REXUS / BEXUS

Experiment Proposal Form

Full experiment title	Light Airbag Protected Lander

☒ **REXUS** ☐ **BEXUS**

- ☒ spinning with 4 Hz
- ☐ despun with Yo-Yo

Science & Organisation

What is the scientific and / or technical objective of your experiment?	*This description should outline the scientific / technical question addressed, the assumptions made and the research methods chosen to solve the question. Expected results should be stated.* The objective of the project is to design, build and validate a prototype of a small ejectable sounding rocket payload capable of collecting data in an on-board memory. The current proposal concerns the airbraking, impact protection and recovery systems, along with the study of flight characteristics to evaluate the payload performance. The **airbraking and impact protection system** will be based on inflatable airbags that serve both to decelerate the payload and to protect it at the moment of impact. After having reached the ground, the payload shall transmit its position via both a satellite link and a radio beacon to allow for **recovery of the payload** and the collected data. Measured data will be used to study the **dynamics of the payload and its thermal behaviour**. We will have multiple sensors (accelerometers, rotation rate, magnetometer, temperature sensors), and **use a novel attitude determination system** based on the dual antenna GPS receiver developed at Cornell University (USA). The design is ultimately intended for ionospheric measurements of electromagnetic fields, where a larger number of small payloads (≥4) will be able to provide both a spatial and temporal resolution of ionospheric characteristics.
Why do you need a rocket / a balloon?	As LAPLander is a prototype of a future payload intended for ionospheric measurements, we wish to put it to test for similar conditions, i.e. a ballistic flight with apogee above ~100 km altitude. A spinning payload is the requirement for the future scientific mission, as the electric field probes utilize the centrifugal force to

	stretch out the wire booms. Understanding dynamics and thermal characteristics of the payload during the descent from high altitudes are crucial for planning for future missions with higher apogee. These demands can be satisfied by a 4Hz spinning rocket.
Where did you get the idea from?	*e.g. research programme at your university, already performed similar experiment, scientific publications, books, etc.* The Division of Space and Plasma Physics (SPP) at the School of Electrical Engineering, KTH, has a long-standing expertise in experimental studies of space plasma, particularly using measurements of electric and magnetic fields. In situ measurements have intrinsic space-time ambiguity, as they are done along the trajectory of a single probe. Multipoint missions, such as the ESA Cluster spacecraft are a step towards resolving spatial and temporal details of plasma electrodynamics. Aurora, and particularly its small scale structure, is an object where important results can be achieved with sounding rockets which have lower velocity across the magnetic field than satellites, and give a chance of measuring the most interesting events by calling a launch based on auroral characteristics. Daughter payloads can be released from rockets, and carry out distributed measurements without active control of the formation, which is important for satellites. The SPP group has been collaborators on NASA multipoint rocket missions, such as Auroral Turbulence, and Cascades. The group at KTH has developed a scalable and lightweight boom deployment system (SCALE), and has suggested a method of fast deployment without boom oscillation [*Ivchenko et al.,* 2007]. This opens an interesting possibility of studying auroral electrodynamics with a large number of small probes released from a single rocket. A recovery system for such small payloads would eliminate the need for multiple TM links, and, in the best scenario, make large parts of the payloads reusable. To our knowledge, there is no standard recovery system for a spinning payload with a mass of a few kilograms. Development and demonstration of such a system will promote multipoint rocket measurements in the ionosphere.

Describe your experiment	*This part should link the scientific objective to the experiment itself. Explain how you are going to fulfil the scientific goal.* We propose to design and build a free-flying payload equipped with an airbraking and recovery system. To achieve this, we will use inflatable airbags both to increase the cross-section of the payload, and protect the payload on impact. The alternative solution of using a parachute is complicated for spinning payloads, and may also lead to a larger mass and volume, without providing the impact protection. For locating the payload on the ground, we will use a redundant system with a radio-beacon and a satellite link transmitting the

	payload's position. The second goal of the project is to investigate the dynamics of the descent of a rapidly spinning disc-shaped body. Here we will use data from multiple attitude sensors to reconstruct the rotation of the payload. Project success criteria (in order of decreasing importance): 1) Payload is successfully ejected from the main rocket, localized and recovered. 2) The collected data are recovered and the payload's behavior is evaluated. 3) The payload has suffered only a limited amount of damage and can be reused in future missions. 4) Payload dynamics is understood in terms of theoretical predictions and simulations
Which data do you want to measure?	LAPLander will record the following parameters during the descent: - Three-axis acceleration - Three-axis rotation rate - Three-component magnetic field - Temperature for various parts of the payload - raw GPS data, for post flight trajectory and attitude reconstruction in collaboration with Cornell University - Payload GPS position on the ground (to relay to localization system) The data will later be used to recreate the trajectory, temperature, deceleration and attitude during the descent and compare it to our modelled results.
How do you want to take measurements?	Data will be continuously collected during the mission and stored in an on-board memory. The memory and data will later will be recovered and analyzed.
Describe the process flow of your experiment?	- the payload will be ejected from the rocket above 90 km. - The payload will free-fall from the apogee altitude (~100 km) while continuously collecting data. - At between 2 and 4 km altitude, the payload will deploy protective airbags to help slow the descent and protect it during the impact. - The satellite localisation system will start up and transmit its GPS position. - The radio beacon will send out a localization signal to facilitate the payload recovery. - The collected data will be recovered and analyzed.
What do you plan to do with your data after the flight?	The recovery of the recorded data is in itself an important objective of the mission. We plan to use the data in order to reconstruct the descent characteristics and compare these to our model. This will give us information on how a small rotating disc-shaped payload behaves in the atmosphere, particularly during the high-altitude stage of the descent.

	The attitude of the payload will be reconstructed from the magnetic field measurement, and from the novel dual antenna GPS receiver. Reconstruction of the attitude will allow reconstruction of the torques on the payload, and its rotational stability. Accelerometer data, along with the accurate GPS position will be used for assessing the drag forces.

Organisation of your project

How will you organise / distribute work within your team? Please note that you are responsible for all aspects of your experiment (science, mechanical & electrical engineering, software, etc.)

The team consists of seven participants (see below). We will work closely as a group with regular group meetings and discussions. In order to facilitate the work and to benefit from the different skills and experiences that the group possesses, every member has primarily been allocated as a primary responsible in charge of one of our four main topics: (1) *General and scientific issues*, (2) *Electrical Engineering, Electronics and software* (3) *Mechanics and design* and (4) *Aerodynamical issues and models*. The work will however require a lot of interplay between the groups and many of the issues are of cross-topical nature.

General and Scientific issues

Group coordination, overall design issues, coordination of the outreach programme and scientific objectives, overall documentation.

Torbjörn Sundberg

- Phd in Space Plasma physics, KTH, Sweden. (ongoing, 3rd year of 5)

- Master of Science in Electrical Engineering, KTH, Sweden

- Work experience in design and implementation of satellite- and telecommunication systems for maritime use, SatPoint AB, Sweden.

Electrical Engineering, Electronics and Software

Design of the control electronics (hardware and software), power system, radio systems and sensors; post flight data analysis.

Oliver Neuner

- Master in Electrophysics, KTH, Sweden (ongoing, 1st year of 2)

- Dipl. Ing. Electrical Engineering & Information Technology, University of applied sciences, Rosenheim, Germany

Malin Gustafsson

- Master of Science in Electrical Engineering, KTH, Sweden (ongoing, 3rd year of 5)

Joakim Sandström

- Master of Science in Electrical Engineering, KTH, Sweden (ongoing, 3rd year of 5)

	Mechanics and Design *CAD design, Airbags and inflation, materials (heat shields etc.)* **Christian Westlund** - Master of Science in Aerospace Engineering, KTH, Sweden (ongoing, 4^{th} year of 4 $^{1}/_{2}$) - Work experience in CAD design, Nolato Sunnex, Sweden. **Matías Wartelski** - Master of Science in Aerospace Engineering, KTH, Sweden (ongoing, 4^{th} year, double-diploma student) - Master in Mechanical Engineering and Materials Science, Ecole des Ponts ParisTech, France (ongoing, 5^{th} year of 5) - Work experience in wind tunnel testing and flight test data analysis, Airbus, France. ***Aerodynamical issues and models*** *Simulations regarding aerodynamics and thermal conditions. Wind tunnel tests. Calculations regarding impact restrictions.* **Xin Li** - Master in Aerospace Engineering, KTH, Sweden (ongoing, 2^{nd} year of 2) - Bachelor degree in Aircraft design and engineering, Fudan University, China
Are you supported by an Institute or a professor?	Yes, the proposal is supported by the Space and Plasma physics department at KTH, with Dr Nickolay Ivchenko as main supervisor. The department has a long experience in designing and building instrumentation for space research.
Do you have a workshop or a laboratory to work?	Yes, the department provides all the tools and facilities necessary for the development. The division of Space and Plasma Physics has a state of the art electronics lab, where electronics for space instruments are constructed. The team will have access both to the equipment, and to the expertise of the senior engineers if required. SPP shares a mechanical workshop with the division of fusion plasma physics, which supports the EXTRAP/T2 fusion experiment. The workshop provides a complete set of processing, and the personnel have long-standing experience with vacuum technology, which will be useful in the project. Access to CNC machining is available through other departments at KTH and independent mechanical companies. The team has access to SPP's computer system, with software for mechanical and electronics CAD and data analysis packages. For the radio components, the division of electromagnetic engineering (school of electrical engineering) has a large expertise in antenna issues, and will be a point of reference for the design.

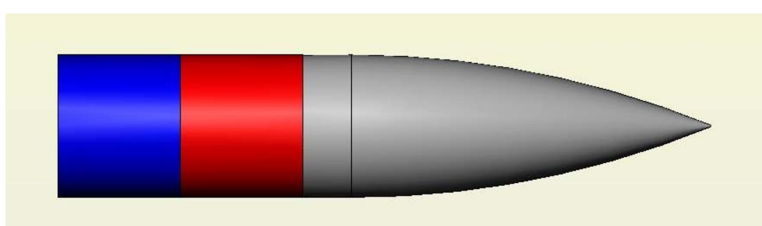
	The division of Aerospace and Vehicle Engineering (school of engineering science) at KTH has a wind tunnel which can be used for aerodynamic testing of the airbraking system. There is also broad expertise in computational fluid dynamics, which can be consulted for modeling the spinning payload descent. The School of Chemical Science and Engineering will be consulted on the chemical processes if required.
Do you have all the material and equipment which is needed for your experiment? If not, how do you plan to obtain it?	Most of the equipment needed is available at the department. The material for the airbag inflation system (nitrocellulose, the zirconium-potassium perchlorate pellets and platinum wires) are all commercially available products. Temperature sensors (Pt1000 resistors), accelerometers and rotation rate sensors (MEMS unit e.g. from Analogue Devices), batteries, conventional GPS module and antennas are all readily available commercially. Professor Paul Kintner (Cornell University, USA) and his group have expressed interest in providing (in kind) a novel miniature GPS system for attitude determination. The operation is based on measuring the phase difference between the GPS signals received on two antennas. The system will also provide precision position information after deployment. To evaluate various algorithms for data analysis and attitude solution, raw data (about 1.8 Mbit/s) will be saved onboard for post-flight analysis. Being an exciting addition to the payload, this measurement is not crucial for success of the project. For magnetic field measurements we will use the miniaturized fluxgate magnetometer (SMILE) that has been recently developed at SPP, and is available to be a part of the LAPLander [*Forslund et al.*, 2007] (Images are included in the appendix). Use of the magnetometer will be important to determining the attitude of the payload during the descent.
How do you plan to finance your expenses?	The expenses will be covered by the Space and Plasma Physics group at KTH.
Who else will support you (sponsors, others)?	We will likely receive an in kind space grade GPS from Cornell University to help with attitude and trajectory determination.

Outreach Programme	
Describe your outreach programme for before, during and after the REXUS / BEXUS flight campaign?	*How are you planning to present your experiment to the public? e.g. newspaper, local radio, webpage, presentation at the university, etc.* *<u>The execution of an outreach programme is mandatory!</u>*

	We are planning the following efforts for the outreach programme: - An article in Osqledaren, a student magazine driven by the KTH student union. The article will reach a broad group of students and will help to promote space research. - The person responsible for information and public outreach at the school of Electrical Engineering will provide additional contacts with the local media and newspapers such as Ny Teknik and Dagens Nyheter (the largest national daily). - The project will partly be considered as an individual project course for the participants, with the possibility of being extended into diploma thesis projects. The examination of these courses will include public presentations of the work at KTH and Ecole des Ponts. - A dedicated webpage at the SPP website will provide detailed and updated information. - A compiled KTH-standard TRITA report (*Transactions of the Royal Institute of Technology*) covering the details of the design and the results of the flight. TRITA reports are all provided with an ISSN number and are well available for the general public.

Experimental Set-up & Technical Information

Mechanics	
Describe your experimental set-up.	*Describe and outline the preliminary set-up of your experiment. Attach relevant documents, such as CAD drawings, to this form.* The LAPLander design will be built around four dummy models of the SCALE probe design developed by the SPP group at KTH. These will be placed in a cross shape with an electronics box in the center, containing all the sensors and control electronics. The design will be covered by circular heat shields on the top and bottom, and the sides will be covered by hatches. The electronics and batteries will be located in the box at the centre of the payload. The electronics include the following main components: - Timing, data acquisition and control system - Flash memory - Battery - Magnetometer - Roll-rate sensor - Accelerometers - Altitude switch - Ignition system for gas generation - Commercial GPS module

	- Dual GPS antenna system for post-flight attitude and trajectory reconstruction. - Radio Beacon The timing, control and data acquisition system will ensure data collection into onboard memory, inflation of the airbags at given altitudes, and switching into the localization mode (initiating transmission of the recovery signals). The system will be based on field programmable gate array(s). The antennas for the radio communications and GPS will be located along the rim of the payload, or on its top and bottom sides. This should allow for best coverage independent of how the payload is oriented on the ground. The airbag inflation is primarily driven by a nitrocellulose compound, with sodium bicarbonate to moderate the combustion rate. The nitrocellulose can generate large amounts of gas, where 1g nitrocellulose gives on the order of 1L of gas at standard atmospheric pressure and temperatures. The compounds generated are carbon dioxide, carbon monoxide, nitrogen and water. Our current worst case estimate requires a total of ~300g of nitrocellulose, however, with an improved airbag design, feedback from the wind tunnel testing and finalized values for how much impact the control electronics can handle should allow for a significant reduction of the amount of nitrocellulose necessary. The ignition of the nitrocellulose will be done by pellets of zirconium-potassium perchlorate and platinum wires. The gas generation will be done in a stepwise manner in order to let the generated gas cool down and to prevent an overheating of the system. We are continuously investigating other means of gas generation in order to verify that we have the most effective and reliable system possible.
Estimate the dimensions and the mass of your experiment.	The payload will be disc-shaped with a diameter of 250 mm and a height of ~60-70 mm. We estimate the mass to be around 2 kg. See attached CAD-drawings at the end of the document.
Indicate the preferred position of your experiment:	*REXUS:* *Indicate the preferred position in the rocket: bottom module, top module or nosecone section. Do you need access to the outside environment? Holes? Hatches?*  We wish to have a position in the rocket that allows the payload to be ejected at or near the apogee. The ejectable nose-cone would thus be a suitable position for the experiment.

Electrics / Electronics	
REXUS only: Will you need the 28 Vdc power supply from the REXUS service system?	*BEXUS experiments cannot be powered by the BEXUS system.* No. The payload will be self-supported by internal batteries.
Will you need (additional) batteries? What do you need for charging?	*Qualified batteries are listed in the REXUS and BEXUS User Manuals.* The payload will likely use SAFT LSH 14 batteries. The reason for the choice of a Lithium battery over the Ni-Cad or Ni-Metal is the more appropriate voltage level and a better performance-to-mass and volume ratio, as well as magnetic cleanliness considerations.
Estimate the electrical consumption of your experiment.	**The payload will be self supporting in terms of battery power.** The electrical consumption will be around 2 Watt during the descent, and below 1 Watt average (at low duty cycle) while on the ground.
Do you use any equipment with high inrush currents?	*e.g. Motors may need high inrush currents which exceed the nominal allowed current limit.* No.
REXUS Only: Do you need auxiliary power? Do you need a separate umbilical?	*Auxiliary power for charging or consumption before launch is not standard. Mention here whether you need auxiliary power and why.* The payload does not need any auxiliary power. We will need a connection to a Lift-Off signal.
Do you need uplink and / or downlink?	*Will you downlink your data or store it during the flight? Will you uplink commands? What is the expected data rate?* **No up or downlink is required.** All data will be stored in a non-volatile memory during the flight. The size of the memory will be appropriate to the data rates. For the primary LAPLander payload the data rate will consist of the magnetic field measurements at 250 samples/s, and signals from the housekeeping channels (temperatures, rotation rates, accelerations) at the rates of up to 100 samples/s. The data are of different resolution (10-20 bits per channel), but certainly well within capability of data acquisition system of moderate complexity. The addition of the space-grade dual antenna GPS provided by Cornell University would add another 1.8 Mbit/s to the data flow, which would be stored in a dedicated memory chip.
REXUS Only: Do you need to use the REXUS TV Channel?	*There is only one TV channel available, so only one experiment can use it. Why should it be your experiment?* No.
Provide an event timeline, including the experiment actions during flight, such	*Describe your event timeline.*

as timer or telecommand events.	1) Start of data collection directly following the lift-off signal. 2) Ejection of payload (timed event) 3) Airbag inflation in between 2-4 km altitude (controlled by an altitude switch) 4) Transmit GPS position 5) Start sending recovery signal (timed event)

Environmental Questions & Safety Issues	
Does the experiment use wireless devices?	*e.g. Wifi (WLAN), Bluetooth, infrared, airport, data transmitters. Describe the type of devices and frequencies used.* Yes, the payload will contain a satellite transmitter and a radio beacon used for triangulating the landing position. The beacon will be a simple low duty cycle pattern transmitter with an omnidirectional antenna, operating on a suitable license-free frequency in the range of 100s of MHz. The beacon will be built using commercially available RF modules. The satellite transmitter will utilize technology available for tracking wild animals (such as polar bears). The system provides a low-mass antenna with low power consumption and an operational temperature down to -30 degrees C.
Does the experiment create a magnetic or electrical field?	No. As the payload includes a magnetometer, we intend to keep the internally generated electric and magnetic fields as low as possible. The inclusion of magnetic materials will in general be avoided.
Could there be an electrostatic discharge from your experiment?	No.
Is the experiment sensitive to light?	No.
Is the experiment sensitive to vibrations?	No.
Does the experiment generate vibrations?	*e.g. Vacuum pump, rotating devices, etc.* No.
Will you use any flammable, explosive, radioactive, corrosive, magnetic or organic products?	*Specify any products you will use with any of these characteristics.* The payload will mainly use nitrocellulose as a gas generator for the airbags. Nitrocellulose is a highly flammable material (however commercially available and safe to use), creating a hot gas. We intend to moderate the combustion speed of the Nitrocellulose by including sodium bicarbonate (a standard technique), and by separating the nitrocellulose into small separate loads that are ignited after a schedule to allow the system some extra cool-down time.

Will you use a laser?	*Which class? Is the lather path securely contained?* No.
Is your experiment airtight? Are parts of your experiment airtight?	*Yields to a pressurized experiment (1 bar) when the vehicle reaches higher altitude with lower pressure values.* *This question should remind you that there will be a very low ambient pressure environment for your experiment.* The airbags along with the ignition system will be airtight. These will be protected by hatches that hold for the pressure imbalance in a low-pressure environment, but which will yield for the higher pressure exerted by the airbags when they inflate.
Are there any hot parts (> 60°C)?	*Mention any parts besides electronics that heat up.* While in the rocket, most of the payload functionalities will be on hold. The nitrocellulose will generate excess heat when ignited, however this will occur after the payload has been ejected from the rocket.
Are there any moving parts?Are the moving parts reachable?	*This is important for the preparation before launch. Access to the experiment will be discussed with EuroLaunch. e.g. a tappet is used for a moving part.* No.
Do you need any pressure systems from Eurolaunch before launch?	*If you know that you need for example a pressurized nitrogen-bottle for your experiment before launch, please mention it here. All pressurized bottles will be handled by EuroLaunch personnel.* No.

Your text should be intelligible to scientists of various fields and engineers with a general scientific background.

Before you submit your proposal, please ensure that you have read the REXUS / BEXUS Technical Overviews available at www.rexusbexus.net You can also refer to the REXUS / BEXUS User Manuals for more detailed information.

To submit your proposal to ESA, please register at www.joinspace.org and download this application form as a Word file. The completed form must be uploaded again before the deadline of 17 November 2008.

APPENDIX – Drawings and images

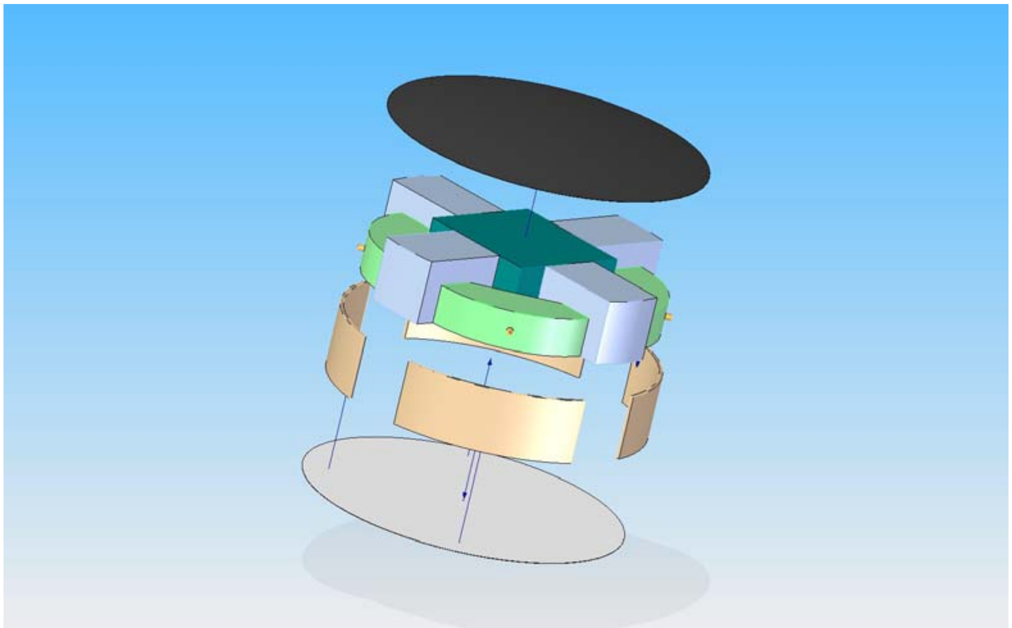


Image 1:
The LAPLander design. The drawing shows the circular heat shields (black and gray), the centrally located electronics box (dark green), the SCALE probe dummies (light blue), the chambers for gas generation (light green) and the covering hatches (beige).

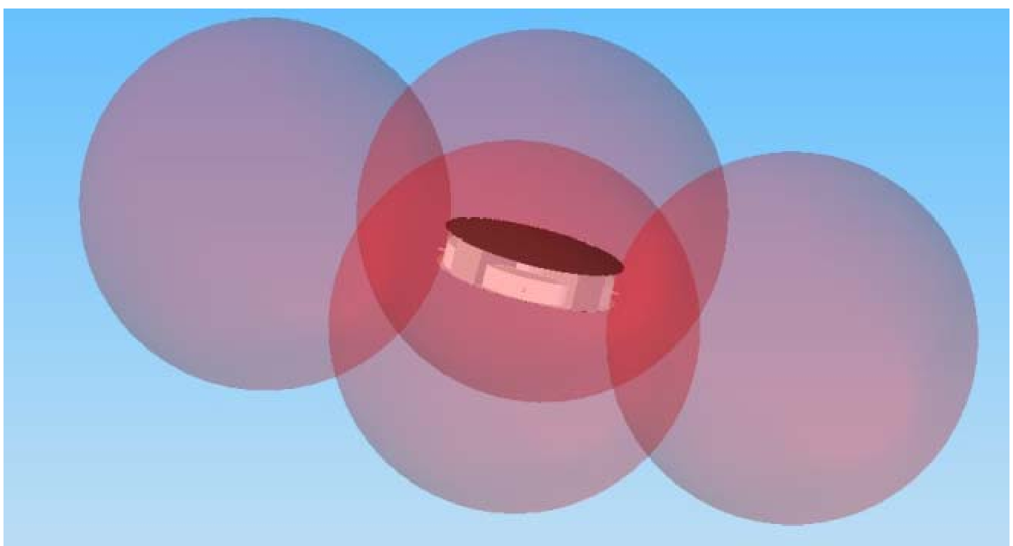


Image 2:
LAPLander, airbags deployed.

Image 3:

The SMILE magnetometer. The sensors dimension is on the order of 20x20x20 mm and requires less than 50x50 mm circuit board space with the electronics included.

REFERENCES

Forslund, A, S. Belyayev, N. Ivchenko, G. Olsson, T. Edberg, and A. Marusenkov, 2008, Miniaturized digital fluxgate magnetometer for small spacecraft applications, Measurement Science and Technology, 19.

Ivchenko, N., L. Bylander, and G. Olsson, 2007, Fast deployment of wire booms without residual oscillations, ESAPAC proceedings, Visby, ESA-SP-647, 211-216.