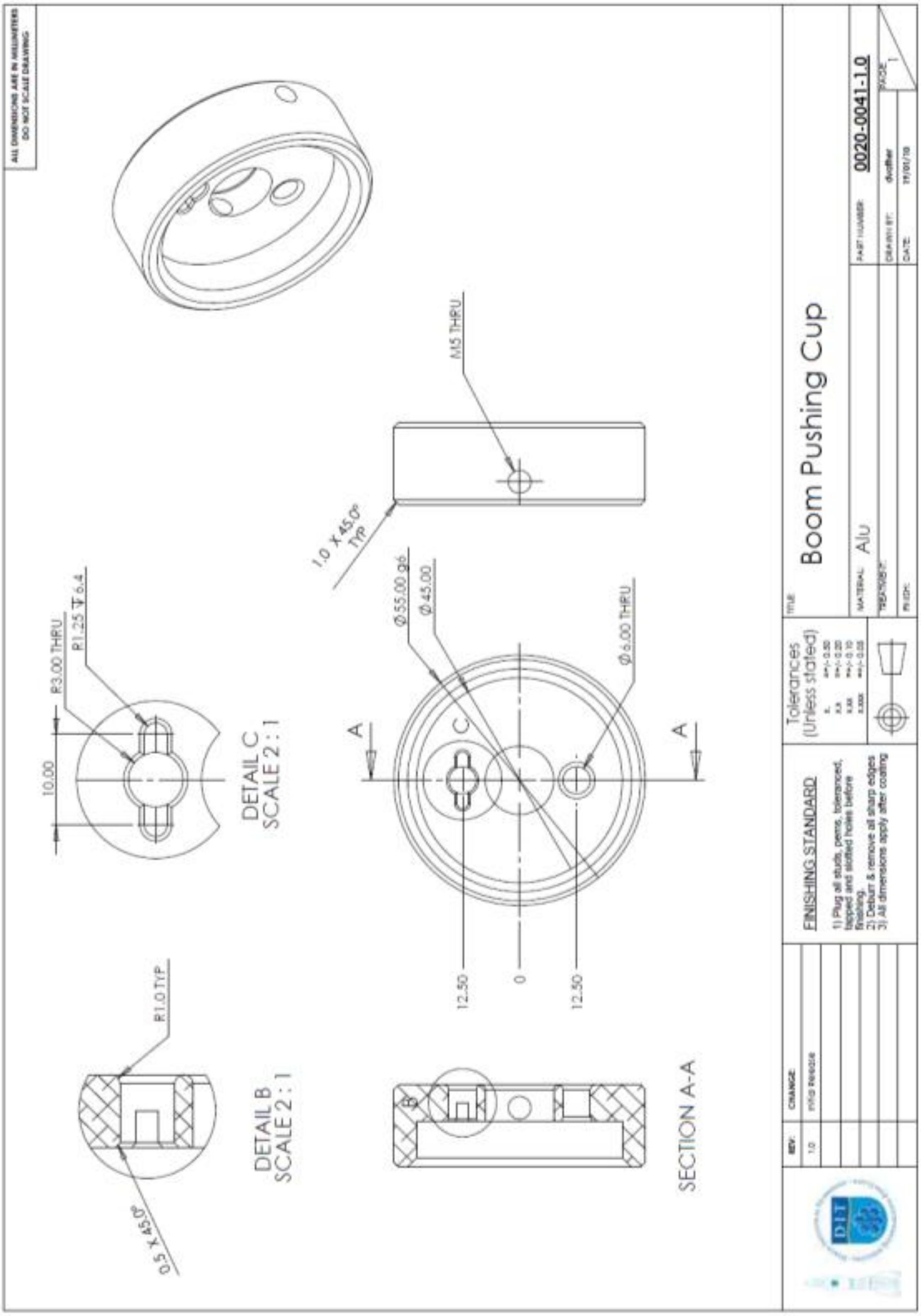
ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
R20.00
M31
Ø26.70
34.50
SECTION B-B
SCALE 1 : 2
R174.00
49.66°
24.83°
12.41°
81.90°
SECTION C-C
SCALE 1 : 2
SECTION E-E
SCALE 1 : 2
Camera Mount Plate
Tolerances
(Unless stated)
FINISHING STANDARD
MATERIAL: Alu
0020-0051-1.0

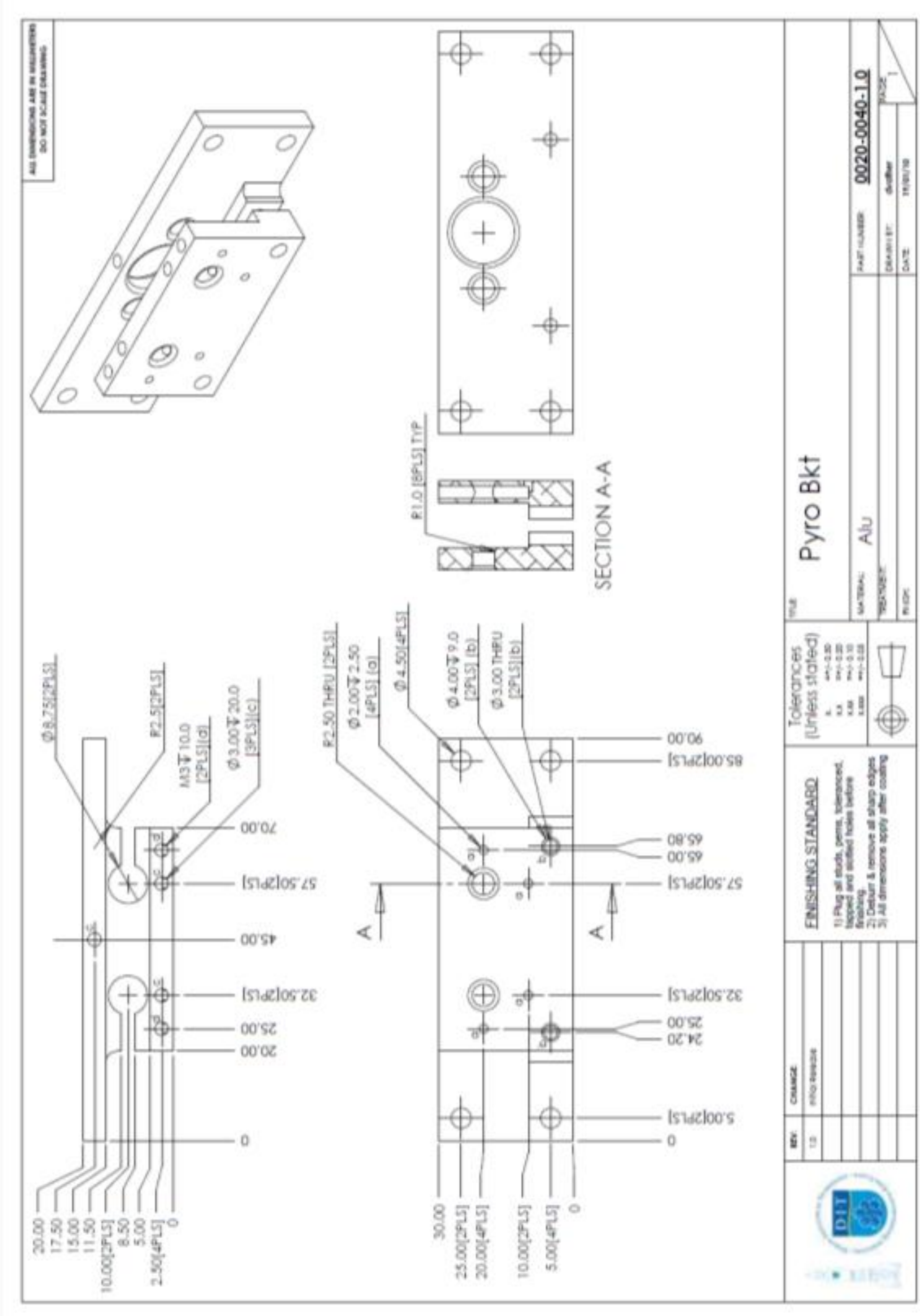

Camera Mount Plate
0020-0051-1.0
Alu
Tolerances
(Unless stated)
FINISHING STANDARD
SECTION I-I
SCALE 1 : 1
R13.50 min.
34.50
4.45 X 45.00°
R3.0TYP
M3 ↧ 10.0
[2PLS]
Ø3.30[6PLS]
182.62
115.00
105.00
102.50[2PLS]
100.00
95.00
90.00
45.00
30.00
27.00[3PLS]
20.00
3.30[3PLS]
60.00
49.00
20.00
8.00
5.00
54.00
44.00
41.00
38.00
34.50[2PLS]
25.00
24.50[2PLS]
14.50[2PLS]
11.00
9.00
8.00
5.00

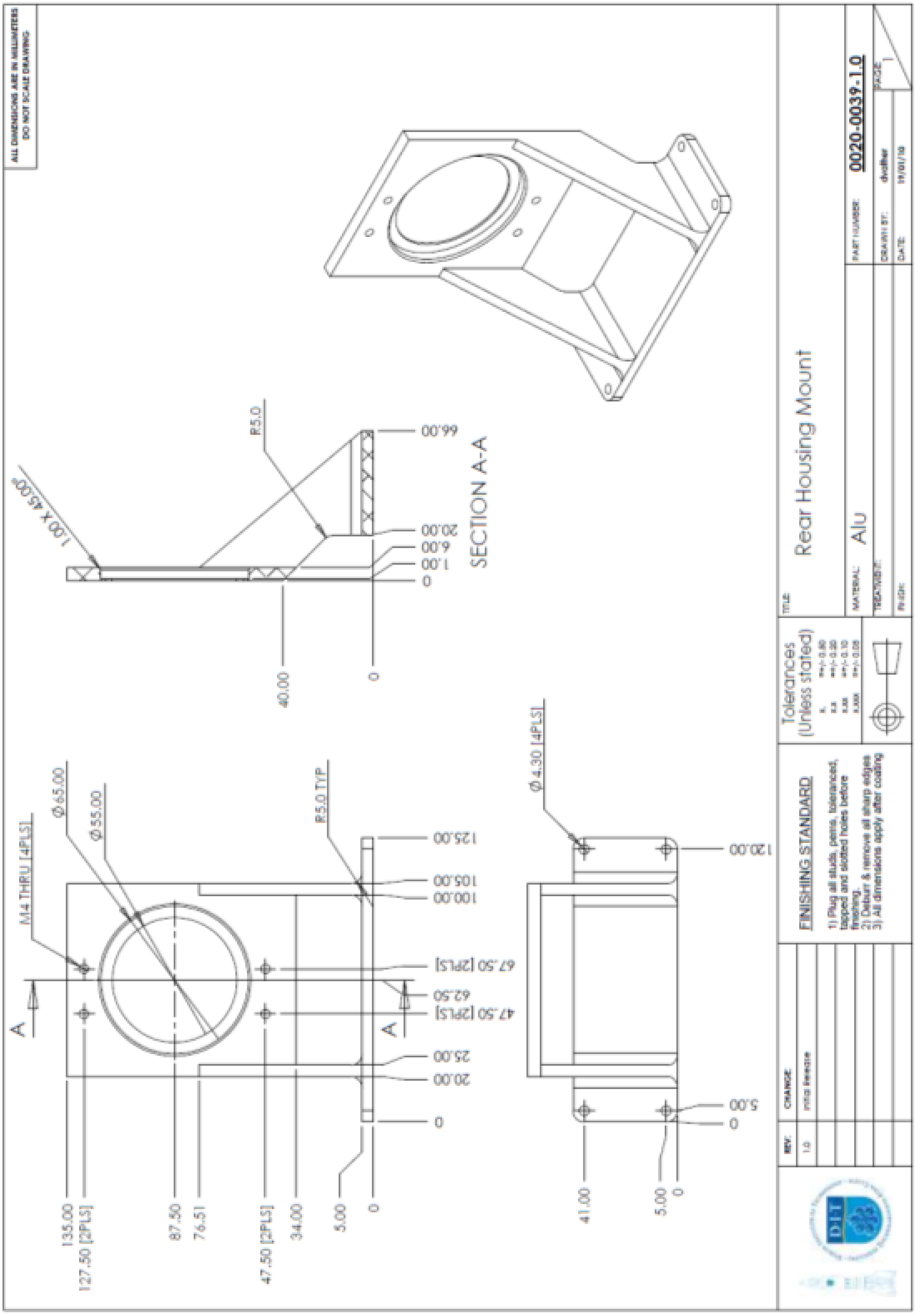

Front Housing Mount
SECTION A-A
0020-0044-1.0
Alu
FINISHING STANDARD
Tolerances (Unless stated)

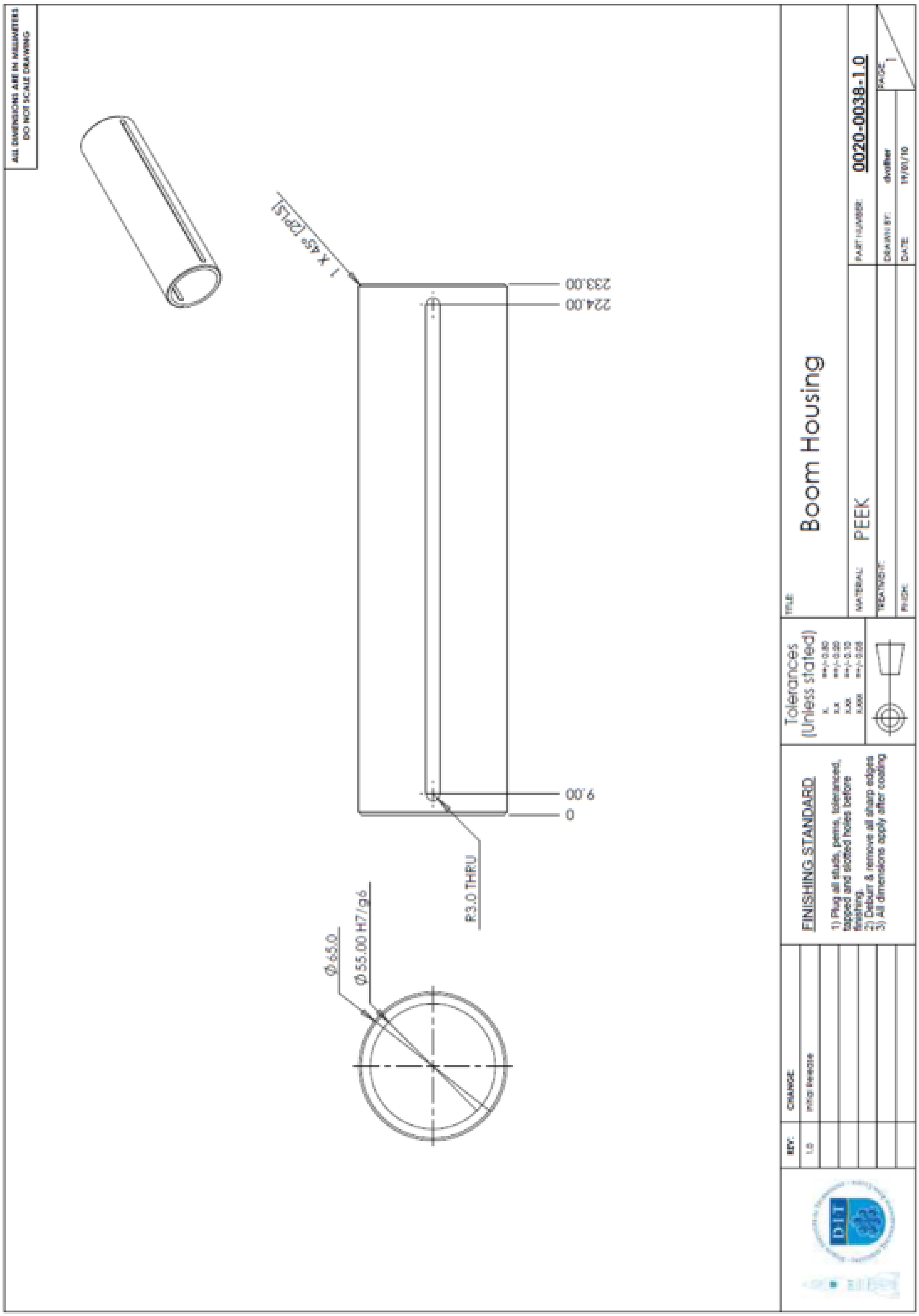

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
Ø3.50[4PLS]
54.00
48.50[2PLS]
5.50[2PLS]
0
0
25.00[2PLS]
85.00[2PLS]
110.00
2.00
REV.
CHANGE
1.0
Initial Release
FINISHING STANDARD
1) Plug all studs, pems, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Tolerances
(Unless stated)
TITLE:
Motor Box Lid
MATERIAL:
Alu
TREATMENT:
Black anodise
FINISH:
PART NUMBER:
0031-0002-1.0
DRAWN BY:
DATE:
PAGE:
1

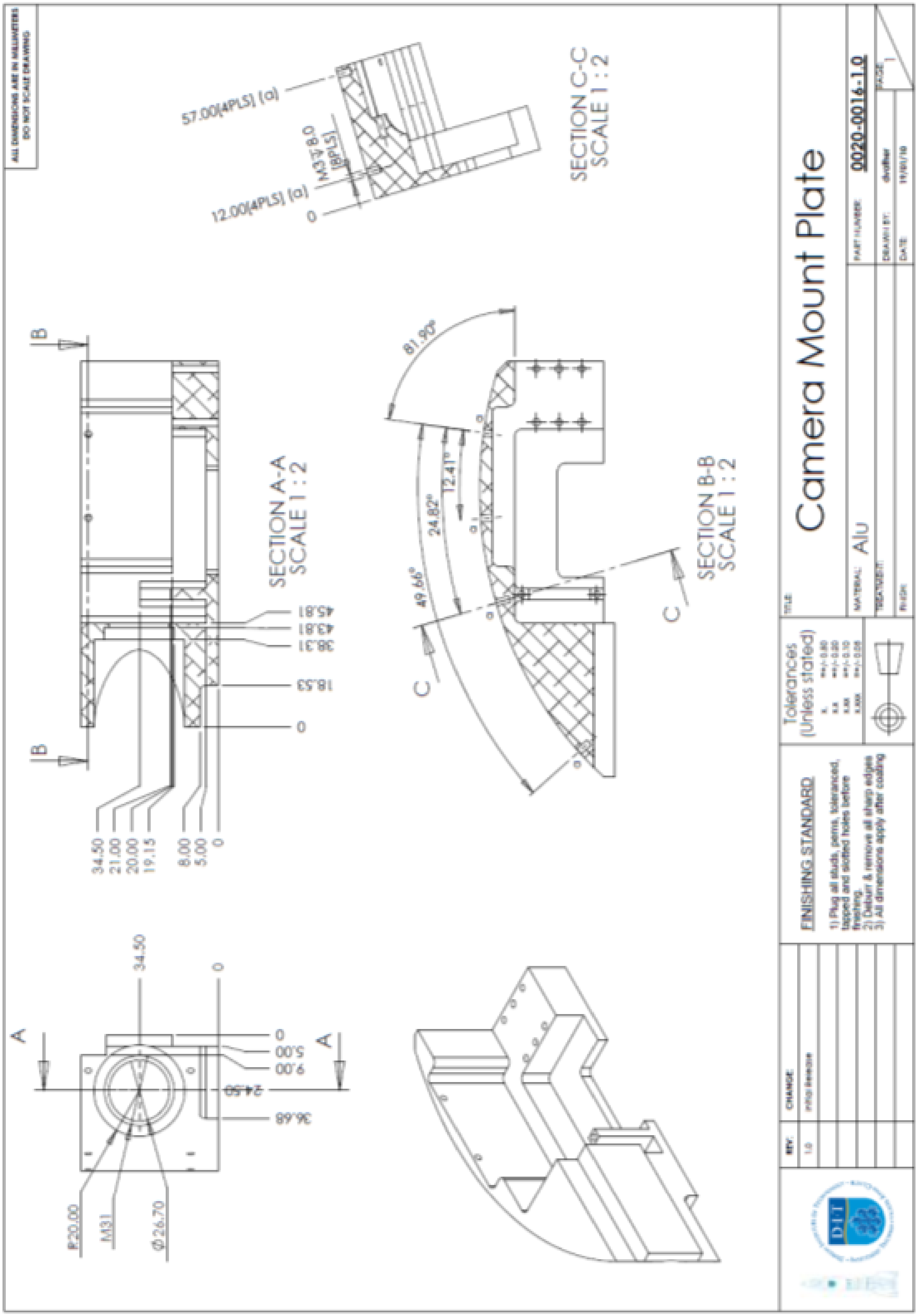

Boom Sleeve
0020-0042-1.0
SECTION A-A
DETAIL B
SCALE 1 : 1
DETAIL C
SCALE 1 : 1
70.00
10.00
45.00
2.0 X 45.0° TYP
R1.0 TYP
0.5 X 45.0°
R3.0 THRU
R1.25 ⊽ 6.4
10.00
Ø 55.00 g6
Ø 39.00
Ø 15.00
12.50
A
B
C
Tolerances
(Unless stated)
FINISHING STANDARD
1) Plug all studs, perms, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Al/u
Initial Release
1.0

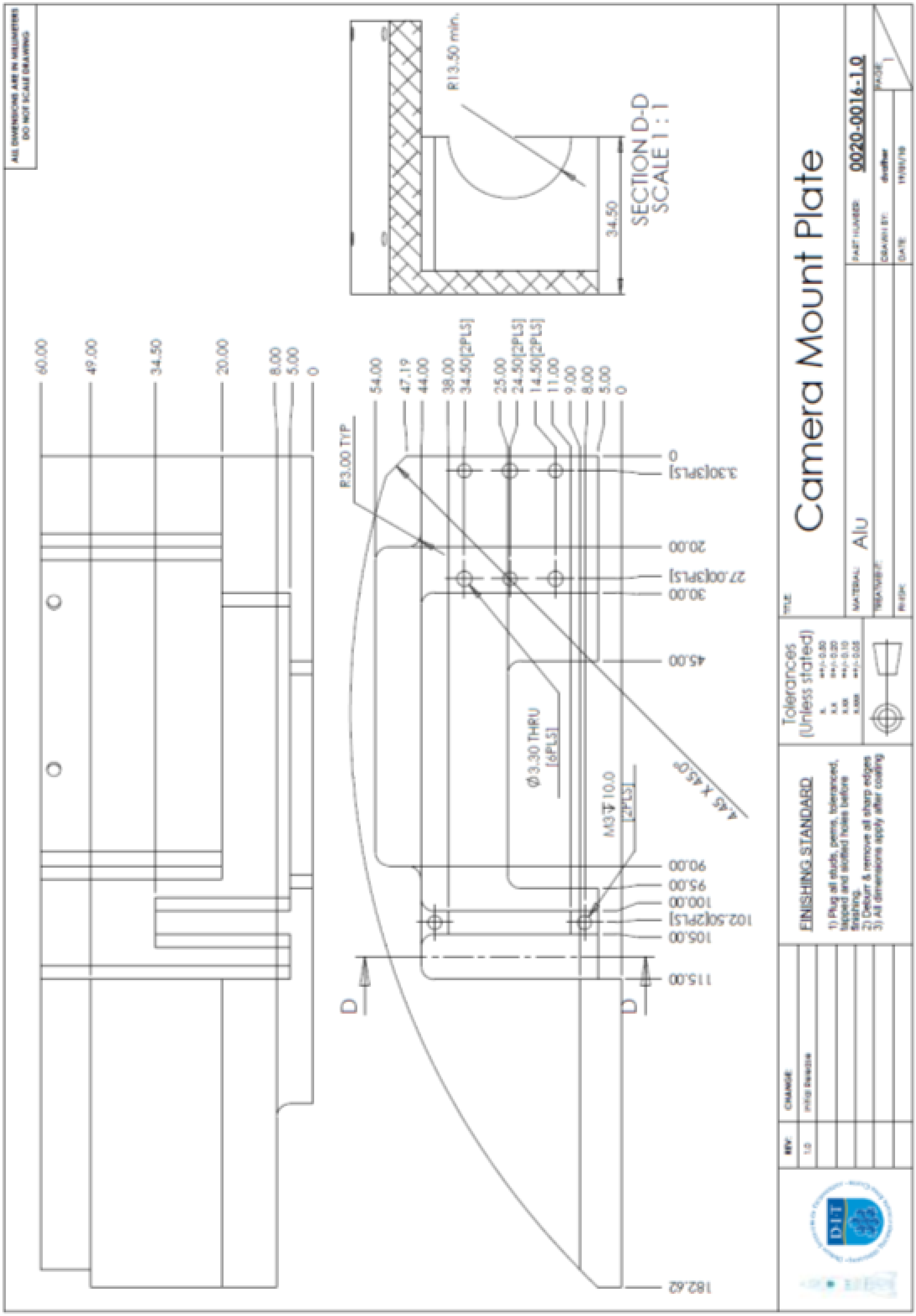

ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
M5 THRU
1.0 X 45.0°
TYP
Ø55.00 g6
Ø45.00
R3.00 THRU
R1.25 ⊽ 6.4
10.00
DETAIL C
SCALE 2 : 1
Ø6.00 THRU
A
A
C
R1.0 TYP
0.5 X 45.0°
DETAIL B
SCALE 2 : 1
B
12.50
0
12.50
SECTION A-A
Boom Pushing Cup
Tolerances
(Unless stated)
FINISHING STANDARD
MATERIAL: Alu
PART NUMBER:
0020-0041-1.0
REV.
CHANGE
1.0
Initial Release


Pyro Bkt
SECTION A-A
Alu
0020-0040-1.0
FINISHING STANDARD
Tolerances (Unless stated)
R1.0 [8PLS] TYP
90.00
85.00[2PLS]
70.00
65.80
65.00
57.50[2PLS]
45.00
32.50[2PLS]
25.00
24.20
20.00
5.00[2PLS]
0


ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
SECTION A-A
M4 THRU [4PLS]
Ø 65.00
Ø 55.00
R5.0 TYP
Ø 4.30 [4PLS]
R5.0
1.00 X 45.00°
FINISHING STANDARD
1) Plug all studs, pems, tolerenced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Tolerances
(Unless stated)
Rear Housing Mount
Alu
0020-0039-1.0
Initial Release


ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
1 X 45° [2PLS]
233.00
224.00
9.00
0
R3.0 THRU
Ø65.0
Ø55.00 H7/g6
REV:
CHANGE:
1.0
Initial Release
FINISHING STANDARD
1) Plug all studs, pems, toleranced, tapped and slotted holes before finishing.
2) Deburr & remove all sharp edges
3) All dimensions apply after coating
Tolerances
(Unless stated)
TITLE:
Boom Housing
MATERIAL:
PEEK
PART NUMBER:
0020-0038-1.0


ALL DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
SECTION A-A
SCALE 1 : 2
SECTION B-B
SCALE 1 : 2
SECTION C-C
SCALE 1 : 2
57.00(4PLS) (a)
12.00(4PLS) (a)
M3∇8.0
(8PLS)
81.90°
12.41°
24.82°
49.66°
Camera Mount Plate
Alu
0020-0016-1.0
FINISHING STANDARD
Tolerances
(Unless stated)


Camera Mount Plate
0020-0016-1.0
Alu
SECTION D-D
SCALE 1 : 1
R13.50 min.
R3.00 TYP.
Ø3.30 THRU [6PLS]
FINISHING STANDARD
Tolerances (Unless stated)

APPENDIX H – EXPERIMENT ARMING PROCEEDURE

The experiment has been designed to be accessed by removing the rocket skin. The main experiment is bolted to the bulkhead while the cameras and camera brackets are mounted to the skin. For assembling and loading the experiment please follow the following steps:

- **Boom Housing**

a. Press fit front and back mountings to peek boom housing tube. Making sure that the guide slots for the spring posts are parallel to the bulkhead surface.
b. Attach front spring brackets to front housing bracket
c. Screw plates to bulkhead (m4).
d. Attach boom guide to front bracket

- **Boom**

a. Clean boom with pressurised air
b. Lube boom using Teflon lubricant.
c. Collapse boom.
d. Make snag on probe PCB cable with green thread at rear of boom sleeve (400mm approx.). This will act to disengage the Winchster plugs
e. Wind boom cable on small diameter rod (approx. 12mm diameter), place retaining probe cable through centre of rod and fix.
f. Tape cable at top end of rod to ensure that it does not unwind while loading through boom.
g. Wind until snag rope and push into boom from back of boom sleeve.
h. Take off tape at top of rod and secure cable to inside of boom to PCB.
i. Wrap by hand the remaining cable (after the snag rope) and fit into rear of boom. Tape against the boom sleeve.
j. Slowly rotate the rod anti-clockwise while pulling from boom.
k. Allow the probe to rotate freely. The boom now has a winded cable inside
l. Fit PCB to front probe and secure to probe back with two screws.
m. Do a power check to ensure that the LEDs and PCB are receiving power

- **Deployment & Jettison**

a. Combine the sleeve and pusher cup

b. Put 400 mm parachute rope (white) through cable post on sleeve, tape ends
c. Put 300mm parachute rope (white) though the insert in the pushing cup
d. Put pusher cup and sleeve together, putting sleeve post and cable through pusher cup hole.

Figure H-1: Deployment & Jettison Configuration

- **Arrange Pyro Bracket**

a. Get pyro bracket with all parts removed.
b. Put pyro's into clamps, align and secure with black socket heads.
c. Put deployment cable (short one) through **top hole** along with green retaining thread, then dowel, making sure that the pyro bracket is topside up and centred and that retaining cable is tight.
d. Put jettison cable through **bottom hole** and dowel
e. Put Winchester through pyro bracket and dowel
f. Fit pyro dowel retaining plate to bracket (not shown below).
g. Boom is now fitted to the pyro bracket

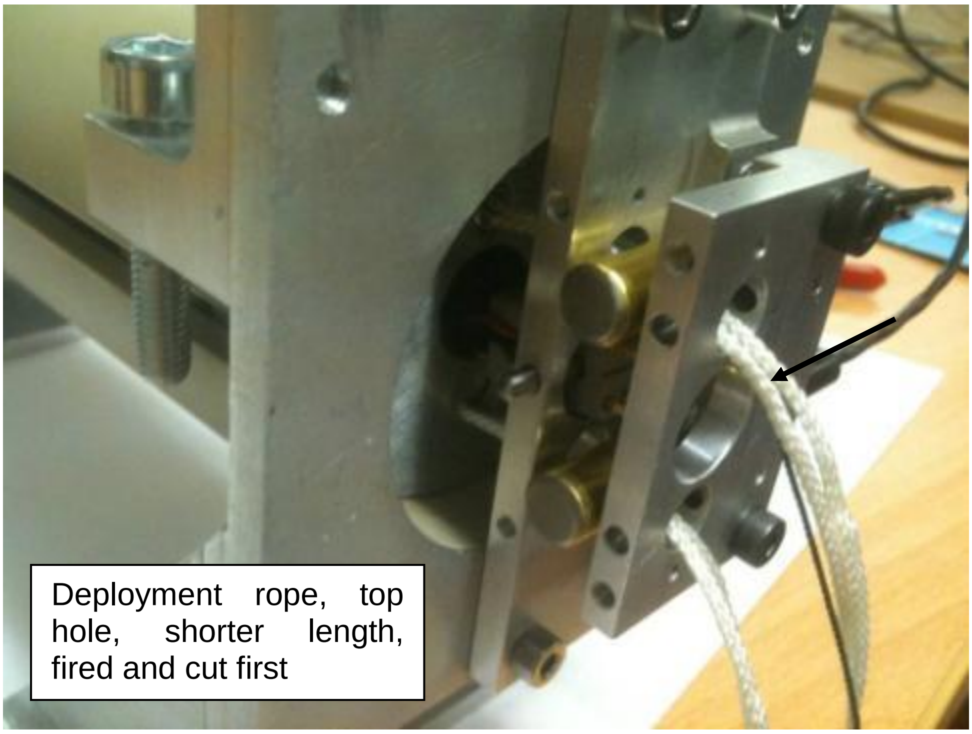


Figure H-2: Pyro bracket in boom housing

- **Loading Boom**

a. Unscrew the back of the housing.
b. Unscrew spring posts from the pushing cup.
c. Tie the green string to the back of the boom [the metal cap.]
d. Coil the wire, place inside the boom and unwind the coil inside it.
e. Parachute cord is used to hold the boom in position. The deployment cord is at the top and tied directly against the pyro bracket, the Jettison cord is at the bottom and 90 mm from the pyro bracket.
f. Tape ends and put under rear bracket for storage.
g. Put the boom inside the housing.
h. Screw spring posts back into pushing bracket.
i. Load the pyros in the pyro bracket.
j. Put on safety glasses.
k. Screw down safety posts with “remove before flight” tags.
l. Put springs in posts.
m. Using rope in the spring eyes, pull the springs past post and into position.

n. Place the three resistance caps into the front of the housing pressing them firmly against the boom.
o. Remove safety post with “remove before flight” tags. The boom is now armed.

- **Arming Boom Retention System**

a. Place the retention chord in one corner of the spring bracket.
b. Press a dowel against the retention chord until it is pressed against the retention chord.
c. A M3 SHC is then screwed through the threaded hole until the dowel is pressed firmly against the retention chord.
d. Pull the string across to the other corner and hold tightly while the dowel is pressed against it.
e. Screw the second M3 SHC against this dowel until the wire is firmly clamped in position. The boom Retention system is now armed.