A FIRST PROTOTYPE OF A SUBORBITAL PLATFORM FOR MULTIPOINT MEASUREMENTS: THE LIGHT AIRBAG PROTECTED LANDER

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ABSTRACT

The aim is to develop a platform for making multipoint electric and magnetic field measurements in the auroral ionosphere. Because of bandwidth limitations data must be stored onboard and a subsequent recovery of the payload is essential. The main objective for the Light Airbag Protected Lander (LAPLander) project was to develop and test such a recovery system. A ballute was designed to take the space probe down safely, and for the localization, an onboard GPS transmitts the location via a satellite modem. LAPLander was launched onboard REXUS 8 from Esrange at 4 March 2010. The rocket reached an apogee of about 88 km. Contact was lost with the space probe after rocket separation, the cause of the failure is unknown. However, the platform design is still considered a viable option for recoverable space probes; it is currently undergoing revision and a new test launch is scheduled with REXUS 10 in 2011.

1. INTRODUCTION

In the last few years, multi-point measurements of plasma characteristics by constellations of satellites, such as the Cluster or Themis missions, have provided a step towards resolving spatial and temporal ambiguities in the magnetosphere. For auroral and ionospheric research, sounding rockets have proved a very efficient means of data collection, and multi-point measurements can here be achieved by ejecting daughter payloads from the main rocket. For a larger number of daughter payloads, radio bandwidth limitations for the data transmission become an issue. By storing data onboard of each daughter and with subsequent recovery of the payloads, the limitations would be lifted, and the collection of large amounts of high resolution data would be possible.

The main objective for the Light Airbag Protected Lander (LAPLander) project was to develop and test a recovery system (RS) customized for a future space probe [1]. Being a project under the REXUS program, a second objective was to provide the involved students with a learning oppurtunity. LAPLander is a disk-shaped space probe with a rotation ($\approx$ 4 Hz at rocket separation) around an axis normal to its flat face. Driving requirements for the RS were:

- Deploy in any mode of flight (wobbling, tumbling or fluttering).
- Minimize the mass and volume required.
- Allocated space inside the probe for the RS is governed by a certain geometry.
- It should (preferably) recover the payload even if it lands in wet terrain (e.g. lake, marsh). Future missions may also be launched over the sea.
- Since the experiment is ultimately intended for measurements of the electric and magnetic fields in the auroral ionosphere, it is vital that it does not contain any magnetic materials.

The idea is to utilize a ballute that will be inflated with CO_2 at an altitude of 5 km. This can in principle satisfy all the above requirements. In addition to the mechanical part of the RS, the payload is also equipped with a radio beacon operating at 169.7 MHz and a satellite modem, which will transmit the payload's GPS position after landing.

LAPLander carried an array of sensors on board in order to post-flight evaluate the performance of the RS:

- One Inertial Measurement Unit consisting of a 3-axis accelerometer and four angular rate sensors.
- One pressure sensor to determine altitude.
- Pressure sensors to record the airbag inflation.
- A number of temperature sensors to monitor the CO_2 cartridge, electronic box, etc.
- One camera to record airbag inflation.
- One state-of-the-art 3-axis digital magnetometer SMILE (Small Magnetometer In Low-mass Experiment).

- One GPS based unit to determine attitude and position, CAGE (Cornell Attitude GPS Experiment).

SMILE is a miniaturized digital fluxgate magnetometer developed by KTH and Lviv Centre of Institute of Space Research of National Academy of Science of Ukraine, based on a miniature sensor (20x20x20 mm) with volume compensation [2]. It has a basic sampling rate of 250 samples/second and resolution of 0.1 nT. CAGE, provided by Cornell University, is treated as stand alone unit, sampling L1 coarse acquisition GPS signals from two antennas at 5.714 MHz. Post flight treatement of the data will yield the payloads attitude and trajectory during the descent by comparing the phase difference of the signals. A FPGA controls all system events and the overall data management.

2. DESIGN OVERWIEW

The exterior of LAPLander with inflated ballute can be seen in Figue 1. Four toroidal airbags are each connected to a CO_2 cartridge and the parachute. The airbags are manufactured using an Aramide fibre sleeve (30 mm diam. at 45 deg, 13 gram/m) on the outside and with a light-weight butyl-rubber bicycle tube inflated on the inside. The later intended to be replaced by a more suitable option in the future. Typical mass of an airbag was 75 grams and the major and minor diameters are 40 and 3.5 cm respectively. Typical inflation pressure is around 6 bar (tested up to 12 bar). Burst pressure is unknown. Each airbag is connected to the parachute at eight points. The parachute is made of coated nylon fabric with a total mass of 66 grams. The beacon antenna is visible as the white cable spaning the airbag to the right in Figure 1.

Figure 1. LAPLander showing the correct ballute geometry.

In Figure 2 the ballute has been folded inside the probe and the hatch is to be closed. LAPLander is a circular cylinder with a diameter of 24 cm and a height of 8.4 cm. On the top disk, the two black GPS antennas from the CAGE experiment are visible. The antenna to the right is an ordinary GPS antenna and to the left is the satellite transmitter. A second GPS antenna and satellite transmitter are present on the botttom disk since the space probe may land on either side. In total LAPLander has seven antennas. Kapton film covers the lander on all sides to thermaly insulate it during reentry. The future aim is to reenter from altitudes up to 250 km. The hatch consists of two 1.5 mm sheet aluminum panels connected by a hinge on the backside (see Figure 8). The hatch is wrapped around the probe by ropes pulling in the ends and is held in place by the grooves on the disks. The disks are made of 3 mm sheet aluminium with 2 mm deep grooves. To eject the hatch, a dyneema rope is melted using an overloaded resistor pushed against the rope by a spring, see Figure 3. The cutter is based on the design of the BUGS experiment (Boom for University Gravity gradient stabilized Satellites), designed by the Gruppo di Astrodinamica dell' Universita degli Studi 'la Sapienza' (GAUSS) [3]. Since the hatch may become hot during reentry, the dyneema rope is thermaly insulated from the hatch using Aramide rope in between.

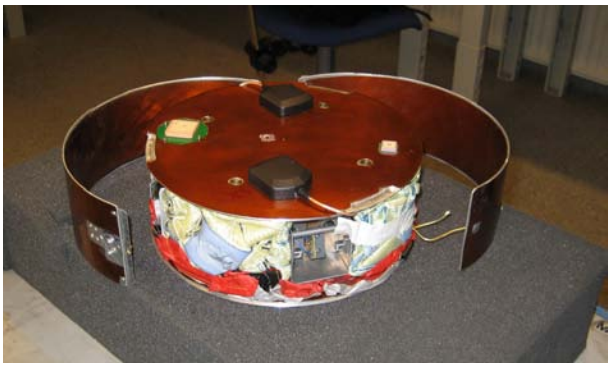


Figure 2. LAPLander with the hatch and the rope cutting mechanism (cutter dummy).

As mentioned before, LAPLander is the first prototype of a miniaturized platform for plasma physics measurements, successors to LAPLander will have four wire-booms for electric field measurements [4]. In LAPLander the wire boom units are represented by four dummies of the same dimensions, see Figure 3. In this version, the dummies are used for alternative purposes:

- Umbilical: where the connection to the rocket service system is located.
- SMILE: contains the SMILE sensor (Small Magnetometer In Low-mass Experiment) and a mascot for the rocket science course at KTH (which also acts as a counterweight towards the heavier Camera dummy).
- Cutter: where the hatch rope is melted and thus ejects the hatch.
- Camera: contains the camera and one analog baroswitch that triggers the RS at 20 000 feet (6.1 km).

The square electronic box is positioned in the middle. The disks are attached to the electronics box using threaded plastic (PEEK) supports. In each corner a CO_2 cartridge is screwed to the electroninc box. The cartridges are CNC-milled aluminium and have an assembled mass, including control circuit boards and cabling, of 89 grams without CO_2. The valves work by the principle that Field's metal plugs four holes on a circuit board, to release the valve, the metal is melted using four resistors, see Figure 11, ref. [1] and [5]. About 1.5 W of input power for 2 s is required to open the valves. Airbag supports are mounted on each side of the cartridges, made of 0.5 mm sheet aluminium, in order to prevent the airbags from moving. A close-up of the airbag supports with airbag can be seen in Figure 4. The blue fabric is glued to the Aramide fibre sleeve and screwed to the supports, black tape covers the screws so that the airbag will not get caught at deployment. Plastic film and tape are used at various locations for this reason.

3. VARIOUS EXPERIMENTAL RESULTS

A wind tunnel experiment indicated that the drag coefficient of the ballute is near 1.0 based on the length L of the sides of the parachute ($A_{ref} = L^2 = 0.74^2$ m^2). This has been confirmed by other tests such as a drop test from a helicopter at 1500 m, see Figure 5. These experiments also showed that the ballute is stable falling with the parachute side down. Both permeable and non-permeable parachute fabric were used and a paper model also indicates that the ballute is stable for low Reynolds numbers ($Re_L \approx 4 \times 10^4$). For LAPLander the landing speed would be less than 10 m/s. The ability for the ballute to take impacts has been tested qualitatively; a landing speed higher than 10 m/s will not result in a "soft landing". Aeroelastic effects must also be considered. The ballute does not deform or flutter notable at an air speed of 8 m/s. A loading test predicts that if LAPLander rests at the floor, it will move the lander ≈ 5 cm closer to the floor if ≈ 8 kg is put on top (at 4 bar). It should be reasonable that it would stand 15-20 m/s in a static point of view (at sea level).

Delays with the CO_2 cartridges resulted in that only one realistic test was performed; that is, with all four cartridges filled and the ballute packed inside with the hatch on, see Figure 6. All four airbags deployed but did not do so correctly. Before this test, different folding strategies had been tested to work under semi-realistic conditions. The frame at $t = 0$ is the instant at valve release. Eventually two airbags exploded because they did not fully unfold and thus reached bursting pressure. In the last frame all motion has ceased.

Under the hypothesis that the deployment failure (in Figure 6) was caused by the folding, a new test was performed, but this time the ballute was not folded inside the space probe. Three airbags inflated successfully, however, the last airbag inflated near 90 $\deg$ from the nominal direction due to the influence from the other airbags. The

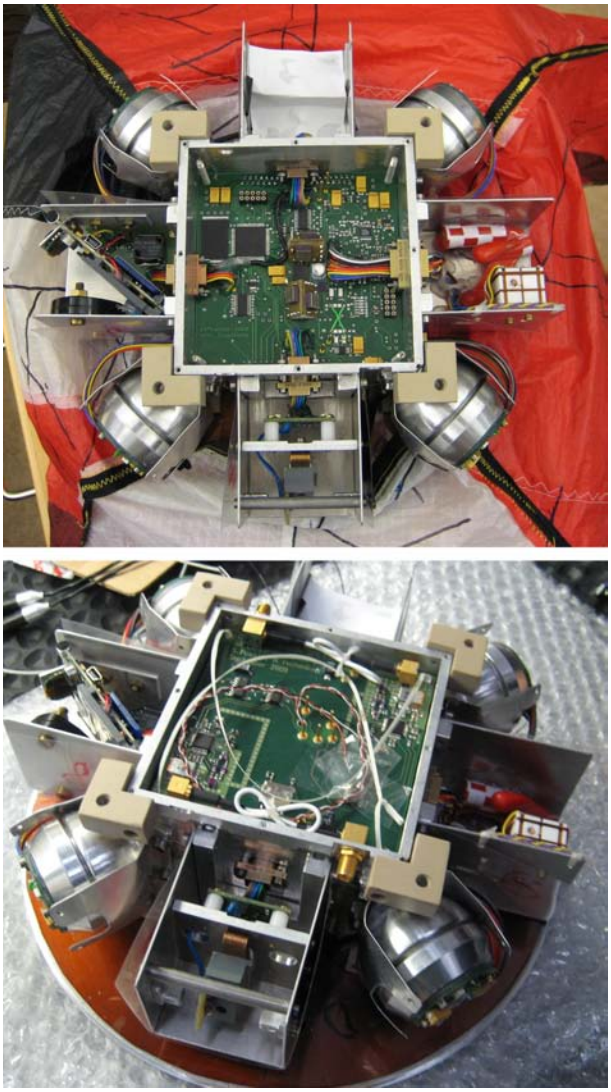


Figure 3. LAPLander with removed top disk, electronic box lid and airbags. The dummies; umbilical (top), SMILE (right), cutter (bottom) and Camera (left). Four angular rate sensors can be seen on in the center of the circuit board on the prism-shaped supports.

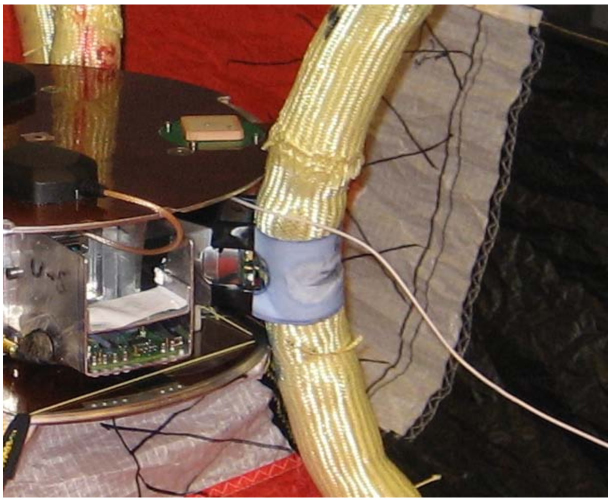
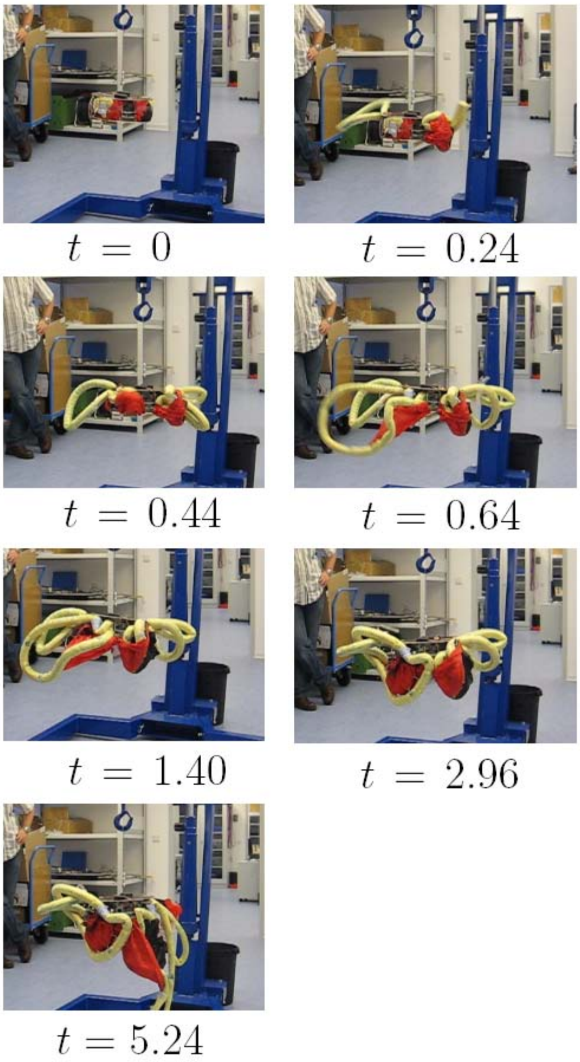


Figure 4. Airbag support and umbilical dummy.

Figure 5. A scale 1:1 model with rigid airbags in free flight from a helicopter at 1500 m, seen from a distance.



$t = 0$

$t = 0.24$

$t = 0.44$

$t = 0.64$

$t = 1.40$

$t = 2.96$

$t = 5.24$

Figure 6. Realistic inflation test at DLR (Deutsches Zentrum für Luft- und Raumfahrt) in Bremen, Germany.

problem may be prevented in future versions by using a coated Aramide fibre sleeve and connecting the parachute to the cartridges. Because the Aramide fibre sleeve was not coated, its diameter varied with pressure, and the individual threads in the sleeve could move about. This seemed to cause many problems.

The cutter system works well. It has been tested at minus 30°C and after mastering a vibration test. Typical cut time is less than 5 sec at 4 W of input power.

4. INTERFACE TO THE ROCKET

LAPLander is positioned inside the nosecone of the rocket and mounted to the adapter for ejectable experiments named the center tube, see Figure 7. On the center tube there was a kicker plate that would prevent the space probe from rotating inside the rocket, and to ensure a successful ejection. Four circular slots with a diameter of 20 mm were milled out in LAPLander's bottom disk and heels were raised out of the kicker plate. Three clamps hold LAPLander safely in place during the ascent of the rocket until ejection. The clamps are pushed against the center tube with a taut wire. Initiating the separation process is done by cutting the wire with two (for redundancy) pyrotechnical cutters. Cutting the wire will lead to that the clamps fall off since their mounting is mechanically unstable in itself but also since the rocket is rotating (≈ 4 Hz) they will be affected by the centrifugal force separating from the rest of the structure. A conical spring is positioned between LAPLander and the kicker plate for safe and quick ejection after the clamps fall off.

An umbilical connector was needed to provide communication and external power while the space probe was mounted inside the rocket, see Figure 8. The umbilical connector consisted of two parts, one mounted on the center tube named Rocket socket (male) and one inside the umbilical dummy (female), see Figure 4. The rocket socket was made out of the plastic VeroWhite since its complex geometry required free form manufacturing. Seven gold plated connector pins was used to penetrate the bottom disk and connect with connector hats inside the umbilical dummy. To isolate the connector pins from the grounded LAPLander aluminum structure Teflon plugs were used. The rocket payload after flight can be seen in Figure 9.

5. LAUNCH CAMPAIN AT ESRANGE

REXUS 8 carrying LAPLander, was launched from Esrange at 11:15 LT the 4th of March 2010. The rocket had an apogee of about 88 km. LAPLander is expected to have a similar apogee. The launch mass of LAPLander was 3043 grams (2747 grams without the hatch). Because of valve failure before launch, LAPLander flew unpressurized.

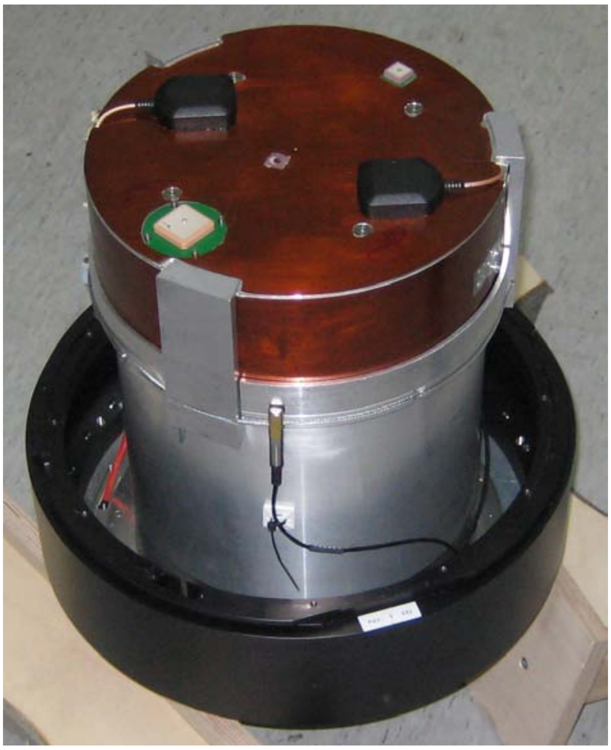


Figure 7. LAPLander integration to the rocket. The nosecone will be attached to the black cylinder which is the fuselage of the rocket. The pyrotechic cutter and wire can be seen holding the three clamps which in turn hold LAPLander.

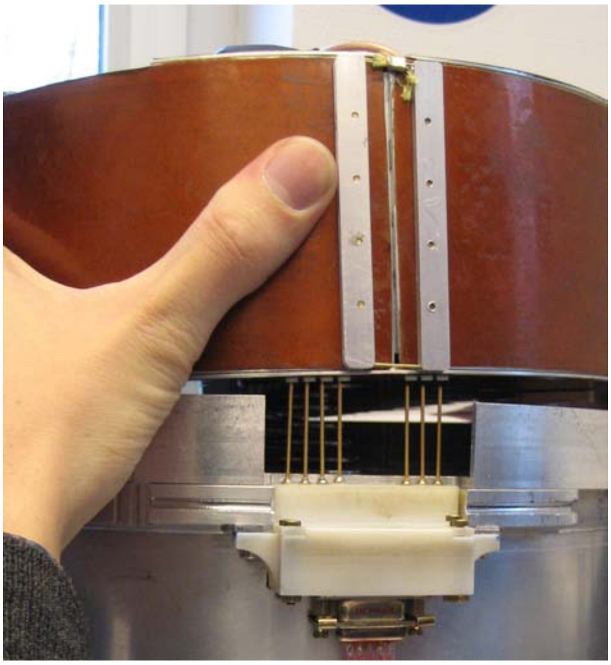


Figure 8. Connection to the rocket. Rocket socket (plastic unit with pins) going into LAPLander, and behind it, a conical spring at the center to eject LAPLander. The hatch hinge can also be seen.

During the ascent, the system provided data from all sensors through the REXUS Service Module up til the point of ejection. No signals were received after LAPLander left the rocket which indicates that the space probe can have been turned off at ejection. Because of this no conclusions can be drawn whether LAPLander would manage an impact or not. In the future someone may find LAPLander in Lapland, Sweden, then some light will be shed on this matter; if the main payload and the hatch are separated, then LAPLander was likely not turned of at ejection and the first part of the recovery system worked as intended.

As mentioned before, there was a problem with the valves. In some occasions, soldering problems caused failure at the second day. To be sure that this would not occur, they were always filled at least two days prior to assembly. The CO_2 cartridges were filled with 9 grams of CO_2 ice (max 13 gram). Six days later one valve failed. At this point LAPLander was situated on the payload in the workshop. Two loud noises could be heard, likely from when the dyneema rope that holds the hatch panels in place snapped, followed by the airbag burst. The wire and clamps succesfully held LAPLander in place (see Figure 7). The inflated airbag damaged the SMILE dummy as can be seen in Figure 10. After this failure the valve was resoldered and the cartridge filled again. Another valve failed the same day eight hours later, fortunately precautions had been taken, and LAPLander was not assembled to the payload. By then it was clear that the system could not be trusted; therefore, the three remaining valves were released on purpose one at the time. This is how Figure 1 came to be.

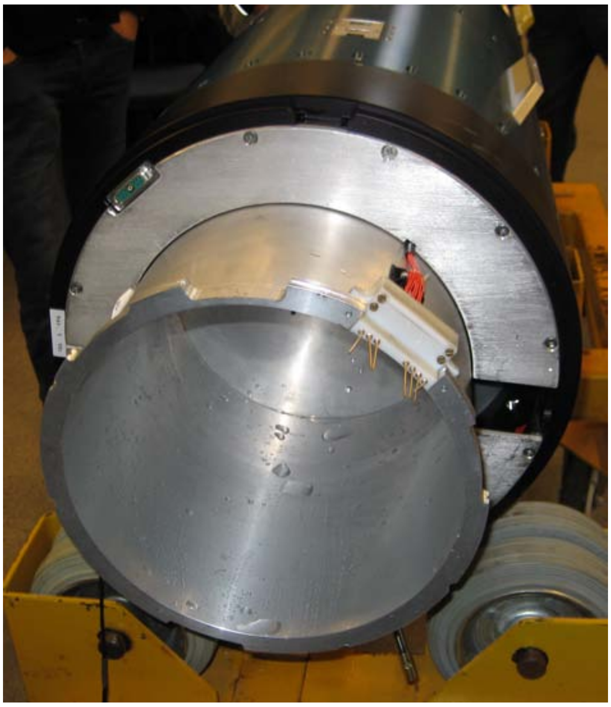


Figure 9. The payload efter flight. LAPLander and the kicker plate has left the rocket as planned. The rocket socket pins are bent from the landing and the deployed pyrotechnic cutter can be seen hanging under the center tube.

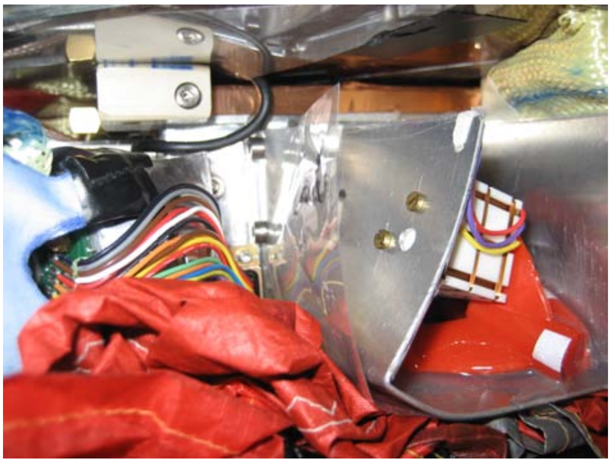


Figure 10. SMILE dummy after valve failure.

When inspecting the failed valve it seemed like the solder had not come loose from the copper laminate, instead it looked smeared over the copper laminate. This may be caused by a shear fracture inside the Field's metal, see Figure 11. Creep may be a central issue in the failure since it is a phenomena that becomes notable for metals at typically half the absolute melting temperature. For solders it is notable in room temperature and a main cause of failure [6]. Since the Field's metal (51%In, 32.5% Bi, 16.5% Sn) has a low melting point near 62C° this is a reason to be alarmed. Another important factor is the wetting of the solder joint, when using a better solder station the valve could manage the load for a longer duration. Using conical and/or smaller holes for the Field's metal in the future may solve this problem.

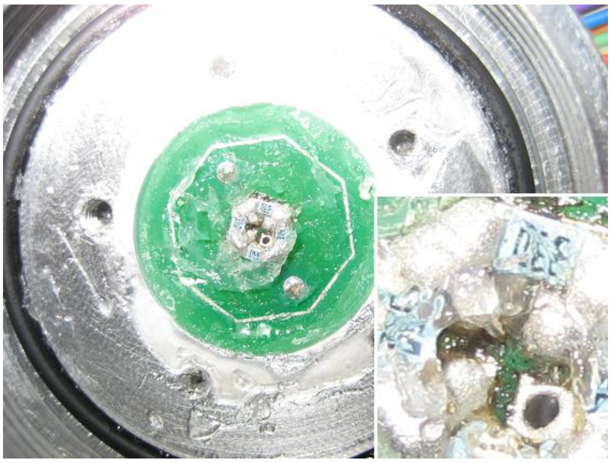


Figure 11. Looking at the pressure side of the CO_2 cartridge lid after the valve failure. The four valve resistors are thermaly insulated by grease and a PEEK plate (removed in figure).

6. CONCLUSION

The RS presented in the report has potential to perform well provided that the inflation and valve/cartridge issues are solved. The solution to the first problem may be to use coated Aramide fibre sleeve and redesign the parachute/airbag interface. The second problem may be solved by a redesign of the valve/cartridge. Because of limited time the successor to LAPLander, SQUID (Spinning QUad Ionospheric Deployer) due for launch with REXUS 10 in 2011, has choosen a parachute as a mean of recovery.

In the future the ballute may be inflated in space to provide a shuttlecock reentry. A silicone based inner bladder can be used. The drag coefficent is higher than other ballutes (e.g. sphere-cone, clamped toroid) in the subsonic regime; however, it is unknown wether this configuraion is stable in the supersonic regime.

ACKNOWLEDGMENTS

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EuroLaunch, a cooperation between the Esrange Space Center 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. REXUS and BEXUS are launched from Esrange Space Center in northern Sweden.

LAPLander was built at the department of Space and Plasma Physics (a unit in the Aflvén laboratory) at the Royal Institute of Technology (KTH), Stockholm, Sweden. CAGE is provided by Cornell University. Additional support in the development has been provided by A-MEK Verkstad, Autoliv, FOLA Airsafe, Försvarsmakten-LedR, KiteKraft, Nanospace, Nolato Sunne, Top Notch Design and TOOLS momentum, listed alphabetically. Special gratitude is directed to the helpful technicians at the Aflvén laboratory that endured having the students in the workshop and our hard working supervisor Nickolay Ivchenko.

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