Report in EF2225 – Project course in Space physics

Design of LAPLander’s mechanical and electrical interface towards the Rexus 8 sounding rocket

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Abstract
This report tells the reader why, how and how good the design of an interface between a scientific payload and a sounding rocket became. The challenge was making the LAPLander solidly mounted inside the rocket during a 20g rocket launch, while easily separating from the rocket given a specific signal. If that was not a challenge enough, there should also be an electrical connector, guaranteeing a connection at all times, but very easily disconnecting during the separation of the payload and the rocket.

The design of the mechanical interface is with the highest probability reusable. The separation mechanism can be reused for the upcoming SQUID project, also the concept with the anti rotation heels and slots.

Tests showed that the mechanical and electrical interface was of flight quality and the ejection mechanism worked during separation in flight. During the campaign the umbilical connector worked flawlessly as well as during launch.
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Introduction/Background

During the 2009 and 2010 a team of students at KTH Plasma and Space Physics Department have been developing a Light Airbag Protected Lander (LAPLander) for scientific research. The LAPLander project is a part of ESA’s Rexus 7/8 program set to be launched in March from ESRange, Kiruna.

The Rexus program allows students from all over Europe to do scientific research with rockets and balloons. Up to 20 student experiments will be carried into space via two rockets or two balloons. The rockets used are 5.6 meters tall with an improved Orion motor with 290kg solid propellant. It is unguided but spin stabilized to reach a maximum altitude of 100 km. Funding of the program is provided by the German Aerospace Center (DLR) and the Swedish National Space Board (Rymdstyrelsen).

The LAPLander is a space probe prototype, intended as a platform for future measurements in the ionosphere. The first prototype will be a ‘proof of concept’ for the general platform, including the impact system (tanks, valves, airbags and parachute). Also the flight characteristics of the LAPLander will be evaluated (e.g border of space to ground travel, air braking). The platform will be used in the future for multi point measurements to investigate complex processes in the ionosphere that cause disturbances for satellite communication and contribute to the northern and southern polar lights.

Since the LAPLander project had been ongoing before the task of interface design towards the rocket was addressed, the LAPLander had already a basic design. That was the biggest constraint when designing the electrical interface. The choice of what technology to be used in the umbilical connector was thus the question the constraint gave. Should pins or springs be used to relay the signals through the connector? In the final design a pin connector was chosen. The biggest mechanical constraint came from the fact that the Suanieadh team’s experiment would be ejected from the rocket and their position in the rocket was directly underneath LAPLander. That affected the ejection mechanism and the overall design of the umbilical connector. The mechanical interface was co-developed with the Swedish Space Cooperation (Rymdbolaget) who also needed to take into consideration the Scottish project Suanieadh interface.

The project started in September 2008 and development continued in to the beginning of 2010. The deadline for applications was in November 2008 and on the 13th of February LAPLander was selected together with six other experiments. The LAPLander team presented their project at the preliminary design review and got vital feedback from experienced personnel in March 2009. At the critical design review in Oberpfaffenhofen the design of the LAPLander was put under evaluation by DLR, ESA and SSC personnel making sure that the LAPLander would not in any way jeopardize the safety of the launch. Topics such as accidental airbag deployment inside the rocket and radio transmitter related issues and more importantly their solutions were discussed and reviewed. The LAPLander team passed it with flying colors with only a few remarks regarding some formalities.

The interface was developed between June 2009 and January 2010. The length of the interface design project was due to several factors, one was that other issues needed to be resolved parallel to the development of the interface in this project, such as general manufacturing of LAPLander parts to name an internal factor. The electrical interface was ready in the beginning of December 2009 and therefore it could be validated by the electrical team of LAPLander. To complete the mechanical interface after a digital development processes between LAPLander and SSC the mechanical interface integration took place at ESRange space center in the beginning of January 2010. The integration
went well with only a few solvable issues that needed to be addressed. During the integration at ESRange the ejection mechanism was tested. Later on during the winter of 2010 a vibration test took place in Bremen at DLR facilities. A first mechanical resonance peak at just above 200Hz were found, but the amplification in the structural system was still low enough even at the resonance frequency. Software integration took place at DLR in Munich (München).

Suanieadh influenced the mechanical interface of LAPLander a great deal since they were supposed to be positioned directly underneath LAPLander in the rocket. From the mechanical perspective this meant that a kicker plate needed to be used as a part of the ejection mechanism to minimize the risk of having a malfunctioning ejection. The ejection system also consists of a wire, a wire cutter and three clamps to safely and securely mount the LAPLander inside the Rexus 8 rocket. To make sure the LAPLander doesn’t twist or turn while mounted, four heals are raised in the kicker plate and four sockets are submerged into the heat shield. The heels and the sockets are necessary to prevent any load on the umbilical connector’s connector pins. The rocket socket (one of the umbilical connector’s connector) is positioned on the side of the magic hat center tube of the rocket which is an adapter for ejectable experiments).

The second part of the umbilical connector is the umbilical dummy. It is composed by an electronic circuit board with has special connector hats. The pins from the rocket socket are inserted into the connector hats to successfully relay the signals. The circuit board relays the signals via a mini D-sub 9 connector to LAPLander’s electronics box. Inside the umbilical dummy there is also a micro switch that switches off dangerous electronics (e.g. airbag deployment, cutter electronics) while inside the rocket. The pins are isolated from the aluminum structure using Teflon plugs. Teflon’s low friction coefficient also has the advantage of enabling a fairly easy separation of the umbilical connector.

LAPLander was launched during a two week long campaign. The liftoff took place on the 4th of March 2010. All working systems were nominal during the countdown and the separation of the LAPLander and the Rocket went very well. That is unfortunately the last thing to date anyone can say anything about the LAPLander since the STX2 satellite modem for some reason neither relay any GPS position of LAPLander’s trajectory nor landing spot. It’s of course a great disappointment not to have retrieved the payload but the greatest value from this project is not the result, but it is the learning journey that each team member has done and the knowledge created about a multi point measuring platform with the intension of using the platform in projects in the future.
Electrical Interface

Requirements
- The umbilical connector must never fail to provide contact.
- It shall relay six signals (+8V, GND, External Rx, External Tx, SOE (Start Of Experiment) & SODS (Start Of Data Storage)).
- Provide a safety switch for potentially harmful electronics.

Solution

General Overview

LAPLander communicates with the Rocket through the Not So Smart Box (NSSB) and the rocket socket. The X1 to X6 makers in the overview are for reference purpose later on in the Electrical Interface section. X1 and X2 are two D-sub 15 pin connectors, X3 and X4 are two D-sub 9 pin connectors, X5 is six pins and X6 are six connector hats.

Schematics
The overall level of the electronics in the umbilical connector was basic; all signals were relayed through to the electronics box except for the powering of the LAPLander were a bi stable latch was used to switch internal battery power on and off. For schematics of the circuit board of the umbilical connector, see Appendix B.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Pin (from the left)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+8v</td>
<td>1</td>
</tr>
<tr>
<td>External Rx</td>
<td>2</td>
</tr>
<tr>
<td>External Tx</td>
<td>3</td>
</tr>
<tr>
<td>GND</td>
<td>4</td>
</tr>
<tr>
<td>SOE</td>
<td>5</td>
</tr>
<tr>
<td>SODS</td>
<td>6</td>
</tr>
<tr>
<td>None (Mechanical)</td>
<td>7</td>
</tr>
</tbody>
</table>

Pin one and four in the connector interface (X5 & X6) provides power to the LAPLander when necessary so batteries can be avoided to be drained. Pin two and three are used for RS-232 communication. The fifth to power on and off the experiment, this is a feature required by ESA for safety reasons during the countdown. SODS (pin six) lets the experiment know when it can start to store data from the rockets service module, this is to avoid wasting memory when data will be anyhow corrupted.
The NSSB is both a RS-422 to RS-232 converter and a 28V to 8V DC/DC converter. It relays the incoming signal from the rocket’s service module through a D-SUB 15 pin connector (X2) to the rocket socket (X4) which is connected with a D-sub 9 pin connector (X3). More about the NSSB can be read in Johan Juhléns and Joakim Sandströms (LAPLander team members) reports about the LAPLander project in the course EF2225.

**Function**
The connector consists of two parts, one rocket socket and one umbilical dummy. The rocket socket is mounted on the rocket while the umbilical dummy is inside the LAPLander. Pins go through the heat shield to connect the connectors. The connector relays signals between the NSSB and LAPLander’s electronics box. Inside the umbilical dummy there is also a power switch.

The connector hats on the circuit board in the umbilical dummy have each three springs inside of them, ensuring contact if the pin is inserted properly. This design has a margin of about 1.5 mm of insertion depth.

The mechanical pin pushes a micro switch lever so that the circuit with possible harmful electronics is open, thus making sure the LAPLander while inside the rocket is not going to start cutting the ropes to the hatches, start inflating the airbags, transmit a homing signal with the beacon or send messages with the satellite transmitter.

**Design concepts**
Two main design concepts where brought forth. The first concept was based on pins that could be inserted into connector hats. The connector hats have springs inside of them thus ensuring contact at all times, as long as the pin is inserted deep enough. The second concept alternative utilized springs that would relay the connection onto tins. Both these methods have been used before in other space projects, but the constraints that were already built into the LAPLander would prove to become the decider.

The pin design was chosen because of two main reasons. The advantage of the tin spring design concept is that it has a low probability to jam compared to the pin design concept however since the LAPLander must have one pin to push a lever on a switch through the bottom heat shield, that advantage is no longer valid. The tin spring design concept also would have meant that cables had to be drawn on the inner side of the bottom heat shield where the parachute is and that could result in implications for parachute deployment mechanism. A suitable connector hat had been found early in the concept evaluation process which meant that the pin design concept could be verified in a proof of concept test. The small test was successful so there was no reason to waste more time and to delay manufacturing even further. The pin design concept was chosen and proved to be successful during the campaign.
One advantage that the spring-tin concept still has over the pin concept is that mounting of the LAPLander in the rocket would have been less complicated of two reasons. First there was a risk of that the folded parachute inside the LAPLander would hinder the pin transmission between the heat shield and umbilical dummy inside the LAPLander. Secondly, to get all seven pins in the holes at the same time was viewed a potential problem, but the final design proved it not to be cumbersome but rather trivial with the right technique.

After the design strategy of using pins instead of springs and tins was decided for an umbilical connector, a more explicit design in CAD was developed. After the development using CAD-software, a first mechanical prototype six pins was developed, to see how much friction and what tolerances the design could handle. It became apparent that under no circumstances would there be a risk of the ejection mechanism jamming due to the friction between the pins and the isolating Teflon plugs. The first preliminary prototype also concluded that the connector would be harder to separate if the LAPLander had rotated inside the rocket, thus a fixing mechanism needed to be designed in the mechanical interface.

Design

Rocket Socket
To manufacture one half of the umbilical connector, the rocket socket (seen in white in Figure 1) a company in Stockholm, called Top Notch Design [1] printed out the base piece of the rocket socket from the 3D-model in a material called VeroWhite. That solution was chosen since VeroWhite does not conduct electricity, is strong enough for this application and it allows for free form manufacturing. Given the complex geometry of the two base pieces of the rocket socket made the rocket socket extremely hard to manufacture properly without computer aided manufacturing due to all the various manufacturing steps that would be needed in a conventional workshop.

![Rocket socket](image)
First the pins were soldered to the cables. Secondly the pin sockets were threaded onto the cables and heated so that the applied soldering filler would float out the make a nice concave joint between the pin and the pin socket. The cables where then soldered onto the back pins of the D-SUB 9 female connector.

A cutout in the bottom piece of the rocket socket allowed the D-sub connector to be passed through its hole with already soldered cables and allowing manufacturing to become easier. The alternative would have been to solder the cables to the D-sub connector when the bottom and the top piece of the rocket socket would have been attached. The problem with the alternative would have been to solder the cables properly with short enough cable length, something that became much easier if the bottom part of the rocket socket could be mounted afterwards.

**Umbilical Dummy**

To manufacture the umbilical dummy (second part of the connector, seen in figure 4 together with rocket socket) a sheet of aluminum was cut out bent into the correct shape, after that another piece of 1mm aluminum was glued on as a bridge to support the micro switch. Cyanacrylat super glue was used to glue the aluminum pieces together and also the micro switch to the bridge.

The circuit board was designed at KTH, manufactured by an external company but soldered at KTH. To isolate the pins from the aluminum dummy (and also the shield) Teflon plugs where used, mainly because their availability, but they proved to be low friction and have the right dimensions for the pins to fit.

![Figure 4 - Umbilical Dummy + Rocket Socket](image-url)
Mechanical Interface

Requirements
- Provide an easy separation only when needed.
- Don’t damage or hinder any of the other functions.
- Prevent rotation of the LAPLander while mounted.

Design

General Solution
LAPLander is solidly mounted into place with the help of three clamps. The three clamps tightly hold down the LAPLander into the kicker plate. Cutouts in the LAPLander upper heat shield, with an angle of 5° ensure that the can clamps press onto the shield hard enough but still fall off easy when separation is initiated. The steel wire holds the clamps solidly into place.

![Figure 5 - LAPLander with mounting mechanism](image)

The steel wire stays in place around the center tube thanks to a notch in the outer ring and the clamps as seen in figure 5.

Ejection mechanism
The ejection system must work flawlessly or else if the LAPLander is still mounted to the Rocket LAPLander will shut off during the flight to protect it from sending radio signals. It is so important that a large standalone part was designed, manufactured and adapted for the single purpose of safely separating the LAPLander from the rocket.

![Figure 6 - Kickerplate (Black Part)](image)  ![Figure 7 - LAPLander (Seen from the bottom side)](image)
In figure 6 and figure 7 one can see the mechanical interface between the LAPLander’s bottom shield and the kicker plate. In figure 7, there is a large cutout in the center of the kicker plate, 3 mm in depth where the 3mm thick conical spring is compressed when the LAPLander is mounted. If you compare the figures 6 and 7 again one sees that there are four slots in the LAPLander and four heels in the kicker plate that prevent rotation.

The ejection process starts by letting both of the wire-cutters (An explosive shoots a razor through the wire) cut off the steel wire. The explosives will be detonated electronically and then, due to tension in the wire and centripetal force the clamps leaves the mounting position and enables the LAPLander be a free satellite after it have been pushed out by the spring.

**Materials & Mounting**

**General**

Since a magnetometer developed in house at Space and Plasma is one of the sensors of the LAPLander only paramagnetic metals such as aluminum and titanium or non ferromagnetic alloys such as brass could be used. Any steel alloy is out of the question.

**Umbilical dummy**

The bridge between the two sides and the dummy itself were made form a 1 mm sheet of aluminum and they were mounted with cyanacrylat glue. For insulation the same kind of Teflon plugs was used in the dummy as well as for the heat shield. PVC rings were used as distances between the umbilical dummy and the umbilical circuit board.

To mount the umbilical dummy L shaped mounting brackets of aluminum were glued onto the electronic box with epoxy. The umbilical dummy was then screwed onto the mounting brackets with titanium screws.

**Rocket socket**

The main body of the rocket socket is made out of a free form manufacturing polymer called VeroWhite. It proved to be a good material for the rocket socket due to its complex shape with the only weakness of having a poor heat resistance, though during launch LAPLander did not become hotter than 40 degrees during launch.

The connector pins were made out of a brass base with a gold and nickel plating. The pins were bought from Wearnes Cambion Ltd in the United Kingdom.
The rocket socket was mounted with two screws onto the center tube into a socket. The magic hat slot is just as deep as the rocket is high socket meaning that the magic hat will provide some mechanical support.

**Tolerances**

The anti-rotation heels in the kicker plate only fulfill their task if they are just the same dimensions as the cutouts in the heat shield. They got to be manufactured with less than 5/100 mm precision.

The relative positioning of the pins with respect to each other and their holes in the free form manufactured top part of the rocket socket are vital. The holes in the heat shield and umbilical dummy are precision drilled using a milling machine with a digital coordinate system capable of drilling a hole with less than 1/100 mm precision in its positioning.

The pins were 1,03mm in diameter and that meant even though the pins could slide within the Teflon plugs without modification, a hole expansion to 1,1mm in diameter was needed for a smoother release.
Tests
Several small and a few large tests have been done making sure the functions can be guaranteed. Two larger test proceedings have taken place, a vibration test at the Experiment Acceptance Review in Bremen and a separation test during the overall integration between the LAPLander and the Rexus rocket at ESRange, Kiruna.

Separation test
A separation test took place at ESRange, Kiruna in January during the integration before the experiment acceptance review, where the LAPLander, the kicker plate, the center tube, the ejection spring, the wire and the clamps where assembled for the first time and the ejection mechanism was tested.

The difference from a nominal ejection mechanism was that the rocket socket was not mounted because of worries if the ejection procedures would bend the rocket socket connector pins. That lead to a second rocket socket was manufactured as a backup when the integration test was over. Another difference was that the wire was not cut by pyrotechnic cutters but with a pair of pliers due to the high cost of an explosive cutter. One cutter was tested after the separation test and it successfully cut the steel wire without any problem.

The test was overall successful. When the wire was cut and the camps fell of LAPLander and the compressed spring ejected LAPLander from the center tube with a pitch slight rotation. The test was filmed.

The test helped the development in two ways. First the spring was flipped so the broad base of the conical spring will at flight press on the LAPLander and the top of the spring will press on the kicker plate instead of the other way around. That is to stabilize the ejection. The other thing that was realized was that even though the clamps flew off fast, the centripetal force will make the clamps leave even faster during separation since the rocket spins at 3Hz.

The test concluded that this is a stable ejection system that will ensure a safe ejection, although manufacturing wise it’s complicated and mounting can be cumbersome due to that the wire needs a high tension and at the same time the clamps won’t stay on themselves (they have been designed that way).
Vibration test
On the 14th of January 2010 during the Experiment Acceptance Review (EAR) at DLR in Bremen the LAPLander was put to a vibration test. The test aimed to ensure that nothing would come loose from the LAPLander, internally or externally, mechanical or electronically components. Extensive test results can be found in test document FAB-ATR-310001 from the Vibration Test Lab at ZARM-FAB, Munich.

Test equipment used for the test was the following. The

- Shaker / Slip Table / Power Amplifier
  Manufacturer: Ling Dynamic Systems.
  Model: LDS V 875-440 / HBT 600 Combo & SPA 40/56K v3.
- Control and Measurement Software
  Manufacturer: Mahrenholtz + Partner.
  Model: VibControl/NT.
- Data Acquisition and Control Unit
  Manufacturer: Hewlett-Packard.
  Model: VXI-Mainframe E1421B Digitizer E1432 Interface E8491B.
- Charge Amplifier
  Manufacturer: Bruel + Kjaer.
  Model: Nexus 2692 A OS4.
- Accelerometer
  Manufacturer: Endevco.
  Manufacturer: Bruel + Kjaer
  Model: 4383.

A resonance search test was performed between 10 and 2000 Hz at an acceleration level of 0.25 g with a sweep rate of 2 octaves per minute. The resonance search was performed on all axes. After the resonance test a random vibration test between 20 and 2000 Hz was performed. In both cases
the power spectral density was 0.018g^2/Hz. The RMS value of the acceleration at the random vibration tests was 5.97g and the test duration was one minute.

During the test, the umbilical connector did not fail to provide contact enabling the software engineer to send commands to and receive status messages from the LAPLander. The clamps held the LAPLander solidly into place during the vibration test the second run so that function is confirmed to work as intended, however during the first run the cable holding the clamping brackets were not tightened enough resulting in the brackets losing their nominal interlock position. This issue was resolved to the second random vibration test. Another resolved issue was that three out of four brass screws and nuts holding the two piece rocket socket together loosened due to improper tightening. Tightening the screws harder resolved the issue.

In the second resonance test run a resonance peak around 220Hz was found for the entire structure and another resonance spectrum around 1000Hz. Subsequently this resulted in vibration amplifications at the resonance frequencies in the structure.

**Discussions & Conclusions**

Overall, the project has resulted in an umbilical connector that worked during the Rexus 8 campaign. It has also developed a mechanical interface and separation mechanism that can be used not only for the LAPLander project, but also serve as a base for future development in the upcoming KTH project SQUID in Rexus 9/10.

The umbilical connector could have been made much simpler if the Suanieadh experiment would not have been directly underneath LAPLander in the center tube. Then a new umbilical connector based on the pin solution could have used, inserting the pins directly into the electronic box inside the LAPLander and thus freeing a dummy for other use.

The development of the mechanical interface was done closely together with SSC. The solution chosen was suggested mainly by SSC and it’s a solution that parts of it have been used before but not all together. At the start of this project, it was already decided that Suanieadh would be positioned underneath us, so the general outline was then decided.

Having to separate from the rocket after launch in a safe way first a system of spring loaded pushing rods were considered, though the problem with that solution would be that the initial ejection trajectory of the LAPLander would possibly go elsewhere but straight up breaking off any of the seven umbilical pins. A kicker plate was introduced as a fix for that problem. The LAPLander should leave the Rexus 8 rocket with the help of a conical spring between the LAPLander and the kicker plate. All these design decisions were taken for with the strategy of getting the LAPLander out of the rocket as safe as possible.

Not only precautions with the separation have been taken, it has also been vital not to allow the ejection mechanism to malfunction. One possible scenario would be that the Laplander would rotate under the camps and the kicker plate, causing stress of the pins that would increase the possibility of pin breakage. Thus the design of the kicker plate and the LAPLander bottom shield was equipped with four slots and four heels, eliminating rotation.
Appendix A – Blueprints

Umbilical dummy
Heat shield
Kickerplate
Appendix B - Schematics
Umbilical Circuit Board