Danish Ørsted Mission In-Orbit Experiences and Status of The Danish Small Satellite Programme

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Abstract

The Danish Ørsted Satellite was successfully launched 23. February 1999 and is now operating nominally in orbit. The 61 kg satellite carries four science experiments with the objectives of mapping the Earth's magnetic field, measure the charged particle environment and collect GPS occultation data. The science data from the 14-month mission will improve geomagnetic models, study auroral phenomena and obtain atmospheric profiles.
The Ørsted satellite has, since the completion of the Flight Model in 1997, raised a considerable interest for small scientific satellites within Denmark and has caused the initiation of the Danish Small Satellite Programme. The first mission, which is carried out in this context, is the Danish contribution to the Argentine SAC-C mission. A Magnetic Mapping Payload similar to the primary payload flown on the Ørsted satellite, is integrated into the SAC-C Earth observation mission and will continue the measurements obtained by the Ørsted mission. Further, four new satellite proposals are under evaluation, where Denmark proposes to continue its line of small scientific satellites. Right now the four competing proposals are in the middle of the evaluation process, and it is planned to start a systems design phase in September or October this year.

Introduction

This paper describes the status of the Danish Small Satellite Programme. The first half describes the in-orbit experiences with the Danish Ørsted satellite. Further, the status of the Danish contribution to the Argentine SAC-C satellite, also denoted the Ørsted-2 mission, is described, and finally the status of the succeeding missions which forms the basis for the Danish Small Satellite Program is described.

Ørsted Mission

Description of the Satellite

The first Danish satellite, Ørsted, was launched from Vandenberg Air Force Base as a secondary payload with the US Air Force ARGOS mission on a Delta II launch vehicle on 23 February 1999. The Ørsted satellite is a small 61 kg research satellite for high precision measurements of the Earth's magnetic field in a polar elliptical orbit at altitudes from ≈650 to ≈850 km

The magnetometer measurements will be used for a precise global survey of the magnetic fields and its variation, which is of importance for a wide spectrum of geo- and space science studies. In spite of the internationally expressed interest in such data and in spite of many attempts by the major space agencies to conduct such a mission, the Danish enterprise is only the second of its kind, during the last 20 years.

A very important contribution was the offer from NASA to provide the launch of the Ørsted satellite as well as a JPL developed TurboRogue GPS receiver for atmospheric sounding. This demonstrated the level of the international scientific interest and confidence in the Danish team. Similarly, the offer from CNES in France to supply a scalar magnetometer demonstrates the large international interest in acquiring the most accurate data ever of the Earth's magnetic field. Finally, ESA has provided technical advice and considerable financial support of the ground segment by incorporating it in its Prodex programme.

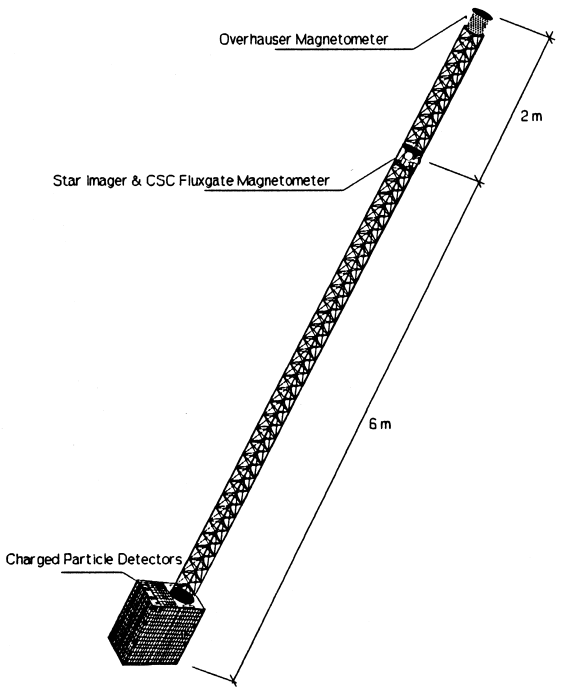
In January 1997, the satellite was completed and successfully passed the necessary environmental tests at the IABG facilities in Munich. A comprehensive magnetic calibration was performed at this facility with financial support from DASA as the German contribution to the mission. The calibration showed that the results could be reproduced with an accuracy of 0.2 nT from -20 to +20 °C and with an offset variation with temperature not exceeding 0.5 nT.

Following Table 1 indicates some of the overall design features of the satellite and Figure 1 shows satellite with the 8 m long boom in its deployed configuration. During launch this boom is coiled up and stowed in a canister.

50 science groups in 17 countries are part of the Ørsted Science Team and are awaiting the first complete datasets for further studies. The early operations phase, the boom deployment and the commissioning of the satellite platform have been completed, and normal operations of the satellite have been initiated.

Table 1: Ørsted Satellite Key Features

Item	Description
Body Size	H680 x W450 x D340 mm
Power	GaAs body-mounted solar panels 54 W EOL. Two Power Control Units. Two 6-cell NiCd 6 Ah battery packs.
Primary Structure	"H" Beam with Honeycomb platforms
Attitude Control	Gravity Gradient and Magnetorquers. (ACS)
Communication	S-Band with ESA Standard Packet TM/TC. Cold Redundant TX/RX units
Computers	Two Computers, 16 Mbyte storage, 80C186 16 MHz CPU
Position	Redundant GPS
Payload	Overhauser Scalar Magnetometer, CSC vector magnetometer, Star Imager, Charged Particle Detectors, TurboRogue GPS
Boom	8 m deployable 3 longeron
Thermal Control	Passive
Mass	60.7 kg



Mission Phases

Launch and Early Operations. . . Ørsted was finally launched 23 February 1999 after almost 2 years in storage. The waiting was due to continued technical problems with the primary spacecraft, the US Air Force ARGOS Satellite, and a record setting 10 unsuccessful count downs, primarily due to high shear winds in the area. Finally, on the 11th attempt Argos, Ørsted and the South African Sunsat was successfully placed into orbit. The Ørsted orbit is a slightly elliptical polar orbit with apogee ≈850 km and perigee ≈650 km and with an inclination of 96.5°. During launch the spacecraft was completely switched off and not until after release from the launch vehicle second stage, the separation switches ensured the correct turn-on of the spacecraft. Power control units, computers and communication units was turned on automatically and 30 s after release from the Delta II second stage, the ground station at Vandenberg Air Force Base was able to verify that the spacecraft had turned on. The CSC Magnetometer was also switched on automatically to determine satellite attitude and motion after separation. Figure 2 shows a printout of the carrier, which was our first sign of life from Ørsted.

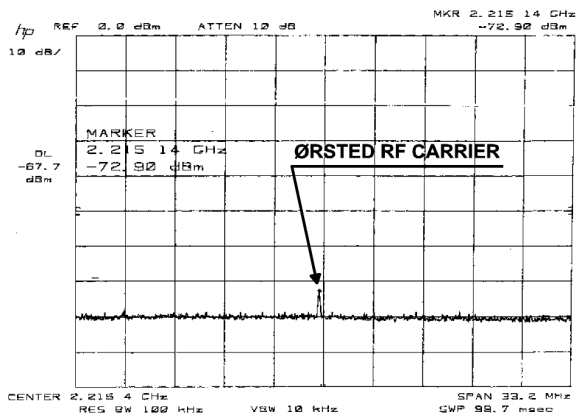


Figure 2: First Received Signal From the Satellite

This ground station was unable to decode the data from the spacecraft and not until the first pass over our two ground stations in Denmark, 100 minutes after separation, the first housekeeping data from the spacecraft were successfully received. It was possible to verify that we had a healthy, but as expected, tumbling spacecraft. The first commands were transmitted to the spacecraft to initiate the ACS subsystem, in order to put the satellite into a controlled motion following the Earth magnetic field lines. (B-dot control).

Commissioning Phase. . . After a few orbits the spacecraft was relatively stable with two full rotations per orbit as expected. Communications to ground was relatively stable despite the rotating satellite. Once fully commissioned, with the boom deployed, the

satellite points the S-band turnstile antennas, in the bottom of the satellite, towards ground at all times. (See Fig. 3)

Figure 3.: Final Orbital Orientation

All subsystems and instruments were turned on one by one and thoroughly tested to verify their correct performance. All systems and science instruments seemed at this time to be working according to specifications, temperatures were within the specified limits and also the power input from the solar panels were within specs. A lot of time was hereafter spent to adjust the more than 250 parameters in the Attitude Control System to increase the pointing performance. During this period it was realized, that we had timing errors on the science data, but that these errors were correctable on ground. It was therefore decided not to change anything on board, as a safety precaution. Unfortunately, the errors cannot all be automatically corrected, and some has to be corrected by hand. This fact has put a high load on the science data center to correct the 16 Mbytes data downlinked every day. The immense work in correcting these timing errors has also been the primary reason for a delay in the distribution of the data to the scientists by several months.

Despite these problems we were ready to attempt the release and deployment of the boom on 14 March 1999, after a period of three weeks.

Boom Deployment. . . The boom deployment was probably the most critical operation which had to be performed during the mission. The boom consists of three coilable longerons as shown in Figure 4. The longerons are separated by radial spacers and tensioned by cross-wires when deployed. This boom-configuration provides high inherent deployment torque without the need for external springs or other mechanical devices. Deployment is controlled by a motor in the bottom of the boom canister using a restraining wire in the center of the boom. During launch, the boom is stowed in the canister depicted in Figure 5.

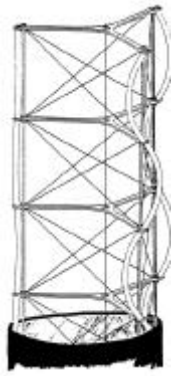


Figure 4.: Ørsted Boom

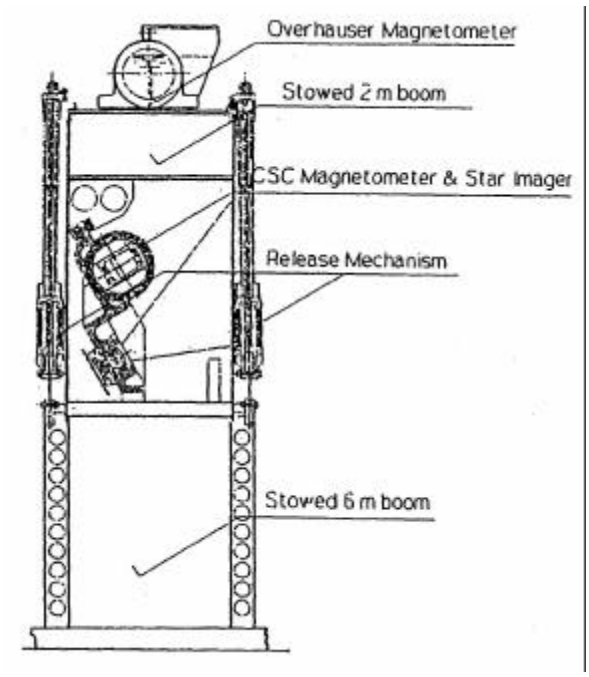


Figure 5: Boom in Stowed Configuration

As Ørsted uses gravity gradient as one of the means for stabilization, it was important to ensure that the satellite ended up in the correct attitude once the boom was deployed. (See Figure 3 The other stable configuration, where the boom was nadir pointing, meant that the communication antennas would be pointing towards zenith, which is an unfavorable position seen from a communications point of view. Careful planning took place before the operation to orient the spacecraft in a way where deployment could take place during the sunlit part of the orbit (to keep the boom warmer) and also where the quick increase in moments of inertia during the deployment would result in the correct attitude once the boom was fully deployed. Three consecutive passes over Denmark were needed to complete the operation. 1st pass was used to release the hold down arms, which ensured the boom stowed configuration during the launch. 2nd pass was used to verify this operation and to up-link the last time-tagged commands to deploy

the boom and the 3rd pass was used to verify that the boom was fully deployed. The deployment itself and the monitoring of this operation was done automatically on-board. Figure 6 illustrates the successful deployment using the vector magnetometer.

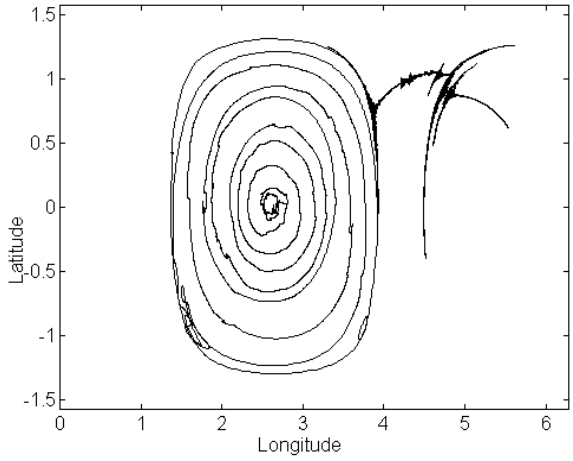


Figure 6: Deployment Verification

The plot shows the direction of the magnetic field vector on a “worls map” using "geographical coordinates". Initially, the field is directed along the direction of deployment. As the satellites moves around the Earth during the 12 min. deployment period, the direction of the magnetic field shifts and causes the field vector to spiral outwards as the gondola with the CSC Magnetometer and Star Imager rotates while the boom deploys. When the inner 6 meter boom is fully deployed, the spiral motion ends and a short period of oscillations is seen as the boom locks into place. Subsequently, the last 2 meter section with the Overhauser Magnetometer deploys and causes the track to deviate from the spiral. The oscillations are caused by jerks of the CSC Magnetometer as the boom locks in the deployed position. This plot together with data from the deployment tachometer, the operating time of the motor and the restraining wire being untensioned shows that the deployment was successful.

Since this operation was conducted we have had a number of experiences with this long boom, which is briefly described in the following.

After deployment the spacecraft was moving like a pendulum with an amplitude of about ±30° and at the same time rotating around the boom axis. This caused severe problems for the primitive active ACS magnetorquer system to regain control of the satellite, but finally after another couple of weeks this motion was dampened and we were able to start getting real science data to the ground. For a period of time we had difficulties in getting the star imager to perform well. The sun blinded the imager for a significant amount of time causing the attitude control subsystem to somewhat loose the control of the spacecraft. Analysis showed that the boom was misaligned by 36° from the satellite body to the boresight of the Star Imager and after having adjusted the transformation matrix between the Star Imager and the satellite body, the satellite was much more stable. The effort in aligning the Star Imager boresight had the consequence of mis-aligning the solar panels with respect to the sun. Fortunately, the panels are performing better than expected causing this problem to go away. Vibrations were also seen in the boom causing disturbances of the data. The vibrations were detectable both on the Star Imager, but also on the CSC Magnetometer, and analyses have shown that the cause probably is thermal effects when parts of the boom shadows other parts of the boom. Hence, the only solution is to filter out the noise when these jerks occur in the data. This is also part of the explanation on the delay of the distribution of science data.

Operational Status. . . At the time of writing (July 1999) after almost 5 months in orbit, all the satellite subsystems and all the instruments are generally performing well. Minor adjustments are continuously being performed and parameters are tuned to ensure the most optimal operation of the satellite. The operations team are still struggling to get a higher degree of coverage as we still have attitude dropouts, causing valuable data to be lost.

Despite the challenges we have had so far, the mission have technically already been a great success, which contributes in paving the way for smaller cheaper, better missions, with highly focused science objectives. Hopefully, the coming distribution of final datasets to the science community will result in a scientific success as well.

Other Danish Magnetometry Missions

In parallel with the delivery and calibration of the magnetometer for the Ørsted satellite further developments have been carried out to fly a 2nd generation Vector Magnetometer and Star Imager on the Swedish Astrid-2 satellite. The instruments for Astrid-2 were calibrated and subsequently delivered at the Flight Acceptance Review in May 1997. The Astrid-2 satellite was shipped to Plesetsk in Russia where the satellite was launched on December 10, on a Kosmos vehicle. The vehicle put the satellite into a 1000 km circular orbit with an inclination of 83°.. The magnetometer was switched on and performed well on 14December 1998 from the Swedish Space Corporation Control Center in Solna, and on 11 January 1999 the boom carrying the magnetometer and the Star Imager was successfully deployed.

After Ørsted and Astrid-2, two second generation vector magnetometers were delivered to the German CHAMP Earth's Potentials and Fields Satellite mission in February 1999 for launch in the beginning of 2000. The flight magnetometer for the next Danish Small Satellite Project MMP or Ørsted-2 on board SAC-C was delivered to Argentina in July 1999 for launch in December 1999.

Danish Small Satellite Programme

In the beginning of 1998, the initiation of a Danish Small Satellite Programme was ensured with an initial funding envelope of 8 MUSD from 1998 to 2001 provided by the Danish Research Councils. The programme is managed by the Danish Space Research Institute (DSRI). The first project is the participation in the Argentine SAC-C mission with a Magnetic Mapping Payload also denoted Ørsted-2, a set of instruments to map the magnetic field similar to the main payload on the Danish Ørsted satellite.

In spring 1998 the so-called "Board for the Danish Small Satellite Programme" established by the Research Councils, issued an Announcement of Opportunity. 8 proposals were received, and during the summer 1998 these proposals went through the first evaluation process which resulted in a selection of 4 proposals. These proposals were hereafter requested to prepare a detailed mission proposal, which was submitted by 1 April this year.

The proposals are now going through a scientific as well as a technical evaluation and in September-October 1999, the next Danish small satellite mission will be selected.

The following paragraphs give an overall introduction to the SAC-C Ørsted-2 mission as well as to the four remaining smallsat proposals, which currently forms the basis for the Danish Small Satellite Programme.

The Ørsted-2 mission concerns the Danish participation in the Argentine SAC-C mission (Satélite de Aplicaciones Científicas-C) with an Ørsted-type payload. Ørsted-2 is the first mission, which is running under the programme.

SAC-C Magnetic Mapping Payload (Ørsted-2) . . . The Ørsted-2 payload will be a direct heritage from the Ørsted mission. Hence, the science objectives for Ørsted-2 are similar to Ørsted, where the mapping of the magnetic field is the primary objective. Secondary science objectives, seen from the Danish point of view, include the use of the TurboRogue GPS system to measure temperature and humidity profiles through the atmosphere and the possibility of receiving images for earth observation. Denmark contributes to the project with an 8 m deployable boom mounted with a vector magnetometer and a star imager. Further, the contribution includes the associated support electronics to control the sensors and the boom deployment, a power control unit and a command and data handling unit. A scalar helium magnetometer placed on the tip of the boom and associated support electronics from JPL completes the Ørsted-2 instrument package.

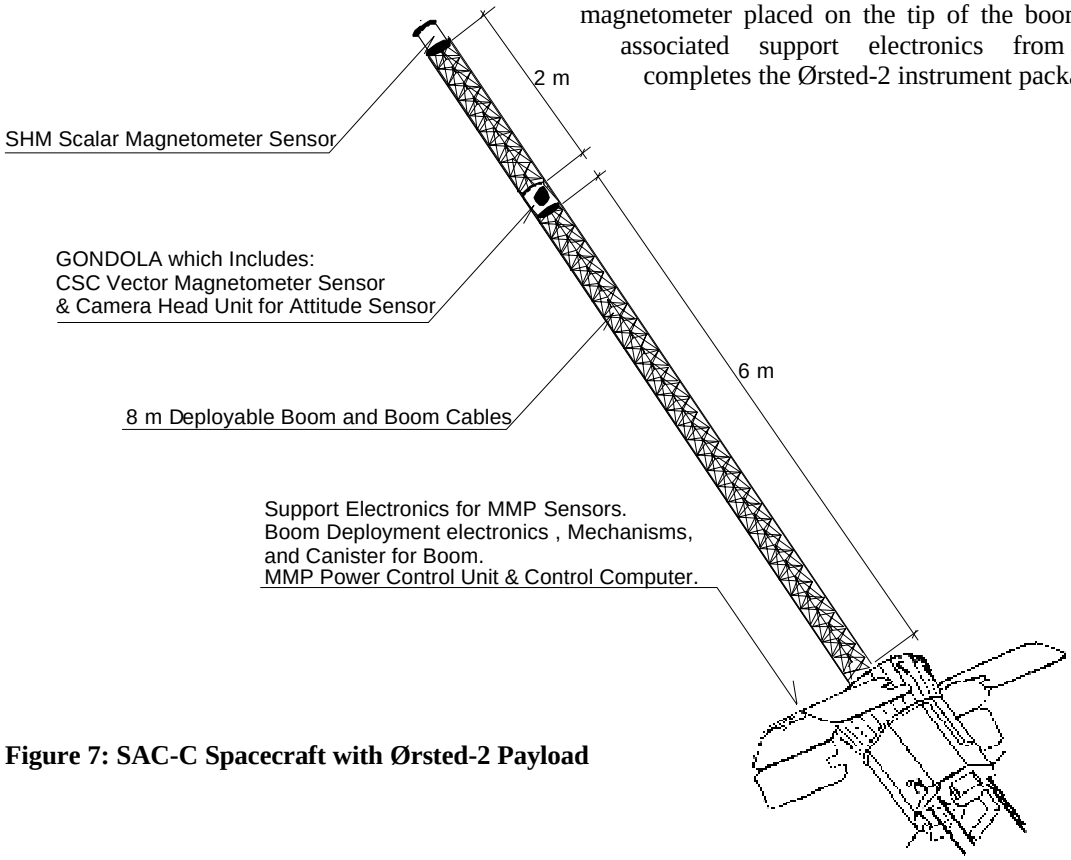


Figure 7: SAC-C Spacecraft with Ørsted-2 Payload

The New Missions

The following describes the four proposals, which were selected during the first evaluation round:

- MONS – Measuring Oscillations in Nearby Stars.
- Ballerina – Search for Gamma Ray Bursts and X-ray Transients.
- AXO – Atmospheric X-ray Observatory.
- FACE-IT – Field-Aligned Currents in the Ionosphere and Thermosphere.

MONS. . . The primary instrument defined on the MONS mission is a 30-cm telescope with a CCD detector. The primary science objective is to observe 25 nearby stars by measuring intensity oscillations by precision photometry. This is done to probe the stellar interior for determination of its composition, age and internal rotation. A typical target star is observed for 30 - 50 days continuously. 22 targets are currently proposed. Today the only star, which has been subject to such measurements, is our own sun. Figure 8 shows the proposed MONS spacecraft configuration

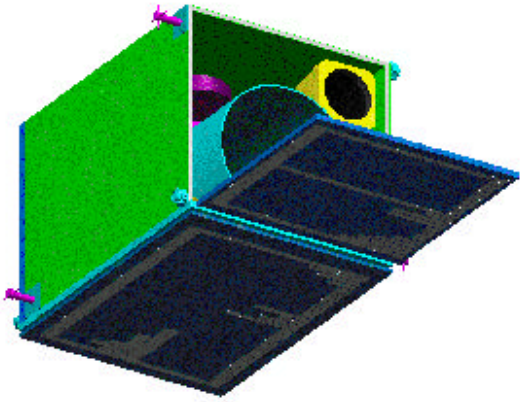


Figure 8: MONS Spacecraft

The satellite has to be 3-axis stabilised to an accuracy of 0.02^{o} rms to ensure that these oscillations can be measured. The current mass of the satellite is estimated to be below 85 kg and the envelope foreseen for the satellite is the ARIANE 5 ASAP (Ariane Structure for Auxiliary Payloads) which is 60x60x80 cm. A Molniya orbit is defined as the preferred orbit, but the final choice of orbit will depend on the launch selection.

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Ballerina. . . The primary science objective for Ballerina is to trace and monitor "Gamma-ray bursts". Although thousands of bursts lasting from seconds to minutes, have been detected, only a few have been monitored from the onset over the rise and peak of emissions through the decay phase. The physical mechanisms leading to gamma ray bursts are very poorly understood. It is known that sources in the universe from time to time are busting with gigantic doses of gamma- and X-ray radiation, but it is unknown today what causes these transients. The bursts occur randomly distributed over the entire sky and are known to be among the farthest objects in the universe.

The Ballerina mission will be equipped with a system of four wide-angle X-ray monitors, Figure 10, which will trace the pulses to a positional accuracy of approximately 1°. When a burst has been detected, the satellite will downlink the coarse position to Earth and turn automatically to point the X-ray telescope within minutes towards the source, cf. green aperture in Figure 9. The telescope then measures the pulse intensity, the spectral composition of the pulse, afterglow, duration etc. and determines its position to an accuracy of ≈ 1 arcmin. The postion wil subsequently be downlinked to Earth. This enables larger and more advanced ground telescopes as well as space based telescopes to perform follow-up observations in the radio, optical or X-ray spectrum within minutes or even seconds of the detection of the burst, before it fades again.

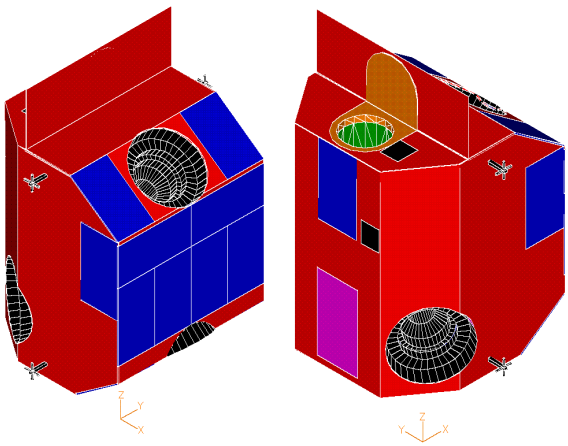

Figure 9: Ballerina Spacecraft

This way of operating a satellite puts strict requirements on the attitude control system and on the on-board autonomy. One advanced feature, which is proposed, is to use the WATCH detectors as part of the attitude control as well as science sensors. This is possible because the front part of the detector rotates with variable speed and therefore can be used as a momentum wheel.

The concept requires long times of visibility from ground as well as unobstructed full-sky view, and as it currently is foreseen only to have ground stations within Denmark, a high inclination, elliptical orbit such as the Molniya orbit is proposed. The Ballerina

satellite will be designed to stay within the available mass and envelope of the Ariane 5 ASAP.

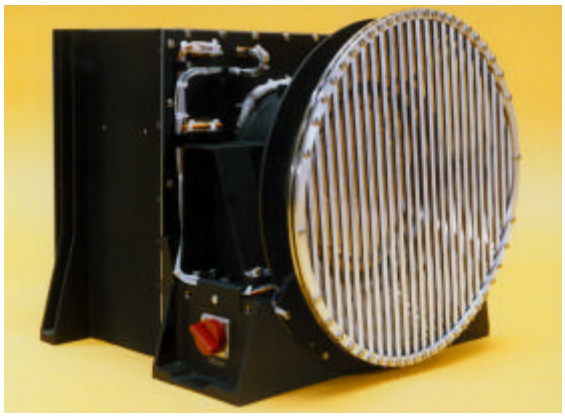

Figure 10: Wide-Angle X-Ray Monitor (WATCH)
(Front Rotor is 26 cm in diameter)

PI: Niels Lund, Danish Space research Institute, nl@dsri.dk

AXO . . . The primary science objectives of this mission is to investigate part of the interaction between the upper atmosphere and space. Especially the emission of visual light and X-rays in connection with larger thunderstorms. This should be seen in relation to the newly discovered phenomenon of upwards going lightning or discharges also called "red sprites" and "blue jets". Further, it is proposed to study the processes of aurora, such as the acceleration of charged particles as well as X-ray emission from such events .

The payload will include an X-ray camera to measure the intensity, position and time for the X-ray sources in the atmosphere, optical cameras for the determination of lightning and aurora activity, particle spectrometers to measure the electron energy levels, a vector magnetometer to measure electrical currents and a GPS receiver to perform atmospheric profiling.

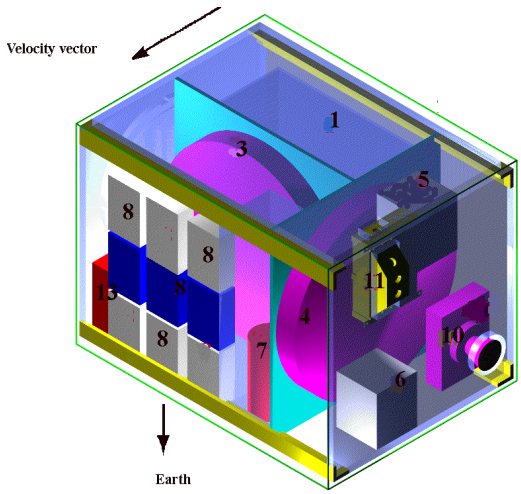

Figure 11: AXO Spacecraft

Also this satellite puts hard requirements on the attitude control system. The system has to be capable of keeping the cameras focussed on the phenomenon as the satellite passes over an event. The satellite should be launched into a high inclination, low earth orbit. This will enable the satellite to investigate both the science requirements. The current design implies a mass of ≈100 kg and within an envelope of 60x60x80 cm (Figure 11).

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FACE-IT . . . FACE-IT will investigate the field-aligned currents in the magnetosphere by using a new type of instrument, the so-called “Faraday Current Meter”, which will make it possible to measure fine structures in the current pattern of the magnetosphere. The scientists are especially interested in the direct geometrical relations, distribution and the magnitude of these currents, as this forms the most important connections in the energy transfer between the solar wind, the magnetosphere and the ionosphere.

Figure 12: FACE-IT Spacecraft

The satellite (Figure 12) will, apart from deployable solar panels, look very much like the Danish Ørsted satellite as the requirements for attitude control, orbit and payload accommodations are similar (10° in 3-axis, Polar Low Earth Orbit, 65 kg). One of the bigger challenges in this mission will probably be the development of the Faraday Current Meter (FCM). The Instrument has previously been flown on a sounding rocket, but never in space. The FCM instrument consists of two perpendicular, fiber-optical rings with a diameter of 10 m and an optical interferometer setup.

PI: Per Høeg, Danish Meteorological Institute, hoeg@dmi.dk

The Future

The four missions, which were selected during the first evaluation round, have submitted detailed mission proposals by 1 April 1999. These proposals will then form the basis for a final evaluation. The final selection will take place in a September-October 1999 and it is hereafter planned to go into a system design phase.

The primary objective for us involved in defining and running the programme is of course to ensure that Denmark within the next few years are able to put the second small satellite in orbit. A follow-on mission to the Ørsted satellite where we again, with joined forces, collaboration and a lot of enthusiasm can give the technological level a push forward. Further, it is also essential to secure the future for the Danish programme. Hence, that the programme is continuously funded. Therefore it is very important at all times to have new and exiting projects which can form the basis for the programme. Projects, which continuously can improve the technological and scientific return and which therefore, ensure a continued political interest in our programme.

During year 2000, the Danish Research Councils, with support from foreign experts, will perform an evaluation of the experiences with the programme over the first two years. This is done to study the possibilities for continuation. It is our hope that this evaluation will show that the investments made has had such a great return that the Research Councils will be willing, not only to continue, but even to expand the programme. To ensure such an evaluation result, it is mandatory to receive active support from everyone, who has an interest in this exiting challenge.

You may find more about the individual missions on our web site including the individual full-text proposals:
http://www.dsri.dk/dssp/DSSP-homepage.uk.html.

Acknowledgements

We wish to acknowledge the Ørsted Team for their outstanding performance throughout the project.

Peter Brauer, Department of Automation, Danish Technical University is acknowledged for providing Figure 6.

We also wish to acknowledge the PI's of the four new mission proposals for providing Figures 8 to 12.